NORWEGIAN INSTITUTE FOR WATER RESEARCH

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Progress Report Concerning International Atomic Energy Agency Research Contract No.: 37.

August 1960 - June 1961.

Report by: Cand.real. Olav Skulberg.

Foreword.

This report describes the work performed by The Institute for Atomic Energy and The Norwegian Institute for Water Research on The International Atomic Energy Agency Research Contract No. 37 in the period August 1st. 1960 - June 1st 1961.

Objectives and functional responsibilities have not changed during the time covered by this paper. With respect to the experimental plant, the physical facilities were expanded. The undertaking in the model recipient and the laboratory work has progressed essentially according to the plan for the project.

Grateful acknowledgement is expressed to The International Atomic Energy Agency for their obliging collaboration.

To Mrs. Karen Halvorsen, civ.eng. I express my gratitude for helpful assistance in editing this report.

For THE NORWEGIAN INSTITUTE FOR WATER RESEARCH

Olav Skulberg

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1. A brief review of the activities during the period.

The experimental plant was ready for operation in the autumn 1960. On August 1st water was led into the model recipient, and the first undertakings were started. The development of biota in the throughflow channels progressed satisfactorily. Collections of aquatic organisms for transplanting in the well system and the recirculation channel were carried out. Experience in their cultivation and maintenance in the experimental plant was obtained.

The introductory experiments performed resulted in several problems which had to be more closely analysed. This work continued until the onset of the winter conditions made it impossible. On November 1st. with a night temperature of -5°C, the water system in the recipient model was covered by a sheet of ice 2 cm thick. The experimental plant was then prepared for the winter conditions, and our activities retained in the laboratory.

During the winter months our interest mainly centered upon the phenomena of sediments - water - radioisotopes interrelationships. From the results obtained in the experimental plant it had become evident that this aspect of the process of turnover of radioactive materials in water must be given particular attention. A better understanding of the behaviour of radionuclides to be used in this investigation, and the special nature of transported sediments in the actual river water was necessary in order to manage practical problems during experiments with the biological systems.

Last winter's work on problems related to river water as substrate for algal growth was continued and expanded. This work consisted of measuring the amounts and availability of essential nutrient salts being intimately associated with the process of uptake and assimilation of radionuclides in protoplasm. A new method for the determination of algal growth in our cultures was developed.

The experiments with species of fish from the river Nitelv commenced in the recipient model, and was continued in aquaria in the laboratory. Several problems developed and are still to be managed.

On April 19th the experimental plant was ready for this summer's work, and water was again led into the system of channels and tanks. The plant had suffered very little from the winter conditions. During the first period of work in the experimental plant this spring considerable efforts were given to preparations for the summer programme of investigation.

The following list gives a short review of experiments performed in chronological order. Note that when organisms were used, species are referred to in the list.

1. Sorption of P^{32} by the component of particles in the river water in the recirculation channel. Selenastrum capricornutum. (August 16th, 1960).

2. Sorption of P^{32} by the component of particles in the river water in the recirculation channel and a tank (August 29th, 1960).

3. Sorption of Cs^{134} to the component of particles in the river water in a tank.(September 2nd - September 9th 1960).

4. Experiments with higher vegetation. Uptake of P^{32}. Scirpus acicularis, Juncus bufonis, Callitriche verna, Scirpus palustris and Carex gracilis (September 16th - September 21st, 1960.)

5. Calibration of the dosing pump (September 22nd, 1960).

6. Sorption of Cs^{134} to the component of particles in river water in the recirculation channel. Selenastrum capricornutum. (October 6th, 1960).

7. Calibration of the recirculation channel (October 27th - October 29th, 1960).

8. Experiments with fish and uptake of P^{32}. Rutilus rutilus and Perca fluvatilis. (October 28th - October 31st, 1960)

9. Laboratory studies of sorption of Cs^{134}, Sr^{89}, Ca^{45}, P^{32} and Ru^{106} to sediments from the river Nitelv (November 10th, 1960 - May 1st, 1961).

10. Experiments with fish and uptake of P^{32} and Cs^{134}. Phoxinus phoxinus and Salmo trutta. (February 8th - July 14th, 1961).

11. Uptake of P^{32} related to the growth of Selenastrum capricornutum. (April 23rd - May 6th, 1961).

12. Calibration of the free jet method of dosing river water to the throughflow channels (May 4th, 1961).

13. Calibration of water flow in the throughflow channels. (May 30th - June 2nd, 1961).

The experimental plant during the time covered by this report was visited by several representatives from foreign universities and research centers.

Members of our research team took part in a symposium on "Monitoring of Radiation around Atomic Energy Establishments" arranged by the European Atomic Energy Society at Risø, Denmark, during October 19th - 21st, 1960; and in the "Second Panel on Coordination of Research Contracts on Selected Topics in Radiobiology" of the International Atomic Energy Agency in Vienna, Austria, March 28th - 30th, 1961. Papers were presented on both occations.

2. The status of tthe experimental plant.

The major parts of the experimental plant are visualised in figure 1 and 2. Short explanations are given with reference to the numbers noted on the photographs.

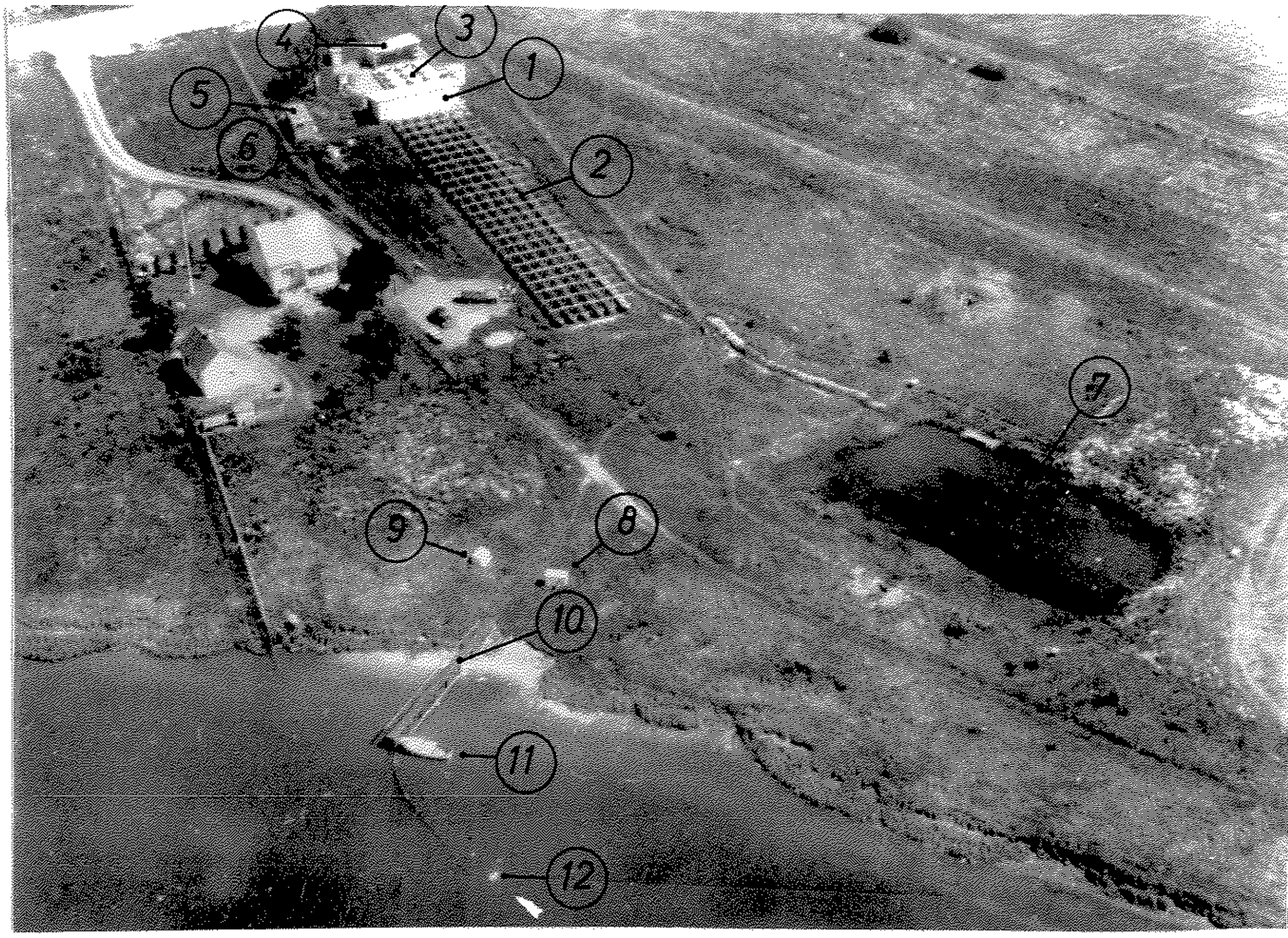

Figure 1. Aerial view of the experimental plant.

1. The control building.
2. The channel system.
3. The well system.
4. The shed (used for sorting of biological materials).
5. The hut (used for field laboratory work).
6. The stand (for meteorological instruments)
7. The retention pond.
8. The shelter (for the centrifugal pump).
9. The shelter (for the outboard motor and the gasoline).
10. The dock.
11. The boat.
12. The location of the water intake point.

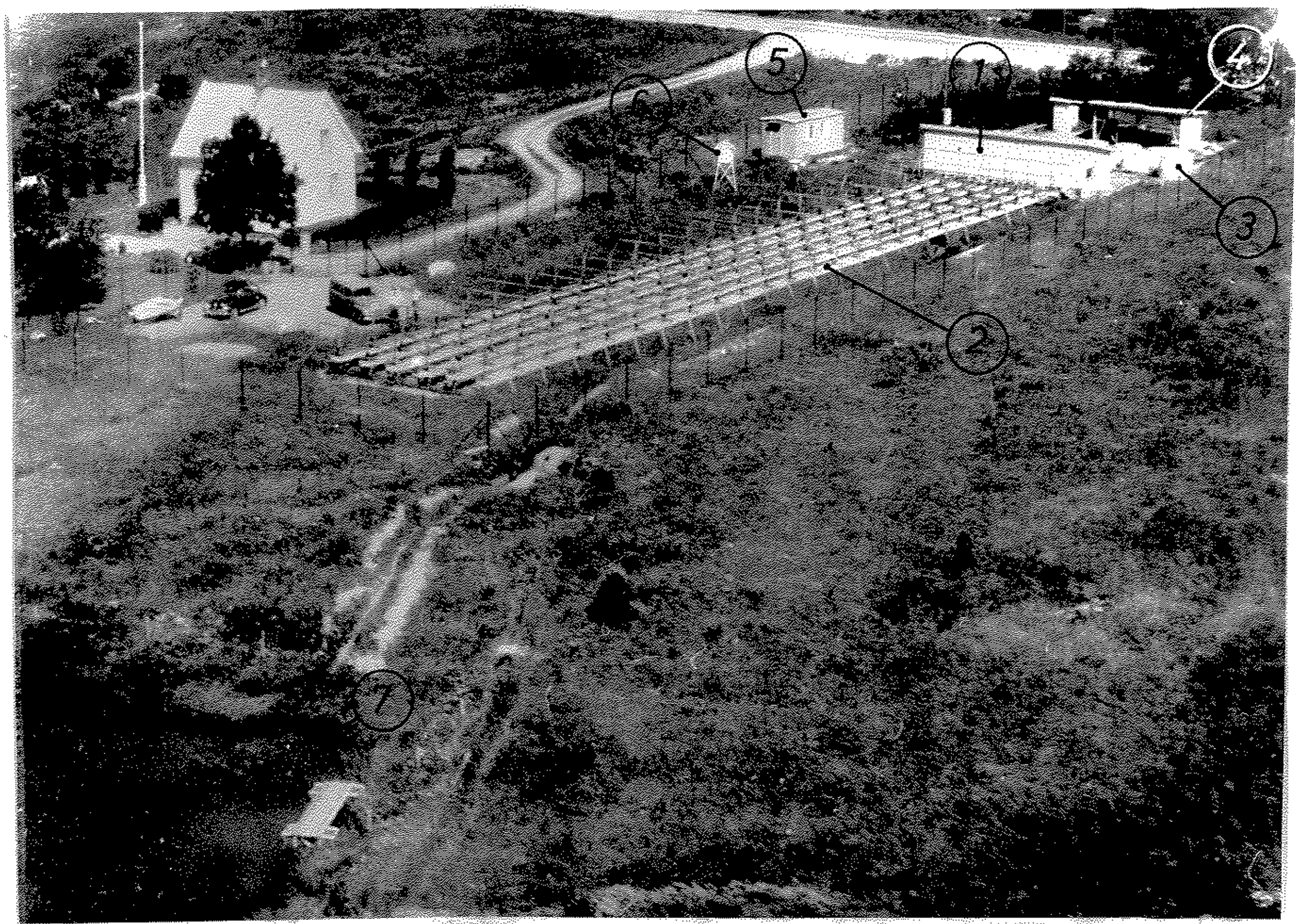

Figure 2. Aerial view of the channel system.

Some new installations have been made during the period reported. The extreme precipitation last summer showed that a weather shield for the sorting of biological materials would be expedient. For this reason the shed shown in figure 3 was built.

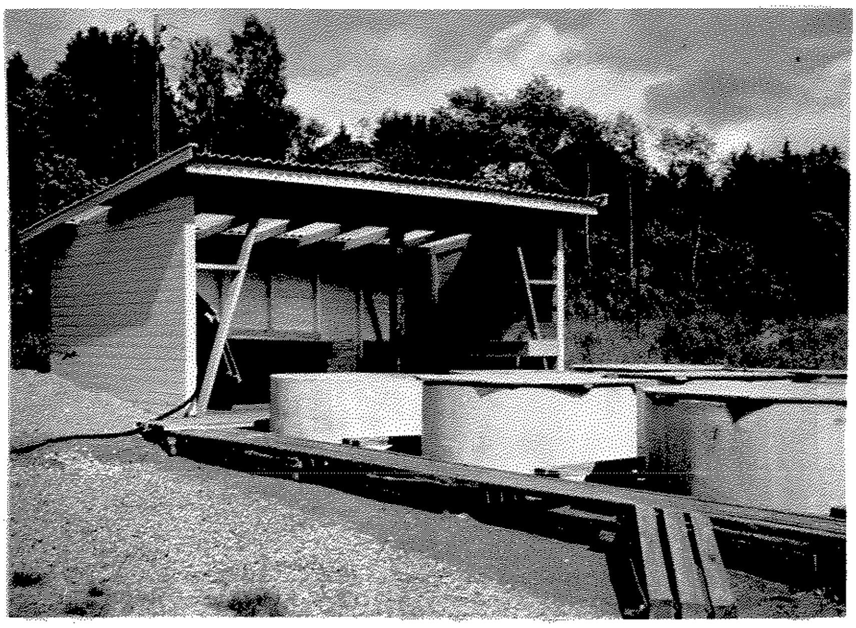

Figure 3. The weather shield.

In order to be able to discribe the weather conditions during experiments in the model recipient, the necessary instruments were procured. The meteorological instruments were placed in position according to Document 76 from The Commission for Climatology of the World Meteorological Organization, London, December 1960.

The critical assumption for the design of the model recipient was that communities of river biota would develop and prosper in the channel system. The first few weeks after the undertakings in the model recipient were commenced, we experienced that no difficulty existed in this respect. We had the opportunity to observe the beginning of community development with pioneer stages and to follow the replacement of these organisms by new ones, until a relatively stable community was established. It proved to be of great importance that the channels were constructed as long as 120 m from end to end. Longitudinal zonation of communities was then very prominently demonstrated. Examples of the visual impression of the communities in the channels are given in the following figures 4 and 5. A few comments will be given. Each of the pictures show sections of the throughflow channels lying almost at the starting point (right side) and at the end of the respective channels chosen for this demonstration. The conspicious difference of the communities developed in these sections represents stages of the change in water quality attributed to the self-purification process. The discharge of river water to the channels has a considerable effect on the orderly process of community change induced. A river water dose of 0,1 liter/sec for example (figure 4) gave rise to an organism developement which changed the nutrient conditions in the water from a rather eutrophic nature at the inlet to an oligotrophic nature in the outlet of the respective channel.

The sampling of the biological materials for the radiochemical analysis has proved to be laborious, but of no practical difficulty when major organisms in the communities are concerned.

Figure 4. Channel biota. Discharge of water 0,1 liter/sec.

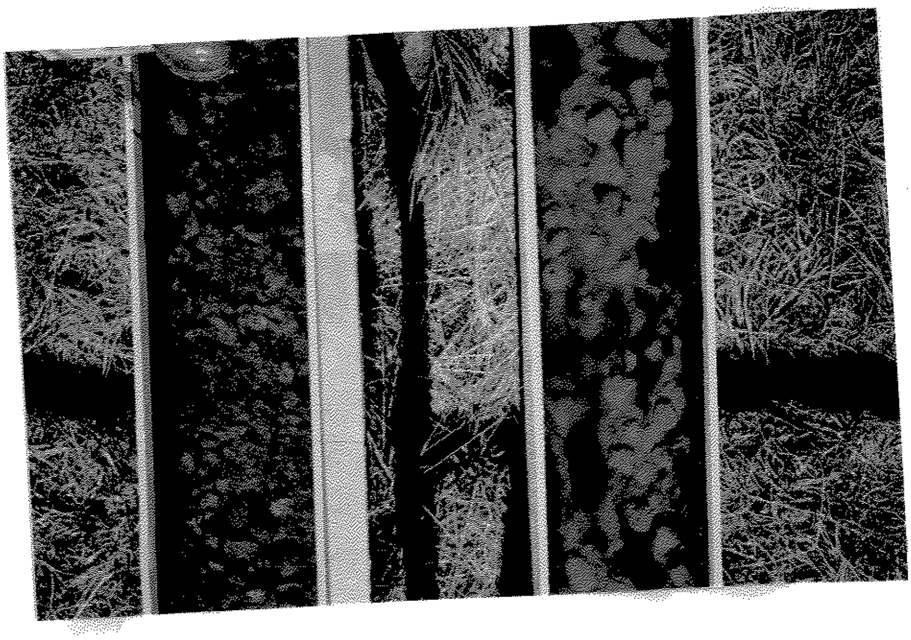

Figure 5. Channel biota. Discharge of water 0,5 liter/sec.

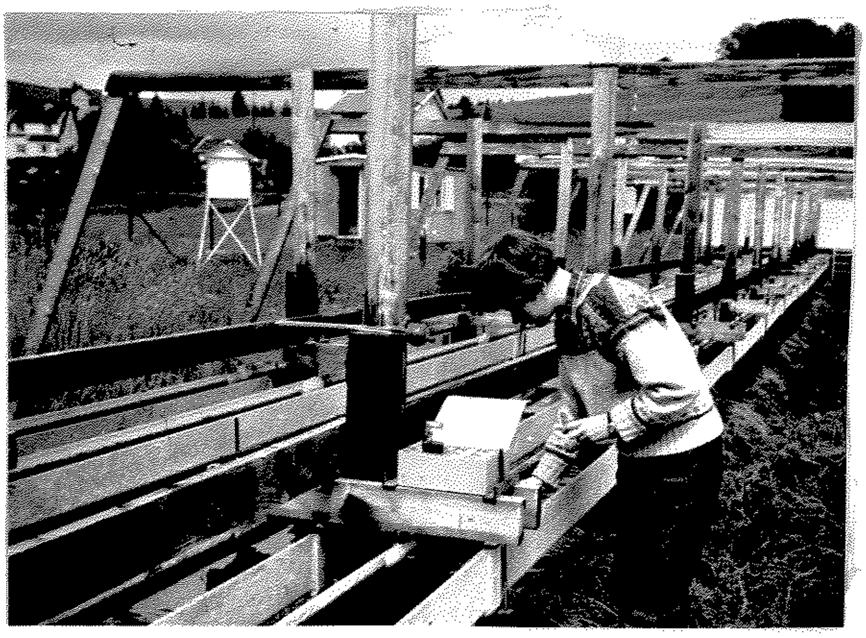

Figure 6. Collecting biological samples in a throughflow channel.

3. Descriptive classification of milieu and objects. The use of some terms.

In the literature on the concentration of radioactivity by natural agents in the aquatic environment, there seems to be a lack of agreed terminology on the systems involved. We found it helpful to outline some of the objects and processes with which the phenomenon is associated.

A river may be regarded as composed of two main sections, the river bottom and the free water masses.

The river bottom.

The river bottom is worked out by the running water in the geologic substratum, but besides erosion, sedimentation and biological activity are important in the process. The following division of the river bottom into categories may be chosen:

A. Exposed areas of the geological formation, rocks and primary sediments.

B. Recent sedimentated materials of mineralogenic and organic nature (secondary sediments).

C. Communities of benthic organisms.

These three categories are regionally in complex distribution.

The free water masses.

The composition of the free water masses may be expressed as per the following categories:

D. The liquid component - a true solution of salts and organic compounds in water.

E. The gaseous component - the same gases as in the air, but in other quantitative proportions.

F. The component of particles - which are of mineral-ogenic and organic nature, composed of the following fractions:

a. Filtrable particles, i.e. colloids of inorganic and organic origin.

b. Not filtrable particles, i.e. inorganic substances and detritus.

c. The organisms, i.e. plankton and nekton.

Between the two river sections, the free water masses and the river bottom, there is a close interrelationship. Examples of these interrelationships are that substances are mutually exchanged, organisms having their sessile stage in one section have their mobile stage in the other section, and processes which are altering one of the sections will influence the other section.

On a larger scale there is an analogous close mutual relationship between the river, the landscape and the atmosphere. Radioactive wastes disposed in a watercourse will be effected by mechanisms operating in the river which may result in reconcentration of radioactive substances by a factor greater than the dilution and dispersion achieved. The many complex mechanisms responsible for this reconcentration are of physical, chemical and biological nature. Some of the most important processes in this connection are listed here, with a brief explanation.

Abiotic.

Sedimentation: Concerns discrete particles settling out of the river water.

Flocculation: The aggregation of particles into small lumps.

Precipitation : The separation of a substance being in state of solution into a solid state.

Sorption : The transfer by any mechanism of ions or molecules from the solution to the component of particles in the free water masses or the respective categories of the river bottom.

Biotic.

Uptake : The entry of ions, molecules or particles into cells, tissues or organs by any mechanism.

Combination : The entering og ions of molecules into the formation of components of protoplasm.

Accumulation : The net result of the processes of uptake and loss of ions or molecules by the organism or its differnt parts at a given moment.

Transport : The mechanisms dependent on metabolism which moves ions or molecules through tissues or from one organism to another in the food chain.

It is desirable to investigate these different processes with respect to each radioelement and evaluating their relative importance. From the standpoint of radiological health the biological concentration is of intrinsic interest. The biological radioelement reconcentration is particularly responsible for the transference of radioelements from the environment into the protoplasm of man. But all the different processes operating represent a complex functioning pattern, and it is therefore difficult to separate them from each other. It is not possible to study one of the processes without taking consideration to the whole complex of phenomena.

There are three principal combinations which have to be considered:

G. Radioelements with the river water.
H. Radioelements with the categories of the free water masses.
I. Radioelements with the categories of the free water masses and the river bottom.

The first combination, and in part the second one, are most conveniently studied in the laboratory. The third combination on the contrary is nearly only approachable for investigations in a model recipient. Here it is possible to carry out experiments with representative communities or organisms under conditions which resemble closely the situation in nature. The factors of the environment in the model recipient are either controllable or subject to measurement.

4. Flow rate and flow pattern studies.

Several experiments were performed to measure volumes and velocities of the water in the model recipient. Radioisotopes have found an extensive use in this connection, and they have made the work both easier and more accurate.

The apparatus used for the addition of river water to the throughflow channels and the recirculation channel have been calibrated. Data in table 1 show that the free jet method suits its purpose. Our experience so far, indicates that the constructed apparatus operates well and only seldom needs adjustment.

The movement of the water masses in the recirculation channel is fairly well understood after the experiments using the beta-emitting isotope P^{32}. The measurement of radioactivity was performed with a Geiger-Müller counter of the "dip" type directly immersed in the channel.

An example from a typical experiment of this kind is given in figure 7. During this particular experiment the water level in the recirculation channel was 10 cm, and the paddle moved with 25 revolutions per minute. Within a fraction of a second P^{32} was given to the water in the recirculation channel at a particular point. The mode of progression of the wave with radioactivity as it passed round the recirculation channel was followed with the counting equipment. The observations are represented in the curves of count per minute (see figure).

1. The dosing of the radioisotope has just been done. The circulation of the substance is marked with distinct maxima on the counting curves.

Table 1.

Calibration of the free jet dosing of water to the channels.

Numbers indicate liter/sec.

Channel	Theoretical value 0,75			Theoretical value 0,75			Theoretical value 0,50			Theoretical value 0,50		
	Observed values		Average values	Observed values		Average values	Observed values		Average values	Observed values		Average values
No. 1	0,76	0,76	0,76	-	-	-	0,50	0,50	0,50	-	-	-
No. 2	0,74	0,74	0,74	0,77	0,76	0,77	0,50	0,50	0,50	0,51	0,53	0,52
No. 3	0,77	0,77	0,77	0,77	0,78	0,77	0,51	0,51	0,51	0,53	0,54	0,54
No. 4	0,76	0,76	0,76	0,78	0,79	0,78	0,51	0,51	0,51	0,53	0,53	0,53
No. 5	0,78	0,79	0,78	0,80	0,80	0,80	0,53	0,53	0,53	0,54	0,54	0,54
No. 6	0,79	0,79	0,79	0,79	0,78	0,78	0,51	0,51	0,51	0,52	0,52	0,52

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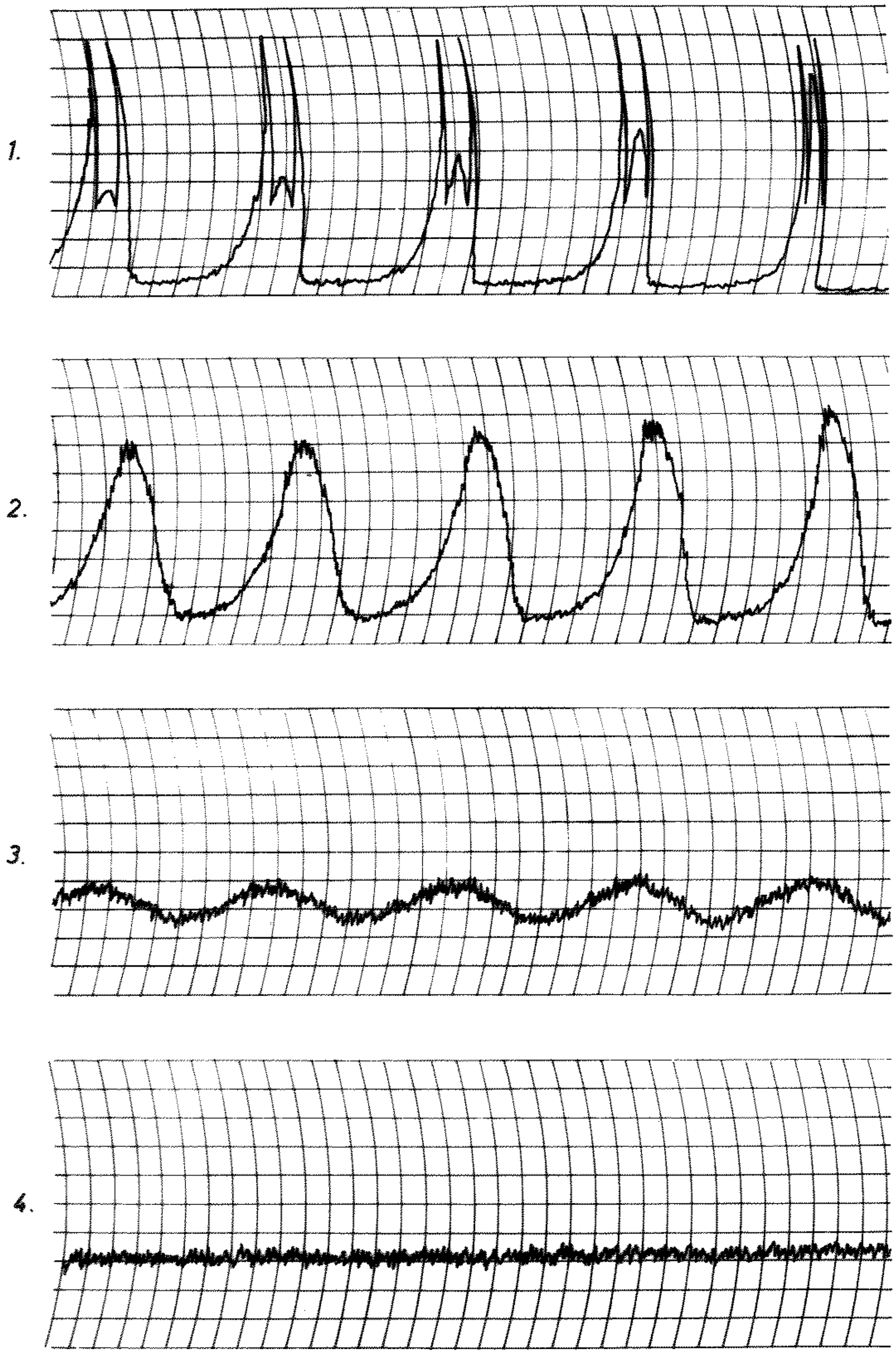
Example from the calibration of the recirculation channel.



Explanation see text.

FIGURE 8.

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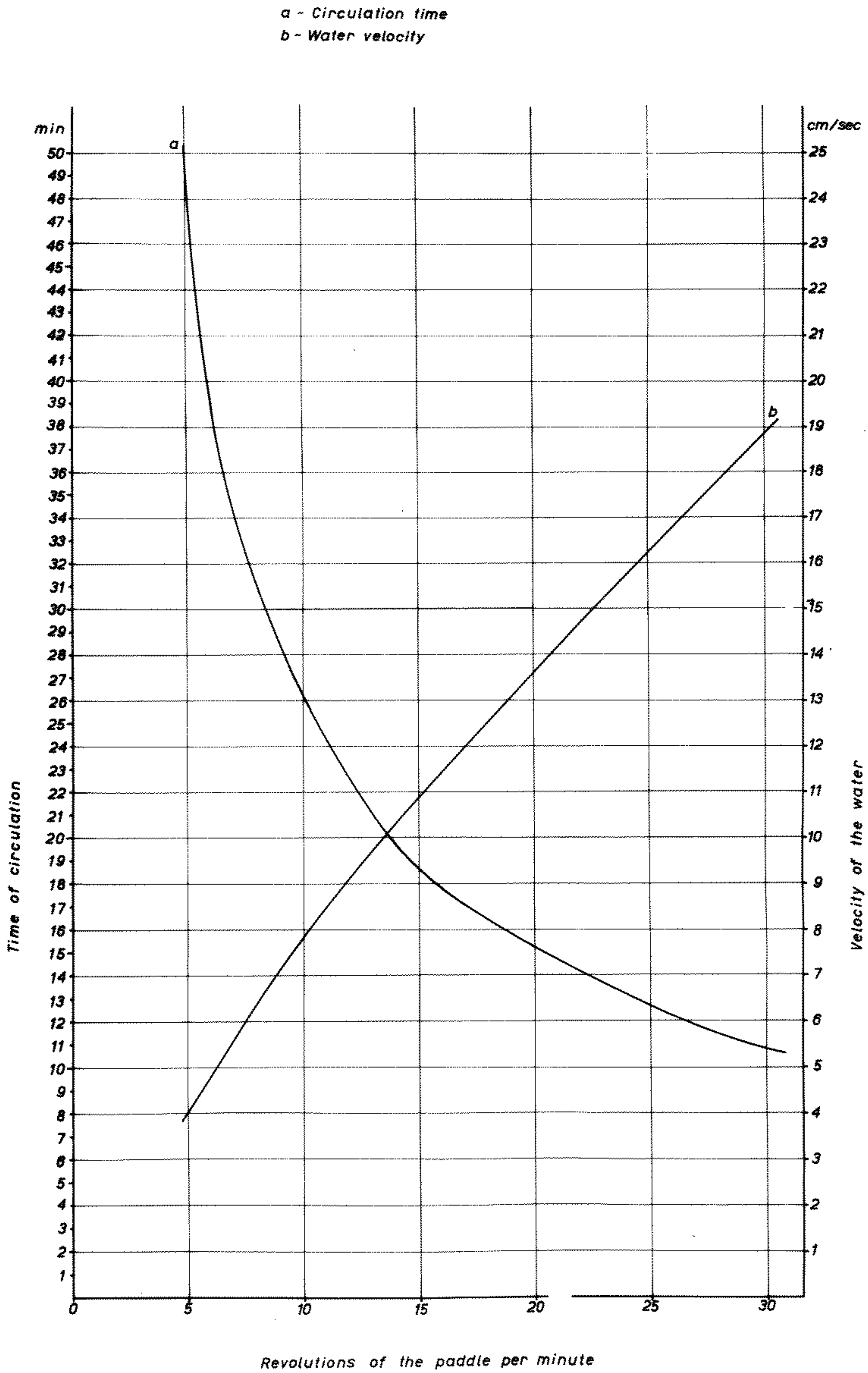
The recirculation channel.



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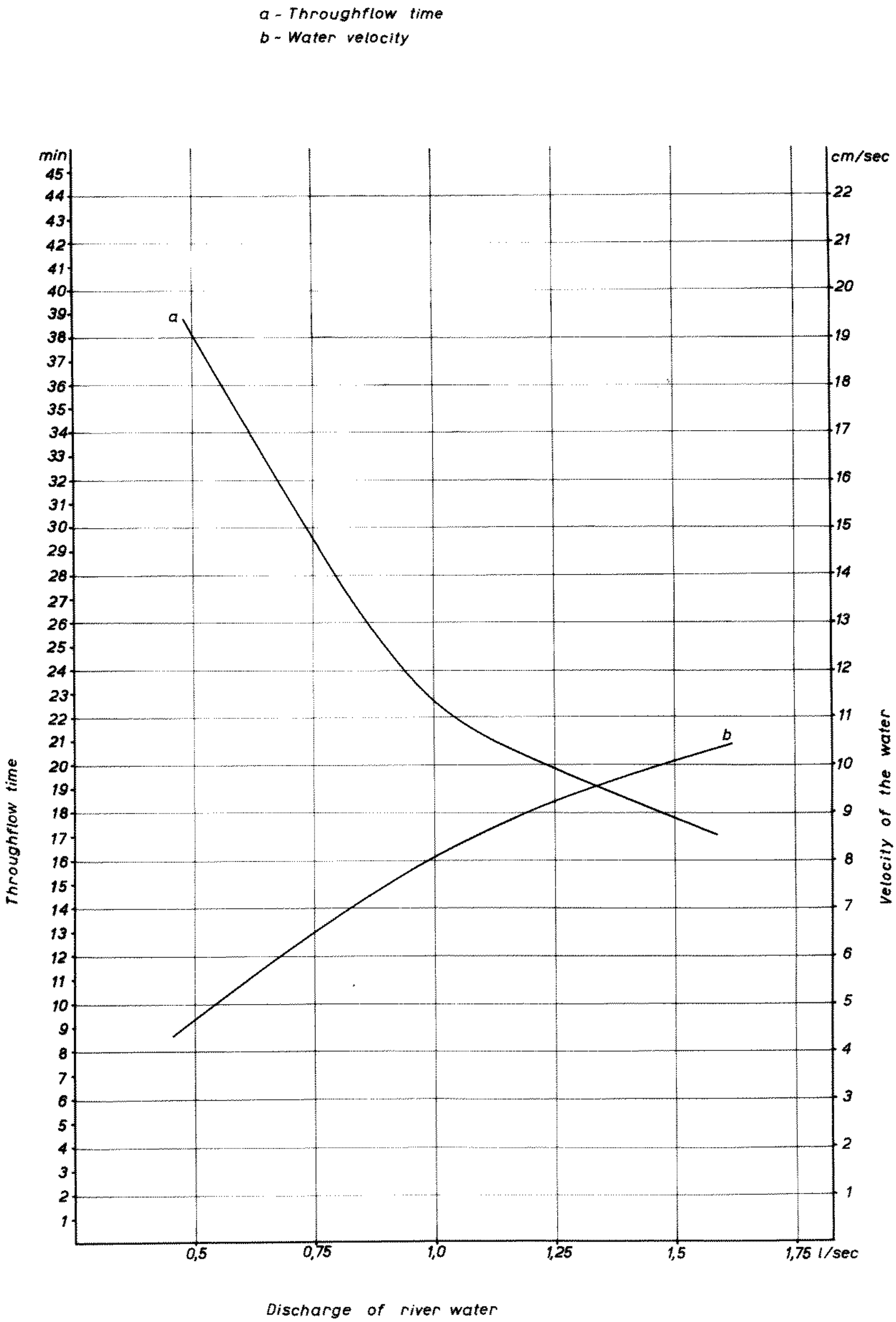
The throughflow channels.



NIVA 1961

2. Approximately five hours have elapsed, and the passing of radioactivity through the channel shows more drawn out maxima.
3 and 4. Further process in the process of mixing the water massed leads gradually to homogenous conditions. Radioactivity is raised to a constant level higher than natural background.

We gained the useful information that under this set of conditions more than twenty hours are needed before total mixing of the water masses is realized.

Circulation time and water velocities in the recirculation channel are represented in figure 8.

Flow measurements in the throughflow channels were also performed according to the total - count principle. A finite quantity of radiotracer was mixed in the flowing water. With the aid of a counter fixed some distance below the starting point the tracer while it passed was registered.

The results of this calibration of the troughflow channels are given in figure 9. Some divergence on the diagram from the theoretical values are still to be analyzed, but the use of this technique for these measurements has proved its definite advantage.

5. <u>The retention pond</u>.

All the water from the experimental plant containing radioactive substances is led into a pond before it is discharged to the nearby river. A detailed journal of the quantities and nature of radioisotopes used in the experimental plant is maintained.

The pond is an artificial pool located in the clay sediments which predominates the ground in the area. The age of the pond is approximately 18 years. A rather stable community of organisms in the series of the aquatic succession has been established. The flora and fauna are rich in species.

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Bathygraphical map of the pond.

Equidistance of depth curves 0,1m.

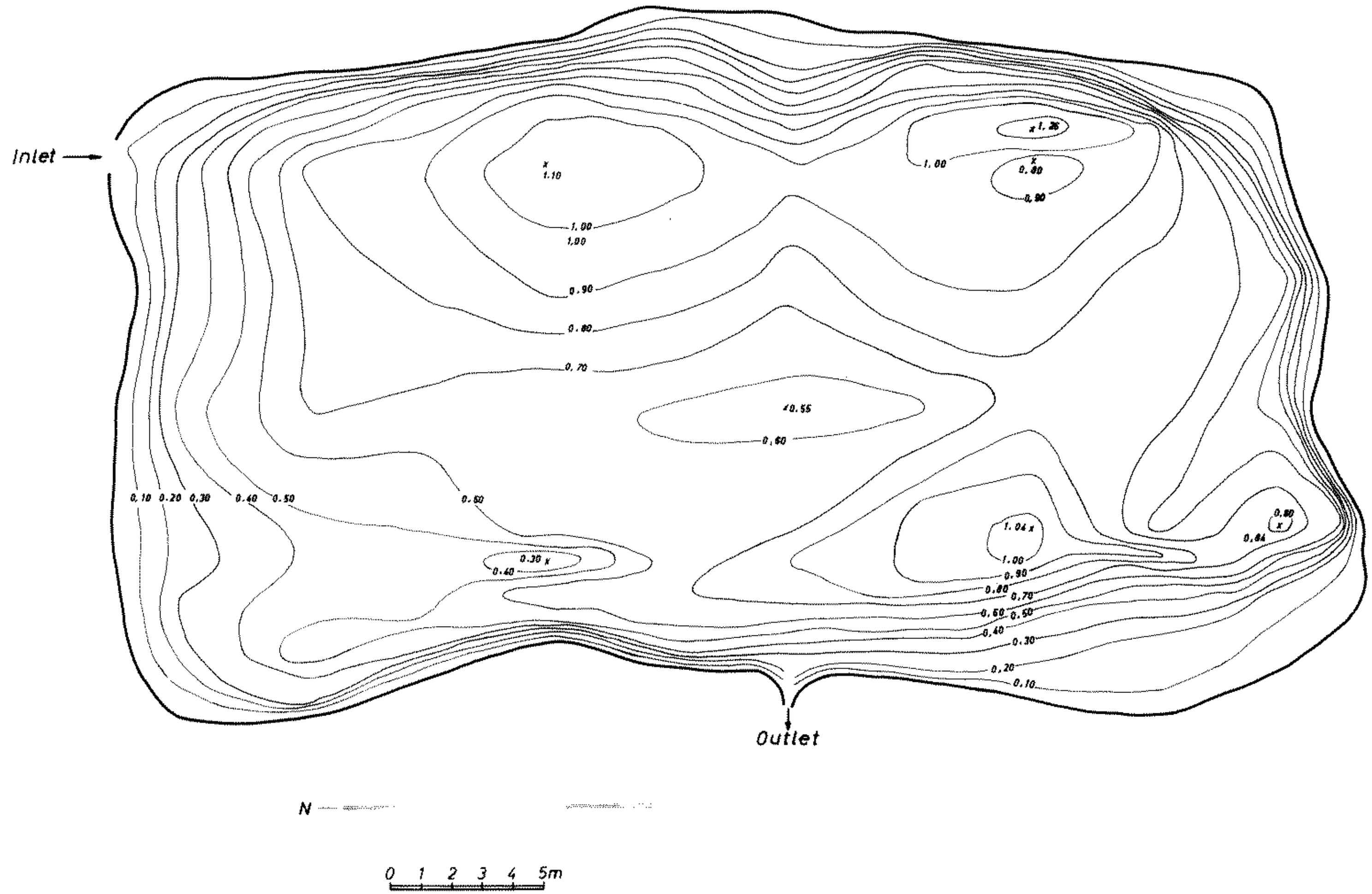

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FIGURE 10.

It has been planned in the present investigation to include a close study of the biota of the pond, and to describe the change of contamination level in the water in responce to biological activity. Apparently, the determination of variation in the level of radioactivity of the chief components in the communities will give information about the availability of some of the radioisotopes to food webs in the pond. We are particularly interested in how the plants may act as reservoirs for radionuclides, holding them in the biomass and releasing them to herbivores and water.

During the present period of work, background measurements of natural radioactivity was performed for some of the more important species. A bathygraphical map is constructed (see figure 10). Precise information, qualitative and quantitative, about the plant communities and associations being gathered will be recorded on the map. The vegetation map serves as a basis for the faunistic description.

6. Experiments with fish in laboratory aquaria and in the well system of the model recipient.

Data available at present in the literature on uptake and re-concentration of the radioactive material by fish are of a more preliminary nature. The different findings reported indicate that considerable variation in accumulation takes place according to the species of fish and the environmental factors such as chemical milieu, season, availability of desirable food and turbidity. Extensive studies are therefore necessary on a wide range of biotopes under different climatic conditions, in order to get a clearer understanding of this important problem.

The experiments with fish in this project will include three modes of administering radioisotopes to the animals.

A. The radioactive substance is added directly to the water in the aquaria. The fish receives no food during the time of experiments.

B. The radioactive substance is added directly to the water in the aquaria. The fish receives un-contaminated food during the time of experiment.

C. The uptake of radioactive substance is realized through feeding with contaminated food, and is similar to the mode of transfer of radioisotopes from food organisms to fish in the food chain.

These three procedures have been tried in preliminary experiments. So far the indication is that only the second and the third mode may give a reasonably consistent concentration of radioactivity in the fish. The work so far performed, mainly involved studies of the immediate dosing type (A).

Table 2 shows the species and numbers of individuals used for the experiments.

Table 2. Fish used in the experiments.

Rutilus rutilus	6
Phoxinus phoxinus	64
Perca fluviatilis	16
Salmo trutta	8

A report on the studies of the uptake of P^{32} and Cs^{134} from low level concentrations in the water to Phoxinus phoxinus will here be given. The fish were kept in four glass-aquaria containing 23 liters of water each, and in two tanks in the well system of the model recipient, each having a volume of 500 liters of water. After the admixture of the respective isotopes, the water of the aquaria and the tanks were maintained in stagnant condition. Air was bubbled through the water in the aquaria via a pump. The test animals represented healthy stocks and were in advance accustomed to their special environment.

The duration of the exposure varied between 15 - 30 days. At different days during the exposure time, samples of fish were taken for determination of radioactivity. Each specimen was dissected and separated into the following parts: The skin from half of the body, the muscles from half of the body, the viscera and the remaining parts. The different fractions were

Table 3. Specimens of Phoxinus phoxinus used for the experiments with uptake of P^{32}.

February 8 - 24, 1961.

Denotation:	Sample analyzed:	Wet weight(a) g	Dry weight(b) g	Ash weight(c) g	$\frac{c}{b} \cdot 100$ %	$\frac{c}{a} \cdot 100$ %
1 P 13/2 1961	Skin	0,1742	0,0435	0,0032	7,35	1,84
	Viscera	0,9095	0,2609	0,0124	4,75	1,36
	Muscles	0,8574	0,1865	0,0119	6,38	1,39
	Remaining parts	3,4821	0,8432	0,1529	18,10	4,40
2 P 13/2 1961	Skin	0,2461	0,0537	0,0041	7,65	1,67
	Viscera	1,2110	0,3514	0,0170	4,85	1,40
	Muscles	1,0884	0,2265	0,0148	6,52	1,36
	Remaining parts	3,7861	0,8751	0,1517	17,30	4,00
1 P 20/2 1961	Skin	0,1877	0,0435	0,0046	10,60	2,45
	Viscera	0,8267	0,2329	0,0132	5,66	1,59
	Muscles	0,8165	0,1704	0,0136	7,95	1,67
	Remaining parts	3,0386	0,6714	0,1329	19,80	4,36
2 P 20/2 1961	Skin	0,2580	0,0543	0,0059	10,80	2,28
	Viscera	1,7464	0,4763	0,0260	5,46	1,49
	Muscles	0,9236	0,1802	0,0150	8,32	1,63
	Remaining parts	3,6971	0,8078	0,1734	21,40	4,70
1 P.1 24/2 1961	Skin	0,1866	0,0516	0,0042	8,15	2,25
	Viscera	0,3831	0,0978	0,0070	7,15	1,83
	Muscles	1,0456	0,2340	0,0166	7,09	1,59
	Remaining parts	3,4592	0,8641	0,1631	18,90	4,72
2 P.1 24/2 1961	Skin	0,1851	0,0375	0,0048	12,80	2,59
	Viscera	0,2217	0,0453	0,0036	7,95	1,63
	Muscles	0,5704	0,1008	0,0109	10,82	1,91
	Remaining parts	2,5193	0,5077	0,1338	26,30	5,32
1 P.2 24/2 1961	Skin	0,1533	0,0343	0,0031	9,05	2,02
	Viscera	0,7928	0,2019	0,0130	6,44	1,64
	Muscles	0,9190	0,1853	0,0147	7,94	1,60
	Remaining parts	3,0231	0,6758	0,1349	19,95	4,45
2 P.2 24/2 1961	Skin	0,3279	0,0631	0,0059	9,35	1,80
	Viscera	2,3676	0,6854	0,0352	5,13	1,49
	Muscles	1,2830	0,2449	0,0257	10,50	2,00
	Remaining parts	4,3948	0,9291	0,1967	21,18	3,47

Table 4. Specimens of Phoxinus phoxinus used for the experiments with uptake of Cs^{134}.

February 8 - 24, 1961.

Denotation:	Sample analyzed:	Wet weight(a) g	Dry weight(b) g	Ash weight(c) g	$\frac{c}{b} \cdot 100$ %	$\frac{c}{a} \cdot 100$ %
1 Cs 13/2 1961	Skin	0,4261	0,0984	0,0082	8,30	1,92
	Viscera	1,6581	0,4847	0,0233	4,80	1,40
	Muscles	1,3760	0,3093	0,0208	6,90	1,52
	Remaining parts	5,4205	1,3134	0,2126	16,25	3,72
2 Cs 13/2 1961	Skin	0,2340	0,0512	0,0036	7,04	1,54
	Viscera	1,1503	0,2811	0,0155	5,50	1,35
	Muscles	1,0472	0,2066	0,0157	7,64	1,50
	Remaining parts	4,2543	0,9850	0,1714	17,40	4,00
1 Cs 20/2 1961	Skin	0,1790	0,0419	0,0042	10,10	2,34
	Viscera	0,3377	0,0761	0,0062	8,14	1,83
	Muscles	0,8033	0,1706	0,0124	7,25	1,54
	Remaining parts	3,3065	0,8049	0,1520	18,90	4,55
2 Cs 20/2 1961	Skin	0,1121	0,0226	0,0029	11,80	2,59
	Viscera	0,5010	0,1258	0,0071	5,65	1,43
	Muscles	0,5605	0,1160	0,0090	7,76	1,61
	Remaining parts	2,1109	0,4441	0,0918	20,60	4,35
1 Cs.1 24/2 1961	Skin	0,1895	0,0430	0,0048	11,15	2,54
	Viscera	0,4411	0,0944	0,0076	8,05	1,72
	Muscles	1,0263	0,2058	0,0174	8,45	1,70
	Remaining parts	4,3773	0,9528	0,2055	21,55	4,69
2 Cs.1 24/2 1961	Skin	0,2599	0,0545	0,0055	10,10	2,12
	Viscera	0,9736	0,2023	0,0135	6,67	1,39
	Muscles	1,0107	0,1984	0,0171	8,63	1,69
	Remaining parts	3,7383	0,7738	0,1530	19,28	4,10
1 Cs.2 24/2 1961	Skin	0,1947	0,0419	0,0041	9,78	2,10
	Viscera	0,3424	0,0752	0,0055	7,32	1,61
	Muscles	0,9523	0,1923	0,0152	7,90	1,60
	Remaining parts	3,9038	0,8746	0,1851	21,19	4,75
2 Cs.2 24/2 1961	Skin	0,1598	0,0393	0,0039	9,92	2,44
	Viscera	0,3484	0,0796	0,0060	7,54	1,72
	Muscles	0,9905	0,2140	0,0151	7,05	1,52
	Remaining parts	3,4182	0,8363	0,1529	18,29	4,47

Table 5.

Conditions in the aquaria during the experiments with *Phoxinus phoxinus*. February 8 - 24 1961. Aquaria contaminated with P^{32}.

Date:	Number:	Turbidity mg/l SiO_2	Radioactivity on the particles $\mu c/ml$	Radioactivity in the water $\mu c/ml$
8/2 1961	1	6,2	$0,45 \cdot 10^{-4}$	$8,9 \cdot 10^{-4}$
	2	6,2	$0,80 \cdot 10^{-4}$	$7,9 \cdot 10^{-4}$
9/2 1961	1	3,5	$0,61 \cdot 10^{-4}$	$9,1 \cdot 10^{-4}$
	2	3,5	$0,57 \cdot 10^{-4}$	$8,5 \cdot 10^{-4}$
10/2 1961	1	6,8	$0,44 \cdot 10^{-4}$	$8,0 \cdot 10^{-4}$
	2	5,8	$0,51 \cdot 10^{-4}$	$7,7 \cdot 10^{-4}$
13/2 1961	1	4,0	$0,73 \cdot 10^{-4}$	$8,3 \cdot 10^{-4}$
	2	6,2	$0,98 \cdot 10^{-4}$	$7,35 \cdot 10^{-4}$
14/2 1961	1	6,4	$1,08 \cdot 10^{-4}$	$7,85 \cdot 10^{-4}$
	2	6,1	$0,55 \cdot 10^{-4}$	$7,60 \cdot 10^{-4}$
15/2 1961	1	9,2	$0,77 \cdot 10^{-4}$	$7,50 \cdot 10^{-4}$
	2	8,8	$0,74 \cdot 10^{-4}$	$7,60 \cdot 10^{-4}$
16/2 1961	1	12,0	$1,42 \cdot 10^{-4}$	$7,70 \cdot 10^{-4}$
	2	7,0	$0,82 \cdot 10^{-4}$	$7,45 \cdot 10^{-4}$
17/2 1961	1	6,4	$0,68 \cdot 10^{-4}$	$7,90 \cdot 10^{-4}$
	2	6,3	$0,64 \cdot 10^{-4}$	$7,20 \cdot 10^{-4}$
20/2 1961	1	5,0	$0,83 \cdot 10^{-4}$	$7,70 \cdot 10^{-4}$
	2	6,0	$0,81 \cdot 10^{-4}$	$7,40 \cdot 10^{-4}$
22/2 1961	1	-	$1,10 \cdot 10^{-4}$	$7,75 \cdot 10^{-4}$
	2	-	$0,97 \cdot 10^{-4}$	$7,40 \cdot 10^{-4}$
24/2 1961	1	-	$0,79 \cdot 10^{-4}$	$7,70 \cdot 10^{-4}$
	2	-	$0,47 \cdot 10^{-4}$	$7,42 \cdot 10^{-4}$

Table 6.

Conditions in the aquaria during the experiments with Phoxinus phoxinus. February 8 - 24 1961. Aquaria contaminated with Cs 134.

Date:	Number:	Turbidity mg/l SiO_2	Radioactivity on the particles $\mu c/ml$	Radioactivity in the water $\mu c/ml$
8/2 1961	1	5,4	$1,5 \cdot 10^{-4}$	$17,8 \cdot 10^{-4}$
	2	6,2	$1,2 \cdot 10^{-4}$	$19,5 \cdot 10^{-4}$
9/2 1961	1	6,4	$1,0 \cdot 10^{-4}$	$16,8 \cdot 10^{-4}$
	2	3,5	$1,16 \cdot 10^{-4}$	$17,7 \cdot 10^{-4}$
10/2 1961	1	6,0	$0,92 \cdot 10^{-4}$	$16,8 \cdot 10^{-4}$
	2	4,0	$0,91 \cdot 10^{-4}$	$18,9 \cdot 10^{-4}$
13/2 1961	1	6,2	$1,0 \cdot 10^{-4}$	$16,5 \cdot 10^{-4}$
	2	6,8	$1,15 \cdot 10^{-4}$	$19,0 \cdot 10^{-4}$
14/2 1961	1	6,3	$0,26 \cdot 10^{-4}$	$16,8 \cdot 10^{-4}$
	2	7,1	$0,32 \cdot 10^{-4}$	$18,9 \cdot 10^{-4}$
15/2 1961	1	8,0	$0,30 \cdot 10^{-4}$	$17,9 \cdot 10^{-4}$
	2	9,2	$0,18 \cdot 10^{-4}$	$20,0 \cdot 10^{-4}$
16/2 1961	1	7,2	$0,23 \cdot 10^{-4}$	$19,1 \cdot 10^{-4}$
	2	7,2	$0,24 \cdot 10^{-4}$	$20,0 \cdot 10^{-4}$
17/2 1961	1	6,8	$0,20 \cdot 10^{-4}$	$17,0 \cdot 10^{-4}$
	2	6,8	$0,16 \cdot 10^{-4}$	$18,6 \cdot 10^{-4}$
20/2 1961	1	5,6	$0,20 \cdot 10^{-4}$	$17,9 \cdot 10^{-4}$
	2	5,0	$0,11 \cdot 10^{-4}$	$19,3 \cdot 10^{-4}$
22/2 1961	1	-	$0,15 \cdot 10^{-4}$	$18,2 \cdot 10^{-4}$
	2	-	$0,16 \cdot 10^{-4}$	$19,5 \cdot 10^{-4}$
24/2 1961	1	-	$0,09 \cdot 10^{-4}$	$18,0 \cdot 10^{-4}$
	2	-	$0,09 \cdot 10^{-4}$	$19,6 \cdot 10^{-4}$

Table 7.

Data obtained from the experiments with Phoxinus phoxinus.
Uptake of P^{32}, February 8 - 24, 1961.

Numbers indicate $\mu c \cdot 10^{-5}$ per mg ash weight.

Denotation:	Skin:	Viscera:	Muscles:	Remaining parts:
1 P 13/2 1961	1,44	2,72	0,35	3,24
2 P 13/2 1961	2,16	0,65	0,20	2,82
1 P 20/2 1961	90,00	380,00	75,50	40,20
2 P 20/2 1961	11,50	36,60	7,80	5,70
1 P.1 24/2 1961	0,78	5,10	0,46	1,10
2 P.1 24/2 1961	4,10	112,00	4,95	2,14
1 P.2 24/2 1961	1,01	2,96	0,34	0,39
2 P.2 24/2 1961	50,00	140,00	27,60	20,20

Table 8.

Data obtained from the experiments with Phoxinus phoxinus.
Uptake of Cs^{134}, February 8 - 24, 1961.

Numbers indicate $\mu c \cdot 10^{-5}$ per mg ash weight.

Denotation:	Skin:	Viscera:	Muscles:	Remaining parts:
1 Cs 13/2 1961	1,47	3,98	1,56	1,18
2 Cs 13/2 1961	2,62	6,82	1,68	1,30
1 Cs 20/2 1961	94,00	356,00	110,00	51,00
2 Cs 20/2 1961	16,70	41,80	18,00	11,80
1 Cs.1 24/2 1961	8,20	134,00	22,00	10,40
2 Cs.1 24/2 1961	15,90	59,20	20,00	12,00
1 Cs.2 24/2 1961	11,90	41,70	12,9	5,20
2 Cs.2 24/2 1961	21,60	43,30	19,8	8,80

then applied to weight analysis, wet weight, dry weight and ash weight being determined. After this procedure the ash was used for measurements of radioactivity. The conditions in the water masses in the aquaria were observed throughout the experiment. Regular testings of turbidity and measurements of the radioactivity associated with the particles and the water in the aquaria were accomplished.

Experiments were conducted at differnt temperature intervals, the intention being to demonstrate a variation in accumulation of radioactive substance attributed to increased metabolism with increased temperatures. The intervals in temperature found convenient for the experiment were 4 - 8°C, 10 - 12°C and 19 - 21°C.

The results obtained from these experiments will not be discussed in length here,but an example of data collected is reported in some detail. Table 3 and 4 contains the actual weights of the different fractions of the specimens of <u>Phoxinus phoxinus</u> used in the experiment carried out February 8 - 24, 1961. The observations of conditions in the aquaria kept in the temperature interval 10 - 14°C are summarized in table 5 and 6. The uptake of the radionuclides by the fish are recorded in table 7 and 8.
This experiment shows that the method of isotope administration, involving direct addition of the radioactive substance to the water in the aquaria, results in great variation in the concentration of radioactivity between individuals of fish. It is generally assumed that the movement of water into teleosts in fresh water, caused by the osmotic effect, is principally confined to the gill membrane where salts also are actively absorbed. It seems unlikely that the observed variation represents individual difference in this ability to absorb P^{32} and Cs^{134} from the water. Further experiments are necessary in order to reveal the circumstances which can explain the results.

7. <u>Investigations on water quality. Experiments with algae</u>.

The examination of the properties of the actual river water has continued. Although much information about this subject was collected during the extensive limnological investigation carried out previous to this research project, further knowledge is required. As a fundamental starting point for an understanding of the phenomena of distribution and reconcentration of radioactive substances in the aquatic environment, experience about the range of variation in water quality is very important. Effort has been expended in these studies to provide a basis for more refined work on the turnover of radionuclides by organisms in the trophic levels of the model recipient.

7.1 Seasonal and daily variations in water quality.

In september 1960 a programme including one daily collection of a water sample from the river Nitelv at the experimental plant started. The observations accomplished was determination of electrolytic conductivity, pH and turbidity. The variations in the values obtained from the measurements of these factors reflect interesting relations with the meteorological conditions and the character of the drainage basin.

During periods with low water flow the highest values of electrolytes are generally registered. This ordinary takes place during winter when the downfall accumulates as snow, and contemporarily with periods of dry weather in summer. The explanation is that when under this set of conditions the percentage of ground water in the water masses is high, as a consequence the river water contains relative much inorganic substancees in solution. Downfall as rain brings along a dilution of the water masses, and the result is a decrease in the values of electrolytic conductivity. With respect to these variations of the content of electrolytes in the river water it is convenient to divide the year in four periods in accordance with the seasons:

1. the cold period,
2. the melting period,
3. the warm period,
4. the autumn rain period.

This general picture of the variations in the water flow and the different contents of electrolytes in the river water is in good agreement with the results of the observations both

Table 9.

Daily observations of electrolytic conductivity, pH, turbidity and rainfall in the period September 19 - October 31, 1960.

Sampling date 1960:	Electrolytic conductivity K_{20}=n . 10^{-6}	H_3O^+ pH	Turbidity mg SiO_2/l	Rainfall mm
19/9	53,7	7,4	8	0,0
20/9	58,2	7,3	15	6,0
21/9	60,1	7,1	26	2,6
22/9	66,1	7,0	14	0,0
23/9	58,7	7,2	49	7,0
24/9	60,1	7,0	22	0,2
25/9	-	-	-	0,2
26/9	46,3	6,8	13	0,0
27/9	43,0	7,0	11	0,0
28/9	43,3	6,8	15	0,0
29/9	44,3	6,5	9	0,0
30/9	46,3	6,9	10	0,0
1/10	-	-	-	0,0
2/10	-	-	-	0,0
3/10	54,0	7,3	11	0,0
4/10	48,6	7,3	9	0,6
5/10	59,2	7,3	40	11,5
6/10	69,6	7,0	173	15,3
7/10	-	-	-	0,0
8/10	55,4	7,0	28	0,0
9/10	-	-	-	4,6
10/10	63,3	7,0	180	21,0
11/10	53,3	6,8	152	21,3
12/10	39,3	6,9	108	4,3
13/10	41,7	7,0	78	6,0
14/10	40,5	6,8	39	1,0
17/10	51,0	7,4	24	0,0
18/10	44,0	6,8	24	0,0
19/10	-	-	-	0,4
20/10	47,3	6,8	21	0,0
21/10	47,3	7,2	20	0,0
22/10	41,2	7,1	21	0,0
23/10	-	-	-	0,2
24/10	44,3	7,5	19	0,0
25/10	46,0	7,3	20	0,0
26/10	54,5	7,2	19	0,0
27/10	54,5	7,2	22	0,0
28/10	42,5	6,9	19	0,0
29/10	-	-	-	0,0
30/10	-	-	-	0,0
31/10	52,5	7,1	18	0,0

from the limnological investigation and last years measurements. But the daily measurements of the hydrographical data mentioned have revealed that a complex relationship exists between them. An important fact stands out, the daily variations in the values of electrolytic conductivity and turbidity can be of the same magnitude as the yearly variation. The monthly observations performed during the limnological investigation have to be characterized as not very satisfactory when an understanding of the variations of the factors is aimed at.

Table 9 gives an extract of the observational data collected. This extract illustrates how rapid a change in water quality results from rainfall in the catchment area. The turbidity of the river water increases simultaneous with the onset of rain: Together with this effect increasing values of the electrolytic conductivity are measured. A fact which deserves attention will be stressed here. In most instances high values of turbidity corresponds to high values of the content of electrolytes in the river water. But this is not always the case. The observations from October 26, 1960 represent for instance a situation when rainfall in the drainage area is combined with low values of turbidity and high content of electrolytes in the river water. It is important to realize that a complex of processes are in operation and determine the hydrographic situation which is predominating at a given time. Factors to take into consideration are among others: Amount of ground water in the free water masses,admixture of surface water from cultivated fields, pollution from sewage and transport of clay into the river. It is hoped that further work on this topic will make it possible to evaluate the relative importance of these different contributions to the water masses and how they exert influence on the ever changing aspects of water quality.

7.2 River water as substrate for algal growth.

Among the primary producers in the river Nitelv the algae play an important role. A floristic diverse selection of species from the classes Chlorophyceae, Bacillariophyceae and Schizophyceae are components of the benthic and planktonic vegetation. Their metabolic activity and biological position rank them within the most interesting group of organisms to study in connection with the topic of the research project. In the first trophic level the algae represent several important entrance possibilities for the transfer of radionuclides into the food chain. The standing crop of algae in the model recipient allows investigations on these problems and their relation to food chains of the predator - and saprophytic type.

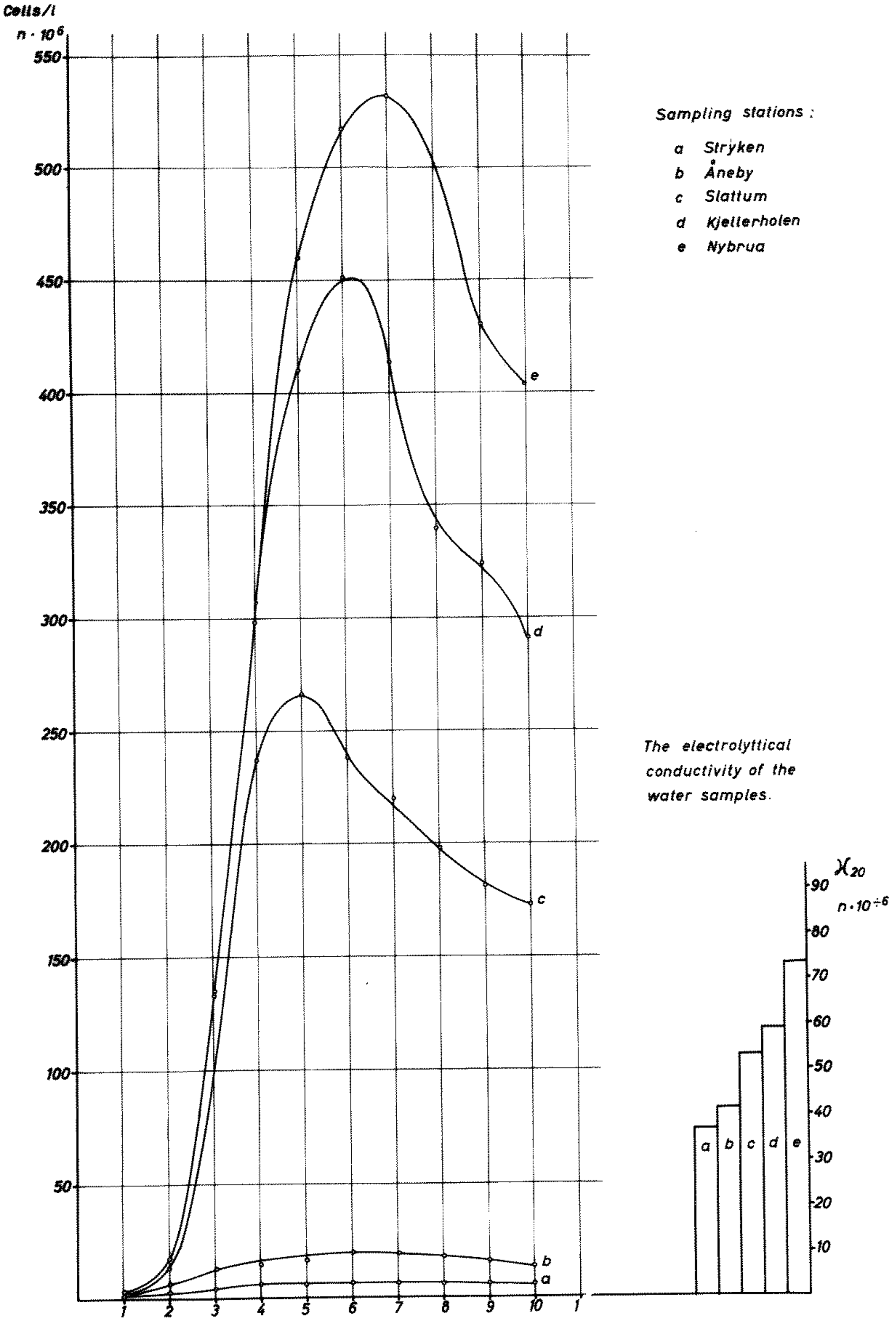
Nutritional problems has been considered in relations to the conditions that favour uptake by algae of radionuclides from contaminated river water. In this connection a new method for the study of growth of algae has been developed and trained. The growing of algae is done in culture vessels of glass of Pyrex quality. The vessels are placed on a table which are kept in swinging movement to prevent the stagnation of the culture media. The illumination is fluorescent lamps. The growth of algae is followed with the production of chlorophyll as parameter. By combining a membrane filter technic with an alcoholic extraction, measurements of the chlorophyll content are performed. The quantitative determination of chlorophyll is accomplished by using the fluorescence effect from irradiation with a mercury lamp. This method has proved to be at high precision, and the results obtained are good reproducable.

Figure 11 represents data obtained from experiments performed with the aim to obtain knowledge about the properties of the river water as substrate for algal growth. Water samples from five locations along the river were collected. After sterilization in the autoclave each water sample was inoculated from a stock culture of the green alga Selenastrum capricornutum. The growth in the culture vessels were observed according to the procedure described. The growth curves acquired clearly demonstrate the diverse possibilities river water from the different locations possess with respect to the support of algal growth. The model recipient is supplied with water of the type denoted "d" in figure 11.

The uptake of minerals by the primary producers is influenced by various factors both external to the organisms and in the organisms themselves. The chemical composition of the actual

River water as substrate for algal growth.

Growth of Selenastrum capricornutum.



NIVA-1961.

water, especially the amounts and availability of various nutrients, make up one of the most important environmental conditions for the process of reconcentration of radioactivity by algae. The external factors belonging to this categori operate through what may be called the water effect on uptake of radioactivity. Introductary experiments to elucidate some problems related to this water effect have been performed. Selenastrum capricornutum has been used in the experiments, which include cultivation of the alga in river water and nutrient solution. Radiotracers are added to the media, and radiochemical changes in the solutions are observed during growth. An experiment with the radiotracer P^{32} is reported in the following.

The procedure by the measurement of P^{32} in the algae and culture medium is here outlined in short.

Measurement of P^{32} in algae.

The membrane filter with the algae is carefully folded together and transferred to an aluminium counting dish.

Aceton is added to the sample until a homogeneous mixture of filter and aceton is obtained. The aceton then is evaporated off under an infrared lamp. A small residue of the filter will be left in the sample, for measurement of P^{32}, however, the self-absorption of beta-particles in this recidue will be negligible.

Measurement of P^{32} in algae and culture medium.

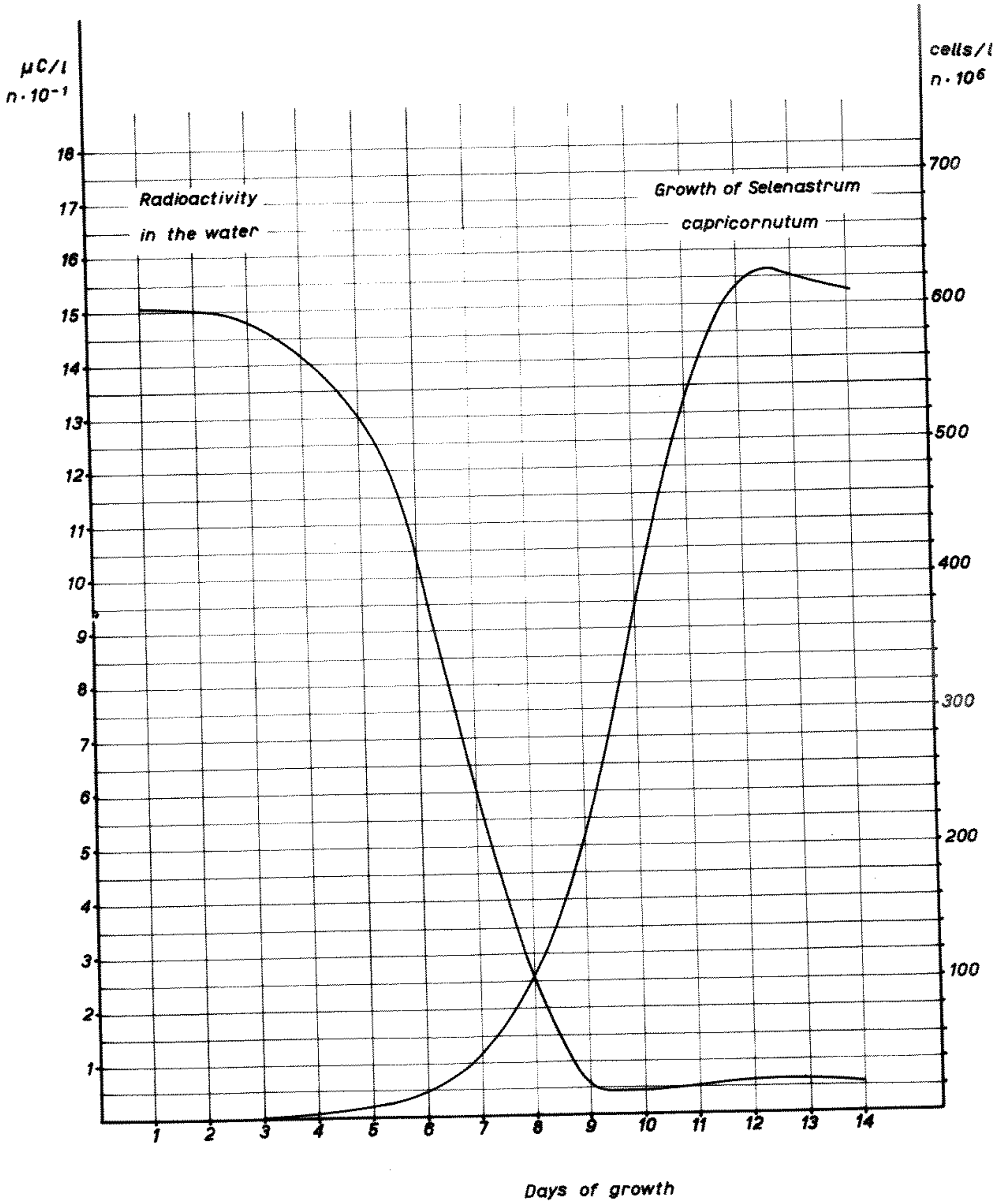
The mixture of algae and culture medium is shaken vigorously and transferred to a small beaker. 2 ml of the solution is immediately pippeted into counting dishes and evaporated to dryness. All samples are run in duplicate.

The counting.

The samples are counted with a proportional counter (flow counter), the counting efficiency has been determined with standardized P^{32}-solutions.

The samples of algae in culture medium were counted to give

Uptake of P^{32} by Selenastrum capricornutum.



NIVA-1961.

At least 10 000 counts, which gives a standard deviation of ± 1 per cent.

Because of the low activity in the culture medium and in the alcoholic extracts, these samples were counted to give at least 1000 counts. The calculated standard deviation (total counts - beckground counts) is ± 5 %.

The uptake of P^{32} during fourteen days of growth of Selenastrum capricornutum was examined. The medium used in this particular experiment was our standard growth solution with 3 % of the PO_4-P concentration. The standard growth solution:

$NaNO_3$	467,0 mg/l
$Ca(NO_3)_2 \cdot 4H_2O$	59,0 "
K_2HPO_4	31,0 "
$MgSO_4 \cdot 7H_2O$	25,0 "
Na_2CO_3	21,2 "
Fe-complexon	10,00 ml/l
Trace element solution	0,8 "

Daily observations on the uptake of the radioisotope and growth of algae were performed. Altogether seventy extractions of chlorophyll were made. Four parallels of cultures were run.

The result obtained is shown i figure 12. The great uptake of the P^{32} reflects the low level of phosphate concentration and the high demand by the growing algae. It is of interest to note that the process of movement of phosphate ions into the cells of the algae is markedly in advance of the growth responce.

8. Sorption of radionuclides to sediments from the river Nitelv.

8.1 Introduction.

Preliminary experiments in the model recipient show that when solutions of radionuclides are mixed with water from the river Nitelv, a significant portion of the radionuclides will be associated with the suspended particles in the water. One example of the experiments is given as follows.

The recirculation channel was filled with 2400 liters of water from the river Nitelv. The velocity of the water during the experiment was approximately 9 cm/sec, corresponding to 15 revolutions of the paddle per minute. P^{32} as orthophosphate was dosed to the water, and at regular time intervals observations were performed to note the behaviour of the radioisotope in the recirculation channel. Water samples were collected at three points along the channel, their relative position being 40 m from each other. The water samples were used for determinations of turbidity, electrolytic conductivity, pH and radioactivity. Measurements of radioactivity was carried out in filtered samples, the activity was measured both on the membrane filter and in the filtrate. The results of the experiments are given in table 10. We learned that only a few hours after the contamination of the water with P^{32}, a considerable fraction of the radioactive substance was removed from the water by sorption to the component of particles. During the 96 hours of the experiment much sedimentation occured. This is demonstrated in the lowering of the turbidity values. The net result of these processes was a transfer of the radioisotope from the free water masses to the bottom deposits.

Pleistocene sediments of clay in the catchment area provide the water masses in the river Nitelv with its greatest part of mineral contents as particles. The aim of this study is to obtain an understanding of the relationship between varying amounts of clay and sorption of radioactive isotopes for this fraction of the river water.

By clay we mean mechanic, inorganic sediments of a grain size less than 0,002 mm. The particles in clay mainly consist of two categories:

A. Fragments built by crushing of rocks. This component will in its mineral composition not differ significantly from that of the ordinary solid rock of Norway, which consists of such minerals as quartz, feldspar, calcite and magnetite.

B. Products formed during decomposition and consolidation of the sediments. Among these secondary com-

Table 10.

Experiment in the recirculation channel demonstrating the effects of sorption phenomena.

Radioisotope P^{32}.

Sampling date & hour 1960	Sampling point (see page 39)	Radioactivity in water $n \cdot 10^{-4}$ μc/ml	Radioactivity on filter $n \cdot 10^{-4}$ μc/ml	H_3O^+ pH	Electrolytic conductivity $K_{20} = n \cdot 10^{-6}$	Turbidity mg SiO_2/l
26/8 13.00	R_1	2,7	1,0	7,0	50,3	36
" "	R_2	3,3	1,4	7,0	50,7	36
" "	R_3	3,7	1,5	7,0	49,9	37
26/8 16.00	R_1	2,1	2,4	-	-	25
" "	R_2	1,9	2,3	-	-	27
" "	R_3	2,1	2,5	-	-	26
26/8 20.00	R_1	0,6	2,9	7,4	54,6	27
" "	R_2	0,5	3,0	-	-	28
" "	R_3	0,6	3,0	-	-	28
27/8 09,00	R_1	0,4	3,0	7,5	55,4	25
" "	R_2	0,4	2,7	-	-	26
" "	R_3	0,4	2,7	-	-	22
27/8 12.30	R_1	0,4	2,7	-	-	24
" "	R_2	0,4	2,8	-	-	23
" "	R_3	0,4	2,7	-	-	25
29/8 09.00	R_1	0,3	2,4	7,4	53,3	13
" "	R_2	0,4	2,3	-	-	13
" "	R_3	0,3	2,4	-	-	13
29/8 14.30	R_1	0,3	1,9	-	-	13
" "	R_2	0,3	1,9	-	-	13
" "	R_3	0,3	1,8	-	-	15

ponents hydrous micas are of special importance in our connection. Norwegian hydrous micas are minerals of a somewhat variable composition belonging to the illite group

Three main types of clay are regionally of greatest importance in the Nitelv area:

C. Deposits of clay with moraine,

D. Glacial clay,

E. Postglacial clay.

The postglacial clay contains per centum most of the hydrous micas minerals. At the same time this type of clay gives in a considerable degree the river water its special turbidity. This postglacial clay was therefore chosen for the experiments described in the following pages.

8.2 Experimental procedure.

Preparations of the sediments.

The collected sediments were allowed to dry at room temperature for several days. In order to destroy the organic material 10 per cent H_2O_2 was added and the sediments were dried at 80-90°C. The sediments were then ground to a fine powder and passed through a 200 mesh sieve.

Control of pH, electrolytic conductivity and turbidity.

Suspensions of the river sediments in distilled water were made, containing 8, 16, 32, 128, 256 p.p.m. of sediments.

The pH of the suspension varied between 6,60 and 7,10. Further adjustment of the pH was not made.

The electrolytic conductivity of the suspensions varied within the range $\varkappa_{20}$: $2{,}8 \cdot 10^{-6}$ - $6{,}2 \cdot 10^{-6}$ $ohm^{-1} cm^{-1}$.

The turbidity of the suspensions was measured, and the measured turbidity values corresponded to the "Fuller's Earth" solutions used as standard for turbidity measurement.

Sample preparations and counting procedure.

The radionuclides used in the experiments were as follows:

P^{32}	specific activity	100 mc P^{32}/g P,
Cs^{134}	" "	50 mc Cs^{134}/g Cs,
Sr^{89}	" "	10 mc Sr^{89}/g Sr.

Ca^{45} specific activity 10 mc Ca^{45}/g Ca.
Ru^{106} 10 mg Ru^{106}/mg of total solids.

Solutions were made by mixing each of these isotopes separately with distilled water, so That the activity in the final solutions was between 1 and 0,5 /uc per liter.

The samples were counted for Beta-activity in an automatic endwindow flow counter. The counting efficiency was determined for each radionuclide, and corrections were made for selfabsorption in the sample.

All samples were counted to give at least 10 000 counts, which gives a standard deviation of $\pm$ 1 per cent.

Sediment testing procedure.

Suspensions of the river sediments were made by adding a known weight of sediment to the solution of radionuclides. The total volume of the solution was 300 ml. The samples were shaken vigorously by hand and left standing at room temperature; further shaking was made occationally during the day.

After the fixed time of contact, 100 ml of the suspension was filtered through a membrane filter (Spezial-Membrane filter Co.5), and the filter was washed with 50 ml of distilled water. The activity was measured both in the filter and in the filtrate. It was desirable to have activity measurement of both the sediments and the supernatant solution in order to have an indication of the extent of side reaction, especially sorption onto the walls of the glass vessel, which is significant for some of the radionuclides.

Sorption to the membrane filter was tested for all radionuclides, by passing a solution of the radionuclides through the filter at approximately the same flow rate as for the sediment suspensions (30-40 ml per min), and washing with 50 ml of distilled water. The sorption to the filters was found negligible for all the radionuclides tested, probably because the solutions had a very short time of contact with the filter (2 - 3 min).

8.3 Experimental results.

The first part of the experiment was carried out on suspensions of river sediments in distilled water.

Sorption to sediment at various times of contact.

The sorption of radionuclides to the sediments as a function of time is reported in table 11. The concentration of 64 p.p.m. of sediments was used in all the tests, and the samples were run in duplicate or triplicate.

For all the radionuclides tested, the sorption to sediments is increasing with increasing time of contact. After 1 day of contact with the radioactive solution, the sorption of Sr^{89}, Ca^{45} and P^{32} has reached a constant value. The sorption of Cs^{134} is increasing very little after one day, the sorption of Ru^{106}, however, did not give a constant value, even after a contact time of 9 days.

Sorption to various concentrations of sediments.

The sorption of radionuclides as a function of sediment concentration was tested at the concentrations of 16, 32, 64, 128, 256 p.p.m. of sediments. These concentrations were chosen because the natural turbidity of the water in the river Nitelv varies within this range. The time of contact with the radioactive solution was 1 day.

The results of the tests are shown in figure 13 and table 12.

It is interesting to note the high sorption capacity of the sediments for cesium, phosphorus and ruthenium, and the much lower sorption capacity for strontium and calcium.

This great variation in sorption capacity may possibly be explained by the structural properties of the sediments. Further experiments to study this effect will be performed when the mineral identification test is completed.

Sorption by sediments in natural river water.

The solutions of radionuclides used in the first part of the experiment were almost carrier-free, and the concentration of

Table 11.

Sorption of radionuclides to river sediments.

(Concentration of sediments: 64 p.p.m. in distilled water).

Contact time:	Per cent activity sorbed to sediments:				
	Cs^{134}	Sr^{89}	Ca^{45}	P^{32}	Ru^{106}
10 min.	20,0 ± 1,5	4,0 ± 0,5	2,5 ± 0,6	41,1 ± 4,0	
20 "	24,5 ± 1,7	7,1 ± 0,8	7,5 ± 0,7	45,2 ± 3,2	2,5 ± 1,2
40 "	29,0 ± 2,0	6,5 ± 0,9	8,0 ± 0,8	46,9 ± 3,1	13,0 ± 2,4
80 "	33,5 ± 1,5	6,7 ± 0,8	-	47,5 ± 2,9	19,2 ± 2,5
160 "	39,5 ± 2,0	7,0 ± 0,7	8,1 ± 0,7	50,3 ± 2,9	25,3 - 2,7
12 hours	45,5 ± 1,5	-	8,4 ± 0,6	57,0 ± 2,5	-
1 day	46,0 ± 1,8	6,9 ± 0,8	7,8 ± 0,6	58,1 ± 2,6	34,0 ± 2,3
2 "	49,0 ± 1,3	-	-	-	42,5 ± 2,0
3 "	50,2 ± 1,3	7,2 ± 0,6	8,1 ± 0,5	57,4 ± 2,5	50,1 ± 2,1
4 "	-	-	8,2 ± 0,5	-	55,3 ± 1,9
5 "	-	7,3 ± 0,6	-	-	58,5 ± 2,0
6 "	49,9 ± 1,1	-	8,3 ± 0,6	58,2 ± 2,4	64,5 ± 3,2
7 "	51,5 ± 1,3	7,0 ± 0,5	-	58,1 ± 2,0	-
8 "	50,0 ± 1,0	-	-	-	70,1 ± 2,5
9 "	48,2 ± 1,8	-	8,2 ± 0,5	58,3 ± 1,5	72,5 ± 2,7

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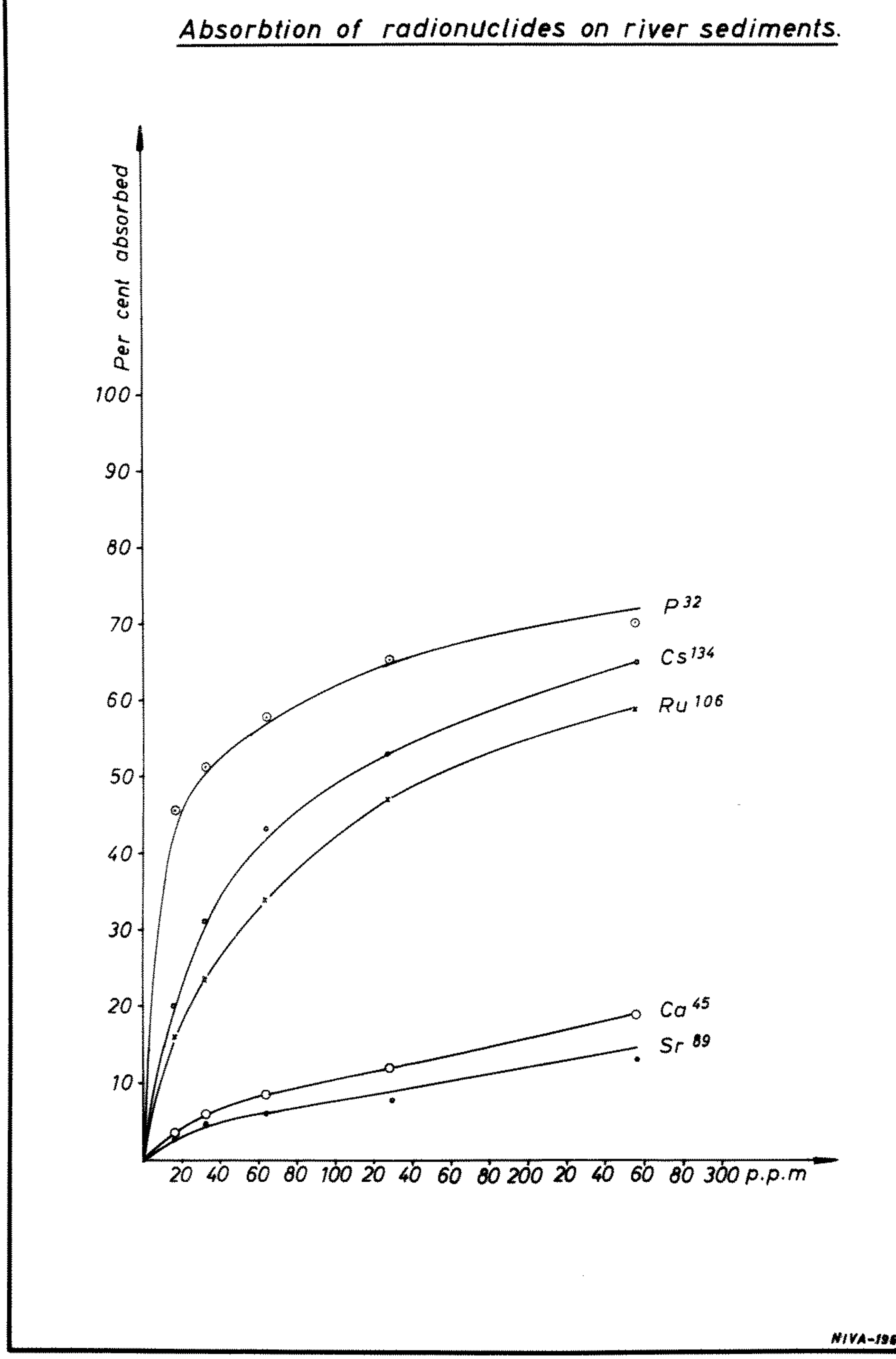

Absorbtion of radionuclides on river sediments.
Per cent absorbed
100
90
80
70
60
50
40
30
20
10
20 40 60 80 100 20 40 60 80 200 20 40 60 80 300 p.p.m
P 32
Cs 134
Ru 106
Ca 45
Sr 89
NIVA-1961

Table 12.

Sorption of radionuclides to river sediments
at various concentrations.

(Sediments suspended in distilled water).

Conc. of sediments	Per cent activity sorbed to sediments:				
	Cs^{134}	Sr^{89}	Ca^{45}	P^{32}	Ru^{106}
16 p.p.m.	20,0 ± 1,2	2,5 ± 0,5	3,5 ± 0,4	45,5 ± 2,1	16,0 ± 1,5
32 p.p.m.	31,0 ± 1,1	4,6 ± 0,4	6,0 ± 0,5	51,5 ± 2,5	23,5 ± 2,0
64 p.p.m.	43,0 ± 2,0	6,2 ± 0,8	8,5 ± 0,7	58,1 ± 2,6	34,0 ± 2,3
128 p.p.m.	58,2 ± 1,8	9,5 ± 0,8	12,1 ± 0,8	65,5 ± 2,6	47,1 ± 2,4
256 p.p.m.	65,2 ± 1,9	14,5 ± 1,0	19,0 ± 0,9	70,0 ± 2,8	59,0 ± 2,6

Tabel 13.

Sorption of radionuclides to river sediments
in natural river water.

Conc. of sediments	Per cent activity sorbed to sediments:		
	Cs^{134}	Sr^{89}	Ru^{106}
16 p.p.m.	12,5 ± 0,8	1,5 ± 0,5	2,5 ± 0,8
32 p.p.m.	19,0 ± 1,0	2,5 ± 0,6	4,0 ± 0,8
64 p.p.m.	26,0 ± 1,1	5,0 ± 0,8	7,0 ± 0,9
128 p.p.m.	39,0 ± 1,4	8,5 ± 0,9	10,5 ± 1,2
256 p.p.m.	50,0 ± 1,6	14,0 ± 1,0	15,0 ± 1,2

inorganic material was very low. Further experiments were necessary to evaluate the influence of inorganic material on the sorption of radionuclides to the sediments.

In order to approach natural conditions, river water was filtered through a membrane filter to remove the natural turbidity, and suspensions of the sediments were prepared from this water.

The water from the river Nitelv is a rather soft water, the main components of inorganic material are:

Ca^{+2}	-	5 - 6 mg/liter
Mg^{+2}	-	1 - 2 " "
Na^{+1}	-	1 " "
K^{+1}	-	0,9 " "
Cl^{-}	-	2 - 6 " "
SO_4^{2-}	-	7 - 9 " "

The pH-value of the water used for the tests was 6,6 and the electrolytic conductivity was K_{20} : $65 \cdot 10^{-6}$ $ohm^{-1} cm^{-1}$.

The tests were made as previously described, the time of contact with the radioactive solution was 1 day.

The sorption of cesium, ruthenium and strontium at various sediment concentrations is shown in figure 14 and table 13.

Compared with the sorption to sediments in distilled water, the sorption of cesium is lower in the river water - sediment suspension, the sorption of strontium is almost the same as in distilled water, but the sorption of ruthenium is greatly depressed.

Variation of sorption with time of contact.

The sorption of cesium, ruthenium and strontium at various times of contact is reported in table 14. The concentration of the sediments was as previously 64 p.p.m.

Figure 15 shows the sorption of cesium and ruthenium, the sorption in distilled water - sediment suspensions is included for comparison.

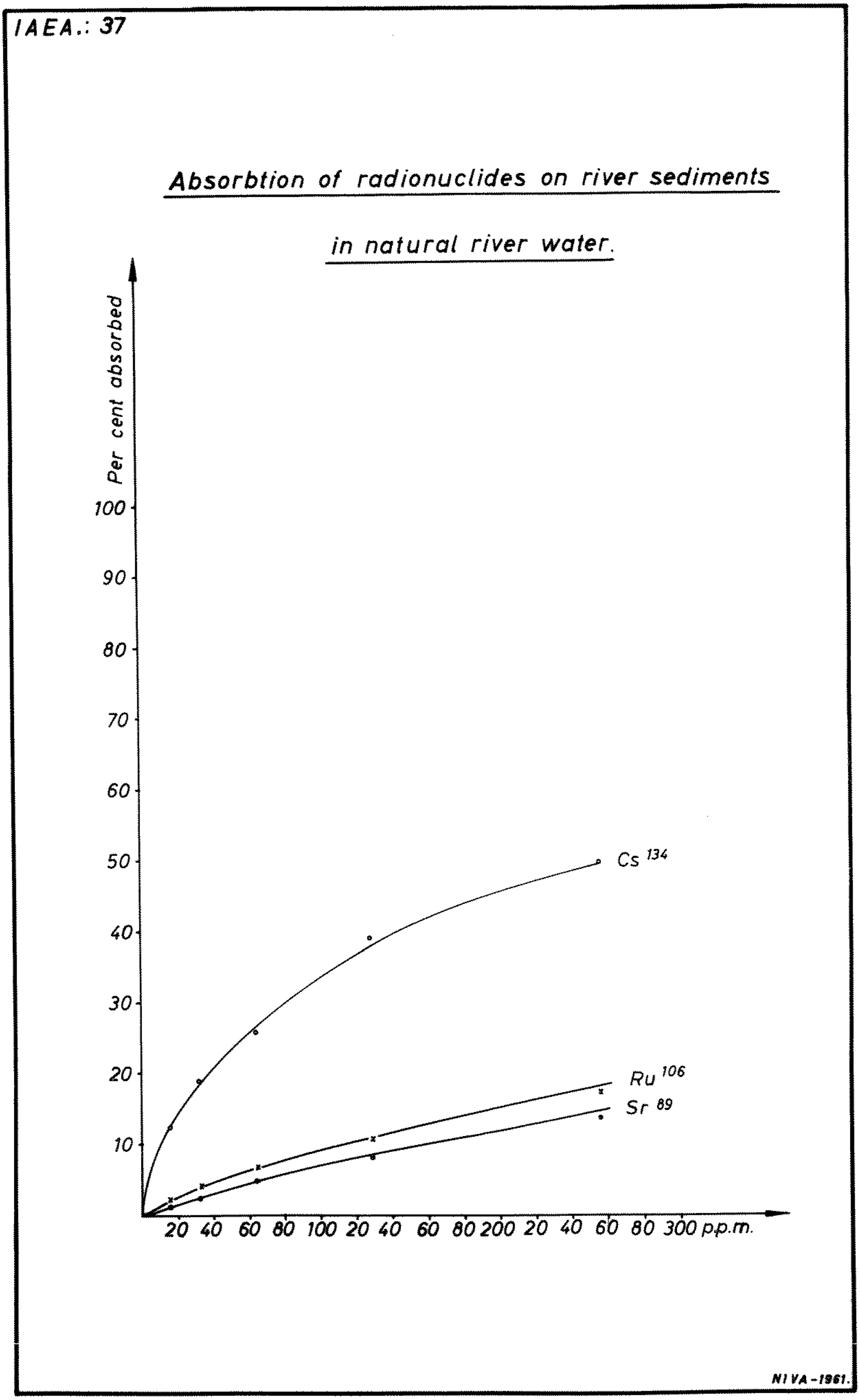

IAEA.: 37
Absorbtion of radionuclides on river sediments
in natural river water.
Per cent absorbed
100
90
80
70
60
50
40
30
20
10
Cs 134
Ru 106
Sr 89
20 40 60 80 100 20 40 60 80 200 20 40 60 80 300 p.p.m.
NIVA-1961.

Table 14.

Sorption of radionuclides to river sediments at various times of contact.

(Concentration of sediments: 64 p.p.m. in natural river water).

Contact time:	Per cent activity sorbed to sediments:		
	Cs^{134}	Ru^{106}	Sr^{89}
0,5 days	22,5 ± 1,2	-	4,8 ± 0,8
1 "	27,0 ± 1,2	6,5 ± 0,9	5,1 ± 0,8
2 "	35,0 ± 1,2	12,0 ± 0,9	5,4 ± 0,9
3 "	37,0 ± 1,3	14,0 ± 1,5	5,2 ± 0,8
4 "	40,0 ± 1,4	16,5 ± 1,7	5,1 ± 0,7
5 "	-	-	-
6 "	-	16,5 ± 2,0	-
7 "	44,5 ± 1,6	-	4,9 ± 0,8
8 "	-	18,3 ± 1,8	-
9 "	45,1 ± 1,7	19,1 ± 2,1	5,1 ± 0,8

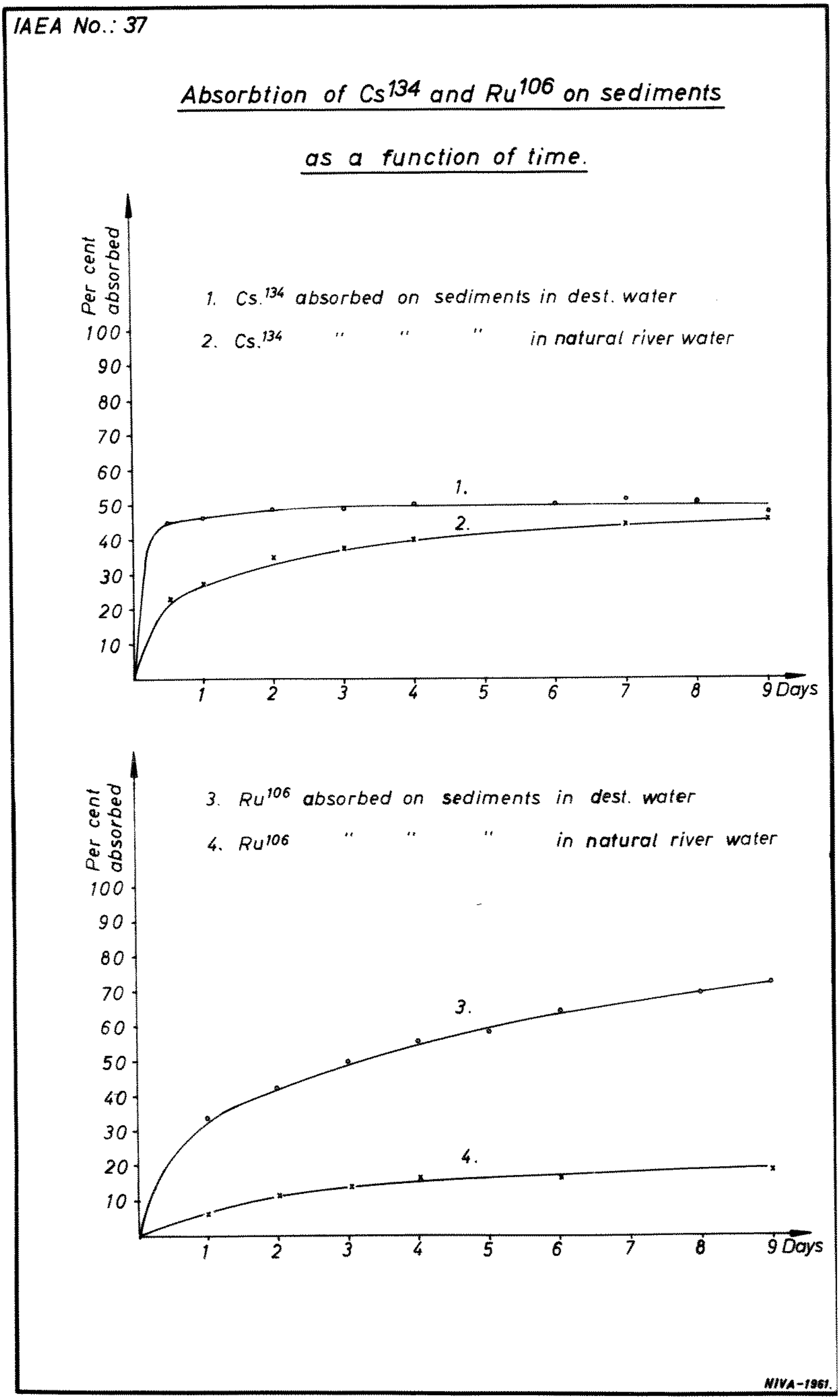
The sorption capacity for ruthenium is greatly depressed by the mineral content of the river water, but the shape of the sorption-time curve is almost the same.

Cesium shows a different behaviour, sorption to the sediments after 1 day is much lower in the river water system, but it is increasing to almost the same level as in distilled water, when the time of contact with the radioactive solution is increased to 9 days.

An explanation of this effect is not offered at this time, but further experiments are planned to study the reaction mechanisms involved.

The results so far obtained is instructive although incomplete, and further experiments are necessary to get a clearer picture of the sorption properties of the sediments.

The results show, however, that the soption of radionuclides to river bottom sediments is important in the accumulation and transport of radionuclides in the water system.


IAEA No.: 37
Absorbtion of Cs134 and Ru106 on sediments
as a function of time.
Per cent absorbed
100
90
80
70
60
50
40
30
20
10
1. Cs.134 absorbed on sediments in dest. water
2. Cs.134 " " " in natural river water
1.
2.
1 2 3 4 5 6 7 8 9 Days
3. Ru106 absorbed on sediments in dest. water
4. Ru106 " " " in natural river water
3.
4.
NIVA-1961.