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THE ECOLOGICAL INVESTIGATION IN THE IFA-NIVA EXPERIMENTAL PLANT AT NITELVA 1960 - 1962

by

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PREFACE

This report presents an account of results obtained through an experimental investigation on problems related to the disposal of radioactive waste to the river Nitelva. The aim of the investigation was to obtain knowledge about important biological and physical-chemical factors that influence the dispersion of radionuclides disposed to this stream and its environment.

The investigation has been performed by the Norwegian Institute for Water Research and the Institute for Atomic Energy in cooperation. Substantial grants from the International Atomic Energy Agency made the investigation possible, but financing of the project has also to a great extent been done by the two institutes.

The experimental part of the research programme was carried out during the three year period December 1959 - December 1962, with concentration of the activities during the included summer seasons. A hydrobiological field station was constructed upon the banks of the river, and operated throughout the summer of 1961 and 1962. Here the main experimental part of the research programme was accomplished.

This report does only include a summary and discussion of the results with direct relevance to ecological interferences of radioactive pollution. It is planned that a revised issue of this report shall be published in an appropriate journal.

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IN THE IFA-NIVA EXPERIMENTAL PLANT AT NITELVA
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1. INTRODUCTION

Increasing volumes of low level concentrations of radioactive waste are being introduced into lakes and rivers (1).

Inland waters serve a multiplicity of purposes, and the consequences of the radioactive discharges for man and nature have to be carfully evaluated.

Three major problems seem to be particularly important for the evaluation.

1. The fate of the radioisotopes released to the recipient. The distribution of the substances in the water masses and their accumulation by biotic and abiotic media.

2. The amount of radioactivity that reach man by direct and indirect route from the recipient.

3. The somatic and genetic effect of the concentration of radioactivity built up in man and biota.

The purpose of the present investigation was to obtain information on the first of these three problems. The work has special reference to the natural conditions in the river Nitelva. This river is located in the South-Eastern part of the country. The map in figure 1 shows the geographical position of the area.

In disposal practice the water masses of a river are used to obtain a dilution of the wastes to acceptable concentrations. However, several processes in the river may reconcentrate the various radioisotopes. These physical, chemical, and biological processes may even concentrate the radioactive substances by factors greater than those achieved by the diluting and dispersing mechanisms.

The factors affecting the dispersion and distribution of radioactive materials released into fresh water environment are of various nature, and they interact in complex manner. The most important processes in a river of the same type as Nitelva are those which are associated with the river biota and the suspended materials.

The particle fraction in the water, which may be of inorganic or organic nature, accumulate the radionuclides by sorption and ion-exchange processes. The bottom sediments accumulate radionuclides from the surrounding water by the same or related processes.

Reconcentration of radionuclides by organisms result both from sorption processes and by physiological uptake. The mechanism of transport of radionuclides from one organism to another through the food chain is furthermore among the important reconcentration phenomena.

These primary processes result in a certain pattern of distribution of the radionuclides in the recipient. The radioactivity will partly be removed from the water by sedimentation, partly be transported out of the system, and a certain fraction will be accumulated by organisms in the communities of river biota.

The significance of these processes may be of different magnitude depending on the prevailing environmental conditions. Variations in milieu factors such as turbidity and ionic concentration may, for instance, cause alterations of the hydrographical and biological conditions and this will successively affect the processes of radionuclide accumulation.

Most of the existing knowledge about the abiotic and biotic factors that influence the dispersion of radionuclides disposed to river environments, has resulted from observations made during survey of water courses contaminated with waste materials from atomic energy installations. The extensive studies performed in the Columbia river (2), the Clinch river (3), and the Thames river (4) are well known examples. Surveys of this kind are regularly made for radiological monitoring purposes and have a descriptive character. The results of the measurements may be difficult to interpret with respect to the causal connection between pollution load and the resulting reconcentration by the various media.

Laboratory investigations have furnished detailed information on selected problems. The physiological understanding of uptake and loss of radionuclides by organisms is an example of results that have been obtained from such investigations (5), (6). This autecological advance is of fundamental importance, but the results are difficult to transfer to natural conditions.

A third category of investigations on these problems is of synecological nature. Investigations of this type either involve experiments where known quantities of isotopes are introduced into the natural environment, or experiments in a model recipient where environmental factors and organisms interact upon each other in a similar way as in the actual recipient. This field of experimental radioecology has been applied by several investigations. Examples of work of this type are given in references (7), (8), (9).

The present investigation was concentrated on experiments performed in a hydrobiological field station. Experimental facilities specially designed for the purpose consisted of a model recipient. The advantages offered by the model recipient were the following:

The experiments were performed with the river water. The changes in water quality with meteorological conditions and the seasons, and the effect of such changes on important processes could be followed.

Environmental factors were either controllable (water flow and velocity nature and degree of radioactive contamination) or could be subject to measurements. The biota that developed in the model recipient consisted of the same species as living in the river. The opportunity to study the organisms and their biotic interrelationships and their relations to the actual problems were provided.

Laboratory investigations were included to the extent that was possible within the frame of the project. The present investigation was preceded by a limnological survey of the river and adjacent waters.

2. EXPERIMENTAL CONDITIONS AND METHODS

2.1 The aquatic environment and biota

The lower course of the river Nitelva from where the water used for the experimental station was taken, is meandering through deposits of pleistocene marine clay. The chemical quality of the water is greatly influenced by this condition. Results of measurements of important chemical components carried out at monthly intervals during a two year period, are given in table I.

TABLE I
CHEMICAL CHARACTERISTICS OF THE WATER

Component	Maximum value	Minimum value	Arithmetic mean value
H_3O^+ (pH)	7,6	6,4	7,1
κ_{20} $(n \cdot 10^{-6})$	103,5	41,3	57,2
$KMnO_4$ mg O_2/l	6,1	3,9	5,2
Ca^{++}, mg/l	6,1	4,8	5,4
Mg^{++}, "	1,5	0,7	1,1
Cl^- , "	9,0	2,1	4,8
SO_4^{--} "	9,0	7,0	7,9
Na^+ "	4,0	0,8	2,1
K^+ "	1,5	0,7	1,0

The highest values of electrolytic conductivity were generally found during periods with low water flow. At the same time the percentage of ground water in the river is assumed to be high, and consequently the water will contain relatively much inorganic substances in solution. Daily measurements of hydrographical data revealed a complex relationship between the meteorological conditions and the composition of river water. Variations in the values of electrolytic conductivity and turbidity during a twenty-four hour period could be of the same magnitude as the yearly variation. Among the factors determining the predominating state of the ever changing water quality, the following ones were the most important:

Flow of water.
Surface water run off from cultivated fields.
Pollution from sewage.
Transport of clay in the river.

The community of biota existing in the actual part of the river consisted of usual types developing in river environments of low water velocity, clayish bottom and high water turbidity, and enriched by sewage and drainage from cultivated fields.

Vegetation of vascular plants formed sociations of magnocaricetum, eleocharetum and potametum types (10). Dominating species were: *Carex gracilis* Curt, *Scirpus acicularis*, L., *Elatine triandra* Schkuhr, *Ranunculus reptans* L., *Potamogeton perfoliatus* L., and *Ranunculus peltatus* Schrank.

Benthic algae were common on the clayish bottom. The dominating algae were: *Chlamydomonas* Ehrenberg sp., *Oscillatoria cf. brevis* (Kütz) Gom., *Oscillatoria limosa* Agardh., and *Phormidium uncinatum* Gom.

A prolific vegetation of diatoms was characteristic for the benthic algal community. Species of frequent occurrence were: *Fragilaria capucina* Desmaziéres, *Melosira varians* C.A.Ag., *Stauroneis phoenicenteron* Ehrenberg, *Nitzschia acicularis* W. Smith, *Gyrosigma acuminatum* (Kütz) Rabh., and *Navicula rhynchocephala* Kützing.

Spirogyra cf. formosa (Transeau) Czurda, *Spirogyra cf. porticalis* (Müller) Cleve, and *Vaucheria walzii* Rothert were present in the benthic communities, but had little importance with respect to the biomass.

The communities of the flowing water also indicated the eutrophic conditions. *Pseudanabaena* Lauterborn sp., *Scenedesmus* Meyen spp., *Chlamydomonas* Ehrenberg sp., and *Asterionella formosa* Hassall were major species of the phytoplankton.

The invertebrate fauna was not rich in species, but was of considerable biomass. Characteristic species to be mentioned were: *Chironomus thummi* K., *Eurycercus lamellatus* (O.F. Müller), *Lymnea pereger* Müller, *Anodonta piscinalis* Nilsson, and *Plumatella fruticosa* Allman.

The important species of fish comprised: *Abramis brama* L., *Leuciscus rutilus* L., *Phoxinus aphya* L., *Perca fluviatilis* L., and *Esox lucius* L.

The development of the communities in the throughflow channels were initiated from organisms and diaspores transported with the river water. No transplantation of organisms was done except for specimens of the lamellibranch *Anodonta piscinalis*. The mature communities in the channels had *Vaucheria walzii*, *Spirogyra cf. formosa*, *Spirogyra cf. porticalis*, and *Oedogonium* Link sp. as dominant species of algae. The component of invertebrates included the major species *Eurycercus lamellatus*, *Chironomus thummi*, *Centropilum luteolum* (Müller), *Lymnea pereger*, and *Charchaesium polypinum* L.

The objects investigated during this study are listed in table II. Most of the work was performed with organisms belonging to ecological important species of the channel communuties. Beside this, experiments with vascular plants and fish have been done in well systems.

TABLE II

EXPERIMENTAL OBJECTS

Sediments	Pleistocene, marine clay of illite type
Algae	Spirogyra cf. porticalis (Müller) Cleve Spirogyra cf. formosa (Transeau) Czurda Vaucheria walzii Rothert Fragilaria capucina Desmaziéres Melosira varians C.A.Ag. Chara Braunii Gemel
Vascular plants	Callitriche verna L. Alisma plantago-aquatica L. Scirpus acicularis L. Elatine triandra Schkuhr
Invertebrates	Eurycercus lamellatus (O.F. Müller) Anodonta piscinalis Nilsson
Fish	Salmo trutta L. Phoxinus aphya L.

2.2 The model recipient

The model recipient (figs. 2 and 3) consisted of channels made of cement-asbestos, each 120 m long and with a cross-section of 0,03 m^2. The channels were continuously charged with river water at one end. A discharge weir at the other end of the channels kept the water depth at 0.10 m. A 3 cm layer of pebbles was placed on the bottom of each channel. During most of the experiments in the model recipient the water flow in the channels was 0.5 l/sec., which corresponded to a water velocity of about 4.5 cm/sec.

One of the channels was constructed for recirculation of the water. The water in this channel was circulated by means of a paddle driven by an electric motor. The velocity of the water was the same as in the through flow channels.

The influence of the channel material on chemical and biological conditions of the water has been tested. Measurements of calcium concentration and electrolytical conductivity, as well as growth tests with species of algae, showed that the effect of the channel material on the water was negligible during the ordinary operation of the model recipient.

The experimental station was also equipped with a well system (fig. 4). Cylindrical concrete tanks with bottom area of 2 m^2 and depth of 1.6 m were used. Most of the experiments in the well system were conducted with 1000 litres of water in each tank.

A detailed description of the model recipient will be published separately (in preparation).

2.3 Radionuclides and exposure time

The experiments have been carried out using the following radionuclides:

P^{32}, Sr^{89}, Cs^{137}, Ce^{144}, Zr^{95}/Nb^{95}, Ru^{103}.

Except for P^{32} the radionuclides are representatives for the most hazardous fission products. P^{32} was included because of the biological importance of this element.

The radionuclides Zr^{95}/Nb^{95} were in equilibrium in the added solution, and no separation of the two isotopes was performed.

The specific activity and some physical and chemical characteristics of the radionuclides are given in table III.

TABLE III

PHYSICAL-CHEMICAL CHARACTERISTICS OF THE RADIONUCLIDES

Radionuclide	Half life	Specific activity	Chemical state
P^{32}	14.2 days	100 mC/mg P	Ortho-phosphate
Sr^{89}	51 days	Carrier free	Sr-chloride
Cs^{137}	30 years	25 mC/mg Cs	Cs-chloride
Ru^{103}	40 days	1 mC/mg Ru	Ru-trichloride
Ce^{144}	285 days	Carrier free	Ce-chloride
Zr^{95}/Nb^{95}	65/35 days	Carrier free	Oxalate-complex

The accumulation of radionuclides by various objects is dependent on the chemical state of the element. In these experiments the chloride form of the radionuclides was chosen to avoid introduction of unwanted chemicals into the water. An exception was Zr^{95}/Nb^{95}, where a complex form was necessary to keep the radionuclides in solution.

The uptake of radionuclides by the fresh water organisms has been measured both after short time exposure and after chronic exposure. It is, however, difficult to distinguish between these two types of exposure. For a unicellular algae, a few hours may represent chronic exposure, while a few weeks may be insufficient for a multicellular organism to reach a steady state condition.

The main part of the work was concentrated on experiments in the through flow channels, where the algal-communities, bottom sediments, and invertebrates were continuously exposed to radioactive materials for approximately five months. The water flow in the channels was 0.5 l/sec., and the concentration of radionuclides in the water was in the order of $2 - 6 \cdot 10^{-6}$ μC/ml.

Experiments on relatively short time exposure of the algae in the through flow channels were also performed, with the exposure time ranging from 6-10 hours.

2.4 Climatic conditions

The meteorological factors observed were air temperature and precipitation. The position and type of the instruments were in accordance to Document 76 from the Commission for Climatology of the World Meteorological Organization. The temperature of the streaming water in the model recipient was measured daily. The results of these observations during the experimental period 1962 are listed in table IV. For the purpose of comparison the average values concerning precipitation are included. The latter data were obtained from the Norwegian Meteorological Institute.

TABLE IV

CLIMATIC CONDITIONS AT THE EXPERIMENTAL STATION

Observation	May	June	July	August	September	October
Average (day and night) air temperature °C	9.4	12.7	14.7	13.1	9.6	6.7
Average (day) water temperature °C	(9.1)[x]	15.0	17.0	13.8	10.6	6.7
Precipitation mm	68.3	40.3	112.6	158.8	79.6	46.3
Precipitation mm 1901 - 1930	52	56	69	98	59	79
Air temperature °C 1901 - 1930	9.3	13.8	16.2	13.9	9.5	4.3

[x] few measurements only.

3. EXPERIMENTAL DESIGN AND RESULTS

3.1 Sediments

Sorption of radionuclides to suspended particles and to bottom sediments is important in the evaluation of radioactive waste disposal problems to rivers. The sorption of radionuclides to river sediments has been investigated, and both laboratory experiments and experiments in the model recipient have been performed. In the laboratory experiments post-glacial clay from the Nitelva area has been used. In the model recipient the investigation was performed on bottom sediments of the same type as in the river Nitelva. The sorption phenomena in the model recipient were studied during the long time exposure experiments described above, and consequently under the same experimental conditions and with the same radionuclides.

The results show that appreciable amounts of cesium and cerium are sorbed to the sediments. The sorption of ruthenium and zirconium-niobium is intermediate, and the sorption of strontium is of little significance. In the laboratory experiments, the sorption of phosphorus to the clay was high, but in the model recipient the sorption of phosphorus was found to be very low. The results also indicate that in the river the suspended clay minerals will account for the major fraction of radionuclide uptake by the particles, and suspended organic matter will be of less importance.

The experiments on sorption of radionuclides by sediments are described in a separate paper (11).

3.2 Algae

The purpose of the experiments was to describe the distribution and accumulation of radionuclides by major species of algae in the channel biotope during short time and long time exposure. It was regarded important to record the accumulation of radionuclides by the algae in situ in their respective communities. The development of algae and the changes of algal communities in the model recipient were observed regularly during the experimental period.

The short time experiments were carried out by adding the radionuclides to the channel water at a constant rate over a period of 4-10 hours. Samples of algae and water were collected at intervals of 1-2 hours during the period of addition of radionuclide, and during the successive 7-8 hours. Samples were further collected up to 20 days following the exposure.

The results of the short time exposure experiments of the communities showed that the uptake of radionuclides by the algae occurred rapidly. The major fraction of the uptake took place within few hours, but variations among the different species were found. Examples of results from these experiments are given in table V.

TABLE V

UPTAKE OF RADIONUCLIDES BY ALGAE DURING SHORT TIME EXPOSURE

Per cent of maximum radioactivity taken up during the first 3 hours

Experimental object	P^{32}	Cs^{137}	Sr^{89}	Ce^{144}
Spirogyra spp.	100	100	100	42
Vaucheria walzii	17	37	-	-
Melosira varians	100	100	66	22

The elimination of radionuclides from the algae was also a relatively rapid process. The results of some observations of this type are listed in table VI.

TABLE VI

ELIMINATION OF RADIONUCLIDES FROM ALGAE

Per cent of initial radioactivity (equilibrium value) retained after 1 week

Experimental object	P^{32}	Cs^{137}	Sr^{89}	Ce^{144}
Spirogyra spp.	14	7	2	5
Vaucheria walzii	27	11	-	-
Fragilaria capucina and Melosira varians	7	9	14	8

The long time exposure experiments were carried out by adding the radionuclides to the channels at an approximately constant rate during the period May 15th - October 10th, 1962. Mixed water samples representative for periods of one week were collected, and sampling of algae was carried out at weekly intervals during the experimental period.

Spirogyra cf. porticalis together with Spirogyra cf. formosa (here included as Spirogyra spp.) and Vaucheria walzii were the only constant constituents of the algal communities throughout the whole experimental period. The results of the long time exposure experiments for these three species are listed in tables VII and VIII.

The highest accumulation of radionuclides in the investigated algae was observed for P^{32}, and the lowest for Cs^{137}. P^{32} and Cs^{137} represented the extreme values both with respect to concentration levels and to concentration variation. The other radionuclides gave intermediate values.

The highest uptake of P^{32} was observed in Spirogyra spp., whereas the uptake of the oterh radionuclides was found to be highest in Vaucheria walzii.

A description and discussion of the experiments with algae will be published separately (in preparation).

3.3 Vascular plants

The hydrophytes used for the experiments (Alisma plantago-aquatica, Callitriche verna, Elatine triandra, and Scirpus acicularis) had been cultivated in the well system of the experimental station in metal baskets with plastic coating. The exposure of the plants to P^{32} was done both in the recirculation channel and in the concrete tanks. The experiments with Cs^{137} were only performed in the concrete tanks. The exposure time varied in both cases from 7 to 9 days. The determination of radioactivity was done on samples of whole plants minus roots. The specimens of plants were in a state of vegetative growth and showed the typical habitus of the species. The temperature in the water varied from 10 to 20°C.

Examples of experimental results are listed in table IX.

TABLE VII

ACCUMULATION OF RADIONUCLIDES BY AQUATIC MEDIA FOLLOWING LONG TIME EXPOSURE

May - October 1962

Average values during steady state conditions with calculated standard deviations

$\mu C \cdot 10^{-4}$ per gram wet weight

Experimental object	P^{32}	Cs^{137}	Sr^{89}	Ce^{144}	Zr^{95}/Nb^{95}	Ru^{103}
Sediments	8,5 ± 3,8	271 ± 39	9,5 ± 2,8	650 ± 88	124 ± 16	
Algae						
Spirogyra spp.	157 ± 26	3,2 ± 0,4	17 ± 3,3	13,7 ± 1,4	9 ± 2	21 ± 2
Vaucheria walzii	83 ± 22	10 ± 2	29 ± 6,3	72 ± 15	21 ± 7	132 ± 60
Invertebrates						
Eurycercus lamellatus	337 ± 87	8 ± 1,3	48 ± 9,2	23 ± 3,7	7,2 ± 2,6	
Anodonta piscinalis (whole animal)	30 ± 3,1	8 ± 0,8	3,5 ± 0,3	7,5 ± 1,1	1,6 ± 0,2	

TABLE VIII

ACCUMULATION OF RADIONUCLIDES BY AQUATIC MEDIA FOLLOWING LONG TIME EXPOSURE

May - October 1962

Average value during steady state conditions with calculated standard deviations

μC · 10^{-4} per gram ash weight

Experimental object	P^{32}	Cs^{137}	Sr^{89}	Ce^{144}	Zr^{95}/Nb^{95}	Ru^{103}
Sediments	9,3 ± 4,2	298 ± 43	10,4 ± 3,1	710 ± 97	136 ± 18	
<u>Algae</u>						
Spirogyra spp.	24200 ± 4000	490 ± 62	2600 ± 510	2100 ± 215	1380 ± 310	3200 ± 310
Vaucheria walzii	3300 ± 880	400 ± 80	1160 ± 250	2900 ± 600	840 ± 240	5280 ± 2400
<u>Invertebrates</u>						
Eurycercus lamellatus	13000 ± 3300	310 ± 50	1850 ± 350	890 ± 140	275 ± 100	
Anodonta piscinalis (whole animal)	100 ± 10	27 ± 2,7	11,6 ± 1,0	25 ± 3,7	5,3 ± 0,7	

TABLE IX

ACCUMULATION OF RADIONUCLIDES BY VASCULAR PLANTS

Radionuclide concentration in water: 10^{-5} μC/ml

Experimental object	Exposure time	P^{32} μC/g wet weight	P^{32} μC/g ash weight	Cs^{137} μC/g wet weight	Cs^{137} μC/g ash weight
Alisma plantago-aquatica	9 days	$3.5 \cdot 10^{-4}$	$3.3 \cdot 10^{-2}$	$0.5 \cdot 10^{-4}$	$0.5 \cdot 10^{-2}$
Callitriche verna	9 days	$25 \cdot 10^{-4}$	$53 \cdot 10^{-2}$		
Elatine triandra	7 days	$22 \cdot 10^{-4}$	$10 \cdot 10^{-2}$	$1.2 \cdot 10^{-4}$	$0.5 \cdot 10^{-2}$
Scirpus acicularis	9 days	$6 \cdot 10^{-4}$	$7.6 \cdot 10^{-2}$		

3.4 Invertebrates

The two species of invertebrates regularly investigated during the experiment with long time exposure in the model recipient were the lamellibranch Anodonta piscinalis and the chydorid cladoceran Eurycercus lamellatus.

Anodonta piscinalis was introduced into the last 2 m length of the through flow channels. The specimens used for the investigation were collected from biotopes in a similar chemical milieu to that of the water supplied to the model recipient. All the test animals were of about the same size and stage of growth. The animals were exposed for 125 days to the approximately constant concentration of the radionuclides. The accumulation of the radionuclides was measured in the body and valves of the lamellibranch. Steady state of radioelement uptake and loss was reached after one months exposure. Subsequently the level of radioactivity showed a fluctuating pattern which was ascribed to seasonal and physiological changes. Accumulation of the radionuclides in the test animals varied according to the following sequence, arranged in order of decreasing affinity:

$$P^{32} > Sr^{89} > Ce^{144} > Ru^{103} > Cs^{137} > Zr^{95}/Nb^{95}.$$

The highest accumulation observed was for P^{32} in the body and Sr^{89} in the valves.

The measured concentrations of the different radionuclides in the whole animal are listed in tables VII and VIII.

A description and discussion of the experiment with Anodonta piscinalis are given in a separate paper (12).

The population of Eurycercus lamellatus in the through flow channels was developed from organisms transported with the river water.

The habits of life of this animal, including the feeding on mainly algal food, makes it a suitable study object for the transfer of radionuclides from one level of the food chain to the next. The concentrations of the various radionuclides measured in Eurycercus lamellatus are given in tables VII and VIII.

Among the experimental objects Eurycercus lamellatus showed the highest accumulation of P^{32} and Sr^{89}.

3.5 Fish

Experiments concerning accumulation of P^{32} and Cs^{137} in young brown trout (Salmo trutta L.) and minnow (Phoxinus phoxinus) were undertaken in the well system of the experimental station. The specimens of brown trout were 7-10 cm in length, and those of minnows were 6-10 cm in length. During these experiments stagnant conditions were maintained in the concrete tanks. The fishes were kept in the radioactive water (about $1 \cdot 10^{-4}$ µC P^{32}/ml and $1 \cdot 10^{-4}$ µC Cs^{137}/ml) for 20-50 days. In one series of experiment the fishes were kept in starving condition. In another series the fishes were fed with uncontaminated food. The temperature in the water varied from 10 to 17°C during the experimental period. The number of brown trout used for the measurements was 200, and of minnows 300 specimens.

There was no significant difference in accumulation of P^{32} and Cs^{137} between the fishes which were fed and those held in starving conditions. The concentration of P^{32} in the brown trout went up to a maximum of about $4 \cdot 10^{-2}$ µC/g wet weight. In the minnows the maximum concentration was about $2 \cdot 10^{-2}$ µC/g wet weight. This means for both species that the concentration of P^{32} is about 100 - 200 times the concentration in the surrounding water. Cs^{137} was not accumulated to more than 10 times the concentration in the milieu. The experiments showed no significant difference in the accumulation of P^{32} and Cs^{137} in the two species.

The experiments with fish will be published separately (in preparation).

4. DISCUSSION

The expression "concentration factor" is in the following used for the purpose of comparing levels of radioactivity in the sampling objects with the levels of radioactivity in the surrounding water milieu. The concentration factor is defined as:

$$\frac{\text{Radioactivity per gram wet weight of object}}{\text{Radioactivity per ml water}}$$

In order to calculate concentration factors it is a presupposition that the level of radioactivity in the water is constant during the period considered, and that the elements in the water and the object is at equilibrium. Equilibrium is reached when there is a constant uptake and a constant loss with a resultant constant maximum level of radioactivity. The time required to reach equilibrium condition is different for the different objects and radionuclides. Thus in measuring the concentration factor it is necessary to know when equilibrium is reached.

The concentration factors for the various radionuclides in sampling objects derived from the experiments described in this report are given in table X.

The table shows that for the elements cesium and cerium, the uptake by clay particles is of greatest magnitude. The measured concentration factors for cesium-137 and cerium-144 in the sediments are 14.000 and 11.000, respectively.

The effect of discharge of radioactive waste, with respect to sorption to the sediments, will vary with the season and meteorological conditions., The turbidity in the water is strongly dependent on meteorological conditions, and great fluctuations from day to day have been observed.

From the laboratory experiments it was estimated that with a turbidity in the water of 100 ppm, the percentage of radioactivity associated with the clay particles would be: Cesium 45 per cent, cerium 40 per cent. During periods of high water turbidity the quantity of suspended materials in the river Nitelva was of this order of magnitude.

Laboratory experiments indicated that phosphorus was sorbed to the sediments to a great extent, however, the field experiments gave variable results. These findings may be explained by the assumption that the biota and the sediments are competing for the phosphorus. Thus in periods with a high biological activity the major fraction of the phosphorus will be accumulated by organisms in the cummunities, and contrary in periods with low biological activity the phosphorus will be sorbed to clay particles and sedimented on the river bottom.

Among the organisms, the algae showed the highest uptake of Cs^{137}, Ru^{103}, Ce^{144}, and Zr^{95}/Nb^{95}. The radioactivity measured in the algae was probably partly from radionuclides adsorbed to their extensive surface areas. In general the concentration factors of radionuclides in algae, found in the present study, are lower than reported by other investigators (13). The concentration factors for P^{32} and Sr^{89}in algae were found to be in the order of 10.000 and 1.000, respectively.

The measured concentration factors for radionuclides in vascular plants were lower than those in algae. The concentration factors for P^{32} and Cs^{137} being in the order of 100-1000 and 10-100, respectively.

The highest concentration of phosphorus and strontium was found in Eurycercus lamellatus. Concentration factors measured were 17.000 and 2.400 for P^{32} and Sr^{89}, respectively. The effect of food chain transfer of radionuclides was here demonstrated.

The lamellibranch Anodonta piscinalis showed a rather low accumulation of radionuclides.

The concentration factors measured for fish, brown trout and minnow, reflected the uptake of radionuclides directly from the water only. Higher concentration factors are to be expected if the accumulation of radionuclides occurs through the food chain.

The importance of changing environmental conditions was demonstrated by the great difference in radioactivity levels measured in the algae during the long time exposure experiments. Although the radioactivity level in the water was constant during the whole period, great variations attributed to changing environmental factors were observed. Similar variations in the radioactivity level were also found in Eurycercus lamellatus. Vascular plants and Anodonta piscinalis did not show such temporary variations.

The rate at which the organisms obtain equilibrium condition is reflected in these results. The algae which reached an equilibrium within a few hours, showed a great sensitivity to changing environmental factors. Vascular plants needed several days to reach equilibrium and were less sensitive to changes of this kind.

TABLE X

CONCENTRATION FACTORS FOR RADIONUCLIDES IN AQUATIC ORGANISMS AND BOTTOM SEDIMENTS

Experimental object	Exposure time	P^{32}	Cs^{137}	Sr^{89}	Ce^{144}	Zr^{95}/Nb^{95}	Ru^{103}
Sediments	146 days	450	14.000	500	11.000	6.000	
Algae							
Spirogyra spp.	146 days	9.000	150	900	250	400	500
Vaucheria walzii	146 days	4.000	500	1.400	1.200	1.100	3.300
Vascular plants							
Alisma plantago aquatica	7 days	50	0,5				
Callitriche verna	9 "	300					
Scirpus acicularis	9 "	100					
Elatine	7 "	175	10				
Invertebrates							
Eurycercus lamellatus	146 days	17.000	400	2.400	400	350	
Anodonta piscinalis	146 days	1.500	200	400	125	80	
Fish							
Salmo trutta L.	20-50 days	100-200	10				
Phoxinus phoxinus L.	20-50 "	100-200	10				

Strong species differences in radionuclide accumulation were apparent among the organisms used in the experiments. Of the vascular plants Callitrice verna was the specie with the highest accumulation of P^{32}. The characean Chara Braunii resembled the vascular plants in response to exposure to the radionuclides, but accumulated the radionuclides to a higher degree. Spirogyra spp. accumulated P^{32} to higher levels than Vaucheria walzii, whereas Vaucheria walzii showed the highest accumulation of the other radionuclides. This indicates that organisms related with respect to taxonomy may behave different with respect to radionuclide accumulation, whereas organisms of remote taxonomic position may behave similarly.

The chief reaction of a water course on a continuous release of low level radioactive materials will be a temporary hold-up or storage of a fraction of the radionuclides. The amount of this fraction as well as the storage time depend on the nature of the contaminates, the aquatic media present, and their abundance. A change in the hydrographical conditions will result in a corresponding change in the radioactivity level.

Based on the present investigation it is possible to point out some important aspects of monitoring practice in fresh water systems polluted with radioactive materials. These are:

1. The suspended particles of the water and the river sediments are important monitoring objects.

2. Organisms using algae as their main food source show high level of accumulation of biogenic elements.

3. Organisms which are sensitive to variations in environmental factors have to be sampled frequently after a programme based on knowledge of the variations of the hydrographical conditions.

4. Multicellular organisms, less sensitive to variations in the milieu, can be representatively monitored at long time intervals.

5. REFERENCES

1. International Atomic Energy Agency:
   Disposal of radioactive wastes into fresh water.
   Safety Series No. 10, Vienna 1963.

2. Davis, J.J. and Foster, R.F.:
   Bioaccumulation of radioisotopes through aquatic food chains.
   Ecology, 39, 530-535 (1958).

3. Morton, R.J. (edit.)
   Status Report No. 1 on Clinch River Study.
   U.S. Atomic Energy Commission, ORNL 3119 (1961).

   Ibid.:
   Status Report No. 2 on Clinch River Study
   ORNL 3202 (1962).

   Ibid.:
   Status Report No. 3 on Clinch River Study
   ORNL 3370 (1962).

4. Morgan, A., Arkell, G.M.:
   The fate of radioactive effluent discharged from A.E.R.E., Harwell, into the river Thames.
   United Kingdom Atomic Energy Authority, AERE-R 3555.

5. Williams, Louis G.:
   Uptake of cesium-137 by cells and detritus of Euglena and Chlorella.
   Limnology and Oceanography, 5, 301-311 (1960).

6. Schurr, J.M. and Stamper, M.N.:
   Model for the accumulation of strontium and calcium by recently molted crayfish (Cambarus longulus longerostris Ort.)
   Limnology and Oceanography, 7, 474-477 (1962).

7. Hutchinson, G. Evelyn and Bower, Vaughan T.:
Limnological studies in Connecticut. IX. A quantitative radiochemical study of the phosphorus cycle in Linsley Pond.
Ecology, 31, 194-203 (1950).

8. Ophel, I.L.:
The fate of radiostrontium in a fresh water community.
Radioecology. Edit. V. Schultz and A.W. Klement, Jr.
Reinhold Publishing Corporation, New York, and The American Institute for Biological Sciences, Washington D.C. (1963).

9. Templeton, W.L.:
Annual report for 1962, Radiobiology Group, Windscale Works.
PG Report 458 (W).
United Kingdom Atomic Energy Authority (1963).

10. Tüxen, Reinhold:
Mitteilungen der Floristisch-soziologischen Arbeitsgemeinschaft in Niedersachen.
Beihefte zu den Jahresberichten der Naturhistorischen Gesellschaft zu Hannover. Heft 3, p. 1-73, 1937.

11. Garder, K., Skulberg, O.:
Sorption phenomena of radionuclides to clay particles in river water. Int. J. Air Wat. Poll. (in press).

12. Garder, K., Skulberg, O.:
Radionuclide accumulation by Anodonta piscinalis Nilsson (Lamellibranchiata) in a continuous flow system.
Hydrobiologia (in press).

13. Eisenbud, Merril:
Environmental Radioactivity, p. 112-118.
McGraw-Hill, New York, 1963.

St.nr. 6396
Skulberg/KGa/MB
14.2.1964.

APPENDIX

REPORTS AND PUBLICATIONS

The experiments performed under the International Atomic Energy Agency Research Project No. 37 are described in the following reports:

First Progress Report to the IAEA	December 1959	- August 1960
Second Progress Report to the IAEA	August 1960	- June 1961
Third Progress Report to the IAEA	November 1961	
Fourth Progress Report to the IAEA	June 1961	- April 1962
Fifth Progress Report to the IAEA	April 1962	- December 1962

The following papers are intented for publications in scientific journals:

1. A hydrobiological field station used for radioecological studies (in preparation).

2. Sorption phenomena of radionuclides to clay particles in river water (Int. J. Air Wat. Poll. - in press).

3. Radionuclide accumulation by *Anodonta piscinalis* Nilsson (*Lamellibranchiata*) in a continuous flow system (Hydrobiologia - in press).

4. Radionuclide accumulation by selected species of fresh water algae in a continuous flow system (in preparation).

5. Accumulation of P^{32} and Cs^{137} by brown trout (*Salmo trutta* L.), minnow (*Phoxinus, phoxinus* L.), and perch (*Perca fluviatilis* L.) (in preparation).

6. Radionuclide accumulation by *Eurycercus lamellatus* (O.F. Müller) (*Crustacea*) through the food chain (in preparation).

7. Radionuclide accumulation by *Chara Braunii* Gemel. (*Chlorophyceae*). (In preparation).

8. An experimental investigation on the accumulation of radionuclides in a fresh water environment (in preparation).

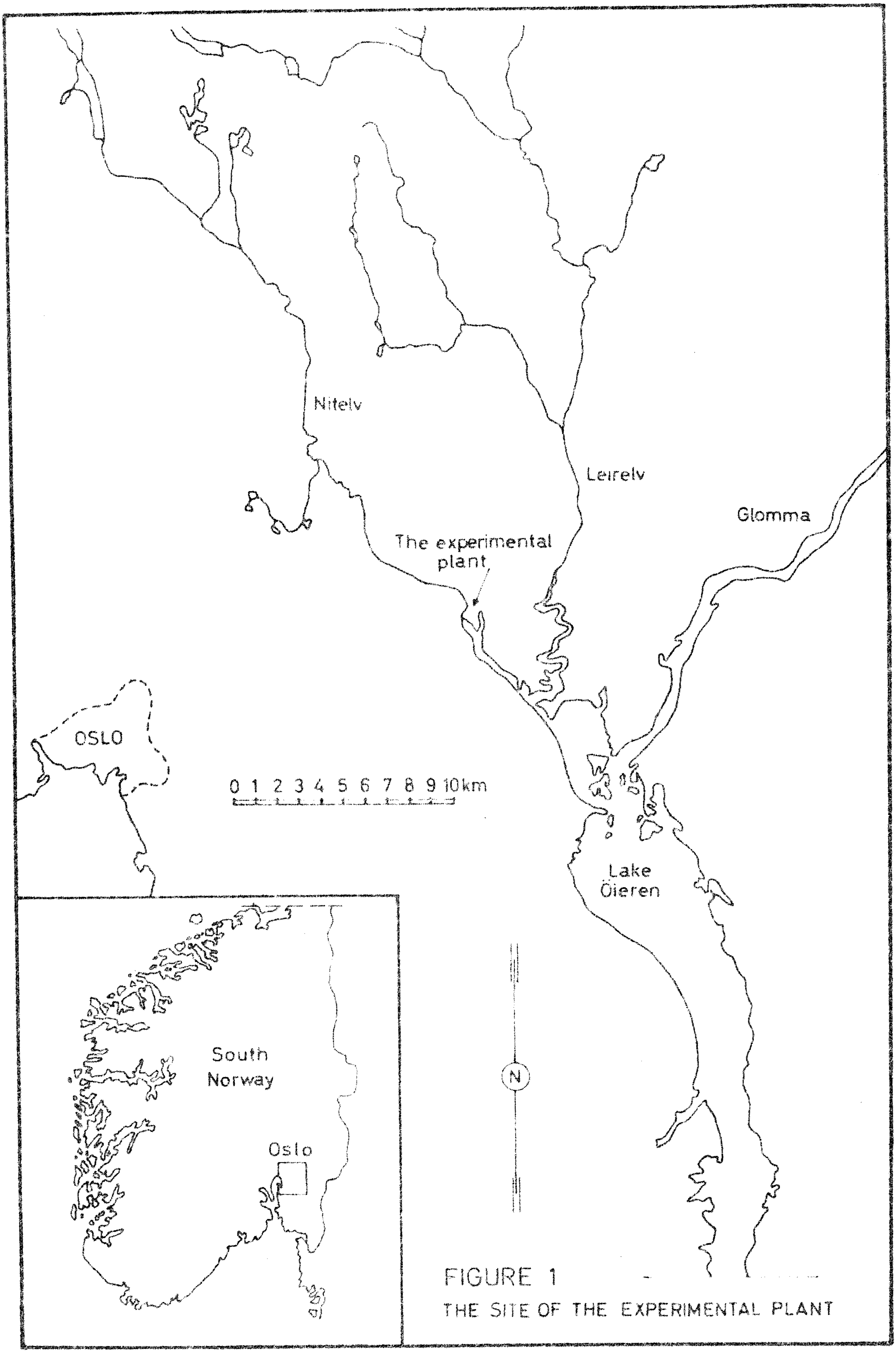

FIGURE 1

THE SITE OF THE EXPERIMENTAL PLANT

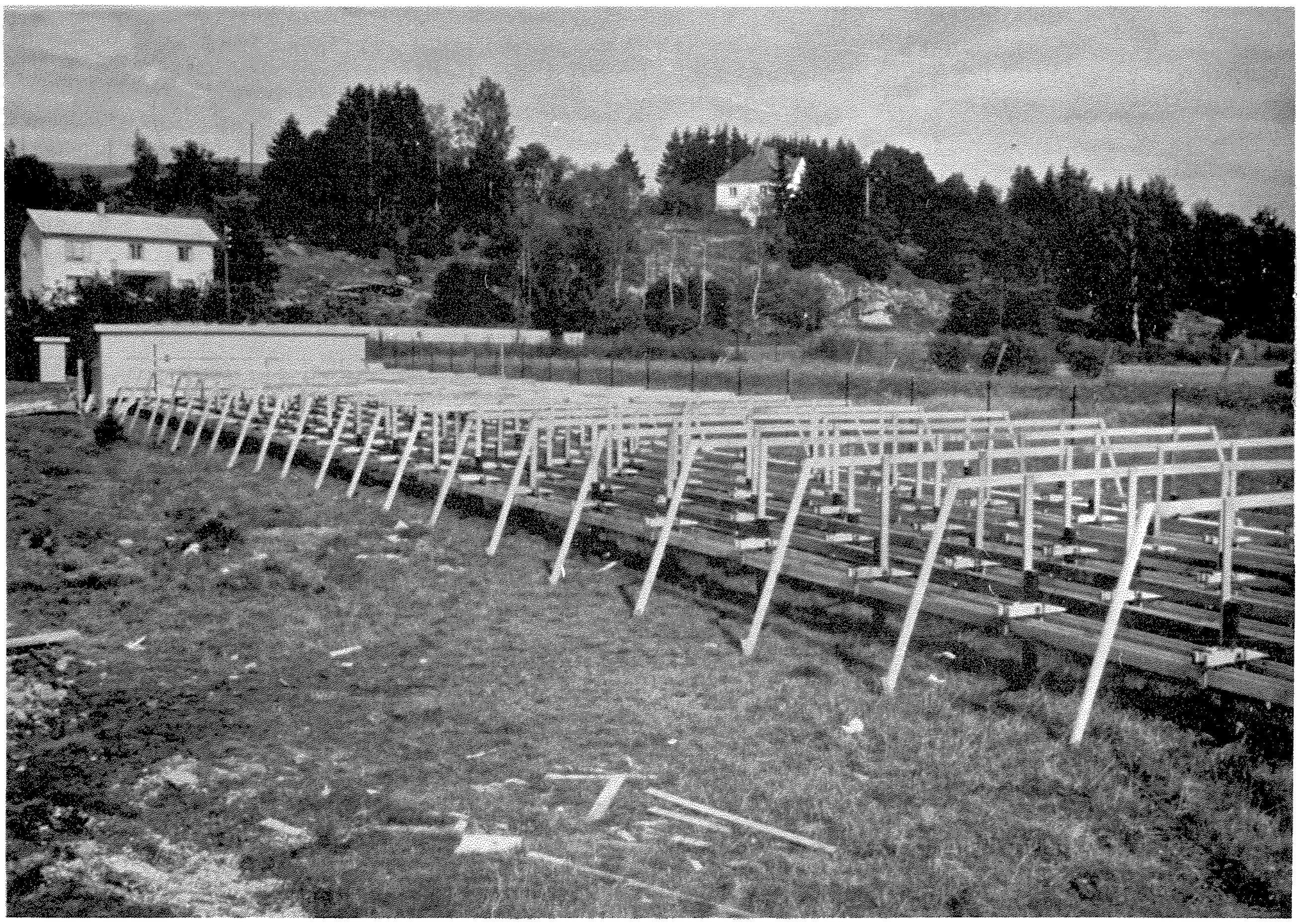

FIGURE 2

THE THROUGHFLOW CHANNEL SYSTEM OF THE MODEL RECIPIENT.

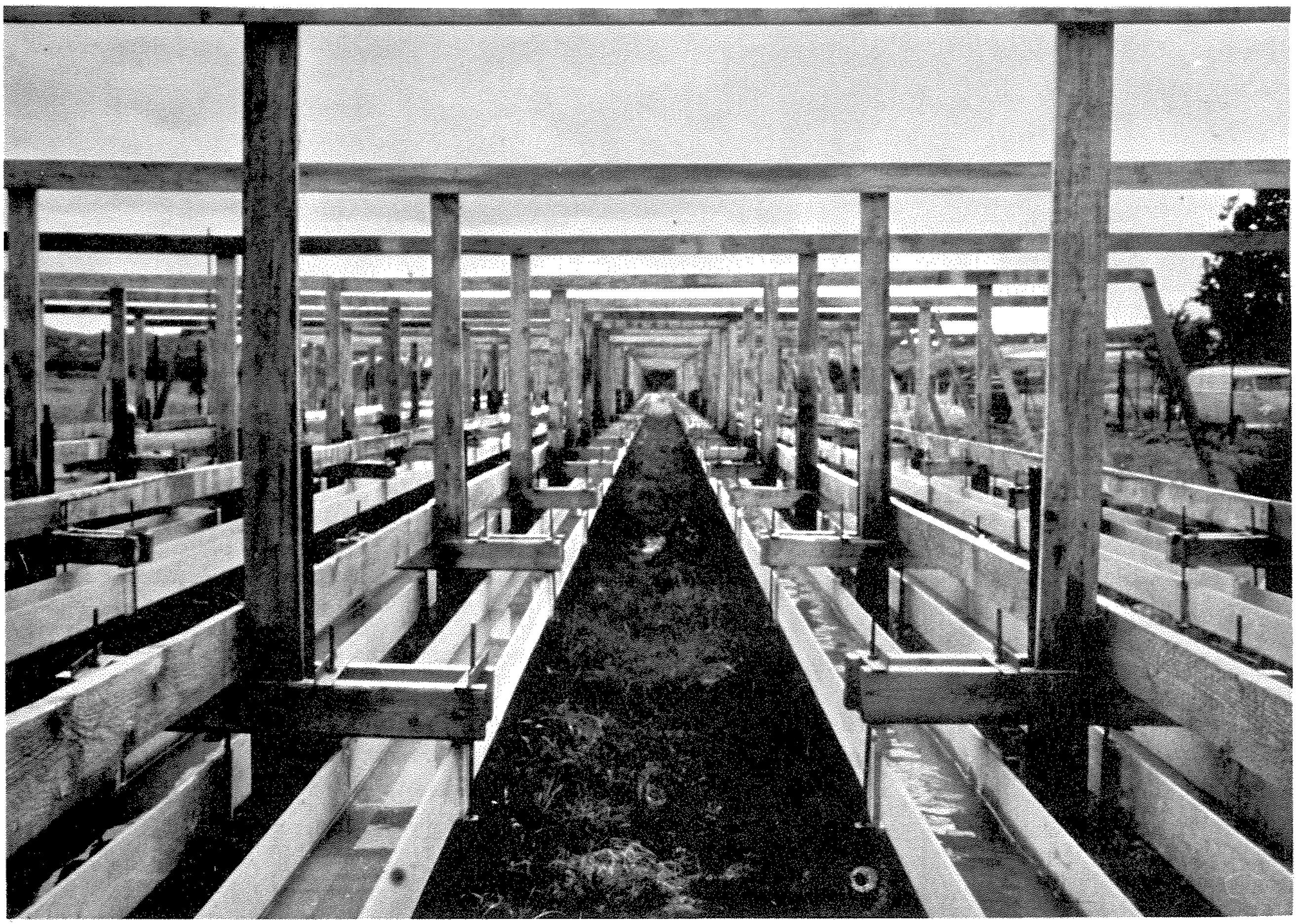

FIGURE 3

DETAILS OF THE THROUGHFLOW CHANNELS.

FIGURE 4

THE CONCRETE TANKS OF THE WELL SYSTEM.