BASIC LEACHING TESTS FOR PURE LONG LIVED BETA EMITTERS IN RADIOACTIVE WASTE

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LEACHING STUDY OF HEAVY AND RADIOACTIVE ELEMENTS PRESENT IN WASTES DISCARDED BY A URANIUM EXTRACTION AND PROCESSING FACILITY

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TABLE OF CONTENTS

1. INTRODUCTION 1
2. METHODS 4
3. RESULTS 13
3.1. Properties and composition of the waste 13
3.2. Characterization of leaching water (leachant) 16
3.3. Leaching of samples with demineralized and sea water 17
3.3.1. Leaching of loparite ore processing wastes (L-experiments) 17
3.3.2. Leaching of uranium ore processing wastes (U-experiments) 20
3.3.2.1. Experiments with dump material from the depth of 14.52÷16.20 m (UI-experiments) 20
3.3.2.2. Experiments with dump material from the depth of 19.44÷20.04 m (UII-experiments) 23
3.4. Migration coefficients of components 25
3.5. Some chemical and physical properties of leaching waters 26
3.6. Application of results 28
4. SUMMARY 28
5. CONCLUSIONS 33
Literature 35
Tables
Figures

Abstract

The present report provides a systematic leaching study of the waste depository at the Sillamäe metallurgical plant "Silmet" (former uranium extraction and processing facility), its construction and environmental impact. The following data is presented:

- γ-activity data of the depository and two drillcores,
- chemical composition and physical properties of depository material and leaching waters,
- results of γ- and α-spectrometric studies,
- leaching (with demineralized and sea water) intensities (ΔI, $mg/m^2 \cdot l \cdot d$) of loparite and uranium ore processing waste components: U, Th, Ta, Ce, La, Fe, Nb, Sr, V, Ti, Si, S, Cl^-, NO_3^-, NH_4^+, Ca, Mg, K, Na and $\Sigma_{min.}$,
- empirical formulae for the dependence of leaching intensity (ΔI) of Th, U and $\Sigma_{min.}$ on cumulative time (d) with different materials, leachants and leaching conditions,
- dependence of Eh of leachants on pH,
- dependence of electric conductivity (G) of leachants on $\Sigma_{min.}$

For all components in all experiments are given:

- weighed means of ΔI in relation to time (ΔI),
- migration coefficients in water (K_x),
- outputs and material balances.

Environmental danger presented by the Sillamäe waste dump to the Gulf of Finland and the surrounding environment in Estonia is mainly due to uranium leaching and the presence of a large array of chemically poisonous substances.

Key words: uranium ore, loparite ore, radioactive waste, depository, γ-ray logging, leaching, microelements, macroelements, element migration coefficients in water, environmental pollution.

1. INTRODUCTION

The town of Sillamäe is situated on the Southern coast of the Finnish Gulf at the mouth of river Sõtke, 172 km east of Tallinn and 25 km from the Russian border. Before WW II the town housed a Swedish oil-shale processing plant, which was totally destroyed during the war. It was rebuilt as a uranium extraction and processing facility (Facility Nr. 7, Oil-shale Processing Plant, Sillamäe Metallurgical Factory, now Silmet). The plant was meant for producing uranium from the local early Ordovician black (Dictyonema) alum shale, found in abundance in Estonia. The first batch of Estonian uranium was produced in Narva at a pilot plant (Cloth Dyeing Factory) during the winter of 1944/45 and building of the Sillamäe plant started in 1946. Sillamäe remained a closed town under direct administration of the Russian Federation until the Republic of Estonia regained its independence in 1991. Everything that went on there was a strictly kept military secret.

The production of uranium at the Sillamäe facility was started at 1949 but the pilot plant in Narva was also operating until 1957 and uranium extraction technologies were elaborated there not only for Estonian alum shale processing, but for all Soviet Union. In 1952 alum shale mining at the Sillamäe underground mine was shut down because better ores were found elsewhere. The production was carried on using richer uranium ores and concentrates from Central Asia, Czechoslovakia, Hungary and first of all East Germany. Beginning 1970 the plant started producing niobium and tantalum from Kola peninsula loparite ore. Besides the above-mentioned target metals, the latter also contains abundant rare earth metals, as well as up to 5-6 kg/t of thorium and 0.2 kg/t of uranium that were at first all discarded as processing waste, but later rare earths were produced. Uranium production was huge, 47334 metric tonnes of uranium (as U_3O_8) were produced in the eighties (1980-1989) alone. In 1982 started enriched (2 to 4% ^{235}U) uranium fuel processing and reconditioning into UO_2. Altogether 1391.9 tonnes of enriched uranium were processed. Both production lines were shut down and uranium processing altogether discontinued in December 1989 as a result of political developments in the Baltics.

From 1945 to 1959 the processing wastes of the Narva pilot plant (known as Cloth Dyeing Factory) and the Sillamäe uranium extraction facility (Facility Nr. 7) were taken to the territory of the present waste depository and stored there. Building of the

waste depository began in mid-fifties by filling a nearly 1/3 km^2 area with shale ashes and radioactive waste. The waste dump and underground mine are shown in Fig. 1, waste dump and its sediment reservoir in Fig. 2. In May 1959 construction of the surrounding and intermediate dams of the "A" and "B" reservoirs was initiated. Construction was gradual and determined by the filling of the reservoirs with process waste. Dams were built with the use of local sands, gravel, production tailings, scraps of limestone, building refuse and garbage. In the course of construction, the embankment of the dams was not tightened. Pumping of wastes into reservoir "A" was stopped in 1962 when their absolute height rose to 12.35 m. Filling of the "B" reservoir was carried out until spring 1964. Then it was stopped and filling of reservoir "A" was started again. In August 1964 filling of reservoir "B" was continued and in November building of the dam for reservoir "C" was started.

At the present time the height of the dams extends to +24.5 to +25.5 m above the sea level. The lower part of the dams consists of sand, gravel and ash layers that are cemented as the result of water infiltration. The upper part consists mainly of gravel, building refuse and broken stones. Distribution of weak sandy clay and ashes in the embankment is very irregular. By now the dam stability reserve has fallen to as low as 20% in some sections and is thus nearly exhausted. This is why a real and present danger of bursting of the dam exists in case of even a small earthquake or explosion. A large amount of radioactive waste with flowing consistency might be swept into the Gulf.

In the waste depository 3 soil layers may be differentiated (Fig. 3):

- grey layer of sandy clay mixed with ashes (layer 3), consisting of loparite ore processing waste;
- brown layer of sandy clay (layer 5), consisting of uranium ore processing waste;
- ashes (layer 6).

For calculating the capacities of waste layers a three-dimensional model of the depository was created on a PC computer using the "Terra Modeler" program. In calculating the capacities the "Terra Quantity" program was used. According to this:

Waste depository area	350 000 m^2
Waste depository total capacity	6 000 000 m^3

wherein:

- water capacity in the depository
  surface layer 140 000 m^3
- loparite processing wastes 2 860 000 m^3
- uranium processing wastes 2 620 000 m^3
- ashes 380 000 m^3

Layer capacities expressed in tonnes:

- layer 3 (δ = 1.4 $t \cdot m^{-3}$) 4 000 000 t
- layer 5 (δ = 1.55 $t \cdot m^{-3}$) 4 052 000 t
- layer 6 (δ = 1.7 $t \cdot m^{-3}$) 648 000 t

By current estimate the waste depository contains approximately 1200 t of uranium, 800 t of thorium, up to 90÷120 kCi of their daughter nuclides and at least 12 kg of ^{226}Ra. The γ-radiation level on the dump surface amounts to 100-1700 mkR/h, in places even 2000-3000 mkR/h.

The floor of the waste depository lower layer (layer 6, in its absence layer 5) consists of natural gravel and pebbles (0.5-7.9 m thick)and a water-tight layer of Cambrian blue clay underneath. The clay layer has a 0.0025-0.004 surface inclination towards the Gulf.

Hydrogeological conditions in the depository are dominated by close connection between the ground, surface and technological waters. Composition of the water flowing into the sea from beneath the dump depends on the same conditions. Waters of the waste depository are drained off through the layer of gravel and pebbles into a water-holding ditch from where they flow into the sea. The bulk of water flowing daily from the waste dump into the sea is estimated approximately as 1600 m^3. The bulk of mineral matter dissolved in water carried into the sea constitutes 6000-12000 tonnes a year. Total mineralization of the water is in g/l: $\Sigma_{min.}$ = 10.4 to 21.2, average 15.1±3.5. Earlier studies show that waters filtrating from the waste deposits carry dissolved natural radionuclides towards the sea, polluting beach sand and the blue clay layers (Makeyev, 1989).

At Sillamäe the currents of the sea move along the coast predominantly eastward. This is why the dissolved waste products carried from the dump into the sea or are wind-blown towards the town are polluting the town of Sillamäe as well as its

eastern beaches. Preliminary data show that the waste depository of the Silmet metallurgy plant is a real threat to the Gulf of Finland as well as for the town of Sillamäe and its nearby environment for several reasons:

- containing a large quantity of various natural radionuclides it is a direct source of radioactivity. Radionuclides spread into the sea-, surface- and groundwaters, disperse through air (deflation of radioactive deposit material and emanation of ^{222}Ra) into the surrounding environment, thus endangering people and the environment in general.

- besides radionuclides, it contains numerous other toxic compounds present in the uranium and niobium ores and concentrates, such as several very poisonory elements and numerous rare earth metals. There is no data available on the environmental impact of the latter.

- stability reserve of the dam surrounding the waste dump is by now nearly exhausted. Taking into consideration the flowing consistency and thixotrophy of the deposited material, in case of a moderate earthquake the dam would burst and let the processing wastes flow into the sea. Sillamäe is situated in a seismically active area. The last quake of dangerous magnitude took place in nearby Narva in 1881 (Sildvee, 1991).

In order to provide an objective estimation of the environmental hazard caused by the processes going on in the depository and to predict them we must know the contents of the waste substances, their radioactivity and first of all, the leaching behaviour.

Leaching experiments were carried out under laboratory conditions with demineralized and sea water.

2. METHODS

To get the necessary samples for investigating the composition and leaching behaviour of the waste depository material at the Sillamäe plant, two boreholes were drilled which penetrated through the surface layer down to the base layer lying under it. Drilling was carried out by the "AS Geotehnika" engineering bureau. In choosing the places for boreholes the following was taken into account:

- experience of earlier drillings on the deposit to have minimal loss of the

drillcores;

- access of heavy boring machines to the selected spot;
- insufficient data on the character and distribution of the deposited wastes.

The locations of the boreholes PA-1 (1347 G) (depth 20.4 m, ø 89 mm) and PA-2 (1346 G) (depth 16.5 m, ø 89 mm) are shown in Fig. 2. Drill core (ø 85 mm) was collected into 3 m length plastic core-receiver tubes. The losses did not exceed 1.4% lengthwise.

γ-ray logging with the CK-1-74 well logging station was carried out in boreholes. Only γ-radiation from the waste products surrounding the boreholes was registered. Measuring results are shown on charts (Figs. 4,5), expressing the γ-radiation exposure rates (mkR/h) in relation to registration depth. A PCKY well logging apparatus with NaI(Cs) single crystal scintillation detector was used as a calibration device, metrologically checked and adjusted according to geophysical studies requirements in force in Estonia.

Containers with drillcores were taken to laboratory where they were sawn into pieces of 12 cm length. The drillcore substance was colloidal sandy clay, saturated with water and liquefied if exposed to vibration. Samples of drillcore were placed into 1.0 l volume hermetically closed plastic containers. All the pieces were weighed, measured, their volume and volume weight (g/cm^3) were calculated. Using the DPГ-01T1 dosimeter, surface γ-fluence per mass ($mkR/h \cdot g$) of the sample was calculated. Fig. 6 shows sections of boreholes, average volume weights of the drillcore substance and γ-fluence per mass in relation to depth. Measuring results of surface γ-fluence of the drillcores are shown on charts (Fig. 7). We used both γ-fluence values and visual observation in choosing suitable sample material for leaching. All the properties and depth distribution of the waste material are quite different in the two boreholes (Figs. 6,7). That was due to the fact that borehole PA-1 was drilled within the boundaries of the sediment reservoir "A", the filling of which was started in 1959. Borehole PA-2 was drilled within the boundaries of sediment pool "C" (Fig. 2) which began to be filled only at the end of 1964. It was thus impossible to unite these samples. For leaching tests we used the core from PA-1 borehole as the more representative. Considering the dependence of core properties on depth (Figs. 4,6,7), and proceeding from γ-fluence of the samples, three different sample groups were taken from PA-1 borehole for

experiments:

1. 6 consecutive core pieces (A-II-31 to A-II-36) were taken from the central part of the loparite waste layer 3 from the depth range of 6.64 to 7.36 m. Their average surface γ-fluence was equal to that of the whole loparite waste layer in the drillcore: 14±3 mkR/h•g. Water content of the pieces was determined by classical methods by drying the samples at 105°C. It varied from 50.9 to 63.2%, average 56.2±5.4%. 3 equal portions of the substance were taken for extraction:

a) with demineralized water (DW) under dynamic conditions (DC) in Soxhlet-apparatus (S), notation DW, DC-S (experiment E-8);
under dynamic conditions, recirculating with peristaltic pump (P), notation DW, DC-P (exp. E-9);

b) with sea water (SW) under dynamic conditions, recirculating with peristaltic pump, notation SW, DC-P (exp. E-5).

All three experiments with the loparite waste are designated L-experiments.

2. 14 consecutive core pieces (A-V-97 to A-V-110) were taken from the central part of the uranium production waste layer 5 from the depth between 14.52 and 16.20 m. Their average surface γ-fluence was equal to 250±30 mkR/h•g, thus being very close to the γ-fluence of the whole uranium waste section 240±90 mkR/h•g. Water content of the pieces was 30.3 to 42.4%, average 32.7. 6 equal portions of the substance were taken for extraction:

a) with demineralized water under dynamic conditions in Soxhlet-apparatus, notation DW, DC-S (experiments E-4 and E-6);
under static conditions (SC) in a standing flask without water circulation, notation DW, SC (exp. P-1);

b) with sea water under dynamic conditions, recirculating with peristaltic pump, notation SW, DC-P (exp. E-1 and E-7);
under static conditions in standing flask, notation SW, SC (exp. P-2).

All these experiments are designated U-experiments I.

3. 5 consecutive core pieces (A-VII-138 to A-VII-142) were taken from the depth between 19.44 and 20.04 m of the lower part of the uranium waste layer 5. Their average surface γ-fluence was the highest and equalled 340±110 mkR/h•g. Water content of the pieces was 32.8 to 37.9%, average 35.5%. 3 equal parts were taken

from this substance for extraction:

a) with demineralized water under dynamic conditions in Soxhlet-apparatus, notation DW, DC-S (exp. E-2); under dynamic conditions, recirculating with peristaltic pump, notation DW, DC-P (exp. E-10);

b) with sea water, recirculating with peristaltic pump, notation SW, DC-P (exp.E-3).

All these three experiments are designatedd U-experiments II.

From the substance chosen for each experiment, samples were taken for determining humidity, density and composition. Physical properties of waste sample material and characteristics of drillcores as well as conditions of all leaching experiments are given in Table 1.

It was impossible to extract the substance in its original state. The core was cut into bits of definite geometry, each packed separately in filter paper before weighing and measuring. This was necessary because the material sampled was sandy colloidal clay which otherwise would have changed into pulp and either clogged the apparatus or got carried out of the extractor by water recirculation. Packed in filter paper, the samples retained their shape throughout the experiment (up to 149 days).

All edges of the samples that were cut prismatic were measured with 1 mm precision. The samples were measured on technical weights with 0.5 g precision. Total weight and total surface of the samples was calculated.

Leaching of the samples under dynamic conditions was carried out in two types of extractors:

1) in Soxhlet-apparatus (Fig. 8), working only with demineralized water;

2) in closed systems working with sea water and in two experiments with demineralized water where water recirculation was carried out with the help of peristaltic pump (Fig. 9). Gross volume of the extractors corresponding to the siphon height was 1.0 l. Volume of leachant (demineralized water or sea water), circulating in the leaching system was 3000 ± 200 cm^3. Demineralized water used for extraction was prepared by distilling tap water. Seawater was collected into 35 l white plastic cans and preserved in freezers until usage. At every change of water we analyzed the sea water poured into extractors, determining its ion and microelement contents.

For laboratory modelling of weathering and leaching processes of rocks, Soxhlet-apparatus was first used by the French geochemist G.Pedro (Pedro, 1964).

His method enabled us for the first time to bring the experimental conditions nearer to the natural ones. In the USSR, proceeding from G.Pedro's experience, A.Afanasyeva and A.-T.Pihlak in 1970-ties modelled Cu-Ni sulfide ore oxidizing and leaching processes in Soxhlet-apparatus (Norilsk mineral deposit studies). In 1979-82 E.Maremäe and A.-T.Pihlak studied alum shale leaching processes using the same method at the Institute of Chemical Physics and Biophysics, Estonian Academy of Sciences (Pihlak, Maremäe, Jalakas, 1985). This method also has been used by V.Bgatov for studying and modelling weathering processes in rocks at the Siberian Department of Russian Academy of Sciences (Bgatov, 1984).

Extraction was in our experiments carried out in 7 cycles. Total change of water in the extractors had to be carried out on the 3^{rd}, 6^{th}, 11^{th}, 27^{th}, 57^{th} and 97^{th} day of the experiment. The experiment had to be finished on the 150^{th} day after start. This scheme was mostly followed. Only the experiment E-8 stopped on the 127^{th} day because the distillation flask broke. In experiments E-9 and E-10 the 97^{th} day changing of water did not take place and the 57^{th} day portion of water was used until the end of the experiment. Ion contents of the water (Na^+, K^+, NH_4^+, Ca^{2+}, Mg^{2+}, total Fe, Cl^-, SO_4^{2-}, NO_3^-, free CO_2, HCO_3^-, SiO_2), dry residue, pH, Eh and electric conductivity were determined for solutions formed in every extraction cycle (1.5 l) with classical methods in the Hydrochemistry Laboratory of Geological Centre in Tallinn, Estonia. The dry residue from 1.0 l of water was weighed, packed in plastic bags and sent to the Nuclear Research Centre of Latvian Academy of Sciences in Riga, Latvia, for neutron activation analysis, where Ti, V, Sr, Nb, La, Ce, Ta, Th and U contents were determined. Duration of each extraction cycle and water volume carried through the extractor were registered. Based on the obtained data, ΔI (leaching intensity index) was calculated for all the determined components of each period of the experiment according to the following formula:

$$\Delta I = \frac{\Delta P}{S \cdot \Delta V \cdot \Delta d}, \ mg/m^2 \cdot l \cdot d$$

where: ΔP - component quantity, leached out during the leaching period, mg

S - total active surface of the material in the extractor (summary surface of the samples), m^2

ΔV - amount of water filtrated through the sample in the extractor during a leaching period, l

Δd - duration of a leaching period, days

Basic data and calculation results necessary for calculating the leaching intensity index ΔI are given in Tables 14, 15, 16. ΔI change in time for all the components in each experiment is shown on charts Fig. 10 to 14, where to each ΔI corresponds the cumulative average time ($\bar{d}_n$) of the period from the beginning of experiment (in days):

$$\overline{d_n} = \frac{d_n + d_{n+m}}{2}, \text{ days}$$

where: d_n - cumulative time at the beginning of period n of the experiment

d_{n+m} - cumulative time at the end of period n of the experiment

Weighed means of leaching intensities $\Delta\bar{I}$ in correlation with time (d) show the intensity of leaching process of every component in every experiment from its very beginning up to 149 days. These weighed means ($\Delta\bar{I}$) were calculated according to the following formula:

$$\Delta\bar{I} = \frac{\Delta I_1 \Delta d_1 + \Delta I_2 \Delta d_2 + \ldots + \Delta I_n \Delta d_n}{\sum_{i=1}^{i=n} \Delta d_i}, \text{ mg/m}^2\text{·l·d}$$

Dependence of leaching intensity on time is determined by the equation

$$\Delta I = A \cdot d^B, \text{ mg/m}^2\text{·l·d}$$

Finding the logarithms of both sides of the equation we get:

$$\ln\Delta I = \ln A + B \ln d$$

Taking $\ln\Delta I = y$; $\ln A = A'$ and $\ln d = x$, a simple linear equation results

$$y = A' + Bx$$

Correlations between pH and Eh (mV) as well as between mineralization $\Sigma_{min.}$ (g/l) and electric conductivity G (mS/cm) of the leaching solutions and also of sea water are also determined by the linear equation:

$$y = A + Bx .$$

While preparing the samples for extraction, it turned out that between different core pieces the humidity was spread unevenly, either giving it away easily or adsorbing it from the environment. Therefore after choosing sample material, cutting it into pieces, measuring, weighing and before packing it in filter paper, water content of the sample material for each experiment was once more determined.

Density of dry waste material was determined in all samples with classical methods in pycnometers (50 cm^3) using petroleum.

Composition of sample material was determined before as well as after leaching in the following manner:

- Total of macrocomponents Al_2O_3, Fe_2O_3, TiO_2, MnO, CaO, MgO, total S, P_2O_5, FeO, Na_2O, K_2O, content of mineral CO_2 as well as heat losses in all samples taken for leaching were determined with classical silicate analysis methods, Zr and Pb-contents by X-ray-fluorescence analysis in the laboratory of the above-mentioned Geological Centre.

- Contents of microcomponents V, Sr, Nb, La, Ce, Ta, Th and U with neutron activation analysis methods in Riga.

- Radioactive isotope contents in samples to be leached were determined by α-spectrometry in the Laboratory of Radiochemistry, St. Petersburg University in Russia, and by γ-spectrometry in the Institute of Chemical Physics and Biophysics, Estonian Academy of Sciences, the latter using γ-spectrometer with high purity germanium detector (HPGe GMX series detector) (EG G Ortec) and a NaI scintillation γ-spectrometer. The EG & G Ortec High-Purity Germanium coaxial photon detector system, Model GmX-1890-P used a 48.4 mm Dia, 50.9 mm Length crystal in a POP-TOP cryostat with 1.80 keV FWHM resolution at 1.33 MeV, ^{60}Co; 46:1 peak-to-compton ratio and 18% relative efficiency for ^{60}Co. The electronics consisted of Silena multichannel analyzer 9308/A card in a Toshiba T-3200 laptop. This detector was quantitatively calibrated using the following IAEA sources:

natural uranium	RGU-1	(400 μg/g)
natural thorium	RGTh-1	(800 μg/g)
potassium	RGK-1	(44.8%)

caesium 134/137 IAEA-154 (^{134}Cs 1355 Bq/kg
^{137}Cs 3749 Bq/kg), Nov. 1988.

As a double check a BICRON Model 3M3/3 scintillation (NaI) γ-spectrometer was also used, but this instrument provided data with larger error margins due do lower spectral resolution and limited sensitivity.

For determining α-active radionuclide contents in the samples a direct method was used in the St. Petersburg University laboratory. This method uses a large surface (0.5 m^2) cylindrical 0.3 m^3 volume A(90%) CH_4(10%) ionization chamber with wiremesh electrode and works in the following manner: samples containing radionuclides with a low activity (up to a few Bq/g) are not chemically processed in order to extract the radionuclides to be determined. After drying the samples are ground into very small particles of only some microns diameter and spread into a rather thin (not more than 10 to 40 mkg/cm^2) and homogeneous layer. Measuring time under these conditions should not be too long and energetic resolution should not be changed as a result of α-particles energy loss in the substance layer. Homogeneous substance layer is carried on the electrode with a special programmed automatic device. Electrodes prepared in this way give at 5.15 MeV α-energy a better than 40 keV resolution.

The energy range of this α-spectrometer is 3.0 to 9.0 MeV, energetic resolution for a 10 mkg/cm^2 sample layer is 28 keV and with a thicker up to 40 mkg/cm^2 layer 60 keV. Effectiveness of registering α-radiation is 0.485. Temporal instability in case of a 10-hour measurement extends to 5.34 keV. Range of possible sample activity is $2 \cdot 10^{-3}$ to 20 Bq. Relative deviation of radionuclide content determination is equal to one average standard deviation ($\pm\sigma$) and does not exceed 15 to 20%, in case of determining isotope contents 3 to 6% and considering divergence of samples - up to 10%. The spectrometer was constantly recalibrated with two 0.5 Bq plutonium samples (^{236}Pu and ^{242}Pu).

The most essential advantage of the method is supposed to be that the sample has not been previously chemically processed (the latter always gives a possible loss of material) and it is possible to determine simultaneously natural as well as technogenic radionuclide contents in samples. This is especially essential when it is necessary to determine the total activity of these samples.

A shortcoming of the method is a 10 to 100 times lower sensitivity than in case

of radiochemical enrichment. That is why isotope contents of U and Th and the total activity were additionaly checked in St. Petersburg with α-spectrometry after chemical extraction of the corresponding fractions from the sample.

Sensitivity of this method for plutonium-239 is 0.01 Bq/g.

The α-spectrometry data provided by the St.Petersburg University Laboratory of Radiochemistry turned out to be erratic and practically impossible to interpret. When contracting for these measurements we understood that normal radiochemical procedures would be followed with measurements carried out using contemporary apparatus. This was, however, not the case. These contradictory α-spectrometry data are, however, presented for reference in Table 7/3.

Leaching of all the elements at all stages of the experiment were calculated according to the following formula:

$$E = \frac{\Delta P \cdot 100}{C}, \%.$$

where ΔP - element (component) quantity leached out of sample at a given stage of the experiment, mg;

C - component contents in the sample of substance to be leached, mg.

Intensity of element migration in water is not dependent on its content in water, but on the ratio of element concentration in water and in the contacting rocks. Proceeding from that A.J.Perelman suggested in 1975 the use of migration coefficient K_x for estimating element migration in water:

$$K_x = \frac{M_x \cdot 100}{A \cdot n_x},$$

where M_x - element content in water, mg/l;

A - total of all the elements (components) in water (total of ions or solid residue), mg/l;

n_x - element content in rock, %.

Using the above-mentioned coefficient K_x for estimating element migration in leaching experiments we equalled:

$M_x = \Delta P$ - total leaching of the element during the whole experiment, mg;

$A = \Sigma_{min.}$ - total leaching of all the elements during this experiment (total dry residue

on evaporation), mg;

n_x - element content in the material under study, %.

3. RESULTS

3.1. Properties and composition of waste storage.

Geological and geophysical investigation of the boreholes PA-1 and PA-2 proved that in the drilling sites (Fig. 2) the depository consists of several layers of different origin (Figs. 3 and 6). The lower layer consists of uranium ore processing waste (h ≈ 11.2 to 11.5 m). Natural blue clay and shore sediment layers (pebbles, gravel, sand, etc.) constitute the floor of the lower layer. The upper layer contains loparite ore processing wastes (h ≈ 3 to 8 m). Both layers are covered by a 1.5 to 2.0 m layer of filling material. Borehole PA-1 was drilled into the oldest (reservoir "A") and borehole PA-2 into the newest part of the depository (reservoir "C"). All following studies were carried out with drillcore material from borehole PA-1 as the most representative.

Volume weight of the process wastes increased under natural conditions in both drillcores downwards from top to bottom: in the loparite waste layer 1.30 to 1.44 g/cm^3 and in the uranium ore waste layer 1.40 to 2.00 g/cm^3. Natural volume weight of the sand layer lying under the depository was 1.64 g/cm^3 (Fig. 6). Density of the dry waste material also increased from top to bottom: 2.25±0.02 g/cm^3 in the loparite waste layer and 2.71±0.06 g/cm^3 in the lower part of uranium ore waste layer (Table 1).

Results of loparite ore and uranium ore processing waste chemical composition (macro- and microcomponents) before and after leaching are given in Tables 2 to 6.

The upper layer (3) consists of loparite ore processing wastes mixed with oil shale ash to cement it. Despite that the layer is plastic and not well cemented. Addition of ashes leads to high CaO (30.37÷30.72%), mineral CO_2 (12.86÷13.68%) and MgO (5.11÷5.80%) contents (Table 2). Results of neutron activation analysis (Table 3) and X-ray fluorescence analysis (Table 6) of depository material before leaching shows us that this layer is characterized by a high content of the following elements: Nb - 0.10÷0.14% or 50÷70 clarkes, La - (4.2÷5.78)·10^{-2}% or 14.5÷21.1 clarkes, U - (2.3÷2.4)·10^{-3}% or 9.2÷9.6 clarkes, Th - (9.32÷11.2)·10^{-3}% or 7.1÷8.6 clarkes and Pb -

(5.5÷7.2)·10^{-3}% or 3.4÷4.5 clarkes. Contents of Ce, Sr and V exceeded the clarke 2.3÷3.2 - fold and content of Zr 1.2÷1.4 times. Contents of Ti and Ta were lower than the clarke.

The data given about Th and U contents corresponds relatively well to the results of α- and γ-spectrometry of these samples (Tables 7/1 and 7/3). Results given in Table 8 express the ratio of radionuclide activity contained in the sample to its clarke activity. In loparite ore processing wastes the ^{226}Ra content was relatively high, 3.22÷18.65 clarkes (average 8.36 clarkes), but at the same time the average ratio of Ra/U α-activities was low: 0.85±0.31 and the γ-activities ratio was 0.93 (see Table 7/1), while the nature ratio is 1.02. This shows that part of ^{226}Ra has been lost, for example leached out and carried into the sea or into lower layers of the dump. Conversely, there may have been other sources of uranium waste (from $U_3O_8 \rightarrow UO_2$ conversion, for example). Geophysical measurings in the boreholes PA-1 and PA-2 (Figs. 4,5) and surface γ-fluence measuring results of core slices with a DPГ-O1T1 dosimeter (Fig. 7) also showed the relatively low γ-activity of the loparite waste layer, but a much higher than average for the depository γ-activity of the uranium ore waste layer.

Isotope activity ratios ^{234}U/^{238}U, ^{235}U/^{238}U, ^{230}Th/^{232}Th in the loparite wastes samples (Table 9) did not essentially differ from these ratios in nature.

High contents of Th, Ti, and of the rare earth (RE) metals in loparite ore processing waste were due to the fact that loparite, present in the raw ore only to a few percent, (Boulah, 1989) contains: Th ≤ 0.5%, TiO_2 - 39.2÷40.0%, RE_2O_3 - 32÷34%, $(Nb,Ta)_2O_5$ - 8÷10%, SrO - 2÷3.4% and UO_2 - n·10^{-2}% (Betehtin, 1961). Only Nb, Ta and partly Ti were at first extracted for usage. Other components were partly discarded as wastes, thus creating a source of environmental pollution with peculiar composition and unknown properties. It should be studied in detail in the future.

Some physical properties of loparite processing wastes in the L-experiments are given in Table 1. Water content of the samples was very high, 49.1÷56.2%.

Uranium ore raw material has changed during the course of operations. The first raw material was Estonian black (dictyonema) alum shale mined in the local underground mine (opened, closed and liquidated in 1949, 1952, 1969, respectively). From 1945 (Althausen, 1992) to 1952 63.3 t of Estonian uranium was produced from

$240.5 \cdot 10^3$ t of this black shale. This is why the lowest layers of depository may be alum shale processing wastes. The plan of mine and the mined regions are given in Fig. 1. There is no direct data on the composition and uranium content of alum shale in the Sillamäe deposit that was actually used. Alum shale resources in Estonia amount to 64 billion tonnes with a potential uranium content equal to millions of tonnes of the natural isotope mix. Uranium content in the Sillamäe alum shale was probably one of the highest in Estonia and its composition resembled that of the Toolse deposit, 75 km to the west of Sillamäe, and the metal-containing black shale in Ansfeld (Germany) (Table 2). After conservation of the Sillamäe mine in 1952, uranium was produced from different ores or ore concentrates imported from Russia and later from East-European countries.

Data about silicate-, neutron activation and X-ray fluorescence analysis of the samples taken for leaching in U-experiments are given in Tables 2 to 6. Processing wastes contained: U $(1.9 \div 2.3) \cdot 10^{-2}$% or 190-230 g/t, exceeding the clarke 76÷92 times; Pb - $(8.49 \div 11.72) \cdot 10^{-2}$% or 53-73 clarkes, Nb - $(8.10 \div 20) \cdot 10^{-2}$% or 40÷100 clarkes. Ce and V-contents exceeded clarke 1.8÷4.3 times. La and Zr-contents did not differ from clarkes significantly. In most cases Th, Ti and Ta-contents were lower than clarke.

Contents of radionuclides ^{238}U, ^{226}Ra, ^{218}Po, ^{214}Po, ^{230}Th, ^{234}U, ^{235}U, ^{232}Th, ^{40}K, ^{137}Cs and ^{60}Co (Bq/g) in the uranium processing wastes are given in Tables 7/1, 7/2 and 7/3. Isotope activity ratios $^{235}U/^{238}U$ and $^{234}U/^{238}U$ (Table 9) did not differ significantly from the ratios in natural uranium. On the other hand, activity ratio of ^{226}Ra and ^{238}U (Ra/U) that in natural conditions is equal to 1.02, amounted to 29.8÷37.8 (Table 8) in the uranium ore waste. Obviously Ra was not extracted during uranium oxide separation processes, and it was left in the production wastes where Ra-contents in that part of the storage exceed clarke (*i.e.* $8.4 \cdot 10^{-11}$%) 3280÷4180 times (Table 8).

Uranium wastes are similar to clays for their high adsorbing ability and thixotrophy. Vibration accompanying drillcore sawing caused its liquefication. We managed to collect and analyze about 400 cm^3 of the water flowing out during liquefication due to vibration of the drillcore of the borehole PA-2 (from the depth interval 11.1÷14.0 m). Ion contents of this water were, mg/l: Na^+ - 1220, K^+ - 820,

NH_4^+ - 4700, Ca^{2+} - 2157, Mg^{2+} - 17.7, Fe_{total} - 0, Cl^- - 522.6, SO_4^{2-} - 42944, NO_3^- - 71.6, NO_2^- - 84.2, HCO_3^- - 1684.1, SiO_2 - 14.8. Total amount of ions in water was Σi = 52.236 g/l, pH = 8.0 and Eh = +174 mV. High contents of NH_4^+ in storage water is caused by neutralizing waste products with NH_4OH.

Considering the volume of water flowing into the sea from beneath the depository as 1610 m^3 per day with an average mineralization equal to Σi = 15.1 g/l (1.51%), taking average mineralization of the groundwaters Σi = 0.2 g/l (0.02%) and the depository water mineralization Σi = 52.2 g/l (5.22%) we find that the volume of groundwater must constitute 71% and the amount of depository water 29% or, according to the daily water flow, the groundwater daily volume is 1150 m^3 and that of depository water 460 m^3. The groundwater thus carries 0.2 t of mineral substances and the depository water 24 t from beneath the depository into the sea per day. Average vertical filtration speed in the depository is:

$$V = Q : S = 460 : 350000 = 1.3 \cdot 10^{-3} \text{ m/day},$$

where: V - speed of filtration, m/day;

Q - daily water flow, m^3;

S - depository surface, m^2.

The speed (V) is very low and is typical of watertight clays. It takes $24:(1.3 \cdot 10^{-3})$ = 18200 days or about 50 years to percolate through the 24 m high depository to the sea level. This approximate calculation gives us some guidance as to how long-lasting the processes polluting the sea and groundwater in this case really are.

3.2. Characterization of the leaching water.

For leaching the samples in experiments E-2, E-4, E-6, E-8, E-9, E-10 and P-1 (called DW-experiments) we used demineralized water, in experiments E-1, E-3, E-5, E-7 and P-2 (SW-experiments) - sea water. Sea water was collected from the breakwater of Leppneeme harbour (125 l in June 1994) and from the coast of Rohuneeme (70 l in August 1994) (Viimsi peninsula, Gulf of Finland). Ion contents and physical properties of the sea water are given in Table 10, content of microelements in Table 11. Water in the Gulf of Finland is of low mineralization: the dry residue on evaporation was 4.99±0.27 g/l. The main ion contents are: Cl^- - 2.42±0.20; Na^+ -

1.37 ± 0.11 and SO_4^{2-} - 0.341 ± 0.038 g/l. Uranium content in the sea water was $(4.23\pm2.39)\cdot10^{-6}$ g/l, thorium content $(1.18\pm0.5)\cdot10^{-6}$ g/l. Mean concentrations of other microelements in sea water were (in diminishing order): Ti - $1.27\cdot10^{-2}$, Sr - $6.68\cdot10^{-4}$, Nb - $5.01\cdot10^{-4}$, Ce - $1.3\cdot10^{-4}$, V - $4.9\cdot10^{-5}$, La - $2.4\cdot10^{-6}$ and Ta - $2.4\cdot10^{-7}$ g/l. Mean pH of the sea water was 7.4 ± 0.4, Eh = $+190\pm18$ mV and electric conductivity G = 7.86 ± 0.55 mS/cm.

Demineralized water did not contain mineral matter. Mean pH of the water was 5.35 ± 0.33 and Eh = $+384\pm15$ mV (Table 12).

Table 12 gives all mineralization, pH, Eh and electric conductivity data of the leaching solutions. Table 13 gives equations determining dependence of sea water and demineralized water Eh on pH and dependence of electric conductivity G of sea water on water mineralization $\Sigma_{min.}$. These are:

in sea water Eh = 473.9-38.2 (pH) mV,

in demineralized water Eh = 384.0-43.8 (pH) mV.

Charts of these equations are given on Figs. 20 and 21 with indices SW and DW. Correlation coefficient $r_{Eh,pH}$ for sea water was -0.860 and that of demineralized water -0.971. This shows their close correlation.

pH-Eh measuring results of our data coincide with the region characteristic for natural and ground waters (Fig. 18).

Correlation between electric conductivity G and mineralization $\Sigma_{min.}$ is expressed by the linear equation:

$$G = -1.425 + 1.86\ \Sigma_{min.}\ , \text{ mS/cm.}$$

Correlation coefficient $r_{G,\Sigma min.} = 0.882$ proves their close correlation.

3.3. Leaching of samples with demineralized and sea water.

3.3.1. Leaching of loparite ore processing wastes (L-experiments)

Leaching of loparite wastes was carried out in experiments E-8, E-9 and E-5 according to methods described above (p. 8,9).

The difference between two DW-experiments E-8 (DC-S) and E-9 (DC-P) (Fig. 10) lies in the conditions of leaching process. In experiment E-8 the sample was in contact only with pure demineralized water, accordingly modelling natural leaching of depository material by rainfall. At the same time in experiment E-9, pure demineralized

water taken for leaching circulated in a closed system through the sample, thereby mineralizing more and more with every cycle on account of substances leached out. That very soon influenced leaching results - leaching intensity decreased (Tables 14/2, 14/3; Fig. 10/1). If at the first cycles of the experiment leaching intensity indices of mineralization ($\Delta I_{min.}$) were almost equal in experiments E-8 and E-9, then during the final cycles of exp. E-9 $\Delta I_{min.}$ were always smaller than those in exp. E-8. At the end of the experiment it was at the same level as in the SW-experiment E-5, where the arithmetical mean of mineralization at the beginning of the cycles was 4.99 ± 0.27 g/l. Higher mineralization level of the leachant inhibited leaching and its change in time. In experiment E-5 leaching speed of $\Sigma_{min.}$ was lower than in experiments E-8 and E-9 (Fig. 10/1; Fig. 11/1). At the same time it is obvious that high mineralization of leachant inhibited leaching of Na, Fe, Cl, S, NO_3^-, Ti, La, Th and U.

In studying the dynamics of leaching intensity (ΔI) in DW-experiments E-8 and E-9 it appeared (Fig. 10) that leaching intensities of Na, K, NH_4^+, Cl^-, SiO_2, V, Th and $\Sigma_{min.}$ decreased, but still stayed positive. Leaching of Ce in experiment E-8 and leaching of Nb, La, Ta and U in experiment E-9 showed the same nature. Leaching intensities of other elements also showed a general tendency to decrease in time while staying positive throughout the experiment. Two types of almoust simultaneous and similar deviations could be noted. Leaching intensity ΔI of some elements (Ca, Fe, Mg, Ti, Sr, Ta and U in exp. E-8, Ca and Fe in exp. E-9) increased at the beginning of the experiment, but then decreased. For some other elements, however, ΔI (NO_3^- in exp. E-8; NO_3^-, Mg, S, Sr and Ce in exp. E-9) decreased abruptly at the beginning of the experiment, then increased and decreased again.

Weighed means of leaching intensities (ΔI) of all components in experiments E-8 and E-9 are given in Table 17.

Leaching intensities (ΔI) in the SW-experiment E-5 Table 15/2, Fig. 11 decreased more or less evenly, staying positive, only for K, NH_4^+ and SiO_2. Leaching intensity of Ca increased at the beginning of the experiment, then decreased evenly until the end of the experiment. Other components were not leached out by sea water. On the contrary, the initial sample adsorbed them from sea water (ΔI is negative). Adsorption of Na, Fe, Cl^-, NO_3^-, Ti, Ta and Th from sea water went on for 2 days, adsorption of Mg and S for 9 days, adsorption of La and U for 19 days. During the

further course of experiment, many rises and falls of ΔI followed with amplitude diminishing in time. In the first stage of leaching (average cumulative time d=2 days) ΔI was positive for V, Nb, Ce and $\Sigma_{min.}$, in the second stage (d=5 days) for Nb, Ce and $\Sigma_{min.}$ and in the third stage (d=9 days) for V, it was negative. In the next leaching stages leaching-adsorbing intensities (ΔI) varied up to the end of experiment, fluctuating around a steady state, constantly changing their sign.

Results of all L-experiments show that the leaching (adsorbtion) was most intensive during first three or four stages (d=9 to 19 days). After that the process turns stable and ΔI starts fluctuating around the ΔI trend line nearing zero, characteristic of every element's balance level between the sample material and leachant. Depending on the component, concentration change in the leaching water ΔI was either bigger or smaller, positive or negative in time.

In DW-experiments E-8 and E-9, the following correlation between leaching intensities (ΔI) (Tables 18,19 and Figs. 15/1, 16/1, 17/1) and the time (d, days) exists:

$$\Delta I = A \cdot d^{-b} \text{ mg/m}^2 \cdot \text{l} \cdot \text{d}$$

The corresponding correlation coefficient $r_{d,\Delta I} = -0.902 \div -0.997$ shows close correlation between d and ΔI. As in the SW-experiment E-5, ΔI was very variable, being once positive, once negative.

Table 17 gives weighed averages ($\Delta \bar{I}$) of ΔI in L-experiments for 149 days from the beginning of leaching. The largest $\Delta \bar{I}$ values were found in the DW-experiment E-8, where the sample was in contact with pure demineralized water. In the DW-experiment E-9, where mineralization of the leachant constantly grew during the experiment, the $\Delta \bar{I}$ values were several times smaller. And finally, in the SW-experiment E-5, where mineralization of the leachant was already high at the beginning of the experiment and increased in the course of it, the smallest $\Delta \bar{I}$ values were found.

In exp. E-5 $\Delta \bar{I}$ was negative for Na, Mg, Cl^-, S, NO_3^-, Ti, Ta, *i.e.* as the result depository material adsorbed these components from sea water more than they were leached into it. That is proved in Table 20 where total leaching outputs are given.

Tables 7/1, 7/2, 7/3 and 8 provide data on radionuclides and their isotope activity in loparite ore processing waste before and after leaching. Activities have been expressed in two ways: as Bq/g and as the ratio of radionuclide activity in the sample and the earth crustal abundance clarke, to show how many times radionuclide activity

of the sample exceeds the earth crust clarke. It is obvious from Table 7/3 that for ^{238}U, ^{226}Ra and ^{232}Th activity of sample material after leaching may be in most cases higher than before leaching. This is partly true and due to differential leaching of more easily soluble components and partly an artifact caused by errors in α-spectrometry, which were later corrected with the use of γ-spectrometry data (Table 7/1).

Results contrary to those given above showed ^{226}Ra and ^{232}Th contents in exp. E-9; ^{210}Po and ^{40}K contents in exp. E-8 and E-9. Decrease of ^{40}K activity by 52÷100% in loparite waste after leaching is due to high solubility of potassium and big output (62.8÷75.3%) in leaching process (Table 20).

U and Th isotope activity ratios in L-experiments samples before and after leaching (Table 9) differed only little from these ratios in nature.

Absolute and relative changes of component contents in samples leached are given in Tables 21/1 and 22/1.

3.3.2. Leaching of uranium processing wastes (U-experiments)

Leaching of uranium processing wastes in experiments E-4, E-6, P-1, E-1, E-7 and P-2 (named UI-experiments) from the depth of 14.52÷16.2 m and experiments E-2, E-10, E-3 from the depth of 19.44÷20.04 m (named UII-experiments) were carried out according to the methods described above. Leaching results of samples from both horizons will be analyzed separately.

3.3.2.1. Experiments with depository material from the depth of 14.52÷16.2 m (UI-experiments)

In studying the dynamics of leaching in this series, we could find both common and different features depending on whether leaching was carried out with demineralized water (DW-experiments) or sea water (SW-experiments).

In all DW-experiments (Tables 14/1, 14/2 and 16) leaching intensities of all components (ΔI) were positive (Fig. 12). That means these components were leached out of depository material. At the same time in SW-experiments (Tables 15/1, 15/2 and 16) ΔI was positive only for the following components (Fig. 13): $\Sigma_{min.}$, NH_4^+, Ca and S in all experiments, NH_4^+ and SiO_2 in exp. E-1, SiO_2, Fe and Ta in exp. E-7, NH_4^+

and Fe in exp. P-2. In all other SW-experiments instead of leaching into the leachant, the same components were adsorbed from the leachant (ΔI changed negative).

ΔI changed evenly for $\Sigma_{min.}$, S and NH_4^+ in all experiments; Na, K, Mg and Cl^- only in DW-experiments; Ca only in SW-experiments.

In all UI-experiments deviations of leaching intensity were quite frequent where ΔI either increased or decreased. Dynamics of leaching may change so that ΔI was low at the beginning, then increased and afterwards decreased, fluctuating in relation to some average trend, is characteristic of the following components: a) with DW - Ca, Fe, NO_3^-, La, Ta (exp. E-4, E-6, P-1); SiO_2, V, Sr, Nb (E-4, E-6); Ce (E-4); Th (E-6); U (P-1) (Fig. 12/1÷23); b) with SW - Fe, NO_3^-, Ti (exp. E-1, E-7, P-2); SiO_2 (E-1, P-2); Ta (E-1, E-7); V, Sr, La (E-7); Na, Ca, Cl^- (P-2) (Fig. 13/1÷22).

While studying leaching process in DW-experiments it appeared that dynamics of ΔI change where ΔI is high at the beginning, then decreases sharply, later increases-decreases again, was characteristic of the components having comparatively low leachability or low concentration in the sample material. These are: Na, Ti (exp. E-4); Ce (E-6); SiO_2 , Ti, V, Sr, Nb, Ce, Th (P-1) (Tables 14/1, 14/2 and 16, Fig. 12).

Dynamics of leaching intensity change where ΔI was negative at the beginning of leaching was characteristic only of the following components in SW-experiments: NO_3^- and Ta, the adsorbing of which began during 2 days, Fe and Th (9 days) and Ti (42 days) in exp. E-1; NO_3^-, Sr, La (2 days) and Ti (19 days) in exp. E-7; Ti (2 days) in exp. P-2 (Tables 15/1, 15/2 and 16, Fig. 13).

In some SW-experiments leaching process dynamics was extremely complicated: in the first stage of leaching there was intensive leaching of the components and ΔI was high, in the next stages leaching was replaced by adsorption and ΔI decreased sharply, changing negative, then it increased again, changing positive. Changing constantly, ΔI fluctuated near 0 until the end of experiment. Such leaching process was characteristic of the following components: Na, K, Mg, Cl^-, Nb and Ce (exp. E-1, E-7, P-2); V, Sr, La (E-1, P-2); Th (E-7, P-2); NO_3^- and Ta (P-2) (Tables 15/1, 15/2 and 16, Fig. 13).

Figs. 12 and 13 show that the most intensive leaching periods differ in DW- and SW-experiments. In DW-experiment the most intensive period ended in stage IV (average cumulative time d=19 days), sometimes in stage V (d=42 days), after that

ΔI stabilized. In SW-experiments most similar to the DW-experiments described above were cases where the most intensive leaching period ended in stages III-IV (d respectively 9 and 42 days) and ΔI either decreased evenly throughout the experiment or was high at the beginning and decreased thereafter, still staying positive. Such components were: $\Sigma_{min.}$, NH_4^+, Ca, S and U. In all other SW-experiments the most intensive leaching period was stage I or stages I+II (d=2÷5 days) which began with active leaching of components (ΔI is positive), after that in stage II or III leaching was replaced by adsorption (ΔI is negative). In later stages ΔI were usually low or fluctuated with small deviations around some steady state.

Tables 18,19 and Fig.-s 15/2,3; 16/2, 17/2,3 show that in all UI-experiments there is gradual dependence between leaching intensity (ΔI) of $\Sigma_{min.}$, Th and U and cumulative time (d, days): $\Delta I = A \cdot d^{-b}$. In DW-experiments correlation coefficients are high: r=-0.902÷-0.990. It was low only in relation to U: r=-0.527. In SW-experiments the same correlation coefficients in relation to U were: r=-0.826÷-0.901 (exp. E-1, E-7) and r=+0.726 (P-2). What concerns leaching of Th into sea water, it was very erratic.

Table 17 gives weighed means of ΔI in relation to time (ΔI, $mg/m^2 \cdot l \cdot d$) in all UI-experiments. They are relatively similar for all the components in simultaneous DW-experiments (E-4, E-6). The highest ΔI found here were for $\Sigma_{min.}$ (356÷365 $mg/m^2 \cdot l \cdot d$), S (73.15÷75.6), Ca (57.46÷60.6), Cl^- (17.81÷19.7), NH_4^+ (16.03÷19.7) and Na (11.62÷12.48). Leaching intensities of Th and U however, were very low: $\Delta I_{Th} = (6.26 \div 8.16) \cdot 10^{-5}$ and $\Delta I_U = (4.74 \div 10.2) \cdot 10^{-4}$ $mg/m^2 \cdot l \cdot d$.

In some SW-experiments ΔI were negative for the following components: K, Ti and Th (exp. E-1, E-7); NO_3^- (E-7); Na, Cl^-, NO_3^- and Ti (P-2).

Table 20 gives leaching outputs that in SW-experiments were negative for the following components: Na, K, Ti, V and Th (exp. E-1); K, V, (E-7); Na, Ti and V (P-2).

Data given in the Tables 7 show that in UI-experiments activities of ^{238}U, ^{234}U and ^{235}U in the sample were after leaching consistently lower than before leaching. In all the samples Th-activities were higher after leaching. Contents of ^{218}Po, ^{214}Po and ^{210}Po were unstable but generally followed the uranium leaching pattern. It is very important to note that leaching of radium ^{226}Ra is generally very small or absent.

Expressed in activities of earth crust clarkes, ^{238}U content of sample taken for UI-experiments decreased from 107.7 down to 84.2 clarkes in DW-experiments and

down to 89.6 clarkes in SW-experiments (Table 8), while ^{226}Ra-content changed but little. Ra/U ratio, which in samples before leaching exceeded the ratio of clarkes 31.4 times, decreased in the course of leaching in DW-experiments down to 30. In SW-experiments this ratio did not change and stayed as it was in the initial material.

Isotope activity ratios $^{234}U/^{238}U$ and $^{235}U/^{238}U$ and $^{230}Th/^{232}Th$ in UI-experiments did not differ essentially from these ratios in nature.

Based on analysis of UI-experiments on samples and outputs of leaching, material balances of all the components are given in Tables 21/2, 21/3, 22/2 and 22/3.

3.3.2.2. Experiments with dump material from the depth of 19.44 to 20.04 m (UII-experiments)

In DW-experiments E-2 and E-10 of this series ΔI of all components was positive. In experiment E-2 $\Sigma_{min.}$, Cl^-, S, Ti, NH_4^+ and V leached out with an evenly decreasing intensity. ΔI of the last two components decreased evenly until the end of stage VI, in the next stage VII their ΔI increased again. In exp. E-10 $\Sigma_{min.}$, Na, K, Mg, Cl^-, S, SiO_2, Ti, V, Nb, Ta and Th leached out with evenly decreasing intensity. In the first stages of leaching evenly decreasing, then increasing and in the end decreasing again - this is how Ca, Fe, Ti, Sr, La, Ce and U leached out
(Tables 14/1 1nd 14/3, Fig. 14).

In the SW-experiment E-3 ΔI was positive only for the following components: $\Sigma_{min.}$, NH_4^+, Ca^{2+}, Mg^{2+}, S, SiO_2 and U. For V ΔI was positive up to the end of stage VI, but changed to negative in stage VII. Right at the beginning of the experiment, sample material started adsorbing several components from the sea water. So, it adsorbed K during 19 days (on the average), Na, Th and Sr - during 5 days and Fe, Cl^-, NO_3^-, Ti, Nb and Ta - during 2 days (Table 15/1, Fig. 14).

Weighed means of ΔI in relation to time (ΔI) in UII-experiments are given in Table 17. Here, using Soxhlet-apparatus in DW-experiments, ΔI of macrocomponents $\Sigma_{min.}$, Na, K, NH_4^+, Ca, Mg, S, NO_3^-, SiO_2, Ti and the same of microcomponents V, Nb and U are also bigger than in exp. E-10 using peristaltic pump. In SW-experiment E-3 ΔI of macrocomponents were all lower than these in DW-experiments (E-2 and E-10) but microcomponents V, Nb, Ta and U had higher ΔI. In SW-experiments all weighed

means (ΔI) were negative for K, Cl^-, Ti and Sr.

Tables 18,19 and Figs. 15/4, 16/3, 17,4 show that leaching intensity (ΔI) for $\Sigma_{min.}$, Th and U and cumulative leaching time (d) in UII-experiments were also interrelated ($\Delta I = A \cdot d^{-b}$) and their correlation coefficients were: $r_{\Sigma min.,d}$ = -0.956÷-0.990, $r_{Th,d}$ = -0.860÷-0.988, $r_{U,d}$ = -0,850÷-0.908.

Fig. 15/4 shows that in experiments E-2 and E-3 the graphs of function $\Delta I_{\Sigma min.}$ = f(d) are practically parallel, while graph of SW-experiment E-3 is lower than that of DW-experiment E-2. Graph of exp. E-10 intersects with the graph of exp. E-2 at the beginning and with graph of exp. E-3 considerably later. This shows that at the later stages of the process, where demineralized water recirculating in the system is quite similar to sea water regarding mineralization, leaching slows down as compared to leaching in the Soxhlet-apparatus. Graphs of uranium leaching ΔI_U = f(d) are very close (Fig. 17/4) but here ΔI is at the end of SW-exp. E-3 also lower than in the DW-exp. E-2. Graph of exp. E-10 intersects also those of E-2 and E-3, but in this case it is due to the fact that in exp. E-10 ΔI_U was low already at the beginning and it decreased in time more slowly than in experiments E-2 and E-3.

Tables 7 and 8 give activities of some radionuclides and their isotopes (Bq/g) as well as contents in clarkes before and after leaching in the sample materials of all UII-experiments.

If expressed in earth crust clarkes (Table 8), content of ^{238}U in sample material decreased in DW-experiments from the average clarke value of 108.3 at the beginning of experiment to 93.4 (exp. E-2) and 101.6 (exp. E-10) at the end of experiment. Th-content in sample material, expressed in clarkes decreased from 1.39 at the beginning to 1.13 in DW-experiments and to 0.38 respectively at the end of SW-experiment.

Activity ratios $^{234}U/^{238}U$, $^{235}U/^{238}U$ and $^{230}Th/^{232}Th$ of samples measured before and after leaching (Table 9) did not differ essentially from the natural ratios in UII-experiments.

Table 20 gives the total output of the components in all UII-experiments. Comparing the DW- and SW-experiments, we can notice higher outputs of Na, Nb, S, Ce, Ta and U by leaching with the sea water (exp. E-3). Outputs of SiO_2, Ti and Th were in exp. E-3 lower than in DW-experiments, outputs of V and Sr appeared negative. Outputs of exp. E-10 were for most components intermediate between

outputs of E-2 and E-3, only for Ca, Sr, La, Ce, Ta and Th the outputs were higher. It should be mentioned that outputs of Th and U were very small. So, output of Th ranged in DW-experiments from 0.157 to 0.21%, in SW-experiment it was only 0.086%. The same values for U: from 0.22 to 0.40%, and 0.53%, respectively.

Tables 21/4 and 22/4 give the leaching balances of macro- and microcomponents in UII-experiments showing absolute and relative changes in component contents in the samples leached.

3.4. Migration coefficients of components

Tables 23 and 24 give migration coefficients K_x for macro- and microcomponents calculated on the basis of experimental results according to A.I.Perelman (Perelman, 1989). For comparison literature data by the same author are given for migration coefficients of components in ground-, surface- and ocean waters of the hypergenesis zone.

Determining migration coefficients is of interest because in several natural systems they are proportional to the corresponding amounts of components migrating in water. We have practically no data on migration coefficients in industrial waste waters.

Table 23 shows that migration coefficients in DW-experiments differ to some extent from the data given in literature on hypergenesis zone and surface waters (Dobrovolsky, 1983; Perelman, 1989). The difference is obviously due to a higher mineralization level of leachates than that of natural waters. There is also a notable difference in leaching waters K_x of loparite ore and uranium ore processing wastes. It is especially clearly seen when comparing the following decreasing sequences of arithmetical means of K_x. The scale of migration intensity (strong, medium, weak) after A.Perelman is given at the end of Tables 23 and 24. The K_x values of the components found in leachates of loparite ore processing waste order as follows:

Cl^- (480) > Na (16.4) > K (11.3) > Sr (2.05) > S (1.8) > Nb (0.85) > Ca (0.81) > Ti (0.67) > Ta (0.33) > Mg (0.11) > Si (0.08) > U (0.036) > V (0.03) > Th (0.0044) > La (0.0017) > Fe (0.0015).

For DW-leachates of uranium ore waste:

Cl^- (144) > S (2.91) > Ca (2.42) > Mg (2.34) > Na (2.09) > Sr (1.83) > Ti (0.61) >

U (0.5) > K (0.15) > Ta (0.13) > Ce (0.1) > Nb (0.01) > La (0.064) > Si (0.05) > V (0.025) > Th (0.019) > Fe (0.0044).

These differences are obviously due to a different composition of the materials leached. Differences are even bigger for K_x values of the same components in leachates of loparite and uranium ore processing wastes in SW-experiments. It is well demonstrated by sequences of the arithmetical means of K_x in analogy to those given above.

For leaching loparite waste with sea water:

K (46.6) > Sr (13.9) > S (3.7) > U (2.42) > Nb (2.16) > Ce (1.56) > Ta (1.08) > Ca (0.44) > Si (0.40) > La (0.24) > Fe (0.003) > Th (-0.001) > Ti (-0.06) > V (-1.40) > Mg (-24.6) > Na (-126.6) > Cl^- (-2869).

For leaching uranium ore waste with sea water:

S (2.90) > Ca (2.59) > Sr (1.27) > Mg (1.08) > Na (0.97) > U (0.52) > Ce (0.25) > Nb (0.21) > Ta (0.18) > V (0.11) > La (0.098) > K (0.040) > Si (0.017) > Th (0.0055) > Fe (0.0015) > Ti (-0.10) > Cl^- (-186.6).

The minus sign before a coefficient shows that the element did not migrate from the studied waste into the water, but *vice versa* - from water into waste, *i.e.* it was adsorbed. Under which conditions these processes occur in a given system and some similar systems, needs further study. At present we can only note that such processes do take place. Their importance lies in the fact that they hinder spreading of certain components in the environment, forming adsorption barriers. Prof. G.L.Stadnikov, a well-known Russian specialist in chemistry of caustobioliths gave much attention to these processes already in the 50-ies in his book "Clayrocks" (Stadnikov, 1957).

It is noteworthy that during leaching uranium ore wastes with demineralized water as well as with sea water, the migration coefficients K_x were very close for S, Ca, Sr, U and La despite big differences in composition and the mineralization level of leachates of these elements.

3.5. Some chemical and physical properties of the leaching water

The properties of water influence natural chemical weathering processes in rocks and migration of the elements leached out from there (Garrels, 1965; Perelman, 1989). This is why pH, Eh and G of the leaching water were determined (Table 12,

Figs. 19/1÷5). It turns out that for loparite waste in DW-experiments (E-8 and E-9) in the solutions formed pH was the highest (11.3÷12.2) and Eh respectively low (-42÷+79 mV), while electric conductivity G fluctuated in the range of 0.49÷4.6 mS/cm. In the SW-experiment E-5 pH equalled 8.0÷12.9, Eh = +10÷+250 mV and G = 7.64÷9.02 mS/cm.

In solutions formed in the uranium waste DW-experiments (E-4, E-6, E-2, E-10), pH equalled 2.6÷7.3, Eh = +58÷+464 mV and G = 1.02÷3.82 mS/cm. In the SW-experiments in the same series (E-1, E-7 and E-3) pH varied between 6.5÷8.1, Eh = +140÷+294 mV and G = 8.7÷10.74 mS/cm. Under static conditions the results were just a little different. In exp. P-1: pH = 6.4÷8.0, Eh = +182÷+342 mV and G = 1.57÷3.24 mS/cm. In exp. P-2: pH = 6.2÷7.2; Eh = -90÷+240 mV and G = 9.14÷10.0 mS/cm. Figures 19/1÷5 show the change of pH in leaching waters from stage I to stage VII of these experiments observed in time. The biggest changes of pH in leaching waters in all experiments occurred up to the stages I, III and IV. Beginning from stage IV in most experiments, except E-3, E-5 and E-6, pH was relatively stable.

Figs. 20 and 21 depict graphs of Eh dependency on pH in DW and SW-experiments. Regression equations of these dependencies for different groups of experiments are given in Table 13. As we can see, this dependence is linear (y = Ax+b). Correlation coefficients $r_{pH,Eh}$ were the highest in the DW-experiments E-8 and E-9 ($r_{pH,Eh}$ = -0.842), in E-4 and E-6 ($r_{pH,Eh}$ = -0.888) and then in demineralized water ($r_{pH,Eh}$ = -0.971). In experiments E-2 and E-10, the correlation coefficient was notably lower ($r_{pH,Eh}$ = -0.487) and under static conditions (exp. P-1) still lower ($r_{pH,Eh}$ = -0.353). If we subject the results of pH and Eh in DW-experiments to mathematical treatment, we get the following regression equation:

$$Eh = 501.41 - 41.87(pH)\ [mV]$$

The correlation coefficient is $r_{pH,Eh}$ = -0.911. This shows that despite some deviations in one or another experiment, there is a good correlation between pH and Eh of leaching waters in DW-experiments.

In the SW-experiments, dependence of Eh on pH varied to a great extent (Tab. 13, Fig. 21). Usually, when pH increases, Eh decreases (Garrels, 1965). In the SW-experiments E-1, E-3 and E-7 it was just the opposite. In the rest of SW-experiments this dependence was usual, but the correlation coefficients $r_{pH,Eh}$ were smaller in the

SW-experiments than in DW-experiments. In the SW-experiments E-1 and E-7 $r_{pH,Eh}$ = +0.549 and in E-3 +0.46.

In the loparite waste leaching SW-experiment E-5 $r_{pH,Eh}$ = -0.434 and for the uranium ore waste leaching experiment P-2 under static conditions $r_{pH,Eh}$ = -0.580. Treating all pH and Eh-results of the SW-experiments together, we get a generalized regression equation:

$$Eh = 286.98 - 13.08(pH) \text{ [mV]}$$

Its correlation coefficient was $r_{pH,Eh}$ = -0.244, which is very low. As dependence of pH and Eh in sea water does not differ from the usual one (Table 13, Fig. 21) and $r_{pH,Eh}$ = -0.860, in this case the unexpected result was caused by unusual results of the SW-experiments E-1, E-7 and E-3 mentioned above. Generally, all results of our experiments coincide with the results in pH and Eh coordinates of natural water (Fig. 18) (Garrels, 1965), locating on that part of the graph that corresponds to ground and surface waters.

Dependence of electric conductivity of leachates G [mS/cm] on their mineralization $\Sigma_{min.}$ [g/l] was linear in DW- as well as in SW-experiments (Table 13):

$G_{DW} = 0.499 + 0.968\ (\Sigma_{min.})$, whereby r = +0.777

$G_{SW} = 4.394 + 0.714\ (\Sigma_{min.})$, whereby r = +0.432.

It may be concluded from the given formulae that when mineralization of leachates grows, the difference between electric conductivities of leachates formed in DW and SW experiments falls, as both electric conductivities rise differently and equalize at the mineralization $\Sigma_{min.}$ = 15.335 g/l.

3.6. Application of results

Leaching intensity indices (ΔI) found as a result of the present study may be used in various calculations if there is a need to estimate the amount of components that flow into the water after leaching out of depository material.

4. SUMMARY

The investigations carried out showed that the waste depository (height from sea level h = 24÷-25 m) at Sillamäe metallurgical plant "Silmet" consists of two waste layers of almost equal thickness. The lower layer is constituted of uranium ore

processing waste, the upper – of loparite ore processing waste and oil shale ash. Both layers differ as to the composition of the material, radioactivity and physical as well as chemical properties.

In loparite ore processing Nb, Ta and some Ti were extracted. Rare earth metals present in loparite in abundance as well as U were at first not extracted and discarded as waste. Oil shale ash from the local thermal power station was added to the dump probably to neutralize and bind them. This is why composition of the waste as to macrocomponents (considering relatively high contents of CaO, MgO and mineral CO_2) is to a certain extent similar to that of oil shale ash. As to content of microcomponents it is similar to the loparite ore. Nb-content in the waste amounted to 50÷70 clarkes, La-content to 15÷21 and Pb-content to 3.4÷4.5 clarkes. Contents of other microelements were smaller than 3 clarkes.

The loparite waste layer has the lowest radioactivity in the depository. ^{226}Ra-content in it exceeds the clarke only up to 18.6 times, ^{238}U-content up to 16.4 times, ^{232}Th-content up to 9.3 times. ^{40}K-content was low and amounted to 0.51 clarkes. Activity ratio Ra/U varied from 0.49 to 1.14, and the average 0.93, although slightly lower than the natural balance ratio, is well within the error limits.

The loparite ore processing waste contains about 100 t ^{238}U, 290 t ^{232}Th and 28 g ^{226}Ra.

Based on the data of γ-logging the level of γ-radiation in the borehole PA-1 in the loparite waste layer was 25÷250 mkR/h and in PA-2 it was 250÷750 mkR/h.

As to the composition of macrocomponents, uranium ore processing waste is similar to that of the alum shale of Toolse (Estonia) and black metalliferous shale of Mansfeld (Germany). Contents of microelements and radionuclides in this waste are high. Earth crust clarke was exceeded by Pb 53÷73 times and for Nb 40÷100 times. Based on single random spectral analysis data Bi-content in the sample amount to 200 g/t (22200 clarkes) and the As-content 1000 g/t (588 clarkes). It is not excluded that contents of Cd, Hg, Se, Sb and other toxic elements in the dump might also prove high. At present we have no data yet on their contents and leachability.

In the uranium producing process used at Sillamäe, ^{226}Ra and ^{232}Th were not extracted from the ore. They were discarded as waste. This is why their share in waste radioactivity is very high. Content of ^{226}Ra in the waste exceeds earth crust clarke up

to 4180 times, that of ^{238}U up to 125 times, ^{232}Th and ^{40}K - up to 1.4 times. Activity ratio Ra/U exceeds the natural balance ratio (Ra/U = 1.02) 30.9 to 38.6 times.

The uranium ore processing waste contains about 1100 t ^{238}U, at least 60 t ^{232}Th and 12 kg ^{226}Ra.

Based on the data of γ-logging, the level of γ-radiation in the borehole PA-1 in the uranium waste layer was 3000÷9000 mkR/h.

Isotope activity ratios of the radionuclides $^{234}U/^{238}U$, $^{235}U/^{238}U$ and $^{230}Th/^{232}Th$ in uranium as well as in loparite ore processing wastes were within the usual limits and did not differ from the natural ones.

As to their physical properties, the loparite and uranium wastes are both similar and form some kind of plastic or fluid sandy clay. Water content in them varies greatly, ranging from 31 to 56% and it is very unevenly distributed in the drillcore. Under the influence of vibration the seemingly solid and only somewhat humid drillcore slice turned into a plastic fluid of flowing consistence. Such qualities of the dump material are very dangerous, because stability reserves of the dams surrounding the waste dump are exhausted at the present time. This is why even a moderate disturbance, for example explosion or a small earthquake may cause extensive liquefication of the dump material. As a result they are likely to break the surrounding dam and flow into the Gulf, causing extensive pollution of the sea and coasts (beaches) with radioactive and toxic substances.

Like all clays and argillites, the clay-like wastes in the dump have low water-permeability. According to our approximate calculations the speed of vertical filtration in the dump is $1.3 \cdot 10^{-3}$ m per day. Consequently, it takes 50 years for the rainfall to percolate through the dump and reach the sea level. Such filtration actually exists. This is proved by the fact that some 1610 m^3 of water with high mineralization (mean 15.1 g/l), which is actually a mixture of dump water ($\Sigma_{min.}$=52.2 g/l) and ground water ($\Sigma_{min.}$=0.2 g/l), flows daily from below the dump into the sea. By our calculations 1150 m^3 (71.4%) of the average daily outflow is attributable to ground water and 460 m^3 (28.6%) to the dump water. With these waters a daily average of 24.3 t of dissolved mineral matter flows from below the dump into the sea, 99% or 24 t of which constitute mineral matter leached out of the dump. Considering the very slow water movement in the dump, the latter is going to pollute the Gulf of Finland for millennia. As the dump

and ground waters were not investigated, it is impossible to state the precise amounts of radionuclides and microcomponents flowing daily into the sea. This could be a topic for separate research.

Depository material leaching experiments with demineralized and sea water under dynamic and static conditions showed that their leaching is a very complicated process. The dynamics of the leaching intensity (ΔI) change in time is dependent on the properties of the material being leached, the leaching conditions and mineralization of the water used for leaching. While analyzing the experimental data a working hypothesis arose that leaching intensity under the conditions of the experiments carried out was not so much dependant on the amount of water getting into contact with the depository material, as on the speed of diffusion of the leached components through the separation layer of the different phases. This suggestion needs further experimental proof.

In studying leaching processes, demineralized water was used for modelling the influence of rainfall and surface water. For modelling leaching in sea water, water from the Gulf of Finland was used. In all experiments both before and after leaching, empirical formulae of mutual correlation between pH and Eh, likewise between $\Sigma_{min.}$ and G were derived showing that these dependences are linear ($y=Ax+B$).

In all experiments with demineralized water (DW), the leaching intensities (ΔI) were only positive, *i.e.* components were leached out of the initial sample material. At the same time in some experiments ΔI decreased evenly throughout the whole experiment, at the end nearing zero. In other experiments ΔI decreased unevenly, once rising, then falling and *vice versa*, fluctuating at the end around some steady state characteristic of every component and system in the experiment. Leaching was most intensive usually in the very beginning, up to the leaching stages III or IV ($d=9\div19$ days).

Leaching dynamics in SW-experiments turned out even more complicated than that in DW-experiments, as leaching intensities (ΔI) were not only positive but sometimes negative, *i.e.* simultaneously with component leaching an opposite process went on - absorption of a component from leachant by the sample material. Leaching began with either positive or negative ΔI, which kept changing its sign and began to fluctuate around a steady state at the end.

Alternation of component leaching with its absorption from leachant is quite a new and unexpected facet that might prove important not only in solving problems of leaching and storing radioactive wastes, but also in finding further use in environmental studies in general. As the phenomenon is not well known at present, it needs detailed investigation in future.

Leaching intensities of Th, U and $\Sigma_{min.}$ as a function of the cumulative time $\Delta I = f(d)$ are best expressed in an exponential form $\Delta I = Ad^{-b}$ which can be applied in determining the amounts of components leaching out of wastes, rocks, etc. in a certain time interval, both in nature as well as under industrial conditions. High correlation coefficients $r_{\Delta I,d} = -0.850 \div 0.997$ confirm their good mutual correlation.

Comparison of dependences $\Delta I = f(d)$ and their graphs led us to conclude that leaching intensity ΔI is reciprocal to mineralization of the leaching water $\Sigma_{min.}$ Accordingly, leaching is the most intensive in demineralized water and the slowest in sea water.

Comparison of weighed means of leaching intensities in relation to time (ΔI) showed that for Th and U they were by 5 to 6 orders smaller than for the macrocomponents, and their outputs (E,%) in the leaching process $E = n(0.01 \div 0.1)\%$ are respectively 2 to 4 orders smaller. As more easily leachable and moving macrocomponents are more energetically carried out of the depository, it gets enriched with comparatively less leachable radioactive components, despite the fact that the absolute amount of the latter in the depository material also diminishes.

Balances of uranium ore waste leaching experiments show that relative concentrations of the macrocomponents SiO_2, Fe and K and of most microcomponents (U, Th, *et al.*) grew throughout the leaching process. It is important to note that radium ^{226}Ra (also ^{210}Po, ^{227}Th) is practically insoluble in all cases, while uranium ^{238}U leaches out quite readily.

Thus for the first time migration coefficients in water (K_x) of the elements leaching out of the Sillamäe waste depository were determined.

Radionuclide contents in samples to be leached determined with γ-spectrometric methods before and after leaching are in satisfactory accordance with neutron activation analysis results for ^{238}U and ^{232}Th and supplement them with data on ^{226}Ra, ^{210}Po, ^{232}Th, ^{227}Th, ^{137}Cs, ^{60}Co and ^{40}K. Some additional α-spectrometric

measurements provide data about ^{218}Po, ^{214}Po, ^{230}Th, ^{234}U, ^{235}U (and ^{239}Pu), but due to the obsolete technique used in these measurements, these data provided is largely contradictory and error-prone. No plutonium ^{239}Pu was found. Using β-spectrometry, it was established that ^{14}C is present in natural abundance and no ^{60}Ni could be detected.

Contents of ^{137}Cs and ^{60}Co were present in the samples on the level of global background, ^{40}K-contents were either considerably smaller than the earth crust clarke or equalled them. Contents of ^{210}Po, ^{214}Po and ^{218}Po in loparite processing wastes were very low and did not exceed 1.2 Bq/g. In uranium wastes they varied from 36 to 100 Bq/g whereby their averages were respectively 73.1, 58.6 and 61.3 Bq/g.

5. CONCLUSIONS

1. The main objectives proposed in the working programme of leaching tests on radioactive waste in the depository at the Sillamäe uranium extraction and processing facility (Metallurgy Plant "Silmet", Estonia), have been met. These studies provided new data on chemical leaching properties of untreated uranium ore processing waste discarded in abundance in this depository. Radioactivity, chemical composition, physical and leaching properties as well as possible environmental dangers were determined and studied in detail.

Leaching of waste samples with demineralized and sea water under dynamic and static conditions were studied, leaching rates (Δl, $mg/m^2 \cdot l \cdot d$) of macro- and microcomponents (Nb, Pb, Zr), among them radioactive elements (U, Ra, Th, Po, Pu, Co, Cs), and regularities of their changes in time, were determined. From the dependences established between the leaching rates and cumulative time, predictive formulae were derived for determining the amounts of components leaching out of various wastes into the water. This approach can be applied for predicting the danger of pollutants spreading from waste dumps.

2. The Sillamäe waste depository is hazardous first of all for the Gulf of Finland on several accounts, because:

a) it contains about 6 mln. m^3 of highly radioactive (90 to 120 KCi) thixotropic waste with a plastic flowing consistence, lying behind a dam, the stability reserve of which is practically exhausted.

b) permanent sea pollution is provided by waters flowing from below the dump and consisting of both ground water and dump water. They carry daily into the sea 24 tonnes of mineral matter leached out of the depository.

c) relative content of practically insoluble components, including such strongly radioactive elements as radium rises constantly in the depository as easily leachable components are washed away. The depository material turns more dangerous with time and may leach at a later date in the sea by biochemical interaction with marine life and bacteria in particular. Some proteins have extremely high binding coefficients for Ca^{2+}, Ba^{2+} (and Ra^{2+}), which may well allow leaching of even sulfates of these elements.

3. In the course of the studies circumstances, essential for estimating the environmental impact of the waste were established. Among them:

- extremely high ^{226}Ra content in the depository;
- high contents of As and Bi and possibly other toxic microelements;
- similarity of depository material behaviour to that of plastic clays;
- selective leaching of components, resulting in selective enrichment of depository material;
- very uneven distribution of γ-radioactive nuclides in the depository.

Investigations carried out so far should be taken as preliminary that need confirmation. As the experience shows these studies are rather labour-consuming, they need extensive fieldwork (more boreholes all over depository), laboratory modelling experiments, and extensive analysis. Modern α-spectrometry must be introduced.

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Table 1

Physical qualities of waste depository sample material and characteristics for drillcores and all leaching experiments

Origin of waste in the sample	Depth interval of the drillcore PA-1 used for the sample, m	Natural average water content of the sample %	Quantity of sample used, (dry mat.), g	Whole surface area of the sample cm^2	Density, g/cm_2	Code of the extractor	Type of leachant water	Leaching method
loparite	6.64-7.36	56.2	282.0	554.5	2.25±0.02	E-8	demineralized	Soxhlet extraction
loparite	6.64-7.36	55.9	182.3	417.1	-"-	E-9	demineralized	recirculation system
loparite	6.64-7.36	49.1	282.6	546.7	-"-	E-5	seawater	recirculation system
uranium ore	14.52-16.20	38.7	533.1	901.4	2.35±0.02	E-4	demineralized	Soxhlet extraction
uranium ore	14.52-16.20	38.7	519.0	926.8	-"-	E-6	demineralized	Soxhlet extraction
uranium ore	14.52-16.20	43.7	463.0	900.8	-"-	P-1	demineralized	static method
uranium ore	14.52-16.20	41.2	500.0	888.3	-"-	E-1	seawater	recirculation system
uranium ore	14.52-16.20	48.0	444.7	915.8	-"-	E-7	seawater	recirculation system
uranium ore	14.52-16.20	45.4	470.8	914.5	-"-	P-2	seawater	static method
uranium ore	19.44-20.04	35.5	455.0	812.2	2.71±0.06	E-2	demineralized	Soxhlet extraction
uranium ore	19.44-20.04	32.4	288.3	558.6	-"-	E-10	demineralized	recirculation system
uranium ore	19.44-20.04	41.0	434.0	829.4	-"-	E-3	seawater	recirculation system

Table 2

Results of analysis of initial samples used for the leaching experiments (in weight %)

Component	Wastes from loparite ore treament		Wastes from uranium ore treatment									Alum shale from the Toolse deposit (Estonia), %	Metalliferous black shale from the Mansfeld deposit (Germany), %
	depth interval 6.64-7.36 m		depth interval 14.52-16.20 m							depth interval 19.44-20.04 m			
	Extractor code												
	E-8	E-9	E-5	E-4	E-6	P-1	E-1	E-7	P-2	E-2	E-10	E-3	
Macro-elemental multicomposition analysis using classical chemical methods													
SiO_2	18.70	20.66	18.96	37.90	36.50	37.90	36.72	35.60	36.64	40.94	44.38	41.38	42.16	33.15
Al_2O_3	4.83	5.07	4.83	10.45	10.21	10.45	10.58	10.58	10.58	11.18	11.05	11.05	9.52	17.30
Fe_2O_3	4.22	4.81	4.22	4.53	4.62	4.71	4.69	4.71	4.79	5.74	6.22	5.74	4.65	2.6(Fe)
TiO_2	0.51	0.58	0.53	0.42	0.43	0.41	0.43	0.41	0.42	0.52	0.55	0.55	0.76	-
MnO	0.080	0.084	0.088	0.21	0.319	0.301	0.296	0.288	0.346	0.149	0.238	0.168	0.06	-
CaO	30.37	30.72	30.37	12.78	13.61	13.13	13.25	13.38	13.13	10.55	9.85	10.55	4.42	10.4
MgO	5.80	5.11	5.72	1.51	1.61	1.36	1.49	1.44	1.39	2.10	2.21	2.10	2.83	1.0
S_{total}	4.22	4.29	4.29	8.14	8.18	8.28	8.42	8.42	8.44	6.19	6.16	6.46	5.01	2.31
P_2O_5	0.16	0.19	0.16	0.28	0.28	0.27	0.28	0.28	0.28	0.26	0.24	0.26	0.10	-
FeO	0.24		0.24	0.96	0.96	0.96	0.80	0.96	0.88	0.96	0.43	0.96	2.87	-
Na_2O	0.26	0.26	0.25	0.91	0.90	0.88	0.91	0.87	0.87	0.92	1.15	0.95	0.10	1.0
K_2O	1.37	2.00	1.42	2.74	2.69	2.96	2.64	2.66	2.69	2.66	2.89	2.69	7.62	3.0
Mineral CO_2	13.07	13.68	12.86	1.89	1.89	1.78	1.89	1.89	1.89	1.78	2.10	1.78	0.21	9.24
Weight loss at 1000 °C	21.50	20.27	20.92	24.30	24.82	24.80	25.33	26.13	25.60	21.68	18.55	21.85	17.79	-

Table 3

Results of neutron activation analysis of initial samples used for the leaching experiments (in weight %)

Component	Wastes from loparite ore treatment			Wastes from uranium ore treatment								Alum shale from the Toolse deposit (Estonia), %	Metalliferous black shale from the Mansfeld deposit (Germany), %
	depth interval 6.64-7.36 m			depth interval 14.52-16.20 m						depth interval 19-44-20.04 m			
	Extractor code and test conditions												
	E-8	E-9	E-5	E-4	E-6	P-1	E-1	E-7	P-2	E-2	E-10	E-3	
V	2.7E-2	3.5E-2	2.4 E-2	3.8E-2	3.8 E-2	4.0E-2	3.8E-2	4.0E-2	3.0 E-2	3.9E-2	2.4E-2	2.9 E-2	0.20	1.3 E-2
Sr	6.0E-2	11.0E-2	6.0 E-2	10.1E-2	4.6 E-2	2.0E-2	2.8E-2	3.2E-2	6.6 E-2	3.0E-2	2.0E-2	2.5 E-2	1.0 E-2	3.4 E-2
Nb	0.1	0.14	0.1	0.1	0.21	0.1	0.1	0.09	0.1	0.2	0.1	0.08	-	2.0 E-3
La	4.2E-2	6.13E-2	5.78E-2	2.2E-3	2.9 E-3	3.2E-3	2.4E-3	2.5E-3	4.5 E-3	5.7E-3	3.9E-3	4.16E-3	-	2.9 E-3
Ce	1.1E-2	1.1E-2	1.6 E-2	1.3E-2	1.25E-2	2.0E-2	1.5E-2	1.5E-2	1.54E-2	3.0E-2	1.5E-2	2.5 E-2	8.0 E-3	7.0 E-3
Ta	7.5E-5	2.4E-5	7.2 E-5	6.0E-5	6.5 E-5	6.2E-5	6.1E-5	5.6E-5	6.0 E-5	5.7E-5	6.9E-5	5.9 E-5	-	2.5 E-4
Th	9.2E-3	11.2E-3	9.32E-3	1.3E-3	1.1 E-3	0.9E-3	1.0E-3	1.0E-3	0.83E-3	1.0E-3	1.1E-3	1.0 E-3	1.0 E-3	1.3 E-3
U	2.3E-3	2.4E-3	2.4 E-3	1.9E-2	2.0 E-2	2.1E-2	2.0E-2	2.2E-2	2.0 E-2	2.1E-2	2.3E-2	2.2 E-2	4.77E-2	2.5 E-4

Table 4

Result of solid phase analysis after leaching experiments (in weight %)

Component	Wastes from loparite ore treatment			Wastes from uranium ore treatment								
	depth interval 6.64-7.36 m			depth interval 14.52-16.20 m						depth interval 19.44-20.04 m		
	Extractor code and test conditions											
	E-8 DW DC-S	E-9 DW DC-P	E-5 SW DC-P	E-4 DW DC-S	E-6 DW DC-S	P-1 DW SC	E-1 SW DC-P	E-7 SW DC-P	P-2 SW SC	E-2 DW DC-S	E-10 DW DC-P	E-3 SW DC-P
Macro-elemental multicomposition analysis using classical chemical methods												
SiO_2	19.78	21.22	20.20	41.80	39.34	40.54	39.90	39.46	39.32	46.38	46.64	45.68
Al_2O_3	4.25	4.54	4.14	11.30	10.28	9.20	9.30	9.20	9.64	11.07	10.26	9.84
Fe_2O_3	4.81	5.00	4.86	5.62	5.37	5.16	5.08	5.35	5.03	6.84	5.54	5.96
TiO_2	0.48	0.58	0.59	0.48	0.43	0.39	0.47	0.41	0.46	0.54	0.56	0.61
MnO	0.082	0.085	0.095	0.119	0.191	0.196	0.191	0.194	0.227	0.086	1.44	0.115
CaO	29.03	30.04	28.57	11.86	12.01	11.45	10.81	10.77	10.91	8.92	7.13	8.14
MgO	6.09	5.14	7.98	1.29	1.34	1.09	1.43	1.36	1.36	2.02	2.07	1.97
total S	3.58	4.05	4.13	7.60	6.61	6.69	6.58	6.42	6.95	4.90	4.40	4.55
P_2O_5	0.16	0.19	0.16	0.33	0.32	0.29	0.29	0.29	0.29	0.30	0.26	0.28
FeO	0	0	0	0.54	0.71	0.80	0.96	0.75	0.90	0.54	1.77	1.00
Na_2O	1.35E-3	8.49E-3	0.75	0.78	0.72	0.66	1.00	0.74	0.94	0.93	1.10	0.78
K_2O	0.36	0.75	0.46	2.94	2.76	3.04	2.93	2.95	2.78	2.89	3.01	2.89
Mineral CO_2	8.50	8.83	9.46	0.54	0.54	0.60	0.81	0.78	0.85	0.50	0.56	0.79
Weight loss at 1000 °C	16.03	19.30	15.68	19.49	18.87	21.06	21.03	21.03	20.37	14.02	16.37	16.68
Weight loss at 450 °C	9.42	15.08	9.42	3.29	3.82	3.52	3.48	2.99	2.93	3.51	5.20	2.93

Table 5

Results of neutron activation analysis of solid phase after leaching experiments (in weight %)

Component	Wastes from loparite ore treatment			Wastes from uraniu ore treatment								
	depth interval 6.64-7.36 m			depth interval 14.52-16.20 m						depth interval 19.44-20.04 m		
	Extractor code and test conditions											
	E-8 DW DC-S	E-9 DW DC-P	E-5 SW DC-P	E-4 DW DC-S	E-6 DW DC-S	P-1 DW SC	E-1 SW DC-P	E-7 SW DC-P	P-2 SW SC	E-2 DW DC-S	E-10 DW DC-P	E-3 SW DC-P
V	2.67E-2	3.4 E-2	2.5E-2	4.5 E-2	4.0E-2	4.1 E-2	4.0 E-2	4.3 E-2	3.1 E-2	4.3E-2	2.5E-2	3.1 E-2
Sr	4.9 E-2	10.0E-2	4.9E-2	10.8E-2	3.6E-2	1.6 E-2	1.7 E-2	3.0 E-2	6.8 E-2	3.1E-2	1.8E-2	2.7 E-2
Nb	1.0 E-1	1.35E-1	1.0E-1	1.17E-1	2.3E-1	1.0 E-1	1.01E-1	9.3 E-2	1.02E-1	2.2E-1	1.0E-1	0.82E-1
La	4.13E-2	6.08E-2	5.9E-2	2.67E-3	3.3E-3	3.18E-3	2.5 E-3	2.7 E-3	4.7 E-3	6.3E-3	4.0E-3	4.4 E-3
Ce	1.1 E-2	1.08E-2	1.6E-2	1.57E-2	1.4E-2	2.05E-2	1.55E-2	1.56E-2	1.6 E-2	3.3E-2	1.3E-2	2.6 E-2
Ta	7.4 E-5	2.3 E-5	7.3E-5	7.1 E-5	7.2E-5	6.3 E-5	6.2 E-5	5.8 E-5	6.1 E-5	6.1E-5	6.8E-5	6.0 E-5
Th	9.1 E-3	11.0E-3	9.5E-3	1.55E-3	1.2E-3	0.89E-3	1.05E-3	1.07E-3	0.85E-3	1.1E-3	1.1E-3	1.05E-3
U	2.3 E-3	2.3 E-3	2.5E-3	2.28E-2	2.2E-2	2.15E-2	1.92E-2	1.9 E-2	2.01E-2	2.3E-2	2.4E-2	2.3 E-2

Table 6

Results of X-ray fluorescence analysis of initial samples before and after leaching experiments, mg/kg

Component	Wastes from loparite ore treatment			Wastes from uranium treatment									Clarke of earth's crust, mg/kg
	depth interval 6.64-7.36 m			depth interval 14.52-16.20 m						depth interval 19.44-20.04 m			
	Extractor code and test conditions												
	E-8 DW DC-S	E-9 DW DC-P	E-5 SW DC-P	E-4 DW DC-S	E-6 DW DC-S	P-1 DW SC	E-1 SW DC-P	E-7 SW DC-P	P-2 SW SC	E-2 DW DC-S	E-10 DW DC-P	E-3 SW DC-P	
Before leaching													
Zr	207	239	208	115	163	152	153	147	154	170	190	177	170
Pb	69	55	72	867	855	861	849	878	836	1142	1021	1172	16
After leaching													
Zr	222	251	216	138	180	160	167	164	166	192	190	196	170
Pb	46	45	79	1016	977	830	856	809	839	1250	1036	1123	16

Table 7/1

Activity of isotopes of radionuclides in the samples before and after leaching experiments, Bq/g. (The data of gammaspectrometry)

Extractor code	Test conditions	Before leaching, after leaching, change, %	Activity, Bq/g					
			^{238}U	^{226}Ra	^{210}Po	^{232}Th	^{227}Th	^{40}K
1	2	3	4	5	6	7	8	9
Isotope clarke in earth crust			3.7 E-2	3.7 E-2		4.9E-2		
I Wastes from loparite ore treatment (depth interval 6.64-7.36m)								
E-8	DW	Before	0.43	0.39	0.23	0.54	-	0.43
	DC-S	After	0.55	0.43	0.27	0.58	0.016	0.14
		%	+17.4	+2.7	+9.8	-0.4	-	-70.3
E-9	DW	Before	0.56	0.62	0.55	0.51	-	0.36
	DC-P	After	0.58	0.47	0.30	0.45	-	0.0
		%	-1.2	-28.3	-47.6	-16.0	-	-100
E-5	SW	Before	0.44	0.37	0.24	0.56	-	0.27
	DC-P	After	0.43	0.50	0.42	0.53	0.02	0.10
		%	-11.4	+22.2	+56.8	-15.0	-	-68.5

Table 7/1(continued)

1	2	3	4	5	6	7	8	9
II Wastes from uranium ore treatment (depth interval 14.52 - 16.20 m)								
E-4	DW DC-S	Before After %	2.6 2.8 -17.1	114 151 +1.8	110 135 -5.7	0.035 0.052 +14.0	4.9 6.35 +0.04	0.68 0.84 -5.0
E-6	DW DC-S	Before After %	3.7 3.2 -27.5	123 153 +3.3	118 138 -2.4	0.082 0.044 -55.2	5.2 6.4 +2.6	0.69 0.81 -1.1
P-1	DW SC	Before After %	2.3 2.4 -4.0	126 142 +3.4	114 130 +4.3	0.062 - -	5.4 5.9 +0.3	0.59 0.66 +3.4
E-1	SW DC-P	Before After %	3.1 2.5 -26.5	119 138 +6.0	113 126 +2.6	0.068 0.068 -8.1	5.0 5.9 +7.1	0.47 0.79 +54.8
E-7	SW DC-P	Before After %	3.2 2.5 -30.2	128 127 -12.6	117 118 -11.2	0.067 0.048 -37.1	5.4 5.4 -11.4	0.63 0.97 +35.0
P-2	SW SC	Before After %	3.1 2.7 -18.8	122 141 +5.6	113 130 +5.5	0.039 0.055 +29.1	5.2 5.9 +4.8	1.15 0.78 -38.1

Table 7/1(continued)

1	2	3	4	5	6	7	8	9
III Wastes from uranium ore treatment (depth interval 19.44-20.04 m)								
E-2	DW DC-S	Before After %	3.9 2.4 -47.5	139 151 -8.2	131 140 -10.0	0.051 0.060 -0.8	6.0 6.9 -3.3	0.68 0.72 -10.5
E-10	DW DC-P	Before After %	2.9 2.7 -13.3	117 138 +6.7	110 124 +2.3	0.091 0.056 -44.1	5.2 6.1 +5.6	0.69 0.62 -17.5
E-3	SW DC-P	Before After %	2.0 2.4 +7.7	135 141 -8.2	124 129 -9.2	0.056 0.056 -12.4	5.9 6.3 -6.3	0.59 0.70 +3.2

Activity of some isotopes of radionuclides in the samples, Bq/g. (The data of gammaspectrometry)

Extrac-tor code	Test condi-tions	Activity, Bq/g			
		^{137}Cs	^{60}Co	^{235}U	^{239}Pu
1	2	3	4	5	6
E-8	DW DC-S	<0.008	<0.008	0.016	<0.08
E-9	DW DC-P	<0.006	<0.006	0.030	<0.07
E-5	SW DC-P	<0.004	<0.005	0.021	<0.05
E-4	DW DC-S	<0.03	<0.04	-	-
E-6	DW DC-S	<0.04	<0.05	-	-
P-1	DW SC	<0.04	<0.05	-	-
E-1	SW DC-P	<0.03	<0.04	-	-
E-7	SW DC-P	<0.03	<0.04	-	-
P-2	SW SC	<0.04	<0.05	-	-
E-2	DW DC-S	<0.03	<0.04	-	-
E-10	DW DC-P	<0.03	<0.03	-	-
E-3	SW DC-P	<0.04	<0.05	-	-

Activity of isotopes of radionuclides in the initial samples before and after leaching experiments, Bq/g. (The data of α-spectrometry)

Extractor code	Test conditions	Before leaching, after leaching, change, ±%	Activity, Bq/g							
			^{238}U	^{218}Po	^{214}Po	^{210}Po	^{230}Th	^{234}U	^{235}U	^{232}Th
1	2	3	4	5	6	7	8	9	10	11
Activity of isotope's clarke in earth crust			3.66 E-2							4.88E-2
I Waste from loparite ore treatment (depth interval 6.64-7.36 m)										
E-8	DW	Before	0.20	-	-	0.9	1.2	0.25	0.008	0.18
	DC-S	After	0.32	-	-	0.5	2.5	0.40	0.010	0.39
		±%	+60.0	-	-	-44.4	+108.3	+60	+25.0	+116.7
E-9	DW	Before	<0.5	-	-	-	-	-	<0.03	0.49
	DC-P	After	0.57	-	-	0.30	-	-	<0.03	0.45
		±%	+14.0	-	-	-	-	-	0	-8.2
E-5	SW	Before	0.2	-	-	1.2	1.4	0.25	0.01	0.21
	DC-P	After	0.26	0.28	0.58	0.35	3.6	0.30	0.01	0.45
		±%	+30.0	-	-	-70.8	+157.1	+20.0	0	+114.3

Table 7/3 (continued)

1	2	3	4	5	6	7	8	9	10	11
II Waste from uranium ore treatment (depth interval 14.52-16.20 m)										
E-4	DW	Before	3.2	56	52	51	45	3.7	0.17	≤0.05
	DC-S	After	2.4	58	49	97	109	2.8	0.13	≤0.06
		±%	-25.0	+3.6	-5.8	+90.2	+142.2	-24.3	-23.5	+˜20.0
E-6	DW	Before	3.2	56	36	64	41	3.5	0.16	≤0.04
	DC-S	After	2.8	60	50	75	83	3.4	0.10	≤0.06
		±%	-12.5	+7.1	+38.9	+17.2	+102.4	-2.9	-37.5	+˜50.0
P-1	DW	Before	3.1	67	66	64	54	3.6	0.10	≤0.04
	SC	After	2.5	50	54	72	89	3.2	0.10	≤0.07
		±%	-19.4	-25.4	-18,2	+18.8	+64.8	-11.1	0	+75.0
E-1	SW	Before	3.5	68	70	65	49	4.1	0.15	≤0.05
	DC-P	After	3.1	53	65	64	77	3.6	0.17	≤0.08
		±%	-11.4	-22.1	-7.1	-1.5	+57.1	-12.2	+13.3	+60.0
E-7	SW	Before	3.4	70	56	57	54	3.8	0.14	≤0.06
	DC-P	After	2.6	54	45	72	85	3.2	0.12	≤0.06
		±%	-23.5	-22.9	-19.6	+26.3	+57.4	-15.8	-14.3	0
P-2	SW	Before	3.3	66	60	65	53	3.7	0.12	≤0.05
	SC	After	2.5	52	60	100	133	3.0	0.11	≤0.18
		±%	-24.2	-21.2	0	+53.8	+150.9	-18.9	-8.3	+260

Table 7/3 (continued)

1	2	3	4	5	6	7	8	9	10	11
III Waste from uranium ore treatment (depth interval 19.44-20.04 m)										
E-2	DW	Before	3.8	95	92	100	90	4.1	0.18	≤0.06
	DC-S	After	2.9	44	50	54	68	3.3	0.12	≤0.06
		±%	-23.7	-53.7	45.7	-46.0	-24.4	-19.5	-33.3	0
E-10	DW	Before	<2.8	-	-	-	-	-	-	<0.1
	DC-P	After	2.8	-	-	-	-	-	-	0.06
		±%	0	-	-	-	-	-	-	-40.0
E-3	SW	Before	3.3	56	64	75	60	3.5	0.16	≤0.06
	DC-P	After	3.1	76	69	94	111	3.5	0.13	≤0.02
		±%	-6.1	+35.7	+7.8	+25.3	+85.0	0	-18.8	˜-66.7

Table 8

Generalized data on ^{238}U and ^{232}Th contents in ore treatment waste before and after leaching them with demineralized or sea water.

Radio-nuclide	Activity of radio-nuclide's clark of earth crust, Bq/g	Test conditions	Contents in clarkes of earth crust, min÷max / mean		
			Wastes from loparite ore treatment	Wastes from uranium ore treatment	
			Depth interval, m		
			6.64-7.36	14.52-16.20	19.44-20.04
^{238}U	$3.05 \cdot 10^{-2}$	Before leaching	6.56÷16.49 9.84±4.64	102÷115 107.7±4.3	91.8÷125 108.3±13.6
		After leaching with DW	10.49÷18.69 14.59±4.10	78.7÷91.8 84.2±5.6	91.8÷95.1 93.4±1.6
		with SW	8.52	82.0÷101.6 89.6±8.6	101.6
Ra/U	1.02	Before leaching	0.49÷1.14* 0.85±0.31	29.8÷32.2 31.4±1.1	33.4÷37.8 35.6±1.8
		After leaching with DW	0.81÷1.13* 0.93±0.16	21.7÷38.8 30.0±7.0	17.6÷49.0 33.3±15.7
		with SW	0.83±0.3* 0.93±0.1**	21.2÷46.7 31.7±10.9	29.4
^{232}Th	$5.29 \cdot 10^{-2}$	Before leaching	3.40÷9.26 5.54±2.64	0.76÷1.13 0.91±0.13	1.13÷1.90 1.39±0.36
		After leaching with DW	7.37÷8.51 7.94±0.57	1.13÷1.32 1.19±0.09	1.13÷1.13 1.13±0
		with SW	8.51	1.13÷3.40 1.89±1.06	0.38

Notice. * From α-spectrometry data
** From γ-spectrometry data
The contents given in clarkes of earth crust are calculated from α-activities of the samples.

Table 9

Isotope activity ratios in the initial samples before and after leaching experiments (The data of α-spectrometry)

Extractor code	Test conditions	Before leaching, after leaching, change, ±%	$^{234}U/^{238}U$	$^{235}U/^{238}U$	$^{230}Th/^{232}Th$
1	2	3	4	5	6
I Wastes from loparite ore treatment (depth interval 6.64-7.26 m)					
E-8	DW	Before	1.22±0.03	0.040±0.007	6.5±0.3
	DC-S	After	1.26±0.018	0.030±0.005	6.5
		±%	+3.3	-25.0	0
E-5	SW	Before	1.23±0.03	0.050±0.007	6.5±0.3
	DC-P	After	1.16±0.02	0.033±0.005	7.9
		±%	-5.7	-34.0	+21.5
II Wastes from uranium ore treatment (depth interval 14.52-16.20 m)					
E-4	DW	Before	1.19±0.02	0.053±0.005	≥ 950
	DC-S	After	1.11±0.02	0.055±0.005	≥1950
		±	-3.36	+3.8	≥+105
E-6	DW	Before	1.09±0.03	0.049±0.005	≥1000
	DC-S	After	1.22±0.02	0.035±0.006	≥1480
		±%	+11.9	-28.6	≥+48.0

1	2	3	4	5	6
E-1	SW DC-P	Before After ±%	1.17±0.02 1.15±0.02 -1.7	0.044±0.005 0.054±0.005 +22.7	≥920 ≥940 ≥+2.2
E-7	SW DC-P	Before After ±%	1.11±0.03 1.22±0.02 +9.9	0.042±0.005 0.047±0.008 +11.9	≥ 880 ≥1360 ≥+54.6
P-1	DW SC	Before After ±%	1.15±0.02 1.28±0.03 +11.3	0.033±0.005 0.040±0.008 +21.2	≥1350 ≥1300 ≥-3.7
P-2	SW SC	Before After ±%	1.13±0.02 1.19±0.05 +5.3	0.037±0.005 0.045±0.007 +21.6	≥1030 ≥ 741 ≥-28.1
III Wastes from uranium ore treatment (depth interval 19.44-20.04 m)					
E-2	DW DC-S	Before After ±%	1.08±0.02 1.14±0.017 +5.6	0.043±0.003 0.043±0.005 ±0	≥1460 ≥1200 ≥-17.8
E-3	SW DC-P	Before After ±%	1.07±0.02 1.12±0.015 +4.7	0.047±0.003 0.042±0.005 -10.6	≥ 980 ≥5600 ≥+471.0

Notice. Activity ratios did not differ essentially from these ratios in nature.

Table 10

Ion composition of sea water and its physical and chemical characteristics

Component	Unit	Series of the experiments							Arithmetical mean x±σ
		I	II	III	IV	V	VI	VII	
1	2	3	4	5	6	7	8	9	10
Dry residue	g/l	4.9565	4.9565	4.7150	4.8360	4.7005	5.3945	5.381	4.991±0.268
Na^+	mg/l	1250.0	1250.0	1277.2	1400.0	1333.4	1542.8	1500.0	1364.8±111.0
K^+	-"-	38.8	41.4	43.7	38.8	42.7	48.0	51.4	43.5±4.3
NH_4^+	-"-	0.16	0.07	0	0	0.07	0.59	0	0.13±0.20
Ca^{2+}	-"-	72.9	77.8	72.9	62.1	65.7	82.4	95.2	75.6±10.2
Mg^{2+}	-"-	162.1	165.0	152.6	158.0	154.5	171.7	191.4	165.0±12.3
Fe_{total}	-"-	0.05	0.05	0	0.05	0.12	0.06	0.05	0.05±0.03
Cl^-	-"-	2239.9	2239.9	2314.7	2408.0	2314.7	2744.1	2706.5	2424.0±197.9
SO_4^{2-}	-"-	330.0	354.0	362.5	336.6	335.0	268.3	403.7	341.4±37.8
NO_3^-	-"-	21.0	11.2	74.1	45.0	42.6	79.5	45.7	45.6±23.2
NO_2^-	-"-	0.212	0.003	0.010	0.004	0.043	0	0.607	0.126±0.209
CO_3^{2-}	-"-	0	0	0	0	0	0	0	0
HCO_3^-	-"-	97.6	103.7	97.6	97.6	91.5	103.7	109.0	100.1±5.3
SiO_2	-"-	0.2	0	0	2.1	1.4	1.6	10.9	2.3±3.6
not bound CO_2	-"-	-	22.2	0	6.6	11.0	17.6	19.8	12.9±7.8
pH		7.3	7.2	8.3	7.1	7.1	7.4	7.6	7.4±0.4
Eh	mV	+194	+190	+160	+220	+195	+186	+174	189.9±17.5
Electric conductivity	mS/cm	7.30	7.63	7.75	7.56	7.40	8.67	8.81	7.86±0.55
Water sampling point		Leppneeme harbour in Viimsi					Rohuneeme sea-side in Viimsi		

Neutron activation analysis of sea water for microelement determination

Water sampling point	Leaching period	Element g/l / statistical error, %								
		Ti 10^{-2}	V 10^{-5}	Sr 10^{-4}	Nb 10^{-4}	La 10^{-6}	Ce 10^{-5}	Ta 10^{-8}	Th 10^{-7}	U 10^{-6}
Leppneeme harbour on the Viimsi peninsula	I	1.8 71%	1.5 68%	7.0 12%	3.0 80%	2.0 75%	1.8 67%	<1 -	16.0 18%	4.0 22%
	II	<1 -	5.2 80%	9.8 10%	<7 -	<6 -	31.3 40%	5.8 77%	16.8 17%	2.9 38%
	III	1.1 43%	5.7 61%	7.5 11%	6.1 50%	4.7 51%	<30 -	6.1 90%	14.1 18%	3.3 40%
	IV	<1 -	5.92 64%	5.3 14%	<7 -	2.5 56%	21.7 73%	9.2 85%	18.7 17%	3.1 19%
Rohuneeme seaside on the Viimsi peninsula	V	1.26 57%	<5 -	8.4 23%	<2 -	0.07 49%	2.5 41%	27.2 53%	5.5 31%	<2 -
	VI	0.92 47%	<6 -	2.1 74%	6.6 71%	<0.2 -	<3 -	<58 -	10.4 79%	4.5 39%
	VII	1.8 52%	67.7* 76%	49.9* 8%	3.4 75%	1.5 60%	<0.5 -	62.9 34%	5.8 38%	9.8 50%
	Arithmetical mean $x \pm \sigma$	1.27± 0.35	4.89± 1.56	6.68± 2.46	5.01± 1.98	2.42± 2.05	12.97± 13.05	24.31± 24.13	11.75± 4.97	4.23± 2.39

Notice * Number not typical and not considered at calculating of arithmetical averages.

Mineralization, pH, Eh and electric conductivity of leaching solutions

Extractor code and test conditions	Leaching period		Dry residue (mineralization), g/l	pH	Eh, mV	Conductivity, mS/cm
	Index	Cumulative mean duration, days				
1	2	3	4	5	6	7
Sea water before leaching in all experiments						
	I	-	4.9565	7.3	+194	7.30
	II	-	4.9565	7.2	+190	7.63
	III	-	4.7150	8.3	+160	7.75
	IV	-	4.8360	7.1	+220	7.59
	V	-	4.7005	7.1	+195	7.40
	VI	-	5.3945	7.4	+196	8.67
	VII	-	5.381	7.6	+174	8.81
Demineralized water before leaching in all experiments						
	I	-	-	5.35	+389	-
	IV	-	-	4.95	+399	-
	VI	-	-	5.75	+364	-
Leaching of waste from loparite ore treatment (depth 6.64-7.36 m) with demineralized water						
E-8	I	1.68	2.0210	12.1	-25	4.60
DW	II	4.70	0.3415	11.5	+14	0.49
DC-S	III	8.49	0.4625	11.4	+24	0.89
	IV	18.80	1.3425	12.1	+16	2.81
	V	41.65	1.6005	12.2	-42	3.29
	VI	76.65	1.5130	11.9	+31	3.47
	VII	-	-	-	-	-
E-9	I	1.44	1.4325	12.1	-19	3.05
DW	II	4.83	0.4500	11.6	+5	1.27
DC-P	III	8.38	0.3095	11.5	+21	0.90
	IV	18.88	0.4035	11.3	+24	0.71
	V	42.38	0.2945	11.5	+39	0.67
	VIa	103.40	0.4095	10.7	+79	0.51

1	2	3	4	5	6	7
Leaching of waste from loparite ore treatment (depth 6.64-7.36 m) with sea water						
E-5	I	1.45	5.2030	11.4	+15	8.86
SW	II	4.40	4.7150	9.8	+147	7.78
DC-P	III	8.44	5.0070	8.6	+230	7.64
	IV	18.86	5.0475	10.9	+10	8.00
	V	41.73	5.0770	10.0	+176	7.94
	VI	76.73	5.6965	12.9	+216	9.02
	VII	121.86	5.9995	8.0	+250	8.80
Leaching of waste from uranium ore treatment (depth 14.52-16.20 m) with demineralized water						
E-4	I	1.68	2.8075	4.5	+325	3.82
DW	II	4.70	1.0550	6.8	+230	1.44
DC-S	III	8.49	1.9045	7.0	+252	2.00
	IV	18.80	2.1805	7.0	+233	2.29
	V	41.65	1.1710	6.8	+185	1.26
	VI	76.65	2.4110	6.6	+259	2.30
	VII	122.32	2.0885	6.8	+312	1.89
E-6	I	1.68	2.1625	4.8	+340	3.14
DW	II	4.70	1.0465	6.3	+222	1.41
DC-S	III	8.49	1.6040	6.3	+256	1.85
	IV	18.80	2.202	6.5	+242	2.19
	V	41.65	2.291	6.7	+210	2.09
	VI	76.65	2.052	6.7	+270	2.09
	VII	122.32	1.882	2.6	+464	3.67
P-1	I	1.68	2.3055	8.0	+200	3.24
DW	II	4.70	1.2155	7.5	+220	1.70
SC	III	8.49	1.3400	6.7	+191	1.57
	IV	18.80	1.7105	6.7	+196	1.85
	V	41.65	1.8420	6.7	+182	2.02
	VI	76.65	1.8290	6.9	+216	1.97
	VII	122.32	1.9380	6.4	+342	1.90

1	2	3	4	5	6	7
Leaching of waste from uranium ore treatment (depth 14.52-16.20 m) with sea water						
E-1	I	1.45	6.895	7.1	+218	10.23
SW	II	4.40	6.002	7.8	201	8.94
DC-P	III	8.44	6.224	6.8	+244	9.40
	IV	18.86	7.301	7.6	+244	9.70
	V	41.73	6.756	6.6	+142	9.28
	VI	76.73	7.252	7.1	+233	10.54
	VII	121.86	8.276	8.1	+285	10.40
E-7	I	1.45	6.6785	7.1	+218	10.02
SW	II	4.40	5.7565	7.3	+175	8.93
DC-P	III	8.44	6.6760	6.7	+245	9.30
	IV	18.86	7.3205	6.8	+185	9.63
	V	41.73	7.3615	6.7	+140	9.73
	VI	76.73	7.9035	7.3	+180	10.57
	VII	121.86	8.2810	7.9	+250	10.38
P-2	I	1.72	6.7540	7.0	+191	9.83
SW	II	4.76	6.0900	6.2	+195	9.14
SC	III	8.70	6.4450	6.6	+246	9.32
	IV	19.16	6.8845	7.0	+220	9.30
	V	41.98	7.0050	7.0	+105	9.27
	VI	76.96	7.7580	7.0	+61	10.00
	VII	122.62	7.4515	7.2	-90	9.59

1	2	3	4	5	6	7
Leaching of waste from uranium ore treatment (depth 19.44-20.04 m) with demineralized water						
E-2	I	1.68	2.8805	4.2	+230	3.49
DW	II	4.70	1.2420	6.3	+210	1.52
DC-S	III	8.49	2.1325	6.6	+249	2.13
	IV	18.80	1.9340	7.3	+194	1.93
	V	41.65	2.0135	6.6	+58	1.94
	VI	76.65	1.9030	5.9	+276	1.98
	VII	122.32	2.0965	4.7	+360	1.90
E-10	I	1.46	1.5105	6.9	+230	2.40
DW	II	4.42	0.8195	7.1	+183	1.02
DC-P	III	8.42	1.0605	7.0	+176	1.26
	IV	18.92	1.5965	6.8	+165	1.72
	V	42.42	2.0860	5.9	+170	1.92
	VIa	103.44	2.2715	4.8	+217	2.25
Leaching of waste from uranium ore treatment (depth 19.44-20.04 m) with sea water						
E-3	I	1.45	6.521	7.7	+220	9.79
SW	II	4.40	5.882	7.9	+201	8.70
DC-P	III	8.44	6.780	6.9	+234	9.16
	IV	18.86	7.466	6.7	+190	9.45
	V	41.73	7.422	6.5	+194	9.73
	VI	76.73	8.060	7.0	+235	10.74
	VII	121.96	8.078	7.8	+294	10.18

Correlation equations characterizing internal dependences between pH and Eh likewise between total mineralization ($\Sigma_{min.}$) and electric conductivity (G) of leaching solutions

Extractor code and test conditions	Number of pairs	Correlation equation	Correl. coeff.
1	2	3	4
Demineralized water experiments			
DW	3	Eh = 384.0 - 43.75 (pH), mV	-0.971
E-8 and E-9	12	Eh = 726.51 - 61.12 (pH), mV	-0.842
E-4 and E-6	14	Eh = 573.70 - 49.55 (pH), mV	-0.888
E-2 and E-10	13	Eh = 416,14 - 33.61 (pH), mV	-0.487
P-1	7	Eh = 462.91 - 34.63 (pH), mV	-0.353
Deminer.water experim-s all together	46	Eh = 501.41 - 41.87 (pH), mV	-0.911
- " -	46	G = 0.499 + 0.968 $\Sigma_{min.}$, mS/cm	0.717
Sea water experiments			
SW	7	Eh = 473.86 - 38.23 (pH), mV	-0.860
E-5	7	Eh = 412.93 - 25.79 (pH), mV	-0.434
E-1 and E-7	14	Eh =-138.04 + 48.49 (pH), mV	0.549
P-2	7	Eh =1507.93 -200.57 (pH), mV	-0.580
E-3	7	Eh = 16.21 + 28.80 (pH), mV	0.460
Sea water experim-s all together	35	Eh = 286.98 - 13.08 (pH), mV	-0.244
SW	7	G = -1.425 + 1.863 $\Sigma_{min.}$, mS/cm	0.882
E-5	7	G = 2.811 + 1.044 $\Sigma_{min.}$, mS/cm	0.800
E-1 and E-7	14	G = 5.565 + 0.599 $\Sigma_{min.}$, mS/cm	0.811
P-2	7	G = 6.694 + 0.405 $\Sigma_{min.}$, mS/cm	0.714
E-3	7	G = 4.773 + 0.684 $\Sigma_{min.}$, mS/cm	0.837
Sea water experim-s all together	35	G = 4.394 + 0.714 $\Sigma_{min.}$, mS/cm	0.432

Demineralized water experiments under dynamic conditions
SUMMARY TABLE

Leaching period	Time, days		Dry weight of initial sample, g	Amount of water flowing through, l ΔV	Total amount of water sample, l	Total dry residue after evaporating the sample				
	Δd	ΣΔd				Content in water sample, g/l	Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-2										
I	3.36	3.36	455.0	10.585	2.880	2.880	8.296	455.0	1.82	2.874
II	2.67	6.03		6.570	2.865	1.242	3.587		0.79	2.518
III	4.92	10.95		14.637	2.540	2.132	5.417		1.19	0.926
IV	15.70	26.65		42.471	2.850	1.934	5.517		1.21	0.101
V	30.00	56.65		63.040	2.940	2.014	5.920		1.30	0.038
VI	40.00	96.65		46.592	2.790	1.903	5.309		1.17	0.035
VII	51.33	147.98		43.575	2.680	2.096	5.619		1.23	0.031
Total	147.98			227.470			39.665		8.71	
Experiment E-4										
I	3.36	3.36	533.1	3.750	2.605	2.808	7.314	533.1	1.37	6.440
II	2.67	6.03		3.000	2.890	1.055	3.049		0.57	4.222
III	4.92	10.95		4.745	2.820	1.904	5.371		1.01	2.552
IV	15.70	26.65		15.334	2.650	2.180	5.778		1.08	0.266
V	30.00	56.65		40.685	2.500	1.171	2.928		0.55	0.027
VI	40.00	96.65		42.082	2.750	2.411	6.630		1.24	0.044
VII	51.33	147.98		40.602	3.160	2.088	6.600		1.24	0.035
Total	147.98			150.198			37.670		7.06	

Leaching period	Na					K				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-2										
I	76.0	218.9	3.106	7.05	75.8	9.8	28.2	10.047	0.28	9.76
II	9.2	26.4		0.85	18.5	2.0	5.7		0.06	4.00
III	7.6	19.3		0.62	3.3	3.0	7.6		0.07	1.30
IV	4.0	11.4		0.37	0.21	3.0	8.6		0.08	0.16
V	5.3	15.6		0.50	0.10	10.8	31.8		0.32	0.21
VI	5.8	16.2		0.52	0.11	16.5	46.0		0.46	0.30
VII	4.5	12.1		0.39	0.07	23.2	62.2		0.62	0.34
Total		319.9		10.30			190.1		1.89	
Experiment E-4										
I	170.8	444.9	3.600	12.4	391.6	13.2	34.4	12.134	0.28	30.34
II	29.0	83.8		2.3	116.1	4.5	12.8		0.11	17.72
III	14.0	39.5		1.1	18.77	3.0	8.5		0.07	4.04
IV	5.2	13.8		0.38	0.64	3.7	9.8		0.08	0.45
V	4.0	10.0		0.28	0.09	4.3	10.8		0.09	0.10
VI	8.3	22.8		0.63	0.15	10.2	28.0		0.23	0.18
VII	5.5	17.4		0.48	0.09	15.2	48.0		0.40	0.26
Total		632.2		17.57			152.3		1.26	

Leaching period	NH_4^+			Ca				
	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-2								
I	194.9	561.3	194.3	384.0	1.106	34.286	3.23	382.8
II	25.58	73.3	51.4	272.1	0.779		2.27	546.7
III	24.65	62.6	10.7	496.0	1.260		3.67	215.4
IV	42.39	120.8	2.23	456.9	1.302		3.80	24.0
V	11.73	34.5	0.22	402.0	1.182		3.45	7.7
VI	2.02	5.64	0.04	441.1	1.231		3.59	8.1
VII	2.93	7.85	0.04	460.5	1.234		3.60	6.8
Total		866.0			8.094		23.61	
Experiment E-4								
I	210.86	549.3	483.5	311.0	0.810	48.713	1.66	713.2
II	59.34	171.5	237.5	183.8	0.531		1.09	735.7
III	34.69	97.8	46.5	404.4	1.140		2.34	542.0
IV	14.40	38.2	1.75	525.0	1.391		2.86	64.1
V	8.73	21.8	0.20	254.7	0.637		1.31	5.79
VI	1.08	3.0	0.02	540.7	1.487		3.05	9.80
VII	0.88	2.8	0.01	426.3	1.347		2.77	7.17
Total		884.4			7.343		15.08	

Leaching period	Mg					Fe_{total}				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-2										
I	97.2	280.0	5.762	4.86	96.9	0	0	24.451	0	0
II	23.6	67.6		1.17	47.5	0.13	0.37		1.5 E-3	26.1 E-2
III	27.3	69.3		1.20	11.8	0.04	0.10		0.4 E-3	1.7 E-2
IV	17.7	50.4		0.87	0.93	0.09	0.26		1.0 E-3	0.5 E-2
V	53.5	157.3		2.73	1.02	1.63	4.79		19.6E-3	3.1 E-2
VI	27.3	76.2		1.32	0.50	0.32	0.89		3.7 E-3	0.6 E-2
VII	53.5	143.4		2.49	0.79	0.38	1.02		4.2 E-3	0.6 E-2
Total		844.2		14.64			7.43		30.4E-3	
Experiment E-4										
I	79.5	207.1	4.854	4.27	182.31	0.03	0.078	29.267	0.3 E-3	6.9 E-2
II	21.3	61.6		1.27	85.32	0	0		0	0
III	31.8	89.7		1.85	42.63	0.23	0.649		2.2 E-3	30.8E-2
IV	48.4	128.3		2.64	5.91	0.32	0.848		2.9 E-3	3.9 E-2
V	33.3	83.2		1.71	0.76	0.35	0.875		3.0 E-3	0.8 E-2
VI	39.5	108.6		2.23	0.72	0.10	0.275		0.9 E-3	0.2 E-2
VII	77.3	244.3		5.03	1.3	0.13	0.411		1.4 E-3	0.2 E-2
Total		922.8		19.0			3.136		10.7E-3	

Leaching period	Cl^-			S				
	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-2								
I	182.9	526.8	182.4	601.0	1.731	28.165	6.15	599.2
II	16.7	47.8	33.6	276.4	0.792		2.81	555.8
III	14.9	37.8	6.47	462.4	1.174		4.17	200.8
IV	11.3	32.2	0.59	414.1	1.180		4.19	21.8
V	14.9	43.8	0.29	402.7	1.184		4.20	7.71
VI	13.1	36.5	0.24	396.8	1.107		3.93	7.31
VII	7.4	19.8	0.11	456.7	1.224		4.35	6.74
Total		744.7			8.392		29.80	
Experiment E-4								
I	295.0	768.5	676.62	549.2	1.431	43.394	3.30	1259
II	24.1	69.6	96.46	228.7	0.661		1.52	915.4
III	11.3	31.9	15.14	403.4	1.138		2.62	540.7
IV	7.4	19.6	0.90	498.0	1.320		3.04	60.8
V	7.4	18.5	0.17	228.6	0.571		1.32	5.19
VI	7.4	20.4	0.13	488.9	1.344		3.10	8.86
VII	7.4	23.4	0.12	449.2	1.419		3.27	7.55
Total		951.9			7.884		18.17	

Leaching period	NO_3^-			HCO_3^-			not bound CO_2		
	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d
Experiment E-2									
I	0.7	2.02	0.698	12.2	35.1	12.16	0	0	0
II	0	0	0	12.2	35.0	24.53	37.4	107.15	75.19
III	10.6	26.92	4.602	24.4	62.0	10.60	28.6	72.64	12.42
IV	6.0	17.10	0.316	30.5	86.9	1.61	13.2	37.62	0.695
V	14.5	42.62	0.278	24.4	71.7	0.47	37.4	109.96	0.716
VI	0	0	0	12.2	34.0	0.22	55.0	153.45	1.014
VII	7.7	20.64	0.114	18.3	49.0	0.27	52.8	141.50	0.779
Total		109.31			373.7			622.32	
Experiment E-4									
I	5.2	13.54	11.93	24.4	63.6	55.96	0	0	0
II	5.5	15.90	22.01	24.4	70.5	97.66	39.6	114.44	158.50
III	3.6	10.15	4.82	24.4	68.8	32.70	30.8	86.86	41.28
IV	9.8	25.97	1.20	36.6	97.0	4.47	37.4	99.11	4.567
V	16.1	40.25	0.37	61.0	152.5	1.39	26.4	66.00	0.600
VI	0	0	0	61.0	167.8	1.11	59.4	163.35	1.076
VII	9.9	31.28	0.17	24.4	77.1	0.41	89.6	125.14	0.666
Total		137.09			697.3			654.90	

Leaching period	SiO_2					Ti				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-2										
I	10.7	30.8	186.277	0.017	10.66	8.0	23.04	1.420	1.62	7.96
II	11.3	32.4		0.017	22.72	3.0	8.60		0.60	6.03
III	19.4	49.3		0.026	8.42	1.1	2.79		0.20	0.478
IV	3.3	9.4		0.005	0.17	1.6	4.56		0.32	0.084
V	87.0	255.8		0.137	1.66	4.0	11.76		0.83	0.077
VI	72.2	201.4		0.108	1.33	4.0	11.16		0.78	0.074
VII	99.9	267.7		0.144	1.47	4.0	10.72		0.75	0.059
Total		846.8		0.454			72.63		5.10	
Experiment E-4										
I	11.0	28.7	202.045	0.014	25.23	5.0	13.03	1.343	0.97	11.47
II	7.3	21.1		0.010	29.22	1.8	5.20		0.39	7.20
III	15.6	44.0		0.022	20.91	3.0	8.46		0.63	4.02
IV	43.4	115.0		0.057	5.30	2.3	6.10		0.45	0.28
V	47.3	118.3		0.059	1.07	3.0	7.50		0.56	0.07
VI	110.1	302.8		0.150	2.00	5.0	13.75		1.02	0.09
VII	99.0	312.8		0.155	1.67	2.0	6.32		0.47	0.03
Total		942.7		0.467			60.36		4.49	

Leaching period	V					Sr				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d
Experiment E-2										
I	2.0 E-2	0.058	177.45	0.033	20.1 E-3	0.08	0.230	136.5	0.17	8.0 E-2
II	0.5 E-2	0.014		0.008	10.1 E-3	0.35	1.003		0.73	70.4 E-2
III	1.0 E-2	0.025		0.014	4.3 E-3	0.14	0.356		0.26	6.1 E-2
IV	2.0 E-2	0.057		0.032	1.1 E-3	1.52	4.332		3.17	8.0 E-2
V	2.0 E-2	0.059		0.033	0.4 E-3	0.10	0.294		0.22	0.2 E-2
VI	0.8 E-2	0.022		0.013	0.1 E-3	0.02	0.056		0.04	0.04E-2
VII	2.0 E-2	0.054		0.030	0.3 E-3	0.10	0.268		0.20	0.1 E-2
Total		0.289		0.163			6.539		4.79	
Experiment E-4										
I	1.6 E-2	0.042	202.6	0.021	3.67 E-2	0.033	0.09	538.4	0.02	7.6 E-2
II	1.8 E-2	0.052		0.026	7.20 E-2	0.55	1.59		0.30	220.1 E-2
III	3.4 E-2	0.096		0.047	4.56 E-2	1.06	2.99		0.56	142.0 E-2
IV	1.0 E-2	0.027		0.013	0.12 E-2	2.67	7.08		1.31	32.6 E-2
V	2.9 E-2	0.073		0.036	0.07 E-2	0.83	2.08		0.39	1.9 E-2
VI	1.1 E-2	0.030		0.015	0.02 E-2	2.10	5.78		1.07	3.8 E-2
VII	0.5 E-2	0.016		0.008	0.01 E-2	1.62	5.12		0.95	2.7 E-2
Total		0.336		0.166			24.73		4.60	

Leaching period	Nb					La				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d
Experiment E-2										
I	0.43	1.238	910	0.136	0.429	0.8 E-3	2.3 E-3	25.9	0.009	8.0 E-4
II	0.2	0.573		0.063	0.402	2.5 E-3	7.2 E-3		0.028	50.3 E-4
III	0.5	1.270		0.140	0.217	5.7 E-3	14.5 E-3		0.056	24.8 E-4
IV	0.1	0.285		0.031	0.005	5.4 E-3	15.4 E-3		0.059	2.8 E-4
V	0.3	0.882		0.097	0.006	3.1 E-3	9.1 E-3		0.035	0.6 E-4
VI	0.4	1.116		0.123	0.007	6.7 E-3	18.7 E-3		0.072	1.2 E-4
VII	0.3	0.804		0.088	0.004	7.4 E-3	19.8 E-3		0.077	1.1 E-4
Total		6.168		0.678			87.0 E-3		0.336	
Experiment E-4										
I	0.3	0.78	533.1	0.15	0.688	0.8 E-3	2.1 E-3	11.73	0.018	18.3 E-4
II	0.2	0.58		0.11	0.801	0.6 E-3	1.7 E-3		0.015	24.0 E-4
III	0.3	0.85		0.16	0.402	3.7 E-3	10.4 E-3		0.089	49.6 E-4
IV	0.1	0.27		0.05	0.012	2.2 E-3	5.8 E-3		0.050	2.7 E-4
V	0.2	0.50		0.09	0.005	0.8 E-3	2.0 E-3		0.017	0.2 E-4
VI	0.1	0.28		0.05	0.002	0.7 E-3	1.9 E-3		0.016	0.1 E-4
VII	0.41	1.30		0.24	0.007	14.4 E-3	45.5 E-3		0.388	2.4 E-4
Total		4.56		0.85			69.4 E-3		0.593	

Leaching period	Ce					Ta				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d
Experiment E-2										
I	2.0 E-2	5.80 E-2	136.5	0.042	2.00 E-2	1.0 E-5	0.29 E-4	0.259	0.011	1.00 E-5
II	0.5 E-2	1.43 E-2		0.010	1.01 E-2	2.8 E-5	0.80 E-4		0.031	5.63 E-5
III	1.4 E-2	3.65 E-2		0.026	0.61 E-2	4.3 E-5	1.09 E-4		0.042	1.86 E-5
IV	1.6 E-2	4.56 E-2		0.033	0.08 E-2	20.0E-5	5.70 E-4		0.220	1.05 E-5
V	0.31 E-2	0.91 E-2		0.007	0.01 E-2	18.0E-5	5.29 E-4		0.204	0.34 E-5
VI	2.7 E-2	7.53 E-2		0.055	0.05 E-2	2 E-5	0.56 E-4		0.022	0.04 E-5
VII	4.6 E-2	12.3 E-2		0.090	0.07 E-2	18.1 E-5	4.85 E-4		0.187	0.27 E-5
Total		36.2 E-2		0.263			18.6 E-4		0.717	
Experiment E-4										
I	1.7 E-2	4.4 E-2	69.3	0.064	39.0E-3	0.1 E-4	0.3 E-4	0.320	0.008	2.3 E-5
II	1.5 E-2	4.3 E-2		0.063	60.0E-3	0.4 E-4	1.2 E-4		0.036	16.0 E-5
III	0.11 E-2	0.3 E-2		0.004	1.5 E-3	0.3 E-4	0.8 E-4		0.026	4.0 E-5
IV	1.5 E-2	4.0 E-2		0.057	1.8 E-3	2.4 E-4	6.4 E-4		0.199	2.9 E-5
V	7.0 E-2	17.5 E-2		0.253	1.6 E-3	1.5 E-4	3.8 E-4		0.117	0.3 E-5
VI	1.2 E-2	3.3 E-2		0.048	0.2 E-3	1.19 E-4	3.3 E-4		0.102	0.2 E-5
VII	5.0 E-2	15.8 E-2		0.228	0.8 E-3	2.6 E-4	8.2 E-4		0.257	0.4 E-5
Total		49.6 E-2		0.717			24.0 E-4		0.745	

Leaching period	Th					U				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d
Experiment E-2										
I	2.1 E-4	6.0 E-4	4.55	0.013	2.1 E-4	8.6 E-3	0.025	95.55	0.026	8.65 E-3
II	3.8 E-4	10.9 E-4		0.024	7.6 E-4	3.6 E-3	0.010		0.011	7.02 E-3
III	5.9 E-4	15.0 E-4		0.033	2.6 E-4	5.7 E-3	0.015		0.015	2.39 E-3
IV	2.2 E-4	6.3 E-4		0.014	0.1 E-4	7.4 E-3	0.021		0.022	0.39 E-3
V	3.0 E-4	8.8 E-4		0.019	0.1 E-4	6.4 E-3	0.019		0.020	0.12 E-3
VI	4.2 E-4	11.7 E-4		0.026	0.1 E-4	22.3 E-3	0.062		0.065	0.41 E-3
VII	4.7 E-4	12.6 E-4		0.028	0.07 E-4	21.9 E-3	0.059		0.062	0.32 E-3
Total		71.3 E-4		0.157			0.211		0.221	
Experiment E-4										
I	6.2 E-4	16.2 E-4	6.93	0.023	142.0 E-5	4.3 E-3	0.011	101.3	0.011	98.6 E-4
II	2.0 E-4	5.8 E-4		0.008	80.1 E-5	1.4 E-3	0.004		0.004	56.0 E-4
III	5.1 E-4	14.4 E-4		0.021	68.3 E-5	3.1 E-3	0.009		0.009	41.5 E-4
IV	6.2 E-4	16.4 E-4		0.024	7.6 E-5	27.0 E-3	0.072		0.071	33.0 E-4
V	3.0 E-4	7.5 E-4		0.011	0.7 E-5	7.3 E-3	0.018		0.018	1.7 E-4
VI	0.5 E-4	1.4 E-4		0.002	0.1 E-5	3.0 E-3	0.008		0.008	0.5 E-4
VII	4.0 E-4	12.6 E-4		0.018	0.7 E-5	4.6 E-3	0.015		0.014	0.8 E-4
Total		74.3 E-4		0.107			0.137		0.135	

Demineralized water experiments under dynamic conditions
SUMMARY TABLE

Leaching period	Time, days		Dry weight of initial sample, g	Amount of water flowing through ΔV, l	Total amount of water sample, l	Total dry residue after evaporating the sample				
	Δd	ΣΔd				Content in water sample, g/l	Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-6										
I	3.36	3.36	519.0	3.84	3.02	2.162	6.531	519.0	1.26	5.462
II	2.67	6.03		2.78	2.97	1.046	3.108		0.59	4.518
III	4.92	10.95		4.30	2.92	1.604	4.684		0.90	2.389
IV	15.70	26.65		12.64	3.45	2.202	7.597		1.46	0.413
V	30.00	56.65		41.99	2.95	2.291	6.758		1.30	0.058
VI	40.00	96.65		52.04	2.70	2.052	5.540		1.07	0.029
VII	51.33	147.98		45.01	2.52	1.882	4.743		0.91	0.022
Total	147.98			162.60			38.961		7.49	
Experiment E-8										
I	3.36	3.36	282.0	7.44	2.715	2.021	5.487	282.0	1.95	3.955
II	2.67	6.03		5.89	2.855	0.342	0.975		0.35	1.117
III	4.92	10.95		11.11	2.900	0.462	1.341		0.48	0.442
IV	15.70	26.65		34.45	3.115	1.342	4.102		1.45	0.137
V	30.00	56.65		54.69	3.193	1.600	5.110		1.81	0.056
VI	40.00	96.65		70.42	3.285	1.513	4.970		1.76	0.032
Total	96.65			184.00			21.985		7.80	

Leaching period	Na					K				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-6										
I	146.0	440.9	3.457	12.75	368.6	11.1	33.52	11.588	0.29	28.03
II	38.0	112.9		3.27	164.1	5.0	14.85		0.13	21.84
III	19.4	56.6		1.64	28.9	3.3	9.64		0.08	4.92
IV	5.6	19.3		0.56	1.05	2.5	8.63		0.07	0.47
V	5.0	14.8		0.43	0.13	5.7	16.82		0.15	0.14
VI	6.3	17.0		0.49	0.09	6.0	16.20		0.14	0.084
VII	6.9	17.4		0.50	0.08	15.2	38.30		0.33	0.179
Total		678.9		19.64			137.96		1.19	
Experiment E-8										
I	158.9	431.4	0.543	79.51	311.2	778.8	2114.4	3.207	65.9	1525.4
II	11.0	31.4		5.79	36.01	45.4	129.6		4.0	148.6
III	10.0	29.0		5.34	9.57	18.2	52.8		1.6	17.4
IV	10.6	33.0		6.08	1.10	18.6	57.9		1.8	1.9
V	4.0	12.8		2.36	0.14	11.8	37.7		1.2	0.4
VI	1.2	3.9		0.72	0.07	7.8	25.6		0.8	0.2
Total		541.5		99.80			2418.0		75.3	

Leaching period	NH_4^+			Ca				
	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-6								
I	207.71	627.3	524.5	213.8	0.646	50.505	1.28	539.9
II	67.22	199.6	290.1	168.5	0.500		0.99	727.3
III	41.38	120.8	61.6	329.7	0.963		1.91	490.9
IV	22.52	77.7	4.21	494.8	1.707		3.38	92.5
V	7.82	23.1	0.20	480.2	1.417		2.81	12.1
VI	1.00	2.7	0.014	490.0	1.323		2.62	6.9
VII	2.99	7.5	0.035	401.8	1.013		2.01	4.7
Total		1058.7			7.569		15.00	
Experiment E-8								
I	12.42	33.7	24.33	9.80	0.027	61.235	0.04	19.91
II	3.95	11.3	12.93	58.3	0.166		0.27	190.87
III	3.16	9.2	3.02	125.5	0.364		0.59	120.08
IV	20.68	64.4	2.15	382.8	1.192		1.95	39.76
V	0.58	1.9	0.02	480.2	1.533		2.50	16.85
VI	0.54	1.8	0.01	460.5	1.513		2.58	10.11
Total		122.3			4.795		7.93	

Leaching period	Mg					Fe_{total}				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-6										
I	70.7	213.5	5.039	4.24	177.9	0.03	0.091	16.784	0.5 E-3	7.6 E-2
II	21.3	63.3		1.26	91.7	0.07	0.208		1.2 E-3	30.2 E-2
III	30.6	89.4		1.77	45.6	0.05	0.146		0.9 E-3	7.4 E-2
IV	40.1	138.3		2.74	7.50	0.12	0.414		2.5 E-3	2.2 E-2
V	59.4	175.2		3.48	1.50	0.26	0.767		4.6 E-3	0.7 E-2
VI	35.6	96.1		1.91	0.50	0.01	0.027		0.2 E-3	0.01 E-2
VII	47.5	119.7		4.24	0.56	0.25	0.630		3.7 E-3	0.29 E-2
Total		895.5		19.64			2.283		13.6 E-3	
Experiment E-8										
I	0	0	9.863	0	0	0	0	8.856	0	0
II	6.0	17.13		0.17	19.64	0.06	0.17		2.0 E-3	0.20
III	0	0		0	0	0.01	0.03		0.3 E-3	0.01
IV	0	0		0	0	0.36	1.12		13.0 E-3	0.04
V	0	0		0	0	0	0		0	0
VI	0	0		0	0	0	0		0	0
Total		17.13		0.17			1.32		15.3 E-3	

Leaching period	Cl			S				
	Content in water sample, mg/l	Leached out ΔP, g	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-6								
I	272.6	0.823	688.3	427.3	1.290	42.454	3.04	1.079
II	37.2	0.111	160.6	220.7	0.656		1.54	0.953
III	18.8	0.055	28.0	341.3	0.997		2.35	0.508
IV	7.4	0.026	1.38	461.2	1.591		3.75	0.086
V	9.2	0.027	0.23	437.3	1.290		3.04	0.011
VI	5.7	0.015	0.08	434.2	1.172		2.76	0.006
VII	9.2	0.023	0.11	400.6	1.010		2.38	0.005
Total		1.080			8.006		18.86	
Experiment E-8								
I	250.3	0.679	490.2	96.57	0.262	11.900	2.20	189.2
II	16.7	0.048	54.7	20.86	0.059		0.50	68.29
III	22.3	0.065	21.3	40.92	0.119		1.00	39.16
IV	42.5	0.132	4.4	155.22	0.484		4.06	16.12
V	30.1	0.096	1.1	202.1	0.645		5.42	7.09
VI	29.4	0.097	0.6	175.0	0.575		4.83	3.68
Total		1.117			2.144		18.01	

Table 14/2-6

Leaching period	NO_3^-			HCO_3^-			not bound CO_2		
	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d
Experiment E-6									
I	5.4	16.3	13.6	12.2	36.8	30.8	0	0	0
II	6.1	18.1	26.3	12.2	36.2	52.7	22.0	65.34	94.77
III	7.6	22.2	11.3	18.3	53.4	27.3	79.2	231.26	117.93
IV	14.4	49.7	2.69	36.6	126.3	6.85	50.6	174.57	9.462
V	20.3	59.9	0.51	61.0	180.0	1.54	39.6	116.82	1.001
VI	0	0	0	54.9	148.2	0.77	24.2	65.34	0.339
VII	18.5	46.6	0.22	0	0	0	0	0	0
Total		212.8			580.9			653.33	
Experiment E-8									
I	14.2	38.6	27.8	*	*	*	*	*	*
II	4.8	13.7	15.7						
III	7.5	21.8	7.2						
IV	11.4	35.5	1.2						
V	3.1	9.9	0.1						
VI	7.3	24.0	0.2						
Total		143.4							

* not determined

Leaching period	SiO_2					Ti				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-6										
I	7.5	22.65	189.435	0.012	18.94	8.0	24.16	1.339	1.80	20.20
II	4.5	13.37		0.007	19.43	3.0	8.91		0.66	12.95
III	12.4	36.21		0.019	18.47	3.0	8.76		0.65	4.47
IV	28.5	98.33		0.052	5.33	4.0	13.80		1.03	0.75
V	182.9	539.6		0.285	4.62	5.6	16.52		1.23	0.142
VI	76.6	206.8		0.109	1.07	2.3	6.21		0.46	0.032
VII	76.1	191.8		0.101	0.90	2.1	5.29		0.40	0.025
Total		1108.8		0.585			83.65		6.23	
Experiment E-8										
I	27.7	75.2	52.734	0.14	54.3	8.0	21.7	0.863	2.51	15.67
II	13.4	38.3		0.07	43.9	3.0	8.6		1.00	9.82
III	31.8	92.2		0.18	30.4	3.0	8.7		1.01	2.87
IV	5.9	18.4		0.04	0.6	1.0	3.1		0.36	0.10
V	4.8	15.3		0.03	0.2	4.4	14.0		1.62	0.15
VI	5.3	17.4		0.03	0.1	0.2	0.7		0.08	0.01
Total		256.8		0.49			56.8		6.58	

Leaching period	V					Sr				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d
Experiment E-6										
I	1.52 E-2	0.046	197.22	0.023	38.4 E-3	0.025	0.08	238.74	0.03	0.063
II	3.1 E-2	0.092		0.047	134.0E-3	0.42	1.25		0.52	1.813
III	1.5 E-2	0.044		0.022	22.3 E-3	0.89	2.60		1.09	1.325
IV	4.4 E-2	0.152		0.077	8.24 E-3	3.14	10.83		4.54	0.589
V	4.0 E-2	0.118		0.060	1.01 E-3	1.72	5.07		2.13	0.043
VI	3.0 E-2	0.081		0.041	0.42 E-3	2.13	5.75		2.41	0.030
VII	7.1 E-2	0.179		0.091	0.84 E-3	1.28	3.23		1.35	0.015
Total		0.712		0.361			28.81		12.07	
Experiment E-8										
I	2.2 E-2	0.060	76.14	0.079	43.1 E-3	0.019	0.05	169.9	0.03	0.04
II	0.4 E-2	0.011		0.014	13.1 E-3	1.36	3.88		2.29	4.45
III	0.6 E-2	0.017		0.022	5.7 E-3	1.83	5.31		3.14	1.75
IV	0.3 E-2	0.009		0.012	0.3 E-3	2.28	7.10		4.20	0.24
V	0.3 E-2	0.010		0.013	0.1 E-3	1.43	4.57		2.70	0.05
VI	0.3 E-2	0.010		0.013	0.01 E-3	2.96	9.72		5.74	0.06
Total		0.118		0.153			30.63		17.10	

Leaching period	Nb					La				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d
Experiment E-6										
I	0.3	0.906	1090.0	8.3 E-2	75.8 E-2	0.8 E-3	2.42E-3	15.051	1.61 E-2	20.2 E-4
II	0.2	0.594		5.4 E-2	86.3 E-2	1.5 E-3	4.46E-3		2.96 E-2	64.8 E-4
III	0.26	0.759		7.0 E-2	38.7 E-2	1.0 E-3	2.92E-3		1.94 E-2	14.9 E-4
IV	0.1	0.345		3.2 E-2	1.9 E-2	1.9 E-3	6.56E-3		4.36 E-2	3.6 E-4
V	0.3	0.885		8.1 E-2	0.8 E-2	0.4 E-3	1.18E-3		0.78 E-2	0.1 E-4
VI	0.24	0.648		5.9 E-2	0.3 E-2	0.7 E-3	1.89E-3		1.26 E-2	0.1 E-4
VII	0.3	0.756		6.9 E-2	0.4 E-2	1.6 E-3	4.03E-3		2.68 E-2	0.2 E-4
Total		4.893		44.8 E-2			23.5E-3		15.6 E-2	
Experiment E-8										
I	0.55	1.49	282.0	0.53	1.075	0.8 E-3	2.2 E-3	118.44	1.83 E-3	15.7 E-4
II	0.21	0.60		0.21	0.688	0.4 E-3	1.1 E-3		0.96 E-3	13.1 E-4
III	0.7	2.03		0.72	0.670	2.6 E-3	7.5 E-3		6.36 E-3	24.9 E-4
IV	0.02	0.06		0.02	0.002	0.4 E-3	1.2 E-3		1.05 E-3	0.4 E-4
V	0.4	1.28		0.45	0.014	0.6 E-3	1.9 E-3		1.62 E-3	0.2 E-4
VI	0.2	0.66		0.23	0.004	1.2 E-3	3.9 E-3		3.32 E-3	0.3 E-4
Total		6.12		2.16			17.8 E-3		15.1 E-3	

Leaching period	Ce					Ta				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d
Experiment E-6										
I	2.7 E-2	0.082	64.875	0.13	68.2 E-3	0.5 E-5	0.15 E-4	0.337	0.44 E-2	1.3 E-5
II	1.39E-2	0.041		0.06	60.0 E-3	4.0 E-5	1.19 E-4		3.53 E-2	17.3E-5
III	1.1 E-2	0.032		0.05	16.4 E-3	5.1 E-5	1.49 E-4		4.42 E-2	7.6 E-5
IV	0.8 E-2	0.028		0.04	1.5 E-3	24 E-5	8.28 E-4		24.6 E-2	4.5 E-5
V	1.0 E-2	0.030		0.05	0.3 E-3	22 E-5	6.49 E-4		19.3 E-2	0.6 E-5
VI	2.1 E-2	0.057		0.09	0.3 E-3	10 E-5	2.70 E-4		8.0 E-2	0.1 E-5
VII	1.9 E-2	0.048		0.07	0.2 E-3	21 E-5	5.29 E-4		15.7 E-2	0.2 E-5
Total		0.318		0.49			25.6 E-4		76.0 E-2	
Experiment E-8										
I	0.6 E-2	0.016	31.02	0.05	11.8 E-3	1.0 E-5	0.27 E-4	0.212	1.27 E-2	2.0 E-5
II	0.3 E-2	0.009		0.03	9.8 E-3	4.3 E-5	1.23 E-4		5.80 E-2	14.1E-5
III	0.78 E-2	0.023		0.08	7.5 E-3	2.4 E-5	0.70 E-4		3.30 E-2	2.3 E-5
IV	2.0 E-2	0.062		0.20	2.1 E-3	1.0 E-5	0.31 E-4		1.46 E-2	0.1 E-5
V	3.0 E-2	0.096		0.31	1.1 E-3	26 E-5	8.30 E-4		39.15E-2	0.9 E-5
VI	0.7 E-2	0.023		0.07	0.1 E-3	0.2 E-5	0.07 E-4		0.33 E-2	˜0
Total		0.229		0.74			10.9 E-4		51.3 E-2	

Leaching period	Th					U				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d
Experiment E-6										
I	3.6 E-4	1.09 E-3	5.709	1.91 E-2	90.9 E-5	1.7 E-3	0.51 E-2	103.8	0.49 E-2	42.9E-4
II	2.1 E-4	0.62 E-3		1.09 E-2	90.7 E-5	0.7 E-3	0.21 E-2		0.20 E-2	30.2E-4
III	3.5 E-4	1.02 E-3		1.79 E-2	52.1 E-5	1.4 E-3	0.41 E-2		0.39 E-2	20.8E-4
IV	1.6 E-4	0.55 E-3		0.96 E-2	3.0 E-5	6.4 E-3	2.21 E-2		2.13 E-2	12.0E-4
V	4.0 E-4	1.18 E-3		2.07 E-2	1.0 E-5	10.8E-3	3.19 E-2		3.07 E-2	2.7E-4
VI	0.4 E-4	0.11 E-3		0.19 E-2	0.1 E-5	2.9 E-3	0.78 E-2		0.75 E-2	0.4E-4
VII	6.4 E-4	1.61 E-3		2.82 E-2	0.8 E-5	14.6E-3	3.68 E-2		3.54 E-2	1.7E-4
Total		6.18 E-3		10.8 E-2			11.0 E-2		10.6 E-2	
Experiment E-8										
I	8.0 E-4	2.17 E-3	25.94	8.36 E-3	15.7 E-4	0.8 E-3	2.17 E-3	6.486	3.34 E-2	15.7E-4
II	4.3 E-4	1.23 E-3		4.74 E-3	14.1 E-4	0.9 E-3	2.57 E-3		3.96 E-2	29.5E-4
III	4.7 E-4	1.36 E-3		5.24 E-3	4.5 E-4	0.8 E-3	2.32 E-3		3.58 E-2	7.7E-4
IV	3.0 E-4	0.93 E-3		3.58 E-3	0.3 E-4	0.2 E-3	0.62 E-3		0.95 E-2	0.2E-4
V	5.0 E-4	1.60 E-3		6.17 E-3	0.2 E-4	0.8 E-3	2.55 E-3		3.93 E-2	0.3E-4
VI	6.1 E-4	2.00 E-3		7.71 E-3	0.1 E-4	0.5 E-3	1.64 E-3		2.53 E-2	0.1E-4
Total		9.29 E-3		35.8 E-3			11.9 E-3		18.3 E-2	

Demineralized water experiments under dynamic conditions
SUMMARY TABLE

Leaching period	Time, days		Dry weight of initial sample, g	Amount of water flowing through ΔV, l	Total amount of water sample, l	Total dry residue after evaporating the sample				
	Δd	ΣΔd				Content in water sample, g/l	Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI, mg/m²·l·d
Experiment E-9										
I	2.88	2.88	182.3	10.258	2.610	1.432	3.739	182.3	2.05	3034.2
II	3.00	5.88		9.978	2.630	0.450	1.184		0.65	947.9
III	5.00	10.88		16.498	2.670	0.310	0.826		0.45	240.2
IV	16.00	26.88		56.613	2.690	0.404	1.085		0.50	28.7
V	31.00	57.88		104.534	2.960	0.294	0.872		0.48	6.45
VI	91.04	148.92		570.765	2.923	0.409	1.197		0.65	0.55
Total	148.92			768.646			8.903		4.78	
Experiment E-10										
I	2.92	2.92	288.3	11.793	2.680	1.510	4.111	288.3	1.43	2028.1
II	3.00	5.92		9.979	2.730	0.819	2.237		0.78	1269.6
III	5.00	10.92		16.498	2.650	1.060	2.810		0.97	578.8
IV	16.00	26.92		56.613	2.710	1.596	4.326		1.50	81.15
V	31.00	57.92		104.534	2.950	2.086	6.154		2.13	32.26
VI	91.04	148.96		570.765	2.925	2.272	6.644		2.30	2.17
Total	148.96			770.182			26.282		9.11	

Leaching period	Na					K				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-9										
I	96.0	250.6	0.352	71.24	203.34	543.3	1418.0	3.026	46.86	1150.8
II	20.0	52.60		14.96	42.13	120.0	315.6		10.43	252.8
III	4.8	12.82		3.64	3.726	37.4	99.86		3.30	29.02
IV	6.0	16.14		4.59	0.427	14.0	37.66		1.24	0.997
V	1.4	4.14		1.18	0.031	8.0	23.68		0.78	0.175
VI	1.3	3.80		1.08	0.002	9.3	27.18		0.90	0.012
Total		340.06		96.69			1922.0		63.51	
Experiment E-10										
I	50.7	135.88	2.460	5.52	67.04	7.0	18.76	6.915	0.27	9.256
II	8.0	21.84		0.89	12.39	2.0	5.46		0.08	3.099
III	3.5	9.28		0.38	1.911	1.5	3.98		0.06	0.820
IV	3.2	8.67		0.35	0.163	2.6	7.05		0.10	0.132
V	0.8	2.36		0.10	0.012	1.3	3.84		0.06	0.020
VI	0.8	2.34		0.10	0.001	2.0	5.85		0.08	0.002
Total		180.37		7.34			44.94		0.65	

Leaching period	NH_4^+			Ca				
	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-9								
I	59.51	155.32	12605 E-2	25.5	0.066	40.042	0.17	56.26
II	3.92	10.31	825.7 E-2	50.9	0.134		0.33	107.22
III	1.96	5.23	152.0 E-2	68.5	0.183		0.46	53.16
IV	0.09	0.242	0.64 E-2	107.8	0.290		0.72	7.675
V	0.06	0.178	0.13 E-2	82.4	0.244		0.61	1.804
VI	0.28	0.818	0.04 E-2	101.6	0.297		0.74	0.137
Total		172.10			1.214		3.03	
Experiment E-10								
I	87.77	235.22	116.05	229.5	0.615	20.304	3.03	303.45
II	29.76	81.24	46.10	162.7	0.444		2.19	252.07
III	11.68	30.95	6.374	232.3	0.616		3.03	126.79
IV	12.05	32.05	0.601	387.2	1.049		5.17	18.54
V	3.89	11.48	0.110	533.5	1.575		7.76	15.03
VI	2.45	7.17	0.002	570.7	1.669		8.22	0.546
Total		398.11			5.968		29.40	

Leaching period	Mg					Fe_{total}				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-9										
I	2.4	6.26	5.617	0.11	5.080	0	0	6.138	0	0
II	0	0		0	0	0.02	0.053		8.6 E-4	4.2 E-2
III	0	0		0	0	0.07	0.187		30.5 E-4	5.4 E-2
IV	14.8	39.81		0.71	1.056	0.02	0.054		8.8 E-4	0.14 E-2
V	2.3	6.81		0.12	0.050	0	0		0	0
VI	0	0		0	0	0	0		0	0
Total		52.88		0.94			0.294		47.9 E-4	
Experiment E-10										
I	64.2	172.06	3.842	4.48	84.888	0.08	0.214	13.521	1.58 E-3	0.106
II	21.4	58.42		1.52	33.154	0.06	0.164		1.21 E-3	0.093
III	16.6	43.99		1.14	9.060	0.08	0.212		1.57 E-3	0.044
IV	20.8	56.37		1.47	1.057	0	0		0	0
V	9.8	28.91		0.75	0.152	0.12	0.354		2.62 E-3	0.002
VI	25.6	74.88		1.95	0.024	1.31	3.832		28.34E-3	0.001
Total		434.63		11.31			4.776		35.3 E-3	

Leaching period	Cl^-			S				
	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d
Experiment E-9								
I	235.1	613.6	497.97	23.16	0.060	7.821	0.77	49.06
II	74.8	196.7	157.54	15.45	0.041		0.52	32.54
III	24.1	64.4	18.70	16.59	0.044		0.57	12.87
IV	56.0	150.6	3.987	19.09	0.051		0.66	1.359
V	13.1	38.8	0.287	29.41	0.087		1.11	0.644
VI	8.0	23.4	0.011	71.43	0.209		2.67	0.963
Total		1087.5			0.492		6.30	
Experiment E-10								
I	149.3	400.12	194.40	320.6	0.859	17.759	4.84	423.90
II	88.5	241.61	137.12	173.7	0.474		2.67	269.11
III	18.4	48.76	10.04	217.9	0.577		3.25	118.92
IV	7.4	20.05	0.376	353.7	0.958		5.40	18.03
V	5.7	16.82	0.088	445.0	1.313		7.39	6.883
VI	2.2	6.44	0.002	502.7	1.470		8.28	0.481
Total		733.80			5.652		31.83	

Leaching period	NO_3^-			HCO_3^-			not bound CO_2		
	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	ΔI mg/m²·l·d
Experiment E-9									
I	7.4	19.31	15.671	*	*	*	*	*	*
II	3.4	8.94	7.160						
III	2.2	5.87	1.706						
IV	15.3	41.16	1.089						
V	0.2	0.59	0.004						
VI	1.9	5.55	0.038						
Total		81.42							
Experiment E-10									
I	*	*	*	24.4	65.39	32.26	52.8	141.50	69.81
II				24.4	66.61	37.80	24.2	66.07	37.50
III				24.4	64.66	13.32	24.2	64.13	13.21
IV				12.2	33.06	0.620	30.8	83.47	1.566
V				12.2	35.99	0.189	17.6	51.92	0.272
VI				9.8	28.67	0.009	30.8	90.09	0.029
Total					294.38			497.18	

* not determined

Leaching period	SiO_2					Ti				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d
Experiment E-9										
I	13.5	35.23	37.663	0.09	28.59	4.0	10.440	634.4	1.64	847.3 E-2
II	9.2	24.19		0.06	19.37	1.0	2.630		0.41	210.6 E-2
III	11.3	30.17		0.08	8.77	0.7	1.869		0.29	54.32 E-2
IV	8.8	23.67		0.06	0.626	0.1	0.269		0.04	0.711 E-2
V	9.1	26.93		0.07	0.199	0.1	0.296		0.05	0.219 E-2
VI	9.4	27.48		0.07	0.013	0.009	0.026		0.004	0.001 E-2
Total		167.76		0.43			15.530		2.43	
Experiment E-10										
I	7.6	20.37	127.948	0.02	10.050	3.0	8.040	720.8	1.12	396.7 E-2
II	4.0	10.92		0.01	6.197	2.0	5.460		0.76	309.9 E-2
III	7.3	19.35		0.02	3.985	0.3	0.795		0.11	16.37 E-2
IV	18.4	49.86		0.04	1.498	3.0	8.130		1.13	15.25 E-2
V	23.9	70.51		0.05	0.370	0.6	1.770		0.24	0.928 E-2
VI	56.9	166.43		0.13	0.054	0.582	1.702		0.23	0.056 E-2
Total		337.44		0.27			25.897		3.59	

Leaching period	V					Sr				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d
Experiment E-9										
I	1.2 E-2	3.13 E-2	63.8	4.91 E-2	254.0 E-4	1.06	2.767	200.5	1.38	224.6 E-2
II	0.4 E-2	1.05 E-2		1.65 E-2	84.1 E-4	0.31	0.815		0.41	65.27 E-2
III	0.3 E-2	0.80 E-2		1.25 E-2	23.2 E-4	0.01	0.027		0.01	0.776 E-2
IV	0.6 E-2	1.61 E-2		2.52 E-2	4.26 E-4	0.57	1.533		0.76	4.058 E-2
V	0.8 E-2	2.37 E-2		3.71 E-2	1.75 E-4	0.86	2.546		1.27	1.884 E-2
VI	0.83E-2	2.43 E-2		3.81 E-2	0.112 E-4	3.30	9.646		4.84	0.445 E-2
Total		11.4 E-2		17.8 E-2			17.334		8.67	
Experiment E-10										
I	2.0 E-2	5.36 E-2	69.19	7.75 E-2	264.4 E-4	0.10	0.268	57.7	0.46	132.2 E-3
II	0.2 E-2	0.55 E-2		0.79 E-2	31.21 E-4	0.47	1.283		2.23	728.1 E-3
III	0.3 E-2	0.80 E-2		1.16 E-2	16.37 E-4	0.10	0.265		0.46	54.58 E-3
IV	0.4 E-2	1.08 E-2		1.56 E-2	2.03 E-4	0.06	0.163		0.28	3.06 E-3
V	0.3 E-2	0.88 E-2		1.27 E-2	0.464 E-4	1.00	2.950		5.11	15.47 E-3
VI	0.26E-2	0.76 E-2		1.10 E-2	0.025 E-4	0.50	1.462		2.53	0.478 E-3
Total		9.43 E-2		13.63E-2			6.391		11.07	

Leaching period	Nb					La				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d
Experiment E-9										
I	0.71	1.853	255.2	0.73	150.4 E-2	21.0E-4	54.81 E-4	111.7	4.91E-3	444.8E-5
II	0.20	0.526		0.21	42.13 E-2	2.0E-4	5.26 E-4		0.47E-3	42.13E-5
III	0.04	0.107		0.04	3.11 E-2	5.0E-4	13.35 E-4		1.19E-3	38.80E-5
IV	0.07	0.188		0.07	0.500 E-2	2.0E-4	5.38 E-4		0.48E-3	1.42 E-5
V	0.01	0.030		0.01	0.022 E-2	0.8E-4	2.37 E-4		0.21E-3	0.17 E-5
VI	0.095	0.278		0.11	0.013 E-2	0.1E-4	0.29 E-4		0.03E-3	0.13 E-6
Total		2.982		1.17			81.46 E-4		7.29E-3	
Experiment E-10										
I	0.30	0.804	288.3	0.28	396.7 E-3	2.4 E-3	6.43 E-3	11.24	0.06	317.2E-5
II	0.04	0.109		0.04	61.86 E-3	2.4 E-3	6.55 E-3		0.06	371.7E-5
III	0.05	0.132		0.04	27.19 E-3	4.6 E-3	12.19E-3		0.11	251.1E-5
IV	0.10	0.271		0.09	5.08 E-3	1.2 E-3	3.25 E-3		0.03	6.10 E-5
V	0.10	0.295		0.10	1.55 E-3	23.2E-3	68.44E-3		0.61	35.88E-5
VI	0.331	0.968		0.34	0.316 E-3	16.1E-3	47.09E-3		0.42	1.54 E-5
Total		2.579		0.89			143.9E-3		1.29	

Leaching period	Ce					Ta				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d
Experiment E-9										
I	1.0 E-2	26.10E-3	20.05	0.13	211.8 E-4	20.0E-5	5.22E-4	0.044	1.19E-2	423.6E-6
II	0.2 E-2	5.26 E-3		0.03	42.13 E-4	8.4 E-5	2.21E-4		0.50E-2	176.9E-6
III	0.2 E-2	5.34 E-3		0.03	15.52 E-4	6.8 E-5	1.82E-4		0.41E-2	52.8 E-6
IV	0.1 E-2	2.69 E-3		0.01	0.712 E-4	2.7 E-5	0.73E-4		0.16E-2	1.92 E-6
V	1.0 E-2	29.60E-3		0.15	2.19 E-4	2.2 E-5	0.65E-4		0.15E-2	0.482E-6
VI	0.1 E-2	2.92 E-3		0.01	0.013 E-4	7.2 E-5	2.10E-4		0.48E-2	0.097E-6
Total		71.91E-3		0.36			12.73E-4		2.89E-2	
Experiment E-10										
I	2.7 E-2	7.24 E-2	43.2	0.17	35.72 E-3	18.5E-5	4.96 E-4	0.199	0.25	24.47E-5
II	1.1 E-2	3.00 E-2		0.07	17.02 E-3	16.0E-5	4.37 E-4		0.22	24.80E-5
III	1.1 E-2	2.91 E-2		0.07	5.99 E-3	7.0 E-5	1.85 E-4		0.09	3.810E-5
IV	5.1 E-2	13.82E-2		0.32	2.59 E-3	21.0E-5	5.69 E-4		0.29	1.067E-5
V	7.6 E-2	22.42E-2		0.52	1.18 E-3	19.9E-5	5.87 E-4		0.30	0.308E-5
VI	7.36E-2	21.53E-2		0.50	0.07 E-3	20.0E-5	5.85 E-4		0.29	0.019E-5
Total		70.9 E-2		1.65			28.59E-4		1.44	

Leaching period	Th					U				
	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d	Content in water sample, mg/l	Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI mg/m²·l·d
Experiment E-9										
I	4.5 E-4	11.74E-4	20.42	5.75E-3	95.28E-5	0.8E-3	2.09E-3	4.37	4.78E-2	169.45E-5
II	0.8 E-4	2.10 E-4		1.03E-3	16.82E-5	0.1E-3	0.26E-3		0.60E-2	21.06 E-5
III	0.7 E-4	1.87 E-4		0.92E-3	5.43 E-5	0.1E-3	0.27E-3		0.61E-2	7.76 E-5
IV	3.0 E-4	8.07 E-4		3.95E-3	2.14 E-5	0.3E-3	0.81E-3		1.85E-2	2.14 E-5
V	5.1 E-4	15.10E-4		7.39E-3	1.12 E-5	0.8E-3	2.37E-3		5.42E-2	1.75 E-5
VI	0.8 E-4	2.34 E-4		1.14E-3	0.011E-5	1.8E-3	5.26E-3		12.04E-2	0.24 E-5
Total		41.22E-4		20.18E-3			11.06E-3		25.3E-2	
Experiment E-10										
I	10.2E-4	27.34E-4	3.171	8.62E-2	134.9E-5	1.0E-3	0.27E-2	66.31	0.40E-2	13.22E-4
II	2.0 E-4	5.46 E-4		1.72E-2	30.98E-5	0.5E-3	0.14E-2		0.20E-2	7.72 E-4
III	1.2 E-4	3.18 E-4		1.00E-2	6.55E-5	1.8E-3	0.48E-2		0.72E-2	9.82 E-4
IV	6.0 E-4	16.26E-4		5.13E-2	3.05E-5	9.9E-3	2.68E-2		4.05E-2	5.03 E-4
V	1.2 E-4	3.54 E-4		1.12E-2	0.185E-5	26.2E-3	7.73E-2		11.66E-2	4.05 E-4
VI	3.7 E-4	10.82E-4		3.41E-2	0.035E-5	53.0E-3	15.5E-2		23.38E-2	0.507E-4
Total		66.6 E-4		21.0E-2			26.8E-2		40.41E-2	

Sea water experiments under dynamic conditions
SUMMARY TABLE

Leaching period	Time, days		Dry weight of initial sample, g	Amount of water flowing through, ΔV, l	Total amount of water sample, l	Total dry residue after evaporating the sample					
	Δd	ΣΔd				Content in water sample, g/l		Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI, $\frac{mg}{m^2 \cdot l \cdot d}$
						Before leaching	After leaching				
Experiment E-1											
I	2.90	2.90	500.0	8.190	3.110	4.103	6.895	7.371	500.0	1.47	3493.70
II	3.00	5.90		110.100	2.920	4.957	6.002	2.723		0.54	928.05
III	5.08	10.98		28.740	2.900	4.715	6.224	4.439		0.89	342.28
IV	15.75	26.73		53.805	2.900	4.836	7.301	6.931		1.39	91.96
V	30.00	56.73		105.918	3.100	4.701	6.756	5.495		1.10	19.47
VI	40.00	96.73		140.340	3.100	5.394	7.252	4.815		0.86	14.54
VII	50.25	146.98		280.650	3.200	5.381	8.276	7.859		1.57	6.61
Total	146.98			628.563				39.633		7.92	
Experiment E-3											
I	2.90	2.90	434.0	10.200	3.085	4.103	6.521	5.927	434.0	1.37	2431.69
II	3.00	5.90		11.185	2.850	4.957	5.882	2.646		0.61	950.74
III	5.08	10.98		28.740	2.900	4.715	6.780	5.786		1.33	477.82
IV	15.75	26.73		54.025	2.900	4.836	7.466	6.471		1.49	91.27
V	30.00	56.73		105.918	3.100	4.701	7.422	5.913		1.36	22.44
VI	40.00	96.73		140.340	3.100	5.394	8.060	7.749		1.79	16.64
VII	50.25	146.98		280.650	3.200	5.381	8.078	8.349		1.92	7.14
Total	146.98			631.058				42.841		9.87	

Leaching period	Na						K					
	Content in water sample, g/l		Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment E-1												
I	1.250	1.486	451.04	3.384	13.33	213.78	38.8	42.8	4.3	10.956	0.04	2.038
II	1.250	1.305	88.83		2.63	30.28	41.4	39.6	-7.4		-0.07	-2.522
III	1.277	1.456	533.08		15.75	41.10	43.7	37.6	-17.3		-0.13	-1.334
IV	1.400	1.365	-143.31		-4.23	-1.90	38.8	34.7	-12.9		-0.12	-0.171
V	1.333	1.247	-431.14		-12.74	-1.53	42.7	36.7	-23.4		-0.21	-0.829
VI	1.543	1.444	-493.41		-14.58	-0.99	48.0	51.4	3.9		0.04	0.008
VII	1.500	1.570	-42.90		-1.27	-0.34	51.4	61.5	21.8		0.19	0.017
Total			-37.81		-1.11				-30.4		-0.26	
Experiment E-3												
I	1.250	1.300	-151.3	3.059	-4.95	-62.07	38.8	40.5	-4.3	9.690	-0.04	-1.764
II	1.250	1.277	77.8		2.54	27.95	41.4	36.7	-13.4		-0.14	-4.815
III	1.277	1.456	474.8		15.52	39.21	43.7	36.3	-22.5		-0.23	-1.858
IV	1.400	1.507	248.9		8.14	3.53	38.8	38.6	-2.1		-0.02	-0.300
V	1.333	1.427	-196.1		-6.41	-0.74	42.7	53.3	14.7		0.15	0.056
VI	1.543	1.600	74.9		2.45	0.16	48.0	80.0	94.1		0.97	0.206
VII	1.500	1.590	233.6		7.64	0.20	51.4	76.9	78.9		0.81	0.067
Total			762.6		24.93				145.4		1.50	

Leaching period	NH_4^+				Ca					
	Content in water sample, mg/l		Leached out ΔP, mg	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching			Before leaching	After leaching				
Experiment E-1										
I	0.16	146.20	426.4	202.1	72.9	354.7	0.809	47.369	1.71	383.41
II	0.07	76.20	218.1	74.4	77.8	340.3	0.748		1.58	255.22
III	0	27.51	80.0	6.2	72.9	462.7	1.135		2.40	87.52
IV	0	20.08	57.6	0.76	62.1	690.2	1.801		3.80	23.88
V	0.07	0.79	2.1	7.4E-3	65.7	641.9	1.703		3.59	6.03
VI	0.59	0.83	0.6	1.2E-3	82.4	735.1	1.928		4.07	3.87
VII	0	0.88	3.9	3.1E-3	95.2	754.5	1.981		4.18	1.58
Total			787.8				10.105		21.33	
Experiment E-3										
I	0.16	111.70	317.8	130.385	72.9	320.8	0.689	32.738	2.10	282.84
II	0.07	54.10	154.5	55.514	77.8	302.4	0.642		1.96	230.82
III	0	36.39	104.4	8.622	72.9	425.6	1.010		3.08	83.42
IV	0	14.82	42.4	0.601	62.1	637.0	1.642		5.01	23.26
V	0.07	0.60	1.5	0.006	65.7	690.8	1.703		5.20	6.46
VI	0.59	1.71	3.4	0.011	82.4	543.9	1.396		4.26	3.00
VII	0	0	0	0	95.2	666.3	1.804		5.51	1.54
Total			624.0				8.886		27.12	

Leaching period	Mg						Fe_{total}					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment E-1												
I	162.1	218.1	132.8	4.470	2.97	62.94	0.05	0.03	-0.07	19.215	-0.36E-3	-33.17E-3
II	165.0	161.5	-19.1		-0.43	-6.52	0.05	0.05	-0.01		-0.05E-3	-3.41E-3
III	152.6	172.1	58.3		1.30	4.49	0	0.02	0.06		0.31E-3	4.63E-3
IV	158.0	171.5	34.0		0.76	0.45	0.05	0.37	0.91		4.73E-3	12.07E-3
V	154.5	187.1	76.7		1.71	0.27	0.12	0.22	0.28		1.46E-3	0.99E-3
VI	171.7	196.1	50.1		1.12	0.10	0.06	0.37	0.91		4.74E-3	1.82E-3
VII	191.4	208.1	18.0		0.40	0.015	0.05	0.05	-0.01		-0.05E-3	-7.8 E-6
Total			350.8		7.83				2.07		10.78E-3	
Experiment E-3												
I	162.1	253.5	222.4	5.468	4.07	91.24	0.05	0.03	-0.068	20.355	-0.33E-3	-2.79E-2
II	165.0	173.9	72.4		1.32	26.01	0.05	0.06	0.029		0.14E-3	1.04E-2
III	152.6	172.1	51.4		0.94	4.24	0	0.08	0.230		0.94E-3	1.90E-2
IV	158.0	181.2	60.0		1.10	0.85	0.05	0.10	0.141		0.69E-3	0.20E-2
V	154.5	190.2	46.0		0.84	0.17	0.12	1.74	4.430		27.76E-3	1.69E-2
VI	171.7	271.6	292.3		5.35	0.63	0.06	0	-0.186		-0.91E-3	-4.00E-4
VII	191.4	202.1	27.1		0.50	0.023	0.05	0.09	0.125		0.61E-3	1.07E-4
Total			771.6		14.12				4.701		22.9E-3	

Table 15/1-5

Leaching period	Cl^-				S					
	Content in water sample, g/l		Leached out ΔP, g	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, g	Content in initial sample, g	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching			Before leaching	After leaching				
Experiment E-1										
I	2.240	2.427	0.102	48.44	110.2	623.0	1.476	42.100	3.51	699.76
II	2.240	2.277	-0.016	-5.67	118.2	426.1	0.876		2.08	298.87
III	2.315	2.427	0.349	26.94	121.1	511.2	1.136		2.70	87.62
IV	2.408	2.277	-0.447	-5.94	112.4	692.8	1.662		3.95	22.06
V	2.315	2.296	-0.357	-1.26	111.9	554.4	1.300		3.09	4.60
VI	2.744	2.669	-0.579	-1.16	89.6	626.2	1.582		3.76	3.17
VII	2.706	2.697	-0.488	-0.39	134.8	697.4	1.682		3.99	1.34
Total			-1.436				9.714		23.08	
Experiment E-3										
I	2.240	2.277	-0.420	-172.50	110.2	563.5	1.266	28.036	4.52	519.47
II	2.240	2.315	0.214	76.86	118.2	367.3	0.712		2.54	256.01
III	2.315	2.408	0.198	16.38	121.1	525.1	1.156		4.12	95.45
IV	2.408	2.371	-0.203	-2.88	112.4	723.2	1.742		6.21	24.69
V	2.315	2.427	-0.477	-1.81	111.9	656.7	1.466		5.23	5.56
VI	2.744	2.688	-0.346	-0.74	89.6	673.4	1.767		6.30	3.79
VII	2.706	2.697	-0.124	-0.11	134.8	697.2	1.775		6.33	1.52
Total			-1.158				9.884		35.25	

Table 15/1-6

Leaching period	NO_3^-				HCO_3^-			
	Content in water sample, mg/l		Leached out ΔP, mg	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	ΔI, mg/m²·l·d
	Before leaching	After leaching			Before leaching	After leaching		
Experiment E-1								
I	21.0	21.6	-2.2	-1.04	97.6	73.2	-89.80	-42.563
II	11.2	68.0	162.1	55.32	103.7	85.4	-58.13	-19.812
III	74.1	47.0	-78.1	-6.02	97.6	85.4	-34.53	-2.662
IV	45.0	14.1	-90.0	-1.19	97.6	109.8	32.09	0.426
V	42.6	33.2	-33.5	-0.12	91.5	134.2	114.92	0.407
VI	79.5	41.6	-122.9	-0.25	103.7	244.1	403.51	0.809
VII	45.7	18.8	-89.2	-0.07	109.0	280.7	501.72	0.400
Total			-253.8				869.78	
Experiment E-3								
I	21.0	8.2	-41.4	-16.99	97.6	85.4	-57.71	-23.677
II	11.2	58.6	135.6	48.72	103.7	85.4	-51.30	-18.433
III	74.1	44.0	-88.6	-7.32	97.6	61.0	-107.97	-8.916
IV	45.0	49.5	11.1	0.16	97.6	67.1	-91.13	-1.291
V	42.6	32.2	-43.2	-0.16	91.5	85.4	-47.95	-0.182
VI	79.5	45.6	-108.0	-0.23	103.7	140.3	104.48	0.224
VII	45.7	0	-146.2	-0.13	109.0	73.2	-117.12	-0.100
Total			-280.7				-368.70	

Leaching period	not bound CO_2				SiO_2					
	Content in water sample, mg/l		Leached out ΔP, mg	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching			Before leaching	After leaching				
Experiment E-1										
I	0	0	0	0	0.2	5.2	14.56	183.600	0.79E-2	6.900
II	22.2	35.2	36.03	12.280	0	9.2	26.36		1.44E-2	8.996
III	0	37.4	108.83	8.392	0	11.8	34.34		1.87E-2	2.648
IV	6.6	39.6	94.51	1.254	2.1	25.3	65.66		3.58E-2	0.871
V	11.0	41.8	90.05	0.319	1.4	16.4	44.37		2.42E-2	0.157
VI	17.6	26.4	23.85	0.048	1.6	18.5	44.99		2.45E-2	0.090
VII	19.8	0	-63.36	-0.050	10.9	20.7	27.84		1.52E-2	0.022
Total			289.91				258.1		14.07E-2	
Experiment E-3										
I	0	0	0	0	0.2	6.2	17.05	179.589	0.95E-2	6.995
II	22.2	4.4	-50.69	-18.214	0	5.0	14.30		0.80E-2	5.138
III	0	30.8	88.40	7.300	0	18.6	53.38		2.97E-2	4.408
IV	6.6	28.6	62.66	0.888	2.1	24.5	63.98		3.56E-2	0.907
V	11.0	44.0	87.34	0.331	1.4	25.8	66.87		3.72E-2	0.254
VI	17.6	37.4	58.99	0.127	1.6	21.3	59.71		3.32E-2	0.128
VII	19.8	24.2	13.23	0.011	10.9	19.3	25.63		1.43E-2	0.022
Total			259.93				300.9		16.75E-2	

Leaching period	Ti						V					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield, Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment E-1												
I	18.0	8.0	-32.6	1.290	-2.53	-15.45	1.5 E-2	8.4 E-2	0.20	190.0	0.10	94.12 E-3
II	10.0	10.0	-0.6		-0.05	-20.5E-2	5.2 E-2	6.4 E-2	0.03		0.02	10.75 E-3
III	11.0	9.0	-5.7		-0.44	-44.0E-2	5.7 E-2	10.8 E-2	0.15		0.08	11.49 E-3
IV	10.0	15.0	-14.0		-1.08	-18.6E-2	5.92E-2	11.0 E-2	0.14		0.08	1.91 E-3
V	12.6	15.0	-5.5		-0.43	-1.97E-2	5.0 E-2	4.7 E-2	-0.01		-0.01	-0.055E-3
VI	9.2	17.0	22.0		1.70	4.41E-2	6.0 E-2	9.0 E-2	0.08		0.04	0.163E-3
VII	18.0	23.4	13.3		1.03	1.06E-2	67.7 E-2	8.0 E-2	-1.92		-1.01	-1.536E-3
Total			-23.1		-1.80				-1.33		-0.70	
Experiment E-3												
I	18.0	8.0	-32.7	1.432	-2.28	-13.416	1.5 E-2	12.1 E-2	0.30	125.86	0.24	122.5 E-3
II	10.0	21.0	31.5		2.20	11.318	5.2 E-2	8.0 E-2	0.08		0.06	28.78E-3
III	11.0	9.0	-6.1		-0.43	-0.504	5.7 E-2	9.0 E-2	0.09		0.07	7.68E-3
IV	10.0	13.2	6.2		0.43	0.088	5.92E-2	8.0 E-2	0.06		0.04	0.81E-3
V	12.6	15.0	2.3		0.16	0.009	5.0 E-2	4.7 E-2	-0.025		-0.02	-0.10E-3
VI	9.2	17.8	25.5		1.78	0.055	6.0 E-2	8.7 E-2	0.08		0.06	0.17E-3
VII	18.0	17.0	-3.8		-0.26	-0.003	67.7 E-2	11.1 E-2	-1.81		-1.44	-1.55E-3
Total			22.9		1.60				-1.23		-0.99	

Leaching period	Sr						Nb					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment E-1												
I	0.70	2.60	5.41	140.0	3.86	256.4 E-2	0.3	0.7	1.111	500.0	0.22	526.5 E-3
II	0.98	1.57	1.64		1.17	55.97E-2	0.7	0.7	-0.039		-0.008	-13.31E-3
III	0.75	2.10	3.94		2.81	30.38E-2	0.61	0.95	0.995		0.20	76.71E-3
IV	0.53	13.21	36.38		26.00	48.29E-2	0.7	0.5	-0.595		-0.12	-7.89E-3
V	0.84	0.50	-1.12		-0.8	-0.397E-2	0.2	1.1	2.647		0.53	9.38E-3
VI	0.21	6.87	19.75		14.11	3.96E-2	0.66	0.6	-0.264		-0.05	0.53E-3
VII	4.99	2.92	-7.12		-5.09	-0.568E-2	0.34	2.11	5.305		1.06	4.23E-3
Total			58.90		42.06				9.160		1.83	
Experiment E-3												
I	0.70	0.06	-1.988	108.5	-1.83	-81.56E-2	0.3	0.3	-0.070	347.0	-0.02	-2.78E-2
II	0.98	0.60	-1.087		-1.00	-39.06E-2	0.7	2.5	5.148		1.48	185 E-2
III	0.75	1.01	0.724		0.67	5.98E-2	0.61	1.2	1.675		0.48	13.83E-2
IV	0.53	0.59	0.150		0.14	0.21E-2	0.7	0.45	-0.743		-0.21	-1.05E-2
V	0.84	0.50	-1.224		-1.13	-0.46E-2	0.2	1.1	2.416		0.69	0.92E-2
VI	0.21	0.90	2.081		1.92	0.45E-2	0.66	0.53	-0.437		-0.13	-0.09E-2
VII	4.99	0.40	-14.704		-0.31	-0.029E-2	0.34	1.3	3.026		0.87	0.26E-2
Total			-16.048		-1.54				11.015		3.16	

Leaching period	La						Ce					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment E-1												
I	2.0 E-3	7.0 E-3	14.2E-3	12.0	0.12	67.3 E-4	1.8 E-2	3.5 E-2	0.046	75.0	0.06	22.04E-3
II	6.0 E-3	5.6 E-3	-1.5E-3		-0.01	-5.12E-4	3.13E-2	3.0 E-2	-0.005		-0.01	-1.87E-3
III	4.7 E-3	7.3 E-3	7.6E-3		0.06	5.86E-4	3.0 E-2	4.58E-2	0.046		-0.06	3.55E-3
IV	2.5 E-3	0.05E-3	-7.1E-3		-0.06	-0.94E-4	2.17E-2	8.8 E-2	0.190		0.25	2.53E-3
V	0.07E-3	5.1 E-3	14.9E-3		0.12	0.53E-4	2.5 E-2	3.0 E-2	0.012		0.02	0.04E-3
VI	0.2 E-3	6.9 E-3	19.9E-3		0.17	0.40E-4	3.0 E-2	4.07E-2	0.028		1.61	0.06E-3
VII	1.5 E-3	13.4 E-3	35.8E-3		0.30	0.28E-4	0.5 E-2	60.3E-2	1.811		2.41	1.45E-3
Total			83.9E-3		0.70				2.128		4.40	
Experiment E-3												
I	2.0 E-3	8.9 E-3	19.2E-3	18.05	10.6E-2	78.73E-4	1.8 E-2	1.8 E-2	-0.004	108.5	-0.04E-1	-17.23E-4
II	6.0 E-3	6.0 E-3	0		0	0	3.13E-2	4.01E-2	0.025		0.23E-1	90.55E-4
III	4.7 E-3	16.7 E-3	34.3E-3		19.0E-2	28.23E-4	3.0 E-2	8.09E-2	0.145		1.34E-1	119.9 E-4
IV	2.5 E-3	0.01E-3	-7.2E-3		-4.0E-2	-1.02E-4	2.17E-2	1.5 E-2	-0.020		-0.18E-1	-2.83E-4
V	0.07E-3	5.1 E-3	13.9E-3		7.7E-2	0.53E-4	2.5 E-2	3.0 E-2	0.005		0.05E-1	0.20E-4
VI	0.2 E-3	0.6 E-3	1.2E-3		0.7E-2	0.03E-4	3.0 E-2	45.8 E-2	1.297		11.95E-1	27.86E-4
VII	1.5 E-3	13.3 E-3	37.3E-3		20.6E-2	0.32E-4	0.5 E-2	4.0 E-2	0.111		1.02E-1	0.94E-4
Total			98.7E-3		54.6E-2				1.559		1.44	

Leaching period	Ta						Th					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·1·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·1·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment E-1												
I	1.0 E-5	1.0 E-5	-0.02E-4	0.305	-0.001	-0.09E-5	16.0 E-4	7.7 E-4	-2.73E-3	5.0	-5.46E-2	-13.01E-4
II	5.8 E-5	10.0 E-5	1.17E-4		0.04	4.02E-5	16.8 E-4	6.0 E-4	-3.19E-3		-6.38E-2	-10.93E-4
III	6.1 E-5	47.1 E-5	11.94E-4		0.39	9.26E-5	14.1 E-4	17.5 E-4	1.00E-3		2.00E-2	0.78E-4
IV	9.2 E-5	47.8 E-5	11.05E-4		0.36	1.48E-5	18.7 E-4	14.8 E-4	-1.18E-3		-2.36E-2	-0.16E-4
V	27.2 E-5	157.2 E-5	38.26E-4		1.25	1.36E-5	5.5 E-4	13.0 E-4	2.16E-3		4.32E-2	0.08E-4
VI	58.0 E-5	29.0 E-5	-9.37E-4		-0.31	-0.19E-5	10.4 E-4	5.7 E-4	-1.53E-3		-3.06E-2	-0.03E-4
VII	62.9 E-5	81.0 E-5	4.42E-4		0.15	0.04E-5	5.8 E-4	14.0 E-4	2.39E-3		4.78E-2	0.02E-4
Total			57.44E-4		1.88				-3.08E-3		-6.16E-2	
Experiment E-3												
I	1.0 E-5	1.0 E-5	-0.02E-4	0.256	0.00	-0.94E-6	16.0 E-4	17.2 E-4	-0.04E-3	4.34	-0.09E-2	-1.64E-5
II	5.8 E-5	10.0 E-5	1.20E-4		0.05	43.15E-6	16.8 E-4	16.4 E-4	-0.11E-3		-0.25E-2	-3.95E-5
III	6.1 E-5	31.1 E-5	7.16E-4		0.28	59.10E-6	14.1 E-4	19.6 E-4	1.54E-3		3.55E-2	12.72E-5
IV	9.2 E-5	10.0 E-5	0.19E-4		0.01	0.27E-6	18.7 E-4	12.6 E-4	-1.82E-3		-4.19E-2	-2.58E-5
V	27.2 E-5	157.2 e-5	34.96E-4		1.36	13.26E-6	5.5 E-4	13.0 E-4	1.88E-3		4.33E-2	0.72E-5
VI	58.0 E-5	86.0 E-5	8.13E-4		0.32	1.74E-6	10.4 E-4	8.6 E-4	-0.61E-3		-1.41E-2	-0.13E-5
VII	62.9 E-5	85.0 E-5	6.77E04		0.26	0.58E-6	5.8 E-4	15.0 E-4	2.89E-3		6.66E-2	0.25E-5
Total			58.39E-4		2.28				3.73E-3		8.6 E-2	

Table 15/1-12

Leaching period	U					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching				
Experiment E-1						
I	4.0 E-3	11.2 E-3	0.021	100.0	0.02	9.95E-3
II	2.9 E-3	11.9 E-3	0.026		0.03	8.87E-3
III	3.3 E-3	40.9 E-3	0.109		0.11	8.40E-3
IV	3.1 E-3	127.4 E-3	0.357		0.36	4.74E-3
V	2.0 E-3	8.4 E-3	0.019		0.02	6.73E-3
VI	4.5 E-3	621.6 E-3	1.831		1.83	3.67E-3
VII	9.8 E-3	1265.0E-3	4.143		4.14	3.31E-3
Total			6.506		6.51	
Experiment E-3						
I	4.0 E-3	11.4 E-3	0.017	95.48	1.78E-2	70.03E-4
II	2.9 E-3	13.4 E-3	0.030		3.14E-2	107.9E-4
III	3.3 E-3	15.5 E-3	0.035		3.66E-2	28.84E-4
IV	3.1 E-3	19.9 E-3	0.048		5.03E-2	6.79E-4
V	2.0 E-3	8.4 E-3	0.017		1.78E-2	0.64E-4
VI	4.5 E-3	106.6 E-3	0.310		32.46E-2	6.65E-4
VII	9.8 E-3	24.5 E-3	0.046		4.82E-2	0.39E-4
Total			0.502		52.6 E-2	

Sea water experiments under dynamic conditions
SUMMARY TABLE

Leaching period	Time, days		Dry weight of initial sample, g	Amount of water flowing through, ΔV, l	Total amount of water sample, l	Total dry residue after evaporating the sample					
	Δd	ΣΔd				Content in water sample, g/l		Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI, $\frac{mg}{m^2 \cdot l \cdot d}$
						Before leaching	After leaching				
Experiment E-5											
I	2.90	2.90	282.6	7.695	3.195	4.103	5.203	1.405	282.6	0.50	1151.6
II	3.00	5.90		10.485	2.900	4.957	4.715	-0.913		-0.32	-530.8
III	5.08	10.98		28.740	2.965	4.715	5.007	0.866		0.31	108.5
IV	15.75	26.73		53.805	2.900	4.836	5.047	0.412		0.14	8.9
V	30.00	56.73		105.918	3.100	4.700	5.077	0.867		0.31	5.0
VI	40.00	96.73		140.340	3.100	5.394	5.696	0.503		0.18	1.6
VII	50.25	146.98		277.200	3.200	5.381	5.999	0.659		0.23	0.9
Total	146.98			624.183				3.799		1.35	
Experiment E-7											
I	2.90	2.90	444.7	4.590	3.120	4.103	6.678	6.707	444.7	1.51	5497.5
II	3.00	5.90		10.785	2.920	4.956	5.756	2.221		0.50	750.3
III	5.08	10.98		28.740	2.920	4.715	6.676	5.726		1.29	428.3
IV	15.75	26.73		53.945	2.900	4.836	7.320	7.209		1.62	92.6
V	30.00	56.73		102.880	3.100	4.700	7.361	7.513		1.69	26.6
VI	40.00	96.73		128.389	3.100	5.394	7.903	6.988		1.57	14.9
VII	50.25	146.98		214.658	3.200	5.381	8.281	9.197		2.07	9.3
Total	146.98			543.987				45.561		10.25	

Leaching period	Na						K					
	Content in water sample, g/l		Leached out ΔP, mg	Content in initial sample, g	Yield, Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment E-5												
I	1.250	1.250	-506.3	0.524	-96.6	-415.00	38.8	600.0	1550.0	3.331	46.54	1270.5
II	1.250	1.285	46.0		8.8	26.74	41.4	155.0	322.4		9.68	187.4
III	1.277	1.393	344.5		65.7	43.16	43.7	76.0	95.7		2.87	11.99
IV	1.400	1.333	-246.5		-47.0	-5.321	38.8	60.0	59.1		1.77	1.276
V	1.333	1.335	-71.6		-13.7	-0.412	42.7	53.3	29.7		0.89	0.171
VI	1.542	1.500	-246.7		-47.1	-0.804	48.0	60.0	32.6		0.98	0.106
VII	1.500	1.538	-215.6		-41.1	-0.283	51.4	55.7	1.5		0.05	0.002
Total			-896.2		-171.0				2091.0		62.78	
Experiment E-7												
I	1.250	1.400	188.0	2.871	6.55	154.10	38.8	42.8	3.9	9.818	0.04	3.200
II	1.250	1.305	134.5		4.69	45.44	41.4	39.6	-6.1		-0.02	-2.061
III	1.277	1.429	445.6		15.52	33.33	43.7	37.6	-17.8		-0.20	-1.331
IV	1.400	1.400	0		0	0	38.8	34.3	-13.0		-0.13	-0.167
V	1.333	1.314	-190.9		-6.65	-0.68	42.7	36.7	-22.3		-0.23	-0.079
VI	1.542	1.511	-249.1		-8.68	-0.57	48.0	52.3	8.1		0.08	0.017
VII	1.500	1.600	304.0		10.59	0.31	51.4	60.0	26.9		0.27	0.027
Total			632.1		22.02				-20.3		-0.19	

Leaching period	NH_4^+				Ca					
	Content in water sample, mg/l		Leached out ΔP, mg	ΔI, $\frac{mg}{m^2 \cdot l \cdot d}$	Content in water sample, mg/l		Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI, $\frac{mg}{m^2 \cdot l \cdot d}$
	Before leaching	After leaching			Before leaching	After leaching				
Experiment E-5										
I	0.16	53.83	149.7	124.80	72.9	131.3	0.133	61.365	0.22	111.2
II	0.07	7.19	20.3	11.94	77.8	165.3	0.246		0.40	144.9
III	0	1.20	3.6	0.450	72.9	254.7	0.539		0.88	67.39
IV	0	1.46	4.2	0.091	62.1	325.3	0.750		1.22	16.21
V	0.07	0.11	0.1	0.001	65.7	343.1	0.840		1.37	4.83
VI	0.59	0.08	-1.6	0.005	82.4	431.3	1.049		1.71	3.42
VII	0	0	0	0	95.2	411.6	0.922		1.50	1.21
Total			176.3				4.479		7.30	
Experiment E-7										
I	0.16	126.50	368.9	302.36	72.9	311.0	0.681	59.503	1.14	557.95
II	0.07	71.50	207.2	69.98	77.8	308.0	0.666		1.12	225.00
III	0	43.49	127.0	9.498	72.9	462.7	1.138		1.91	85.13
IV	0	24.27	70.4	0.904	62.1	637.0	1.667		2.80	21.43
V	0.07	0.60	1.6	5.59E-3	65.7	720.2	1.957		3.29	6.92
VI	0.59	0.50	-0.3	-0.70E-3	82.4	744.7	1.987		3.34	4.22
VII	0	0.88	2.8	2.84E-3	95.2	735.1	2.040		4.04	2.07
Total			777.6				10.136		17.64	

Leaching period	Mg						Fe_{total}					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield, Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment E-5												
I	162.1	2.9	-509.8	9.699	-5.26	-417.9	0.05	0.03	-0.08	8.823	-0.91E-3	-6.67E-2
II	165.0	25.9	-406.6		-4.19	-239.2	0.05	0	-0.15		-1.70E-3	-8.82E-2
III	152.6	16.5	-403.6		-4.16	-50.45	0	0.04	0.12		1.36E-3	1.50E-2
IV	158.0	9.5	-431.0		-4.44	-9.309	0.05	0.08	0.08		0.91E-3	1.73E-3
V	154.5	0	-479.0		-4.94	-2.758	0.12	0.18	0.18		2.04E-3	1.04E-3
VI	171.7	0	-532.3		-5.49	-1.734	0.06	0.10	0.11		1.25E-3	3.58E-4
VII	191.4	50.6	-461.7		-4.76	-0.606	0.05	0.09	0.11		1.25E-3	1.44E-4
Total			-3224.0		-33.24				0.37		4.2 E-3	
Experiment E-7												
I	162.1	259.3	215.4	3.842	5.61	176.56	0.05	0.06	0.019	1.765	1.08E-4	15.57E-3
II	165.0	165.6	-1.6		-0.04	-0.54	0.05	0.08	0.086		4.87E-4	29.05E-3
III	152.6	172.1	56.9		1.48	4.26	0	0.13	0.380		21.52E-4	28.42E-3
IV	158.0	184.2	76.0		1.98	0.98	0.05	0.36	0.899		50.93E-4	11.54E-3
V	154.5	193.1	100.3		2.61	0.35	0.12	1.78	4.966		281.3E-4	17.57E-3
VI	171.7	178.3	2.6		0.07	5.5E-3	0.06	0.44	1.134		64.25E-4	2.41E-3
VII	191.4	190.2	-5.8		-0.15	-5.9E-3	0.05	0.16	0.350		19.83E-4	0.52E-3
Total			443.8		11.56				7.834		44.4E-3	

Leaching period	Cl^-				S					
	Content in water sample, g/l		Leached out ΔP, mg	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, g	Content in initial sample, g	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching			Before leaching	After leaching				
Experiment E-5										
I	2.240	2.277	-803.4	-669.50	110.2	100.1	-0.073	12.124	-0.60	60.67
II	2.240	2.277	6.0	3.53	118.2	102.0	-0.052		-0.43	30.35
III	2.315	2.382	198.6	24.82	121.1	113.1	-0.024		-0.19	2.95
IV	2.408	2.315	-363.2	-7.86	112.4	128.4	0.041		0.34	0.892
V	2.315	2.305	-165.5	-0.953	111.9	147.9	0.103		0.85	0.592
VI	2.744	2.706	-322.2	-1.050	89.6	197.4	0.319		2.63	1.040
VII	2.706	2.734	-512.0	-0.672	134.8	244.6	0.298		2.45	0.391
Total			-1961.7				0.612		5.05	
Experiment E-7										
I	2.240	2.427	97.8	80.2	110.2	568.7	1.317	37.445	3.52	1079.3
II	2.240	2.277	63.1	21.3	118.2	402.6	0.822		2.20	277.8
III	2.315	2.427	327.4	24.5	121.1	508.2	1.130		3.02	84.5
IV	2.408	2.361	-135.7	-3.1	112.4	661.6	1.593		4.25	20.5
V	2.315	2.315	-231.5	-0.8	111.9	641.6	1.578		4.21	5.6
VI	2.744	2.669	-498.8	-1.1	89.6	621.4	1.586		4.24	3.4
VII	2.706	2.669	-145.7	-0.2	134.8	716.1	1.853		4.95	1.9
Total			-523.4				9.879		26.39	

Leaching period	NO_3^-				HCO_3^-			
	Content in water sample, mg/l		Leached out ΔP, mg	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	ΔI, mg/m²·l·d
	Before leaching	After leaching			Before leaching	After leaching		
Experiment E-5								
I	21.0	0	-67.1	-55.92	*	*	*	*
II	11.2	55.1	124.8	73.41				
III	74.1	45.0	-86.3	-10.79				
IV	45.0	58.5	36.8	0.795				
V	42.6	52.5	27.8	0.160				
VI	79.5	20.0	-186.0	-0.606				
VII	45.7	14.3	-103.6	-0.136				
Total			-253.6					
Experiment E-7								
I	21.0	4.0	-53.8	-44.10	97.6	85.4	-55.14	-45.234
II	11.2	61.4	145.4	49.12	103.7	109.8	15.62	5.272
III	74.1	21.5	-153.6	-11.49	97.6	79.3	-53.43	-3.996
IV	45.0	45.2	0.6	-0.008	97.6	97.6	0	0
V	42.6	35.4	-25.9	-0.092	91.5	299.0	613.35	2.170
VI	79.5	33.9	-144.8	-0.308	103.7	280.7	520.63	1.107
VII	45.7	27.2	-59.4	-0.060	109.0	213.6	332.58	0.337
Total			-291.5				1373.6	

* not determined

Leaching period	not bound CO_2				SiO_2					
	Content in water sample, mg/l		Leached out ΔP, mg	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching			Before leaching	After leaching				
Experiment E-5										
I	0	0	0	0	0.2	20.4	56.3	53.581	0.11	46.92
II	22.2	0	-64.38	-37.430	0	8.9	25.4		0.05	14.94
III	0	0	0	0	0	19.0	56.3		0.11	7.038
IV	6.6	0	-19.14	-0.413	2.1	31.3	83.4		0.16	1.801
V	11.0	0	-34.10	-0.196	1.4	12.0	32.2		0.06	0.185
VI	17.6	0	-54.56	-0.178	1.6	12.3	32.2		0.06	0.105
VII	19.8	15.4	-17.47	-0.023	10.9	12.8	3.2		0.01	0.004
Total			-189.65				289.0		0.56	
Experiment E-7										
I	0	0	0	0	0.2	3.5	9.60	158.317	6.06E-3	7.869
II	22.2	22.0	-1.02	-0.344	0	5.2	15.08		9.52E-3	5.095
III	0	44.0	128.48	9.609	0	9.2	26.68		16.85E-3	1.996
IV	6.6	24.2	51.04	0.656	2.1	18.6	47.85		30.22E-3	0.614
V	11.0	0	-34.10	-0.121	1.4	23.9	67.36		42.55E-3	0.238
VI	17.6	35.2	50.74	0.108	1.6	14.9	39.74		25.10E-3	0.098
VII	19.8	30.8	34.89	0.035	10.9	18.6	24.45		15.44E-3	0.025
Total			230.03				230.76		145.7E-3	

Leaching period	Ti						V					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield, Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment E-5												
I	18.0	8.0	-35.19	0.897	-3.92	-2884.5E-2	1.5 E-2	15.3E-2	0.379	67.82	55.9E-2	310.6E-3
II	10.0	11.0	2.41		0.27	139.9E-2	5.2 E-2	8.6E-2	0.095		14.0E-2	55.1E-3
III	11.0	9.0	-5.93		-0.66	-74.3E-2	5.7 E-2	5.8E-2	0.003		0.4E-2	0.4E-3
IV	10.0	11.0	2.46		0.27	5.3E-2	5.92E-2	10.0E-2	0.114		16.9E-2	2.5E-3
V	12.6	10.0	-8.65		-0.96	-5.0E-2	5.0 E-2	5.2E-2	0.003		0.5E-2	0.2E-4
VI	9.2	9.0	-1.30		-0.15	-0.4E-2	6.0 E-2	7.0E-2	0.026		3.8E-2	0.1E-3
VII	18.0	9.7	-28.69		-3.20	-3.8E-2	67.7 E-2	8.9E-2	-1.901		-280.3E-2	-2.5E-3
Total			-74.89		-8.35				-1.281		-188.8E-2	
Experiment E-7												
I	18.0	8.0	-32.80	1.094	-3.00	-2690.7E-2	1.5 E-2	2.0E-2	1.16 E-2	177.9	0.65 E-2	95.16E-4
II	10.0	2.0	-23.40		-2.14	-789.7E-2	5.2 E-2	10.8E-2	16.14 E-2		9.07 E-2	544.7 E-4
III	11.0	9.0	-5.84		-0.53	-43.7E-2	5.7 E-2	9.0E-2	9.64 E-2		5.42 E-2	72.10E-4
IV	10.0	18.3	24.07		2.20	30.9E-2	5.92E-2	8.0E-2	6.03 E-2		3.39 E-2	7.75E-4
V	12.6	15.0	5.94		0.54	2.1E-2	5.0 E-2	8.0E-2	8.50 E-2		4.78 E-2	3.01E-4
VI	9.2	19.0	28.48		2.60	6.0E-2	6.0 E-2	7.0E-2	2.40 E-2		1.35 E-2	0.51E-4
VII	18.0	22.0	12.58		1.15	1.3E-2	67.7 E-2	9.0E-2	-187.9E-2		-105.6E-2	-19.02E-4
Total			9.03		0.82				-144 E-2		-80.9E-2	

Leaching period	Sr						Nb					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment E-5												
I	0.70	0.11	-1.930	169.6	-1.14	-158.2E-2	0.30	1.25	2.529	282.6	0.89	207.3E-2
II	0.98	3.52	7.208		4.25	419.1E-2	0.70	0.70	-0.031		-0.01	-1.8E-2
III	0.75	3.50	8.154		4.81	102.2E-2	0.61	0.51	-0.297		-0.10	-3.7E-2
IV	0.53	3.87	9.531		5.62	20.6E-2	0.70	0.79	0.229		0.08	0.5E-2
V	0.84	0.58	-0.840		-0.50	-0.5E-2	0.20	1.55	4.094		1.45	2.4E-2
VI	0.21	7.47	21.938		12.94	7.1E-2	0.66	0.70	0.071		0.02	0.2E-3
VII	4.99	1.21	-12.360		-7.29	-1.6E-2	0.34	0.90	1.594		0.56	0.2E-2
Total			31.701		18.69				8.189		2.89	
Experiment E-7												
I	0.70	0.08	-1.950	142.3	-1.37	-160.0E-2	0.30	0.76	1.283	400.2	0.32	105.2E-2
II	0.98	2.61	4.707		3.31	158.8E-2	0.70	0.89	0.537		0.13	18.1E-2
III	0.75	1.81	3.095		2.17	23.2E-2	0.61	1.0	1.139		0.28	8.52E-2
IV	0.53	5.27	13.746		9.66	17.7E-2	0.70	0.4	-0.870		-0.22	-1.12E-2
V	0.84	0.5	-1.104		-0.78	-0.4E-2	0.20	1.0	2.380		0.59	0.84E-2
VI	0.21	1.82	4.809		3.38	1.0E-2	0.66	0.4	-0.846		-0.21	-0.18E-2
VII	4.99	2.49	-8.025		-5.64	-0.8E-2	0.34	1.4	3.378		0.84	0.34E-2
Total			15.278		10.73				7.001		1.73	

Leaching period	La						Ce					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment E-5												
I	2.0 E-3	0.8 E-3	-4.2E-3	163.34	-2.6E-3	-34.1E-4	18.0E-3	125 E-3	29.12E-2	45.22	0.64	238.7E-3
II	6.0 E-3	5.4 E-3	-2.0E-3		-1.2E-3	-11.5E-4	31.3E-3	27.0E-3	-1.37E-2		-0.03	-8.0E-3
III	4.7 E-3	4.3 E-3	-1.2E-3		-0.7E-3	-1.5E-4	30.0E-3	17.6E-3	-3.68E-2		-0.08	-4.6E-3
IV	2.5 E-3	0.03E-3	-7.2E-3		-4.4E-3	-1.5E-4	21.7E-3	70.0E-3	13.73E-2		0.30	3.0E-3
V	0.07E-3	6.0 E-3	18.0E-3		11.0E-3	1.0E-4	25.0E-3	20.0E-3	-1.67E-2		-0.04	-0.1E-3
VI	0.2 E-3	0.3 E-3	0.3E-3		0.2E-3	0.1E-5	30.0E-3	201.0E-3	51.48E-2		1.14	1.7E-3
VII	1.5 E-3	18.0 E-3	48.2E-3		29.5E-3	0.6E-4	5.0E-3	30.0E-3	7.34E-2		0.16	0.1E-3
Total			51.9E-3		31.8E-3				94.9 E-2		2.09	
Experiment E-7												
I	2.0 E-3	0.8 E-3	-0.39E-2	11.118	-0.35E-3	-31.99E-4	18.0E-3	20.0E-3	0.22E-2	66.71	0.34E-2	18.37E-4
II	6.0 E-3	8.9 E-3	0.83E-2		0.75E-3	27.98E-4	31.3E-3	21.6E-3	-2.88E-2		-4.31E-2	-97.06E-4
III	4.7 E-3	13.9 E-3	2.69E-2		2.42E-3	20.10E-4	30.0E-3	50.5E-3	5.99E-2		8.97E-2	44.77E-4
IV	2.5 E-3	0.02E-3	-0.72E-2		-0.65E-3	-0.92E-4	21.7E-3	56.0E-3	9.95E-2		14.91E-2	12.78E-4
V	0.07E-3	14.9 E-3	4.45E-2		4.00E-3	1.57E-4	25.0E-3	208.0E-3	54.65E-2		81.91E-2	19.33E-4
VI	0.2 E-3	1.3 E-3	0.33E-2		0.29E-3	0.07E-4	30.0E-3	324.0E-3	87.90E-2		131.8 E-2	18.69E-4
VII	1.5 E-3	55.8 E-3	17.32E-2		15.58E-3	1.75E-4	5.0E-3	272.0E-3	85.17E-2		127.7 E-2	8.62E-4
Total			24.5E-2		22.0 E-3				241 E-2		361 E-2	

Leaching period	Ta						Th					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment E-5												
I	1.0E-5	1.0E-5	-0.04E-4	0.203	-0.2E-2	-3.3E-6	16.0E-4	11.9E-4	-1.79E-3	26.34	-6.8 E-3	-146.7E-5
II	5.8E-5	10.0E-5	1.27E-4		5.8E-2	68.2E-6	16.8E-4	17.3E-4	0.07E-3		0.26E-3	4.07E-5
III	6.1E-5	12.6E-5	1.93E-4		9.5E-2	24.1E-6	14.1E-4	17.8E-4	1.10E-3		4.18E-3	13.75E-5
IV	9.2E-5	18.0E-5	2.48E-4		12.2E-2	5.4E-6	18.7E-4	6.7E-4	-3.50E-3		-13.29E-3	-7.56E-5
V	27.2E-5	80.2E-5	15.96E-4		78.6E-2	9.2E-6	5.5E-4	9.0E-4	1.03E-3		3.91E-3	0.59E-5
VI	10.4E-5	42.0E-5	9.48E-4		46.7E-2	3.1E-6	10.4E-4	11.0E-4	0.10E-3		0.38E-3	0.03E-5
VII	62.9E-5	63.0E-5	-1.35E-4		-6.7E-2	-0.2E-6	5.8E-4	15.0E-4	2.61E-3		9.91E-3	0.34E-5
Total			29.7E-4		145.9E-2				-0.38E-3		-1.45E-3	
Experiment E-7												
I	1.0E-5	1.5E-5	0.13E-4	0.249	0.51E-2	10.34E-6	16.0E-4	23.3E-4	1.8E-3	4.447	4.0E-2	147.5 E-5
II	5.8E-5	27.4E-5	6.25E-4		25.11E-2	211.0E-6	16.8E-4	14.0E-4	-0.8E-3		-1.8E-2	-27.03E-5
III	6.1E-5	20.2E-5	4.04E-4		16.21E-2	30.19E-6	14.1E-4	6.5E-4	-2.2E-3		-4.9E-2	-16.46E-5
IV	9.2E-5	49.6E-5	11.72E-4		47.07E-2	15.06E-6	18.7E-4	4.7E-4	-4.0E-3		-9.0E-2	-5.14E-5
V	27.2E-5	75.0E-5	14.07E-4		56.51E-2	4.98E-6	5.5E-4	14.0E-4	2.5E-3		5.6E-2	0.88E-5
VI	10.4E-5	62.0E-5	0.62E-4		2.49E-2	0.13E-6	10.4E-4	10.0E-4	-0.2E-3		-0.4E-2	-0.04E-5
VII	62.9E-5	92.0E-5	9.22E-4		37.03E-2	0.93E-6	5.8E-4	15.0E-4	2.9E-3		6.5E-2	0.29E-5
Total			46.0 E-4		184.9E-2				0		0	

Table 15/2-12

Leaching period	U					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield, Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching				
Experiment E-5						
I	4.0 E-3	1.7 E-3	-8.1E-3	6.782	-11.94E-2	-67.50E-4
II	2.9 E-3	2.7 E-3	-0.7E-3		-1.03E-2	-4.12E-4
III	3.3 E-3	2.8 E-3	-1.5E-3		-2.21E-2	-1.88E-4
IV	3.1 E-3	2.0 E-3	-3.3E-3		-4.86E-2	-0.71E-4
V	2.0 E-3	2.5 E-3	1.4E-3		2.06E-2	0.81E-5
VI	4.5 E-3	2.0 E-3	-8.0E-3		-11.80E-2	-2.61E-5
VII	9.8 E-3	11.0 E-3	1.4E-3		2.06E-2	0.18E-5
Total			-18.8E-3		-27.7E-2	
Experiment E-7						
I	4.0 E-3	11.4E-3	0.021	97.836	0.02	1.70E-2
II	2.9 E-3	7.6E-3	0.013		0.01	0.46E-2
III	3.3 E-3	45.7E-3	0.124		0.13	0.92E-2
IV	3.1 E-3	106.4E-3	0.300		0.31	0.38E-2
V	2.0 E-3	3931.1E-3	11.787		12.15	4.17E-2
VI	4.5 E-3	694.0E-3	2.068		2.13	0.44E-2
VII	9.8 E-3	752.4E-3	2.369		2.45	0.24E-2
Total			16.682		17.20	

Demineralized and sea water experiments under static conditions
SUMMARY TABLE

Leaching period	Time, days Δd	Dry weight of initial sample, g	Amount of water flowing through ΔV, l	Total amount of water sample, l	Total dry residue after evaporating the sample					
					Content in water sample, g/l		Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI, $g/m^2 \cdot l \cdot d$
					Before leaching	After leaching				
Experiment P-1										
I	3.36	463.0	2.940	2.940	0	2.306	6.778	463.0	1.46	7.616
II	2.67		2.865	2.865	0	1.216	3.482		0.75	5.054
III	5.21		2.950	2.950	0	1.340	3.953		0.85	2.855
IV	15.71		3.000	3.000	0	1.710	5.132		1.11	1.209
V	29.96		3.000	3.000	0	1.842	5.526		1.19	0.682
VI	40.00		2.800	2.800	0	1.829	5.121		1.11	0.508
VII	51.33		3.105	3.105	0	1.938	6.017		1.30	0.419
Total	148.24		20.660				36.009		7.77	
Experiment P-2										
I	3.45	470.84	3.000	3.000	4.103	6.754	5.929	470.84	1.26	6.445
II	2.63		3.000	3.000	4.956	6.090	2.304		0.49	3.291
III	5.25		2.900	2.900	4.715	6.445	4.372		0.93	3.145
IV	15.67		2.900	2.900	4.836	6.884	5.803		1.23	1.395
V	29.96		3.000	3.000	4.700	7.005	5.687		1.21	0.715
VI	40.00		3.000	3.000	5.394	7.758	5.538		1.18	0.522
VII	51.33		3.000	3.000	5.381	7.451	5.090		1.08	0.374
Total	148.29		20.8				34.723		7.38	

Leaching period	Na						K					
	Content in water sample, g/l		Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment P-1												
I	0	168.4	495.1	3.023	16.38	556.3	0	12.5	36.75	10.337	0.36	41.30
II	0	51.0	146.1		4.83	108.7	0	5.0	14.32		0.14	20.79
III	0	18.9	55.8		1.85	40.27	0	3.0	8.85		0.09	6.39
IV	0	7.2	21.6		0.71	5.09	0	3.0	9.00		0.09	2.12
V	0	4.0	12.0		0.40	1.48	0	4.1	12.30		0.12	1.52
VI	0	3.2	9.0		0.30	0.89	0	3.8	10.64		0.10	1.05
VII	0	9.5	29.5		0.98	2.05	0	9.5	29.50		0.29	2.05
Total			769.1		25.45				121.36		1.19	
Experiment P-2												
I	1.250	1.466	208.2	3.039	6.85	226.3	38.8	44.3	3.2	10.512	0.03	3.48
II	1.250	1.500	480.0		15.79	685.7	41.4	41.0	-8.6		-0.08	-12.29
III	1.277	1.387	179.7		5.91	129.3	43.7	38.8	-18.1		-0.17	-13.02
IV	1.400	1.388	-62.0		-2.04	-14.9	38.8	37.3	-5.1		-0.05	-1.23
V	1.333	1.297	-336.2		-11.06	-42.3	42.7	41.3	-11.4		-0.11	-1.43
VI	1.543	1.550	-288.4		-9.49	-27.2	48.0	61.8	29.0		0.28	2.73
VII	1.500	1.465	-323.6		-10.65	-23.8	51.4	72.3	53.1		0.51	3.90
Total			-142.3		-4.69				42.1		0.41	

Leaching period	NH_4^+				Ca					
	Content in water sample, mg/l		Leached out ΔP, mg	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching			Before leaching	After leaching				
Experiment P-1										
I	0	196.00	576.24	647.50	0	228.5	0.672	43.466	1.55	754.87
II	0	96.89	277.59	402.87	0	182.8	0.524		1.20	760.08
III	0	42.39	125.05	90.33	0	267.5	0.789		1.82	570.00
IV	0	32.66	97.98	23.08	0	369.9	1.110		2.55	261.38
V	0	22.73	68.19	8.42	0	426.3	1.279		2.94	157.96
VI	0	8.35	23.38	2.32	0	465.5	1.303		3.00	129.19
VII	0	4.70	14.59	1.02	0	431.3	1.339		3.08	93.28
Total			1183.0				7.016		16.14	
Experiment P-2										
I	0.16	178.14	480.50	522.2	72.9	301.4	0.595	44.202	1.35	646.8
II	0.07	75.00	211.29	301.8	77.8	297.4	0.605		1.37	864.7
III	0	68.34	191.35	137.7	72.9	404.4	0.921		2.08	662.5
IV	0	34.79	100.20	24.1	62.1	521.0	1.320		2.99	317.4
V	0.07	0.79	2.02	0.25	65.7	695.8	1.769		4.00	222.5
VI	0.59	0.60	-0.09	-0.01	82.4	690.8	1.687		3.82	159.0
VII	0	1.01	2.88	0.21	95.2	735.1	1.836		4.15	134.9
Total			988.15				8.733		22.56	

Leaching period	Mg						Fe_{total}					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment P-1												
I	0	73.6	216.38	3.797	5.70	243.14	0	0.02	0.059	18.376	0.32 E-3	0.066
II	0	30.6	87.67		2.31	127.24	0	0.05	0.143		0.78 E-3	0.208
III	0	30.6	90.27		2.38	65.20	0	0.05	0.148		0.80 E-3	0.106
IV	0	30.6	91.80		2.42	21.62	0	0.07	0.210		1.14 E-3	0.050
V	0	44.6	133.80		3.52	16.53	0	2.94	8.820		48.0 E-3	1.089
VI	0	30.6	85.68		2.26	8.49	0	0.47	1.316		7.16 E-3	0.130
VII	0	62.3	193.44		5.09	13.47	0	1.18	3.664		19.94 E-3	0.255
Total			831.84		23.68				14.360		78.14 E-3	
Experiment P-2												
I	162.1	206.3	70.7	3.927	1.80	76.85	0.05	0.08	0.066	18.688	0.35 E-3	0.072
II	165.0	172.1	-9.7		-0.25	-13.86	0.05	0.13	0.217		1.16 E-3	0.310
III	152.6	186.3	79.1		2.01	56.91	0	0.23	0.644		3.45 E-3	0.463
IV	158.0	177.4	52.7		1.34	12.67	0.05	0.10	0.143		0.76 E-3	0.034
V	154.5	172.3	23.2		0.59	2.92	0.12	0.53	1.137		6.08 E-3	0.143
VI	172.3	193.1	43.1		1.10	4.06	0.06	0.73	1.864		9.97 E-3	0.176
VII	191.4	190.2	-32.1		-0.82	-2.36	0.05	0.16	0.306		1.64 E-3	0.022
Total			227.0		5.77				4.377		23.41 E-3	

Leaching period	Cl^-				S					
	Content in water sample, g/l		Leached out ΔP, g	ΔI, $mg/m^2 \cdot l \cdot d$	Content in water sample, mg/l		Leached out ΔP, g	Content in initial sample, g	Yield Δ%	ΔI, $mg/m^2 \cdot l \cdot d$
	Before leaching	After leaching			Before leaching	After leaching				
Experiment P-1										
I	0	268.7 E-3	0.790	887.68	0	454.4	1.336	38.105	3.51	1501.2
II	0	63.5 E-3	0.182	264.03	0	280.2	0.803		2.11	1165.1
III	0	22.3 E-3	0.066	47.52	0	293.6	0.866		2.27	625.6
IV	0	11.3 E-3	0.034	8.042	0	356.5	1.069		2.81	251.9
V	0	7.4 E-3	0.022	2.742	0	409.6	1.229		3.22	151.8
VI	0	7.4 E-3	0.021	2.054	0	381.4	1.068		2.80	105.8
VII	0	14.9 E-3	0.046	3.222	0	409.8	1.272		3.34	88.6
Total			1.161				7.643		20.06	
Experiment P-2										
I	2.240	2.482	-0.017	-18.7	108.9	523.0	1.085	39.739	2.73	1179.8
II	2.240	2.576	0.545	778.0	116.8	396.3	0.767		1.93	1096.0
III	2.315	2.389	-0.023	-88.4	119.6	502.2	1.059		2.67	762.2
IV	2.408	2.352	-0.209	-50.3	111.1	559.2	1.288		3.24	309.7
V	2.315	2.091	-1.038	-130.6	110.6	527.4	1.158		2.91	145.7
VI	2.744	2.706	-0.654	-61.6	88.5	451.4	1.211		3.05	114.2
VII	2.706	2.613	-0.672	-49.4	133.2	429.5	0.824		2.07	60.6
Total			-2.068				7.394		18.60	

Table 16/6

Leaching period	NO_3^-				HCO_3^-			
	Content in water sample, mg/l		Leached out ΔP, mg	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, g	ΔI, mg/m²·l·d
	Before leaching	After leaching			Before leaching	After leaching		
Experiment P-1								
I	0	8.4	24.70	27.75	0	48.8	0.143	473.97
II	0	11.4	32.66	47.40	0	36.6	0.105	436.01
III	0	9.6	28.32	20.46	0	24.4	0.072	153.38
IV	0	5.5	16.50	3.886	0	30.5	0.092	64.66
V	0	2.8	8.40	1.037	0	85.4	0.256	94.93
VI	0	0.3	0.84	0.083	0	73.2	0.205	56.88
VII	0	17.2	53.41	3.720	0	85.4	0.265	57.35
Total			164.83				1.138	
Experiment P-2								
I	21.0	31.4	21.8	23.70	97.6	97.6	-0.029	-31.83
II	11.2	28.1	45.6	65.14	103.7	97.6	-0.036	-51.24
III	74.1	42.0	-97.3	-70.00	97.6	85.4	-0.044	-31.60
IV	45.0	3.3	-121.0	-29.09	97.6	115.9	0.051	12.20
V	42.6	31.4	-39.1	-4.918	91.5	890.9	2.242	282.05
VI	79.5	22.8	-174.7	-16.47	103.7	897.0	2.200	207.40
VII	45.7	0	-137.1	-10.07	109.0	1080.0	2.751	202.13
Total			-501.8				7.135	

Leaching period	not bound CO_2				SiO_2					
	Content in water sample, mg/l		Leached out ΔP, mg	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching			Before leaching	After leaching				
Experiment P-1										
I	0	0	0	0	0	14.8	43.51	175.477	2.48E-2	48.89
II	0	44.0	126.06	524.16	0	7.0	20.06		1.14E-2	29.11
III	0	26.4	77.88	165.95	0	7.6	22.42		1.28E-2	16.19
IV	0	33.0	99.00	69.95	0	13.9	41.70		2.38E-2	9.822
V	0	48.4	145.20	53.80	0	27.3	81.90		4.67E-2	10.116
VI	0	17.6	49.28	13.68	0	18.0	50.40		2.87E-2	4.996
VII	0	44.0	136.62	29.55	0	18.1	56.20		3.20E-2	3.914
Total			634.04				316.19		18.02E-2	
Experiment P-2										
I	0	0	0	0	5.2	3.6	-5.9	172.516	-0.34E-2	-6.41
II	22.2	0	-66.6	-95.14	0	10.7	30.2		1.75E-2	43.14
III	0	44.0	123.20	88.63	0	7.8	21.8		1.26E-2	15.68
IV	6.6	79.2	208.96	50.23	2.1	16.7	42.0		2.43E-2	10.10
V	11.0	0	-33.00	-4.151	1.4	30.9	83.1		4.82E-2	10.45
VI	17.6	0	-52.80	-4.976	1.6	23.4	60.7		3.52E-2	5.72
VII	19.8	0	-59.40	-4.364	10.9	18.6	20.3		1.18E-2	1.49
Total			120.36				252.2		14.62E-2	

Leaching period	Ti						V					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, g	Yield Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment P-1												
I	0	8.0	23.52	1.139	2.06	26.429	0	1.7 E-2	0.050	185.2	2.70E-2	5.62E-2
II	0	1.5	4.30		0.38	6.237	0	1.0 E-2	0.029		1.56E-2	4.16E-2
III	0	2.1	6.20		0.54	4.475	0	0.5 E-2	0.015		0.81E-2	1.06E-2
IV	0	3.0	9.00		0.79	2.120	0	1.6 E-2	0.048		2.59E-2	1.13E-2
V	0	5.0	15.00		1.32	1.853	0	1.5 E-2	0.045		2.43E-2	5.56E-2
VI	0	1.2	3.36		0.29	0.333	0	2.0 E-2	0.056		3.02E-2	5.55E-2
VII	0	5.0	15.52		1.36	1.081	0	2.0 E-2	0.062		3.35E-2	4.32E-2
Total			76.90		6.74				0.305		16.46E-2	
Experiment P-2												
I	18.0	10.0	-27.0	1.186	-2.28	-29.35	1.5E-2	8.0 E-2	17.1E-2	141.25	12.1E-2	0.186
II	10.0	11.0	1.02		0.09	1.46	5.2E-2	8.0 E-2	7.0E-2		5.0E-2	0.100
III	11.0	8.0	-9.50		-0.80	-6.84	5.7E-2	5.3 E-2	-1.7E-2		-1.2E-2	-0.012
IV	10.0	19.0	25.72		2.17	6.18	5.92E-2	7.0 E-2	3.0E-2		2.1E-2	0.007
V	12.6	4.0	-26.50		-2.23	-3.33	5.0E-2	2.0 E-2	-9.3E-2		-6.6E-2	-0.012
VI	9.2	16.0	17.20		1.45	1.62	6.0E-2	5.4 E-2	-2.9E-2		-2.1E-2	-0.003
VII	18.0	14.3	-13.24		-1.12	-0.97	67.7E-2	9.1 E-2	-177.2E-2		-125.4E-2	-0.143
Total			-32.30		-2.72				-164E-2		-116.1E-2	

Leaching period	Sr						Nb					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment P-1												
I	0	1.58	4.645	92.6	5.01	5.220	0	0.30	0.882	463.0	0.19	0.991
II	0	0.66	1.891		2.04	2.744	0	0.22	0.630		0.14	0.915
III	0	0.08	0.236		0.26	0.170	0	0.60	1.770		0.38	1.278
IV	0	2.16	6.480		7.00	1.526	0	0.08	0.240		0.05	0.056
V	0	1.06	3.180		3.43	0.393	0	0.40	1.200		0.26	0.148
VI	0	0.58	1.624		1.75	0.161	0	0.09	0.252		0.05	0.025
VII	0	0.36	1.118		1.21	0.078	0	0.40	1.242		0.27	0.086
Total			19.174		20.70				6.216		1.34	
Experiment P-2												
I	0.70	3.08	6.22	310.75	2.00	6.76	0.30	0.70	0.990	470.8	0.21	1.076
II	0.98	0.73	-0.88		-0.28	-1.26	0.70	0.67	-0.206		-0.04	-0.294
III	0.75	1.01	0.65		0.21	0.47	0.61	1.00	1.031		0.22	0.742
IV	0.53	5.45	14.16		4.56	3.40	0.70	0.36	-0.993		-0.21	-0.239
V	0.84	0.10	-2.24		-0.72	-0.28	0.20	0.30	0.248		0.05	0.031
VI	0.21	0.57	0.97		0.29	0.09	0.66	0.54	-0.468		-0.10	-0.044
VII	4.99	0.40	-13.83		-4.43	-1.01	0.34	1.30	2.685		0.57	0.197
Total			5.05		1.63				3.287		0.70	

Leaching period	La						Ce					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment P-1												
I	0	0.8 E-3	2.35 E-3	14.82	1.58E-2	2.64 E-3	0	1.6 E-2	0.047	92.6	5.08E-2	5.29E-2
II	0	1.1 E-3	3.15 E-3		2.12E-2	4.57 E-3	0	0.5 E-2	0.014		1.51E-2	2.08E-2
III	0	3.2 E-3	9.44 E-3		6.37E-2	6.82 E-3	0	0.85E-2	0.025		2.70E-2	1.81E-2
IV	0	0.2 E-3	0.60 E-3		0.40E-2	0.141E-3	0	0.80E-2	0.024		2.59E-2	0.56E-2
V	0	0.2 E-3	0.60 E-3		0.40E-2	0.074E-3	0	19.0 E-2	0.570		61.55E-2	7.04E-2
VI	0	2.2 E-3	6.16 E-3		4.16E-2	0.610E-3	0	0.1 E-2	0.003		0.32E-2	0.03E-2
VII	0	7.0 E-3	21.74E-3		14.67E-2	1.514E-3	0	6.2 E-2	0.192		20.73E-2	1.34E-2
Total			44.0E-3		29.7 E-2				0.875		94.48E-2	
Experiment P-2												
I	2.0 E-3	20.5 E-3	49.4 E-3	21.19	23.31E-2	53.70E-3	1.80E-2	3.00E-2	0.027	72.51	3.72E-2	2.93E-2
II	6.0 E-3	6.0 E-3	-1.1 E-3		-0.52E-2	-1.57E-3	3.13E-2	2.07E-2	-0.036		-4.96E-2	-5.14E-2
III	4.7 E-3	4.6 E-3	-0.7 E-3		-0.33E-2	-0.50E-3	3.00E-2	2.93E-2	-0.005		-0.69E-2	-0.36E-2
IV	2.5 E-3	0.5 E-3	-5.8 E-3		-2.74E-2	-1.39E-3	2.17E-2	7.20E-2	0.144		19.9 E-2	3.46E-2
V	0.07E-3	3.1 E-3	8.6 E-3		4.06E-2	1.08E-3	2.50E-2	2.20E-2	-0.013		-1.79E-2	-0.16E-2
VI	0.2 E-3	0.1 E-3	-0.3 E-3		-0.14E-2	-0.03E-3	3.00E-2	10.30E-2	0.198		27.3 E-2	1.79E-2
VII	15.0 E-3	17.0 E-3	3.4 E-3		1.60E-2	0.25E-3	0.50E-2	14.20E-2	0.390		53.8 E-2	2.87E-2
Total			53.5 E-3		25.2 E-2				0.705		97.28E-2	

Leaching period	Ta						Th					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI, mg/m²·l·d	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI, mg/m²·l·d
	Before leaching	After leaching					Before leaching	After leaching				
Experiment P-1												
I	0	1.0 E-5	0.29E-4	0.287	0.01	3.30E-5	0	7.7 E-4	22.6E-4	4.167	5.42E-2	25.44E-4
II	0	9.6 E-5	2.75E-4		0.10	39.92E-5	0	0.98E-4	2.8E-4		0.67E-2	4.08E-4
III	0	5.5 E-5	1.62E-4		0.06	11.72E-5	0	5.6 E-4	16.5E-4		3.96E-2	11.93E-4
IV	0	9.1 E-5	2.73E-4		0.10	6.43E-5	0	1.7 E-4	5.1E-4		1.22E-2	1.20E-4
V	0	26.0 E-5	7.80E-4		0.27	9.63E-5	0	4.0 E-4	12.0E-4		2.88E-2	1.48E-4
VI	0	44.4 E-5	12.43E-4		0.43	12.32E-5	0	2.0 E-4	5.6E-4		1.34E-2	0.555E-4
VII	0	23.0 E-5	7.14E-4		0.25	4.97E-5	0	4.0 E-4	12.4E-4		2.98E-2	0.865E-4
Total			34.76E-4		1.22				77.0E-4		18.5E-2	
Experiment P-2												
I	1.0 E-5	10.0 E-5	2.40E-4	0.282	8.5E-2	26.09E-5	16.0 E-4	37.9 E-4	54.3E-4	3.91	13.9E-2	59.02E-4
II	5.8 E-5	8.3 E-5	0.60E-4		2.1E-2	8.57E-5	16.8 E-4	13.4 E-4	-12.6E-4		-3.2E-2	-18.00E-4
III	6.1 E-5	6.7 E-5	0.11E-4		0.4E-2	0.79E-5	14.1 E-4	12.8 E-4	-5.1E-4		-1.3E-2	-3.67E-4
IV	9.2 E-5	46.1 E-5	10.61E-4		37.6E-2	25.50E-5	18.7 E-4	14.5 E-4	-10.6E-4		-2.7E-2	-2.55E-4
V	27.2 E-5	18.0 E-5	-2.93E-4		-10.4E-2	-3.69E-5	5.5 E-4	3.0 E-4	-8.0E-4		-2.0E-2	-1.01E-4
VI	58.0 E-5	51.0 E-5	-3.12E-4		-11.1E-2	-2.94E-5	10.4 E-4	1.2 E-4	-27.8E-4		-7.1E-2	-2.62E-4
VII	62.9 E-5	85.0 E-5	5.35E-4		19.0E-2	3.93E-5	5.8 E-4	15.0 E-4	25.4E-4		6.5E-2	1.87E-4
Total			13.02E-4		46.1E-2				15.6E-4		4.1E-2	

Table 16/12

Leaching period	U					
	Content in water sample, mg/l		Leached out ΔP, mg	Content in initial sample, mg	Yield Δ%	ΔI, $mg/m^2 \cdot l \cdot d$
	Before leaching	After leaching				
I	0	0.6E-3	0.18E-2	97.23	0.18E-2	1.98E-3
II	0	4.6E-3	1.32E-2		1.36E-2	19.1E-3
III	0	4.2E-3	1.24E-2		1.27E-2	8.95E-3
IV	0	7.7E-3	2.31E-2		2.38E-2	5.44E-3
V	0	87.3E-3	26.19E-2		26.9 E-2	32.4E-3
VI	0	39.6E-3	11.09E-2		11.4 E-2	11.0E-3
VII	0	116.7E-3	36.24E-2		37.3 E-2	25.2E-3
Total			78.57E-2		80.79E-2	
I	4.0 E-3	12.6E-3	2.20E-2	94.16	2.3E-2	2.39E-2
II	2.9 E-3	6.1E-3	0.85E-2		0.9E-2	1.21E-2
III	3.3 E-3	19.6E-3	4.51E-2		4.8E-2	3.24E-2
IV	3.1 E-3	117.9E-3	33.06E-2		35.1E-2	7.95E-2
V	2.0 E-3	6.4E-3	1.21E-2		1.3E-2	0.15E-2
VI	4.5 E-3	196.3E-3	53.61E-2		56.9E-2	5.09E-2
VII	9.8 E-3	317.1E-3	87.43E-2		92.8E-2	6.42E-2
Total			182.9E-2		194.1E-2	

Table 17

Weighed averages of leaching intensities in relation to time ($\Delta\bar{I}$) of components contained in the ore treatment wastes

Component	Weighed means of leaching intensities ($\Delta\bar{I}$), $mg/m^2 \cdot l \cdot d$											
	Leaching with demineralized water							Leaching with sea water				
	Extractor code and test conditions											
	E-8 DC-S	E-9 DC-P	E-4 DC-S	E-6 DC-S	P-1 SC	E-2 DC-S	E-10 DC-P	E-5 DC-P	E-1 DC-P	E-7 DC-P	P-2 SC	E-3 DC-P
	Duration of leaching experiment, days											
	97	149	148	148	148	148	149	149	147	147	148	147
$\Sigma_{min.}$	244	89.4	365	356	912.1	180	101.5	17.8	120	161.2	881.8	105.2
Na	12.55	4.96	11.68	12.48	17.40	2.26	1.66	-7.12	5.36	4.93	-3.7	1.04
K	58.54	28.47	1.35	1.36	3.06	0.60	0.29	29.51	-0.18	-4.5E-2	1.07	-0.111
NH_4^+	1.72	2.65	16.03	19.70	30.23	6.00	3.51	2.73	5.80	24.59	27.59	4.07
Ca	27.75	6.32	60.6	57.46	177.6	34.37	20.73	11.55	21.18	24.11	221.9	18.33
Mg	0.005	0.22	8.45	8.80	22.68	4.16	2.80	-17.11	1.40	3.80	5.76	2.78
Fe^{total}	0.013	0.001	0.019	0.013	0.36	1.6E-2	6.46E-3	2.05E-3	1.42E-2	4.42E-3	1.11E-1	5.01E-3
Cl^-	20.44	13.93	17.81	19.71	29.62	5.19	6.94	-13.83	0.43	2.00	-62.2	-2.18
S^{total}	16.80	1.58	75.60	73.15	193.60	38.50	21.35	-1.28	27.56	34.80	187.82	23.99
NO_3^-	1.86	0.65	1.07	1.62	4.13	0.296	0	-7.15E-2	0.66	-0.388	-12.77	0.297
SiO_2	4.85	1.35	5.65	3.50	7.99	2.16	0.73	1.74	0.57	0.48	6.71	0.58
Ti	0.68	0.23	0.61	0.97	1.93	0.37	0.23	-0.58	-0.33	-0.65	-1.14	-2.6E-2
V	2.72E-3	0.79E-3	4.0E-3	5.51E-3	7.03E-3	1.11E-3	0.67E-3	6.71E-3	2.19E-3	1.06E-3	4.2E-2	2.85E-2
Sr	0.29	6.6E-2	0.14	0.12	0.48	2.95E-2	6.84E-2	12.48E-2	13.23E-2	2.70E-2	12.7E-2	-2.58E-2
Nb	9.7E-2	3.93E-2	4.9E-2	5.15E-2	15.6E-2	2.94E-2	1.10E-2	4.54E-2	1.54E-2	2.86E-2	8.3E-2	4.34E-2
La	2.42E-4	1.09E-4	3.7E-4	2.62E-4	10.97E-4	3.04E-4	3.12E-4	-1.53E-4	1.64E-4	1.49E-4	13.5E-4	2.65E-4
Ce	1.38E-3	0.6E-3	2.9E-3	3.55E-3	2.18E-2	1.78E-3	1.81E-3	5.18E-3	1.24E-3	1.33E-3	1.77E-2	1.33E-3
Ta	0.87E-5	1.39E-5	1.04E-5	1.29E-5	8.88E-5	0.47E-5	1.3E-5	0.53E-5	0.8E-5	0.85E-5	3.30E-5	0.84E-5
Th	13.1E-5	2.84E-5	8.16E-5	6.26E-5	19.4E-5	3.53E-5	3.88E-5	-2.9E-5	-4.57E-5	-1.50E-5	3.91E-5	0.25E-5
U	1.92E-4	0.47E-4	10.2E-4	4.74E-4	1.94E-2	6.90E-4	2.44E-4	-1.5E-5	4.68E-3	1.17E-2	4.66E-2	7.38E-4

Intensity of leaching mineralization ($\Delta I_{min.}$) from the wastes of Sillamäe Metallurgy Plant with demineralized or sea water depending on time (d, days)

Sample	Extractor code	Test conditions	Regression equation $\Delta I = A \cdot d^{-n}$, $mg/m^2 \cdot l \cdot d$	Correlation coefficient $r_{\Delta I/d}$
Wastes from loparite ore treatment (depth interval 6.64-7.36 m)	E-8	DW, DC-S	$\Delta I_{min.} = 7466.5\ d^{-1.30}$	-0.997
	E-9	DW, DC-P	$\Delta I_{min.} = 13230.1\ d^{-2.077}$	-0.987
	E-5	SW, DC-P	$\Delta I_{min.} = 1715.7\ d^{-1.62}$	-0.994
Wastes from uranium ore treatment (depth interval 14.52-16.20 m)	E-4	DW, DC-S	$\Delta I_{min.} = 24277.0\ d^{-1.47}$	-0.949
	E-6	DW, DC-S	$\Delta I_{min.} = 27307.0\ d^{-1.51}$	-0.970
	P-1	DW, SC	$\Delta I_{min.} = 12583.6\ d^{-0.736}$	-0.990
	E-1	SW, DC-P	$\Delta I_{min.} = 6750.0\ d^{-1.46}$	-0.996
	E-7	SW, DC-P	$\Delta I_{min.} = 7940.2\ d^{-1.456}$	-0.996
	P-2	SW, SC	$\Delta I_{min.} = 10384.2\ d^{-0.687}$	-0.992
The same (depth interval 19.44-20.04 m)	E-2	DW, DC-S	$\Delta I_{min.} = 8445.2\ d^{-1.27}$	-0.956
	E-10	DW, DC-P	$\Delta I_{min.} = 8984.9\ d^{-1.622}$	-0.965
	E-3	SW, DC-P	$\Delta I_{min.} = 5778.0\ d^{-1.38}$	-0.990

Intensity of Th and U leaching (ΔI_{Th}, ΔI_U) from the wastes of Sillamäe metallurgical plant with demineralized or sea water depending on time (d, days)

Sample	Extractor code	Test conditions	Th		U	
			Intensity of Th leaching ΔI_{Th} depending on time (d, days), $mg/m^2 \cdot l \cdot d$	Correl. coeff. $r_{\Delta I/\Delta d}$	Intensity of U leaching ΔI_U depending on time (d, days), $mg/m^2 \cdot l \cdot d$	Correl. coeff. $r_{\Delta I/\Delta d}$
Wastes from loparite ore treatment (depth interval 6.64-7.36 m)	E-8	DW,DC-S	$\Delta I_{Th} = 5.90 \cdot 10^{-3} \cdot d^{-1.51}$	-0.960	$\Delta I_U = 9.32 \cdot 10^{-3} \cdot d^{-1.59}$	-0.904
	E-9	DW,DC-P	$\Delta I_{Th} = 3.22 \cdot 10^{-3} \cdot d^{-1.90}$	-0.947	$\Delta I_U = 2.25 \cdot 10^{-3} \cdot d^{-1.45}$	-0.987
	E-5	SW,DC-P	*	*	*	*
Wastes from uranium ore treatment (depth interval 14.52-16.20 m)	E-4	DW,DC-S	$\Delta I_{Th} = 7.88 \cdot 10^{-3} \cdot d^{-1.70}$	-0.929	$\Delta I_U = 4.10 \cdot 10^{-2} \cdot d^{-1.26}$	-0.914
	E-6	DW,DC-S	$\Delta I_{Th} = 4.98 \cdot 10^{-3} \cdot d^{-1.60}$	-0.917	$\Delta I_U = 1.23 \cdot 10^{-2} \cdot d^{-1.02}$	-0.913
	P-1	DW,SC	$\Delta I_{Th} = 2.91 \cdot 10^{-3} \cdot d^{-0.83}$	-0.902	$\Delta I_U = 3.28 \cdot 10^{-2} \cdot d^{0.39}$	+0.527
	E-1	SW,DC-P	*	*	$\Delta I_U = 1.23 \cdot 10^{-2} \cdot d^{-0.25}$	-0.901
	E-7	SW,DC-P	*	*	$\Delta I_U = 1.30 \cdot 10^{-2} \cdot d^{-0.20}$ $\Delta I_U' = 1.38 \cdot 10^{-2} \cdot d^{-0.34}$ **	-0.322 -0.826
	P-2	SW,SC	*	*	$\Delta I_U = 9.87 \cdot 10^{-3} \cdot d^{0.313}$ $\Delta I_U' = 1.58 \cdot 10^{-2} \cdot d^{0.31}$ **	+0.345 +0.726
The same (depth interval 19.44-20.04 m)	E-2	DW,DC-S	$\Delta I_{Th} = 1.13 \cdot 10^{-3} \cdot d^{-1.17}$	-0.860	$\Delta I_U = 1.73 \cdot 10^{-2} \cdot d^{-1.06}$	-0.908
	E-10	DW,DC-P	$\Delta I_{Th} = 4.48 \cdot 10^{-3} \cdot d^{-1.98}$	-0.988	$\Delta I_U = 2.51 \cdot 10^{-3} \cdot d^{-0.66}$	-0.871
	E-3	SW,DC-P	*	*	$\Delta I_U = 2.45 \cdot 10^{-2} \cdot d^{-1.23}$	-0.850

* During the leaching experiments E-5, E-1, E-7, P-2, E-3 with sea water, the leaching of Th into water alternated periodically with the adsorption of it. The same is valid for E-5 during leaching of U.

** In case of experiments E-7 and P-2, the data of the tests E-7V and P-2V, as essentially differing, are not taken into account.

Table 20

Total yields of components leached from ore treatment wastes at the Sillamäe Metallurgy Plant

	Total yield, %											
	Wastes from loparite ore treatment			Wastes from uranium ore treatment								
	depth interval 6.64-7.36 m			depth interval 14.52-16.20 m						depth interval 19.44-20.04 m		
Extractor code	E-8	E-9	E-5	E-4	E-6	P-1	E-1	E-7	P-2	E-2	E-10	E-3
Test conditions	DW DC-S	DW DC-P	SW DC-P	DW DC-S	DW DC-S	DW SC	SW DC-P	SW DC-P	SW SC	DW DC-S	DW DC-P	SW DC-P
Duration, days	97	149	147	148	148	148	147	147	148	148	149	147
1	2	3	4	5	6	7	8	9	10	11	12	13
Component												
Σ mineral	7.80	4.78	1.35	7.06	7.49	7.77	7.92	10.25	7.38	8.71	9.11	9.87
Na	99.80	96.69	-171.0	17,57	19.64	25.45	-1.11	22.02	-4.69	10.30	7.34	24.93
K	75.30	63.51	62.78	1.26	1.19	1.19	-0.26	-0.19	0.41	1.89	0.65	1.50
Ca	7.93	3.03	7.30	15.08	15.00	16.14	21.33	17.64	22.56	23.61	29.40	27.12
Mg	0.17	0.94	-33.24	19.00	19.64	23.68	7.83	11.56	5.77	14.64	11.31	14.12
Fe_{total}	0.015	0.005	0.004	0.011	0.014	0.078	0.011	0.044	0.023	0.030	0.035	0.023
S_{total}	18.01	6.30	5.05	18.17	18.86	20.06	23.08	26.39	18.60	29.80	31.83	35.25
SiO_2	0.49	0.43	0.56	0.47	0.58	0.18	0.14	0.15	0.15	0.46	0.27	0.17
Ti	6.58	2.43	-8.35	4.49	6.23	6.74	-1.80	0.82	-2.72	5.10	3.59	1.60
V	0.15	0.18	-1.89	0.17	0.36	0.16	-0.70	-0.81	-1.16	0.16	0.14	-0.99
Sr	17.10	8.67	18.69	4.60	12.07	20.70	42.06	10.73	1.63	4.79	11.07	-1.54

1	2	3	4	5	6	7	8	9	10	11	12	13
Nb	2.16	1.17	2.89	0.85	0.45	1.34	1.83	1.73	0.70	0.68	0.89	3.16
La	0.015	0.007	0.032	0.593	0.156	0.297	0.700	0.022	0.252	0.336	1.280	0.546
Ce	0.74	0.36	2.09	0.72	0.49	0.94	4.40	3.61	0.97	0.26	1.65	1.44
Ta	0.51	2.89	1.46	0.74	0.76	1.22	1.88	1.85	0.46	0.72	1.44	2.28
Th	0.036	0.020	-0.001	0.107	0.108	0.185	-0.062	±0	0.041	0.157	0.210	0.086
U	0.18	0.25	-0.28	0.14	0.11	0.81	6.51	17.20	1.94	0.22	0.40	0.53
Average mineralization of leaching agent, g/l												
At the beginning of leaching period	0	0	4.870± 0.412	0	0	0	4.870± 0.412	4.870± 0.412	4.870± 0.412	0	0	4.870± 0.412
At the end of leaching period	1.214± 0.610*	0.550± 0.399	5.250± 0.410	1.945± 0.589*	1.891± 0.406*	1.740± 0.341	6.958± 0.701	7.140± 0.785	6.913± 0.526	2.029± 0.445*	1.557± 0.514	7.173± 0.756
Mean change, ±g	+1.214	+0.550	+0.380	+1.945	+1.891	+1.740	+2.088	+2.270	+2.043	+2.029	+1.557	+2.303

Notice. "-" sign indicates that the corresponding element was not leached from waste into the leaching agent but to the contrary, the element was adsorbed from the leaching agent (water) by wastes.

* For these experiments the mean mineralization of water is given because in the Soxleth extractors E-8, E-6, E-4 and E-2 the sample contacted frequently only with pure demineralized water. At the same time in extractors E-9 and E-10 this contact took place with demineralized water, the mineralization of which continuously increased.

Leaching balances of macrocomponents for the ore treatment wastes of Sillamäe Metallurgy Plant

Extractor code and test conditions	Characteristics	Quantity of sample used, g	Unit	Component						
				SiO_2	Ca	Mg	S_{total}	Na	K	Fe_{total}
1	2	3	4	5	6	7	8	9	10	11
Wastes from loparite ore treatment (depth interval 6.64-7.36 m)										
E-8	Initial sample									
DW	- before the leaching	282.0	%	18.70	21.71	3.50	4.22	0.193	1.14	3.12
DC-S	experiment		g	52.734	61.222	9.870	11.900	0.544	3.215	8.798
	- after the leaching	260.0	%	19.78	20.76	3.67	3.58	0.001	0.30	3.37
	experiment		g	51.428	53.976	9.542	9.308	0.0026	0.780	8.762
	- weight difference	22.0	g	1.306	7.246	0.328	2.592	0.541	2.435	0.036
	Leached out	20.986	g	0.257	4.795	0.017	2.144	0.541	2.418	1.32E-3
	Losses	1.014	g	1.049	2.451	0.311	0.448	0	0.017	0.035
			%	2.0	4.0	3.2	3.8	0	0.5	1.0
E-9	Initial sample									
DW	- before the leaching	182.3	%	20.66	21.97	3.08	4.29	0.193	1.66	3.37
DC-P	experiment		g	37.663	40.051	5.615	7.821	0.352	3.026	6.144
	- after the leaching	173.0	%	21.22	21.48	3.10	4.05	6.3E-3	0.62	3.50
	experiment		g	36.71	37.160	5.363	7.006	0.011	1.073	6.055
	- weight difference	9.3	g	0.953	2.891	0.252	0.815	0.341	1.953	0.089
	Leached out	8.9	g	0.168	1.214	0.053	0.492	0.340	1.922	0.29E-3
	Losses	0.4	g	0.785	1.677	0.199	0.323	0.001	0.031	0.089
			%	2.1	4.2	3.5	4.1	0.3	1.0	1.4
E-5	Initial sample									
SW	- before the leaching	282.6	%	18.96	21.71	3.45	4.29	0.186	1.18	3.12
DC-P	experiment		g	53.581	61.352	9.750	12.124	0.526	3.335	8.817
	- after the leaching	253.2	%	20.20	20.43	4.81	4.13	0.56	0.38	3.40
	experiment		g	51.15	51.729	12.179	10.457	1.418	0.962	8.609
	- weight difference	29.4	g	2.431	9.623	-2.429	1.667	-0.892	2.373	0.208
	Leached out	3.8	g	0.289	4.480	-3.224	0.613	-0.896	2.091	0.37E-3
	Filtered precipitation	1.657	g	0.340	0.360	0.057	0.071	0.003	0.020	0.074
	Losses	23.943	g	1.802	4.783	0.738	0.983	0.001	0.262	0.134
			%	3.4	7.8	7.6	8.1	0.2	7.8	1.5

1	2	3	4	5	6	7	8	9	10	11
Wastes from uranium ore treatment (depth interval 14.52-16.20 m)										
E-4	Initial sample									
DW	- before the leaching	533.1	%	37.90	9.14	0.91	8.14	0.68	2.27	3.84
DC-S	experiment		g	202.04	48.725	4.851	43.394	3.625	12.101	20.471
	- after the leaching	409.0	%	41.80	8.48	0.78	7.60	0.58	2.44	4.31
	experiment		g	170.96	34.683	3.190	31.084	2.372	9.980	17.628
	- weight difference	124.1	g	31.08	14.042	1.661	12.31	1.253	2.121	2.843
	Leached out	37.67	g	0.943	7.344	0.923	7.884	0.632	0.152	3.14E-3
	Filtered precipitation	52.30	g	19.413	4.671	0.463	4.114	0.348	1.175	2.006
	Losses	34.13	g	10.724	2.027	0.275	0.312	0.273	0.794	0.834
			%	5.3	4.2	5.7	7.2	7.5	6.6	4.1
E-6	Initial sample									
DW	- before the leaching	519.0	%	36.50	9.73	0.97	8.18	0.67	2.23	3.91
DC-S	experiment		g	189.44	50.499	5.034	42.454	3.477	11.574	20.293
	- after the leaching	433.0	%	39.34	8.59	0.81	6.61	0.54	2.29	4.26
	experiment		g	170.34	37.195	3.507	28.632	2.338	9.916	18.44
	- weight difference	86.0	g	19.10	13.304	1.527	13.822	1.139	1.658	1.853
	Leached out	38.96	g	1.109	7.569	0.896	8.006	0.679	0.138	2.28E-3
	Filtered precipitation	42.30	g	15.341	4.065	0.407	3.396	0.274	0.925	1.624
	Losses	4.74	g	2.650	1.670	0.224	2.420	0.186	0.595	0.227
			%	1.4	3.3	4.4	5.7	5.3	5.1	1.1
P-1	Initial sample									
DW	- before the leaching	463.0	%	37.90	9.39	0.82	8.28	0.65	2.46	3.97
SC	experiment		g	175.48	43.476	3.797	38.336	3.010	11.390	18.381
	- after the leaching	425.6	%	40.54	8.19	0.66	6.69	0.49	2.52	4.17
	experiment		g	172.54	34.852	2.809	28.473	2.085	10.725	17.748
	- weight difference	37.4	g	2.940	8.624	0.988	9.863	0.925	0.665	0.633
	Leached out	36.009	g	0.316	7.016	0.832	7.643	0.769	0.121	0.014
	Filtered precipitation	1.323	g	2.624	1.608	0.156	2.220	0.156	0.544	0.619
	Losses	0.068	%	1.5	3.7	4.1	5.8	5.2	4.8	3.4

1	2	3	4	5	6	7	8	9	10	11
E-1	Initial sample									
SW	- before the leaching	500.0	%	36.72	9.47	0.898	8.42	0.68	2.19	3.84
DC-P	experiment		g	183.600	47.350	4.490	42.100	3.400	10.950	19.200
	- after the leaching	449.4	%	39.90	7.73	0.864	6.58	0.74	2.43	4.23
	experiment		g	179.311	34.739	3.883	29.570	3.326	10.920	19.010
	- weight difference	50.6	g	4.289	12.611	0.607	12.53	0.074	0.03	0.190
	Leached out	39.633	g	0.258	10.105	0.351	9.714	-0.038	-0.031	0.002
	Losses	10.967	g	4.031	2.506	0.256	2.816	0.112	0.061	0.192
			%	2.2	5.3	5.7	6.7	3.3	2.8	5.0
E-7	Initial sample									
SW	- before the leaching	444.7	%	35.60	9.57	0.868	8.42	0.646	2.21	3.97
DC-P	experiment		g	158.313	42.558	3.860	37.444	2.873	9.828	17.655
	- after the leaching	390.2	%	39.46	7.70	0.818	6.42	0.551	2.45	4.27
	experiment		g	153.973	30.045	3.192	25.051	2.150	9.560	16.662
	- weight difference	54.5	g	4.34	12.513	0.668	12.393	0.723	0.268	0.993
	Leached out	45.561	g	0.231	10.136	0.444	9.879	0.632	-0.020	0.008
	Filtered precipitation	0.400	g	0.142	0.038	0.003	0.029	0.003	0.009	0.017
	Losses	8.539	g	3.967	2.339	0.221	2.485	0.088	0.279	0.968
			%	2.5	5.5	5.7	6.6	3.1	2.8	5.5
P-2	Initial sample									
SW	- before the leaching	470.8	%	36.64	9.39	0.84	8.44	0.646	2.23	3.97
SC	experiment		g	172.501	44.208	3.955	39.736	3.041	10.499	18.691
	- after the leaching	431.0	%	39.32	7.80	8.23	6.95	0.70	2.31	4.15
	experiment		g	169.469	33.618	3.547	29.954	3.017	9.956	17.886
	- weight difference	39.8	g	3.032	10.59	0.408	9.782	0.024	0.543	0.805
	Leached out	34.723	g	0.252	8.734	0.227	7.394	-0.142	0.042	0.004
	Filtered precipitation	0.305	g	2.780	1.856	0.181	2.388	0.166	0.501	0.801
	Losses	4.772	%	1.6	4.2	4.6	6.0	5.5	4.8	4.3

1	2	3	4	5	6	7	8	9	10	11
Wastes from uranium ore treatment (depth interval 19.44-20.04 m)										
E-2	Initial sample									
DW	- before the leaching	455.0	%	40.94	7.54	1.27	6.19	0.68	2.21	4.69
DC-S	experiment		g	186.277	34.307	5.778	28.164	3.094	10.056	21.339
	- after the leaching	383.7	%	46.38	6.38	1.22	4.90	0.69	2.40	5.17
	experiment		g	177.960	24.480	4.681	18.801	2.647	9.209	19.837
	- weight difference	71.3	g	8.317	9.827	1.097	9.363	0.447	0.847	1.502
	Leached out	39.66	g	0.847	8.094	0.844	8.392	0.320	0.190	7.43E-3
	Filtered precipitation	31.6	g	7.47	1.733	0.253	0.971	0.127	0.657	1.495
	Losses		%	4.0	5.0	4.4	3.4	4.1	6.5	7.0
E-10	Initial sample									
DW	- before the leaching	288.3	%	44.38	7.04	1.33	6.16	0.85	2.40	4.66
DC-P	experiment		g	127.948	20.296	3.834	17.759	2.450	6.919	13.435
	- after the leaching	262.0	%	46.64	5.10	1.25	4.40	0.82	2.50	5.12
	experiment		g	122.197	13.362	3.275	11.528	2.148	6.473	13.414
	- weight difference	26.3	g	5.751	6.934	0.559	6.231	0.302	0.446	0.021
	Leached out	26.3	g	0.337	5.968	0.435	5.652	0.180	0.045	4.78E-3
	Losses	0	g	5.414	0.966	0.124	0.579	0.122	0.401	0.016
			%	4.2	4.8	3.2	3.3	5.0	5.8	1.2
E-3	Initial sample									
SW	- before the leaching	434.0	%	41.38	7.54	1.27	6.46	0.705	2.23	4.69
DC-P	experiment		g	179.589	32.724	5.512	28.036	3.060	9.678	20.355
	- after the leaching	380.0	%	45.68	5.82	1.19	4.55	0.58	2.40	4.87
	experiment		g	173.584	22.104	4.522	17.29	2.204	9.120	18.506
	- weight difference	54.0	g	6.005	10.62	0.99	10.746	0.856	0.558	1.849
	Leached out	42.84	g	0.301	8.887	0.772	9.884	0.763	0.145	4.7E-3
	Filtered precipitation	11.16	g	5.704	1.733	0.218	0.862	0.093	0.413	1.844
	Losses		%	3.2	5.3	3.9	3.1	3.0	4.3	9.1

Leaching balances of microelements for the ore treatment wastes of Sillamäe Metallurgy Plant

Extractor code and test conditions	Characteristics	Quantity of sample used, g	Unit	Element								
				Ti	V	Sr	Nb	La	Ce	Ta	Th	U
1	2	3	4	5	6	7	8	9	10	11	12	13
Wastes from loparite ore treatment (depth interval 6.64-7.36 m)												
E-8 DW DC-S	Initial sample - before the leaching experiment	282.0	%	0.306	2.7E-2	6.0E-2	1.0E-1	4.2E-2	1.1E-2	7.5E-5	9.2E-3	2.3E-3
			mg	862.9	76.14	169.2	282.0	118.44	31.02	0.212	25.94	6.486
	- after the leaching experiment	260.0	%	0.288	2.67E-2	4.9E-2	1.0E-1	4.13E-2	1.1E-2	7.4E-5	9.1E-3	2.3E-3
			mg	748.8	69.42	127.4	260.0	107.38	28.60	0.192	23.66	5.980
	- weight difference	22.0	mg	114.1	6.72	41.8	22.0	11.06	2.42	0.02	2.28	0.506
	Leached out	20.986	mg	56.8	0.117	30.630	6.120	0.018	0.229	0.001	0.009	0.012
	Filtered precipitation	0.381	mg	0.023	0.012	0.377	0.057	7.0E-4	0.001	3.0E-5	3.0E-4	5.0E-4
	Losses	0.633	mg	57.3	6.591	10.79	15.823	11.041	2.19	0.019	2.271	0.494
			%	6.6	8.6	6.4	5.6	9.3	7.0	9.0	8.7	7.6
E-9 DW DC-P	Initial sample - before the leaching experiment	182.3	%	0.348	3.5E-2	11.0E-2	1.4E-1	6.13E-2	1.1E-2	2.4E-5	11.2E-3	2.4E-3
			mg	634.4	63.80	200.53	255.22	111.75	20.05	0.044	20.42	4.375
	- after the leaching experiment	173.0	%	0.348	3.4E-2	10.0E-2	1.35E-1	6.08E-2	1.08E-2	2.3E-5	11.0E-3	2.3E-3
			mg	602.04	58.82	173.00	233.55	105.18	18.68	0.040	19.03	3.979
	- weight difference	9.3	mg	32.36	4.98	27.53	21.67	6.57	1.37	0.004	1.40	0.396
	Leached out	8.9	mg	15.53	0.114	17.33	2.982	0.008	0.072	0.001	0.004	0.011
	Losses	0.4	mg	16.83	4.866	10.2	18.688	6.562	1.298	0.003	1.396	0.385
			%	2.6	7.6	5.1	7.3	5.9	6.5	6.8	6.8	8.8
E-5 SW DC-P	Initial sample - before the leaching experiment	282.6	%	0.318	2.4E-2	6.0E-2	1.0E-1	5.78E-2	1.6E-2	7.2E-5	9.32E-3	2.4E-3
			mg	898.66	67.82	169.56	282.6	163.34	45.22	0.203	26.338	6.782
	- after the leaching experiment	253.2	%	0.354	2.5E-2	4.9E-2	1.0E-1	5.9E-2	1.65E-2	7.3E-5	9.5E-3	2.5E-3
			mg	896.33	63.30	124.07	253.2	149.39	41.78	0.185	24.054	6.330
	- weight difference	29.4	mg	2.33	4.52	45.49	29.4	13.95	3.44	0.018	2.284	0.452
	Leached out	3.8	mg	-74.90	-1.281	31.701	8.189	0.052	0.949	0.003	-3.8E-4	-0.019
	Filtered precipitation	1.657	mg	0.121	0.037	1.695	0.586	0.081	0.005	8.69E-5	6.74E-4	0.003
	Losses	23.943	mg	77.109	5.764	12.094	20.625	13.817	2.486	0.015	2.284	0.468
			%	8.6	8.4	7.1	7.3	8.4	5.4	7.4	8.7	6.9

1	2	3	4	5	6	7	8	9	10	11	12	13
Wastes from uranium ore treatment (depth interval 14.52-16.20 m)												
E-4	Initial sample											
DW	- before the leaching	533.1	%	2.52E-1	3.8E-2	10.1E-2	1.0E-1	2.2E-3	1.3E-2	6.0E-5	1.3E-3	1.9E-2
DC-S	experiment		mg	1343.4	202.578	538.431	533.10	11.728	69.303	0.320	6.930	101.289
	- after the leaching	409.0	%	2.90E-1	4.5E-2	10.8E-2	1.17E-1	2.67E-3	1.57E-2	7.1E-5	1.55E-3	2.28E-2
	experiment		mg	1186.1	184.050	441.720	478.53	10.920	64.213	0.290	6.339	93.252
	- weight difference	124.1	mg	157.3	18.528	96.711	54.57	0.808	5.090	0.030	0.591	8.037
	Leached out	37.67	mg	60.36	0.336	24.730	4.54	0.070	0.496	2.4E-3	7.43E-3	0.137
	Filtered precipitation	52.30	mg	9.94	0.942	35.041	5.23	0.047	0.157	2.2E-3	11.5E-3	0.267
	Losses	34.13	mg	87.00	17.250	36.940	44.80	0.691	4.437	0.025	0.572	7.633
			%	6.5	8.5	6.9	8.4	5.9	6.4	7.8	8.2	7.5
E-6	Initial sample											
DW	- before the leaching	519.0	%	2.58E-1	3.8E-2	4.6E-2	2.1E-1	2.9E-3	1.25E-2	6.5E-5	1.1E-3	2.0E-2
DC-S	experiment		mg	1339.0	197.22	238.74	1089.9	15.051	64.875	0.337	5.709	103.80
	- after the leaching	433.0	%	2.60E-1	4.0E-2	3.6E-2	2.3E-1	3.3E-3	1.4E-2	7.2E-5	1.2E-3	2.2E-2
	experiment		mg	1125.8	173.20	155.88	995.9	14.289	60.620	0.312	5.196	95.26
	- weight difference	86.0	mg	213.2	24.02	82.86	94.0	0.762	4.255	0.025	0.513	8.54
	Leached out	38.96	mg	83.65	0.712	28.81	4.893	0.023	0.318	2.6E-3	6.2E-3	0.110
	Filtered precipitation	42.30	mg	29.61	14.932	41.88	2.96	0.161	0.520	1.8E-3	21.2E-3	1.239
	Losses	4.74	mg	99.96	8.376	12.17	86.15	0.578	3.417	0.021	0.486	7.191
			%	7.5	4.2	5.1	7.9	3.8	5.3	6.1	8.5	6.9
P-1	Initial sample											
DW	- before the leaching	463.0	%	2.46E-1	4.0E-2	2.0E-2	1.0E-1	3.2E-3	2.0E-2	6.2E-5	0.9E-3	2.1E-2
SC	experiment		mg	1139.0	185.2	92.60	463.0	14.816	92.60	0.287	4.167	97.23
	- after the leaching	425.6	%	2.36E-1	4.1E-2	1.6E-2	1.0E-1	3.18E-3	2.05E-2	6.3E-5	0.89E-3	2.15E-2
	experiment		mg	1004.4	174.5	68.10	425.6	13.534	87.25	0.268	3.788	91.50
	- weight difference	37.4	mg	134.6	10.7	24.50	37.4	1.282	5.35	0.019	0.379	5.73
	Leached out	36.009	mg	76.900	0.305	19.174	6.216	0.044	0.875	3.48E-3	77.0E-4	0.786
	Filtered precipitation	1.323	mg	0.251	0.024	0.886	0.132	1.2E-3	0.004	5.7E-5	2.91E-4	6.8E-3
	Losses	0.068	mg	57.449	10.371	4.440	31.052	1.237	4.471	0.016	0.371	4.937
			%	5.0	5.6	4.8	6.7	8.3	4.8	5.6	8.9	5.1

1	2	3	4	5	6	7	8	9	10	11	12	13
E-1	Initial sample											
SW	- before the leaching	500.0	%	0.258	3.8E-2	2.8E-2	1.0E-1	2.4E-3	1.5E-2	6.1E-5	1.0E-3	2.0E-2
DC-P	experiment		mg	1290	190.0	140.00	500.0	12.00	75.00	0.305	5.0	100.0
	- after the leaching	449.4	%	0.283	4.0E-2	1.7E-2	1.01E-1	2.5E-3	1.55E-2	6.2E-5	1.05E-3	1.92E-2
	experiment		mg	1272	179.76	76.40	453.89	11.235	69.657	0.279	4.719	86.285
	- weight difference	50.6	mg	18.0	10.24	63.6	46.11	0.765	5.343	0.026	0.281	13.715
	Leached out	39.633	mg	-23.1	-1.335	58.90	9.16	0.084	2.128	0.006	-0.003	6.506
	Losses	10.967	mg	41.1	11.575	4.7	36.95	0.681	3.215	0.020	0.284	7.209
			%	3.2	6.1	3.4	7.4	5.7	4.3	6.5	5.7	7.2
E-7	Initial sample											
SW	- before the leaching	444.7	%	0.246	4.0E-2	3.2E-2	9.0E-2	2.5E-3	1.5E-2	5.6E-5	1.0E-3	2.2E-2
DC-P	experiment		mg	1094.0	177.88	142.30	400.23	11.118	66.70	0.249	4.447	97.834
	- after the leaching	390.2	%	0.266	4.3E-2	3.0E-2	9.3E-2	2.7E-3	1.56E-2	5.8E-5	1.07E-3	1.9E-2
	experiment		mg	1037.9	167.79	117.06	362.89	10.535	60.87	0.226	4.175	74.138
	- weight difference	54.5	mg	56.1	10.09	25.24	37.34	0.583	5.83	0.023	0.272	23.696
	Leached out	45.561	mg	9.03	-1.44	15.278	7.001	0.245	2.41	4.6E-3	0	16.682
	Filtered precipitation	0.4	mg	4.007	2.406	0.266	0.159	0.004	0.010	5.0E-5	1.4E-3	1.288
	Losses	8.539	mg	43.063	9.124	9.696	30.18	0.334	3.41	0.018	0.271	5.726
			%	3.9	5.1	6.8	7.5	3.0	5.1	7.4	6.1	5.8
P-2	Initial sample											
SW	- before the leaching	470.8	%	0.252	3.0E-2	6.6E-2	0.100	4.5E-3	1.54E-2	6.0E-5	0.83E-3	2 E-2
SC	experiment		mg	1186.4	141.24	310.73	470.80	21.186	72.50	0.282	3.91	94.16
	- after the leaching	431.0	%	0.273	3.1E-2	6.8E-2	0.102	4.7E-3	1.6E-2	6.1E-5	0.85E-3	2.01E-2
	experiment		mg	1176.6	133.61	293.08	439.62	20.257	68.96	0.263	3.66	86.63
	- weight difference	39.8	mg	9.8	7.63	17.65	31.18	0.929	3.54	0.019	0.250	7.53
	Leached out	34.723	mg	-32.3	-1.64	5.05	3.287	53.5E-3	0.705	1.3E-3	1.56E-3	1.829
	Filtered precipitation	0.305	mg	3.074	1.85	0.204	0.122	0.003	0.008	4.0E-5	1.05E-3	0.989
	Losses	4.772	mg	39.026	7.42	12.396	27.771	0.872	2.827	0.018	0.247	4.712
			%	3.3	5.2	4.0	5.9	4.0	3.9	6.4	6.3	5.0

1	2	3	4	5	6	7	8	9	10	11	12	13
Wastes from uranium ore treatment (depth interval 19.44-20.04 m)												
E-2	Initial sample											
DW	- before the leaching	455.0	%	0.312	3.9E-2	3.0E-2	2.0E-1	5.7E-3	3.0E-2	5.7E-5	1.0E-3	2.1E-2
DC-S	experiment		mg	1419.6	177.45	136.50	910.00	25.935	136.50	0.259	4.550	95.55
	- after the leaching	383.74	%	0.325	4.3E-2	3.1E-2	2.2E-1	6.3E-3	3.3E-2	6.1E-5	1.1E-1	2.3E-2
	experiment		mg	1247.2	165.00	118.96	844.23	24.176	126.63	0.234	4.221	88.26
	- weight difference	71.26	mg	172.40	12.45	17.54	65.77	1.759	9.87	0.025	0.329	7.29
	Leached out	39.66	mg	72.630	0.289	6.539	6.168	0.087	0.361	1.86E-3	7.13E-3	0.210
	Filtered precipitation	31.60	mg	1.582	0.095	3.164	3.164	0.063	0.241	0.001	0.006	0.006
	Losses	0	mg	98.188	12.066	7.837	56.438	1.609	9.268	0.022	0.316	7.074
			%	6.9	6.8	5.7	6.2	6.2	6.8	8.5	6.9	7.4
E-10	Initial sample											
DW	- before the leaching	288.3	%	0.330	2.4E-2	2.10E-2	1.0E-1	3.9E-3	1.5E-2	6.9E-5	1.1E-3	2.3E-2
DC-P	experiment		mg	951.39	69.19	57.66	288.3	11.243	37.479	0.199	3.171	66.309
	- after the leaching	262.0	%	0.334	2.5E-2	1.6E-2	1.0E-1	4.0E-3	1.3E-2	6.8E-5	1.1E-3	2.4E-2
	experiment		mg	875.08	65.50	47.16	262.0	10.480	34.060	0.178	2.882	62.88
	- weight difference	26.3	mg	76.31	3.69	10.50	26.30	0.763	3.419	0.021	0.289	3.429
	Leached out	26.3	mg	25.897	0.094	6.391	2.579	0.144	0.709	2.86E-3	6.6E-3	0.268
	Losses	0	mg	50.413	3.598	4.109	23.721	0.619	2.71	0.018	0.282	3.161
			%	5.8	5.2	7.1	8.2	5.5	7.2	9.0	8.9	4.8
E-3	Initial sample											
SW	- before the leaching	434.0	%	0.330	2.9E-2	2.5E-2	0.8E-1	4.16E-3	2.5E-2	5.9E-5	1.0E-3	2.2E-2
DC-P	experiment		mg	1432.2	125.86	108.5	347.2	18.05	108.5	0.256	4.34	95.48
	- after the leaching	380.0	%	0.366	3.1E-2	2.7E-2	0.82E-1	4.4E-3	2.6E-2	6.0E-5	1.05E-3	2.3E-2
	experiment		mg	1390.8	117.8	102.6	311.6	16.72	98.8	0.228	3.99	87.40
	- weight difference	54.0	mg	41.4	8.06	5.90	35.6	1.33	9.70	0.028	0.35	8.08
	Leached out	42.84	mg	22.9	-1.23	-0.334	11.015	0.099	1.559	0.006	3.7E-3	0.502
	Filtered precipitation	1.50	mg	3.05	1.16	0.115	0.46	0.026	0.073	0	3.6E-3	0.146
	Losses	9.66	mg	15.45	8.13	6.119	24.125	1.205	8.068	0.022	0.343	7.432
			%	1.1	6.4	5.6	7.0	6.7	7.4	8.6	7.9	7.8

Migration coefficients of elements in water (K_x) in leaching experiments with demineralized water on the wastes of the Sillamäe metallurgical plant

Element	Migration coefficient, K_x								
	Wastes from loparite ore treatment		Wastes from uranium ore treatment					In underground waters of hypergenesis zone (after A.Perelman)	In surface water (after V.Dobrovolsky)
	depth interval 6.64-7.36 m		depth interval 14.52-16.20 m			depth interval 19.44-20.04 m			
	E-8 DC-S	E-9 DC-P	E-4 DC-S	E-6 DC-S	P-1 SC	E-2 DC-S	E-10 DC-P		
1	2	3	4	5	6	7	8	9	10
Na	12.95	19.79	2.47	2.60	3.29	1.19	0.80	4.2	-
K	9.65	13.01	0.18	0.16	0.14	0.22	0.071	0.43	-
Ca	1.00	0.62	2.13	2.00	2.08	2.71	3.22	3.3	-
Mg	$2.3 \cdot 10^{-2}$	0.20	2.69	2.37	3.73	1.68	1.24	2.3	-
Cl*	282	679	140	154	179	104	3749	644	-
S	2.31	1.29	2.57	2.51	2.56	3.42	3.49	**	-
Si	$6.2 \cdot 10^{-2}$	$9.1 \cdot 10^{-2}$	$6.6 \cdot 10^{-2}$	$7.8 \cdot 10^{-2}$	$2.3 \cdot 10^{-2}$	$5.2 \cdot 10^{-2}$	$2.9 \cdot 10^{-2}$	0.08	-
Ti	0.84	0.49	0.64	0.83	0.85	0.35	0.36	0.005	0.01
V	$2.0 \cdot 10^{-2}$	$3.7 \cdot 10^{-2}$	$2.3 \cdot 10^{-2}$	$4.8 \cdot 10^{-3}$	$2.1 \cdot 10^{-2}$	$1.9 \cdot 10^{-2}$	$1.5 \cdot 10^{-2}$	0.05	0.10
Sr	2.32	1.77	0.65	1.61	2.65	0.55	1.22	1.2	2.9
Nb	1.46	0.24	$3.4 \cdot 10^{-2}$	$6.0 \cdot 10^{-2}$	$9.1 \cdot 10^{-2}$	$7.8 \cdot 10^{-2}$	$9.8 \cdot 10^{-2}$	-	-

1	2	3	4	5	6	7	8	9	10
Fe	$2.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2.0 \cdot 10^{-3}$	0.010	$4.0 \cdot 10^{-3}$	$4.0 \cdot 10^{-3}$	0.02	-
La	$2.0 \cdot 10^{-3}$	$1.5 \cdot 10^{-3}$	$8.4 \cdot 10^{-2}$	$2.1 \cdot 10^{-2}$	$3.8 \cdot 10^{-2}$	$3.8 \cdot 10^{-2}$	$1.4 \cdot 10^{-1}$	-	-
Ce	$9.4 \cdot 10^{-2}$	$7.3 \cdot 10^{-2}$	0.10	$6.5 \cdot 10^{-2}$	0.12	$3.0 \cdot 10^{-2}$	0.18	-	-
Ta	$6.5 \cdot 10^{-2}$	0.59	$1.1 \cdot 10^{-1}$	$2.0 \cdot 10^{-5}$	$1.6 \cdot 10^{-1}$	$8.4 \cdot 10^{-2}$	$1.6 \cdot 10^{-1}$	-	-
Th	$4.6 \cdot 10^{-3}$	$4.1 \cdot 10^{-3}$	$1.5 \cdot 10^{-2}$	$1.4 \cdot 10^{-2}$	$2.3 \cdot 10^{-2}$	$1.8 \cdot 10^{-2}$	$2.3 \cdot 10^{-2}$	0.07	0.06
U	$1.9 \cdot 10^{-2}$	$5.2 \cdot 10^{-2}$	$1.9 \cdot 10^{-2}$	$1.6 \cdot 10^{-3}$	2.5	$2.5 \cdot 10^{-2}$	$4.4 \cdot 10^{-2}$	3.1	0.96
Mean mineralization, g/l	1.214± 0.610	0.550± 0.399	1.945± 0.589	1.891± 0.406	1.740± 0.341	2.029± 0.445	1.557± 0.514	0.43	-

Notice * K_{Cl} is calculated relative to the corresponding crustal abundance clarke, for all other components
– in respect of the composition of the corresponding samples.
** Very strong migration intensity (after A.Perelman).

Migration coefficients of elements in water (K_x) in leaching experiments with sea water on the wastes of the Sillamäe metallurgical plant

Element	Migration coefficient, K_x					
	Wastes from loparite ore treatment	Wastes from uranium ore treatment				K_x in ocean water (after A.Perelman)
	depth 6.64-7.36 m	depth interval 14.52-16.20 m			depth 19.44-20.04 m	
	E-5 DC-P	E-1 DC-P	E-7 DC-P	P-2 SC	E-3 DC-P	
1	2	3	4	5	6	7
Na	-126.57	-0.14	2.15	-0.64	2.52	12.0
K	46.61	-0.04	-0.02	0.05	0.15	0.44
Ca	0.44	2.69	2.25	2.68	2.75	0.41
Mg	-24.59	0.99	1.12	0.77	1.42	2.0
Cl*	-2869.0	-201.32	-63.82	-331.0	-150.22	3200
S	3.76	2.91	2.58	2.52	3.57	53
Si	0.401	0.018	0.014	0.020	0.017	2.9E-4
Ti	-0.06	-0.23	0.06	-0.37	0.16	6.4E-6
V	-1.404	0.088	0.079	0.157	0.099	9.6E-4
Sr	13.90	5.31	1.05	0.22	-1.50	6.8E-3
Nb	2.16	0.23	0.17	0.10	0.32	1.5E-7
Fe	3.0 E-3	1.0 E-3	5.0 E-5	3.0 E-3	2.0 E-3	6.2E-6
La	0.237	0.088	0.215	0.034	0.055	2.9E-6
Ce	1.56	0.36	0.35	0.13	0.15	5.3E-7
Ta	1.08	0.24	0.18	0.06	0.23	-
Th	-1.0 E-3	-8.0 E-3	0	5.0 E-3	9.0 E-3	6.6E-3
U	2.420	0.082	1.664	0.264	0.053	8 E-4
Mean mineralization g/l	7.140± 0.785	6.958± 0.701	5.249± 0.410	6.913± 0.526	7.173± 0.756	35.0

* K_{Cl} is calculated relative to the corresponding crustal abundance clarke.

** K_x characterizes the intensity of element migration in actively circulating water but the accumulation of elements in water dry residue in case of stagnant water. The accumulation and distribution of elements in the oceans is valued according to the scale proposed by A.Perelman as follows: very strong accumulation – K_x = 700÷1000000, strong – K_x = 20÷700, middle – K_x = 1÷20, weak dispersion – K_x = 0.05÷1.0, strong dispersion – K_x = 0.001÷0.05.

FIGURES

Fig.1. Territory map of Sillamäe Metallurgy Plant "Silmet" (I), alum shale mine (closed) (II) and the waste dump (III).

Fig.2. Waste dump of the Sillamäe Metallurgy Plant, its waste depository reservoirs A, B, C and locations of the boreholes PA-1 and PA-2 drilled for sampling.

Fig.3. Location chart of soil layers at the Sillamäe waste dump.

Fig.4. Diagram of γ-logging of the borehole PA-1.

Fig.5. Diagram of γ-logging of the borehole PA-2.

Fig.6. Cross-sections of boreholes PA-1 and PA-2.
I - average surface γ-activities of drillcore, μR/hg;
II - volume weight of dump material, g/cm^3.
1 - filling material, 2 - loparite ore processing waste, 3 - uranium ore processing waste, 4 - sand.

Fig.7. Diagrams of surface γ-activity (μR/h of drillcores in boreholes PA-1 and PA-2).

Fig.8. Soxhlet apparatus for modelling leaching processes of ore treatment waste with demineralized water. 1 - heater plate, 2 - sand bath, 3 - flask-evaporator (4 l), 4 - extractor with the sample, 5 - condenser.

Fig.9. Device for modelling leaching processes of ore treatment waste with sea water or demineralized water. 1 - peristaltic pump, 2 - extractor with the sample, 3 - water container.

Fig.10. Changing of leaching intensity (rate) $\frac{\Delta}{\Delta t}$I in time in experiments E-8 (with Soxhlet apparatus) and E-9 (with peristaltic pump) with demineralized water in dynamic conditions. 1 - $\Sigma_{min.}$, 2 - Na, 3 - K, 4 - NH_4^+, 5 - Ca, 6 - Mg, 7 - Fe_{total}, 8 - Cl^-, 9 - S_{total}, 10 - NO_3^-, 11 - SiO_2, 12 - Ti, 13 - Sr, 14 - V, 15 - Nb, 16 - La, 17 - Ce, 18 - Tl, 19 - Th, 20 - U.

Fig.11. Changing of leaching intensity ΔI in time in experiment E-5 (with peristaltic pump) with sea water under dynamic conditions. 1 - $\Sigma_{min.}$, 2 - Na,Mg, 3 - K, 4 - NH_4^+, 5 - Ca, 6 - SiO_2, 7 - Fe_{total}, 8 - Cl^-, 9 - S_{total}, 10 - NO_3^-, 11 - Ti, 12 - V, 13 - Sr, 14 - Nb, 15 - La, 16 - Ce, 17 - Ta, 18 - Th, 19 - U, 20 - CO_2.

Fig.12. Changing of leaching intensity ΔI in time in experiments E-4 and E-6 (with Soxhlet apparatus) with demineralized water in dynamic conditions and in experiment P-1 (in standing flask). 1 - $\Sigma_{min.}$, 2 - Na, 3 - K, 4 - NH_4^+, 5 - Ca, 6 - Mg, 7,8 - Fe_{total}, 9 - Cl^-, 10 - S_{total}, 11 - NO_3^-, 12 - SiO_2, 13 - Ti, 14 - V, 15 - Sr, 16 - Nb, 17 - La, 18 - Ce, 19 - Ta, 20 - Th, 21 - U, 22 - CO_2, 23 - HCO_3^-.

Fig.13. Changing of leaching intensity ΔI in time in experiments E-1 and E-7 (with peristaltic pump) with sea water under dynamic conditions and in experiment P-2 under static conditions (in standing flask). 1 - $\Sigma_{min.}$, 2 - Na, 3 - K, 4 - NH_4^+, 5 - Ca, 6 - Mg, 7 - Fe_{total}, 8 - Cl^-, 9 - S_{total}, 10 - NO_3^-, 11 - HCO_3, 12 - CO_2, 13 - SiO_2, 14 - U, 15 - Ti, 16 - V, 17 - Sr, 18 - Nb, 19 - La, 20 - Ce, 21 - Ta, 22 - Th.

Fig.14. Changing of leaching intensity ΔI in time under dynamic conditions with demineralized water E-2 (with Soxhlet apparatus), E-10 (with peristaltic pump) and E-3 (with sea water and peristaltic pump). 1 - $\Sigma_{min.}$, 2 - Na (exp.-s E-2,E-10), 3 - Na (exp. E-3), 4 - K (exp. E-3), 5 - K (exp.-s E-2,E-10), 6 - NH_4^+, 7 - Ca, 8 - Mg, 9 - Fe_{total}, 10 - Cl^- (exp.-s E-2,E-10), 11 - Cl- (exp. E-3), 12 - Ti (exp. E-3), 13 - S, 14 - NO_3^- (exp.-s E-2,E-3), 15 - SiO_2, 16 - Ti (exp.-s E-2,E-10), 17 - V (exp.-s E-2,E-10), 18 - Sr (exp.-s E-2,E-10), 19 - V (exp. E-3), 20 - Sr (exp. E-3), 21 - Nb (exp.-s E-2,E-10), 22 - La (exp.-s E-2,E-10), 23 - Nb (exp. E-3), 24 - La (exp. E-3), 25 - Ce (exp.-s E-2,E-10), 26 - Ta (exp.-s E-2,E-10), 27 - Ce (exp. E-3), 28 - Ta (exp. E-3), 29 - Th (exp. E-3), 30 - CO_2, 31 - Th (exp.-s E-2,E-10), 32 - U, 33 - HCO_3^- (exp. E-3).

Fig.15. Regression equation graphs on dependence of dump material leaching intensity ($\Delta I_{min.}$) and cumulative time (d). 1 - exp.-s E-5,E-8,E-9, 2 - exp.-s E-4,E-6,P-1, 3 - exp.-s E-1,E-7,P-2, 4 - exp.-s E-2,E-3,E-10.

Fig.16. Regression equation graphs on dependence of Th-leaching intensity (ΔI_{Th}) and cumulative time (d). 1 - exp.-s E-8,E-9, 2 - exp.-s E-4,E-6,P-1, 3 - exp.-s E-2,E-10.

Fig.17. Regression equation graphs on dependence of U-leaching intensity (ΔI_U) and cumulative time (d). 1 - exp.-s E-8,E-9, 2 - exp.-s E-4,E-6,P-1, 3 - exp.-s E-7,P-2, 4 - exp.-s E-2,E-3,E-10.

Fig.18. Location of natural waters on the Eh-pH diagram (by R.M.Garrels and Ch.L.Christ).

Fig.19. pH of leaching water in different stages (I-VII).

Fig.19-1 - pH of leachants in all experiments at the beginning of stage before leaching.

Fig.19-2 - pH of leachants in experiments E-5, E-8 and E-9 at the end of stage after leaching.

Fig.19-3 - pH of leachants in experiments E-2, E-3 and E-10 at the end of stage after leaching.

Fig.19-4 - pH of leachants in experiments E-4, E-6 and P-1 at the end of stage after leaching.

Fig.19-5 - pH of leachants in experiments E-1, E-7 and P-2 at the end of stage after leaching.

Fig.20. Regression equation graphs on dependence of Eh and pH of demineralized water before leaching and at the end of leaching stages.

Fig.21. Regression equation graphs on dependence of sea water Eh and pH before leaching and at the end of leaching stages.

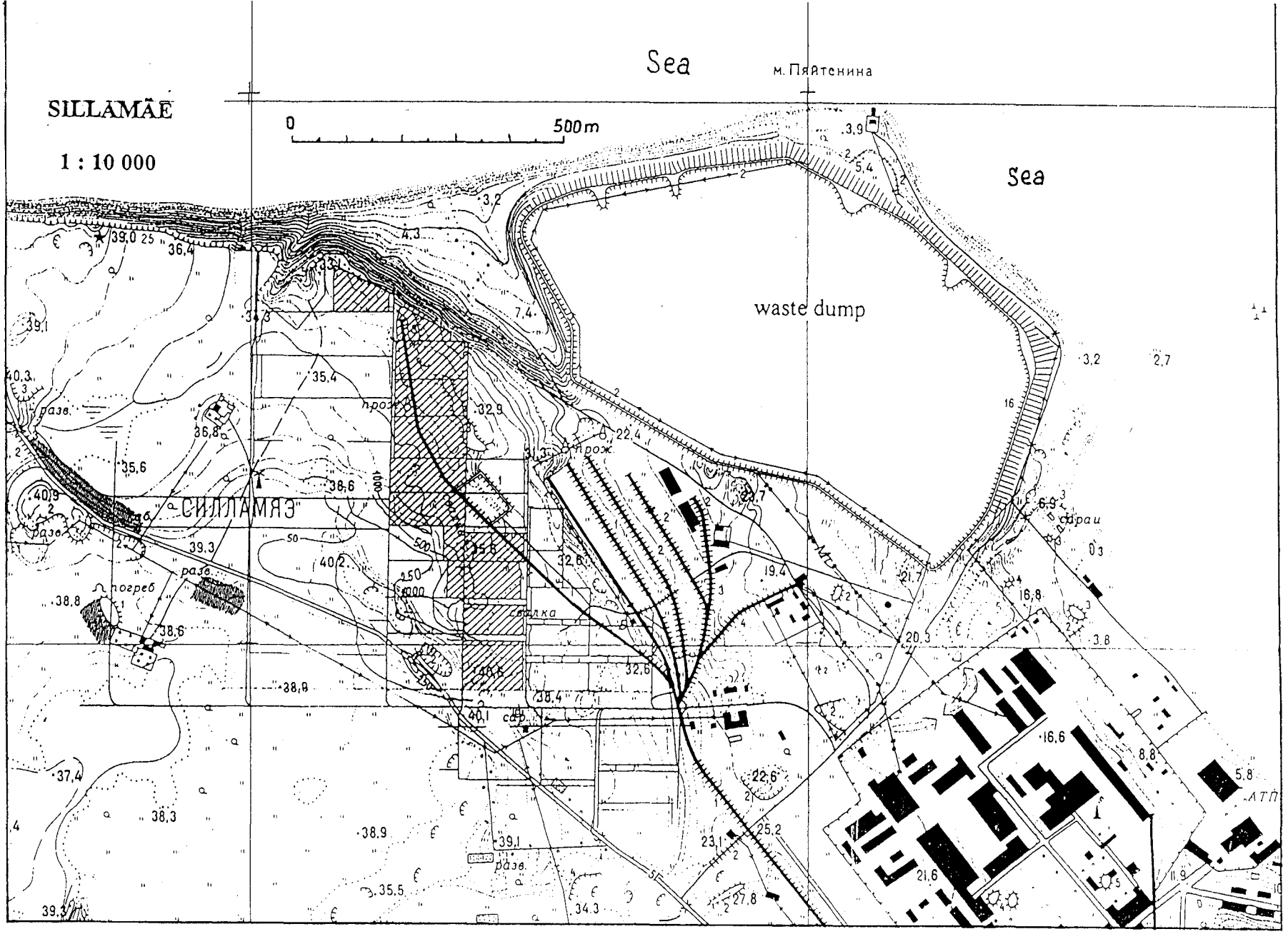

Sea
м. Пяйтенина
SILLAMÄE
1 : 10 000
0
500 m
Sea
waste dump
СИЛЛАМЯЭ

Fig. 1

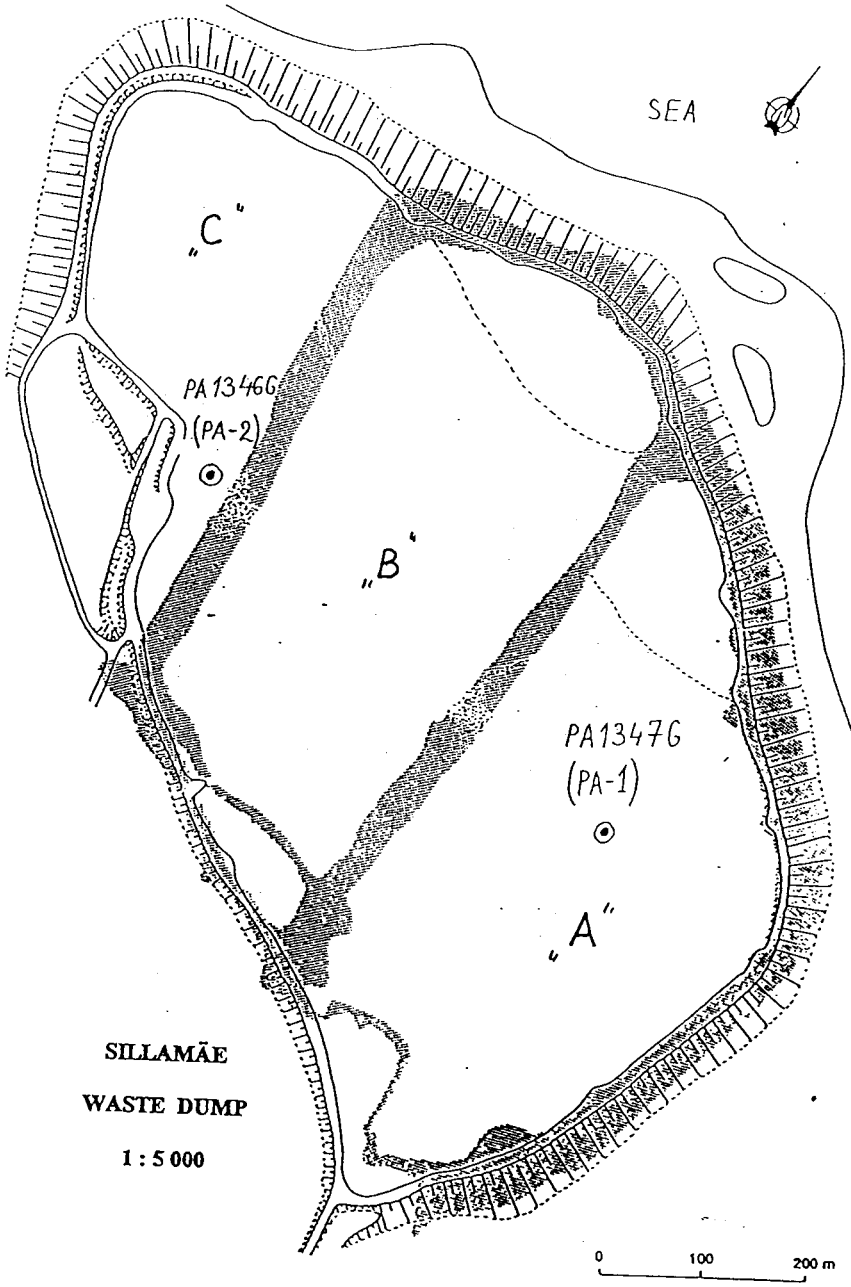
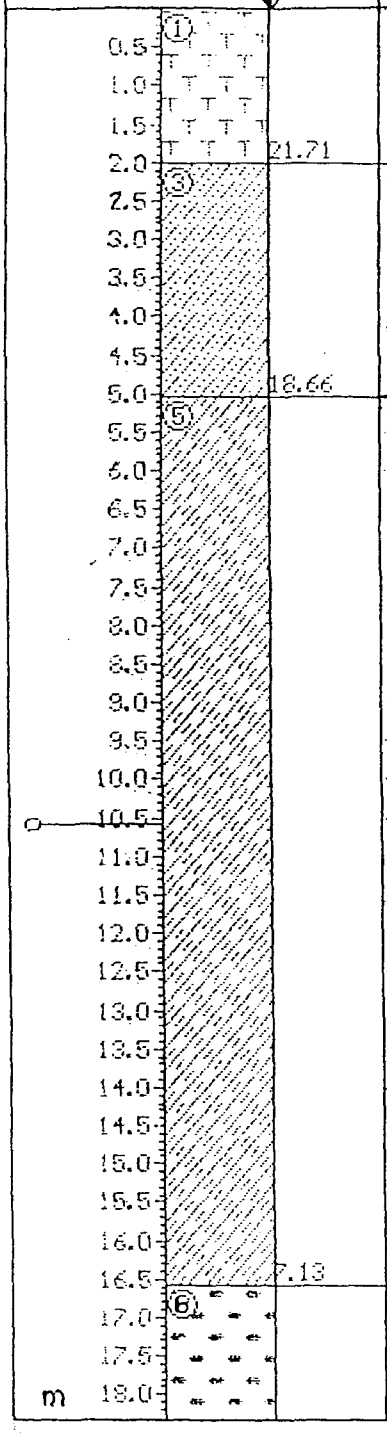

SEA
„C"
PA 13466
(PA-2)
„B"
PA13476
(PA-1)
„A"
SILLAMÄE
WASTE DUMP
1 : 5 000
0
100
200 m

Fig. 2



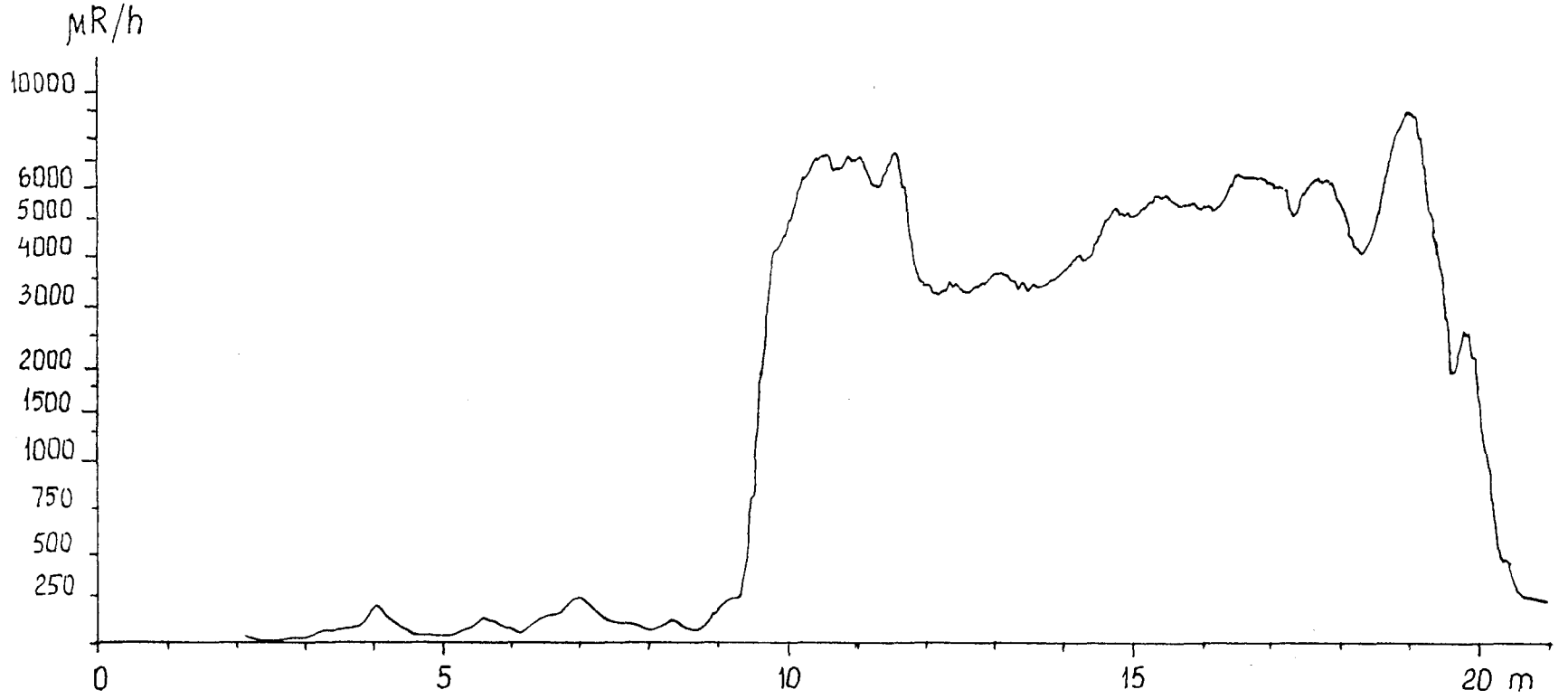
Layer 1. Filling: earth, pebbles, limestone lumps

Layer 3. Wastes from loparite ore treatment, ashes, soft plastic

Layer 5. Wastes from uranium ore treatment, sandy clay, brownish grey, from fluid to fluid plastic

Layer 6. Pebbles with fillings of ashes and sandy clay, dark grey, weakly cemented

Fig. 3


Borehole PA-1 (1347g)
MR/h
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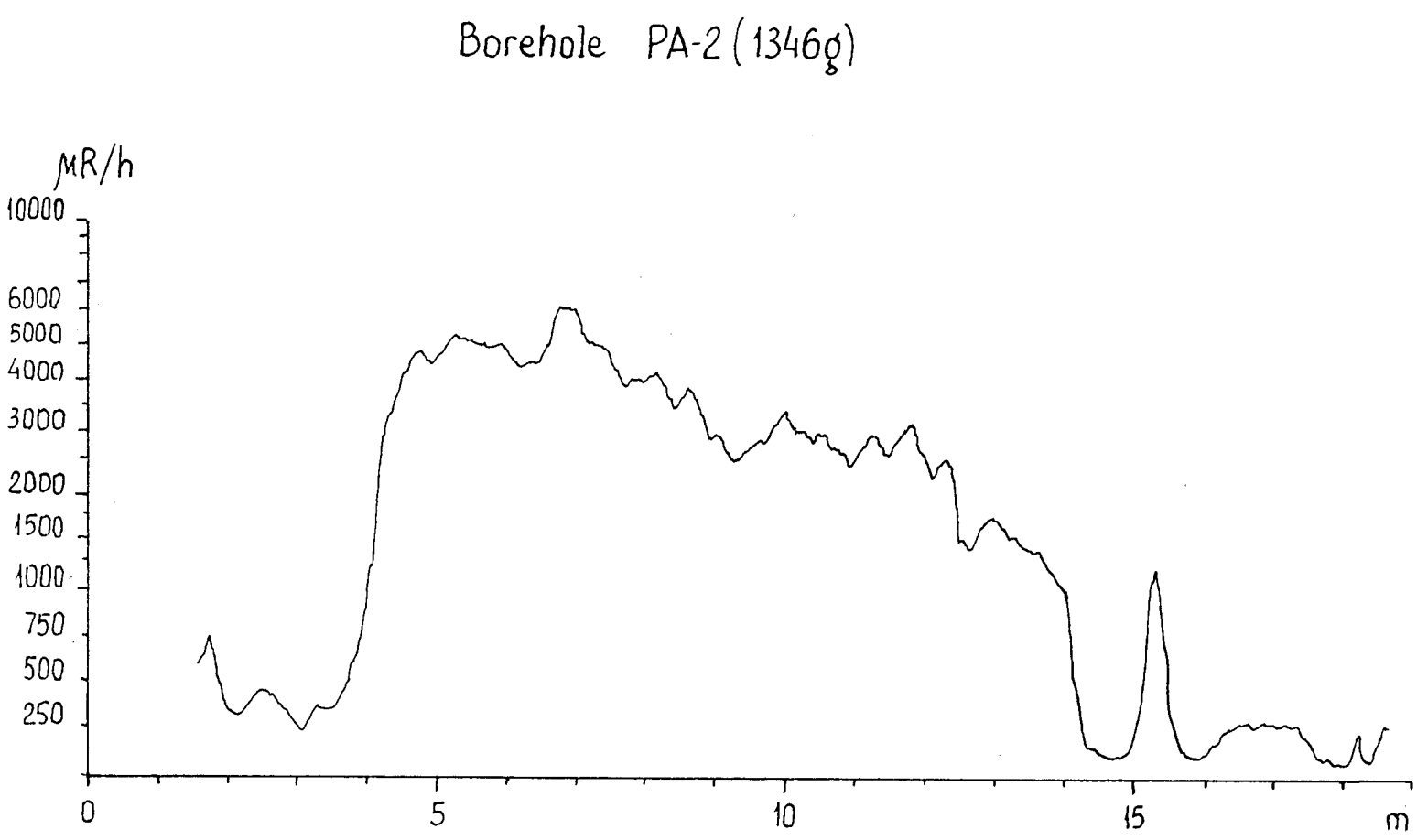
5000
4000
3000
2000
1500
1000
750
500
250
0
5
10
15
20 m

Fig. 4


Borehole PA-2 (1346g)
μR/h
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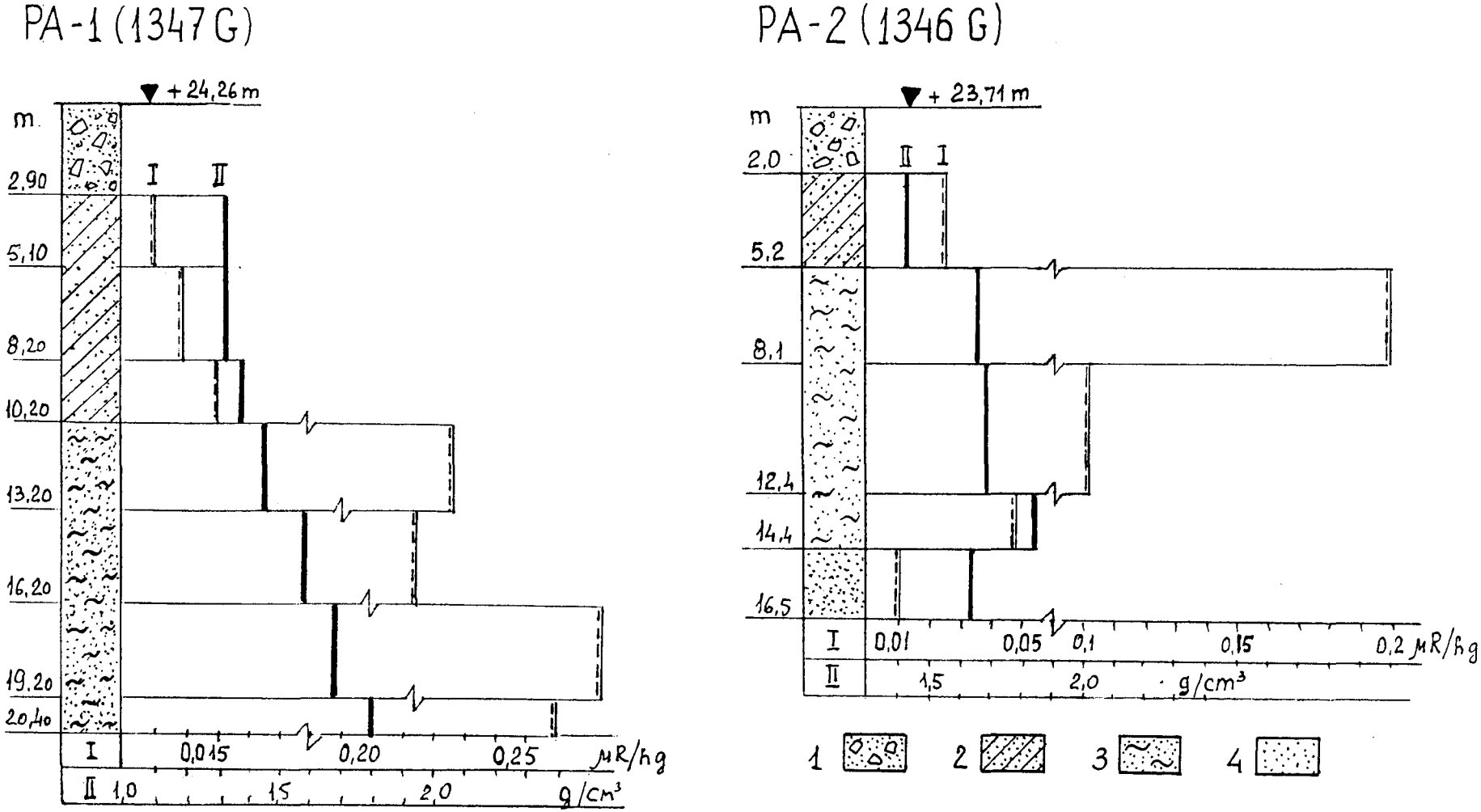
5000
4000
3000
2000
1500
1000
750
500
250
0
5
10
15
m

Fig. 5


PA-1 (1347 G)
+ 24,26 m
m
2,90
5,10
8,20
10,20
13,20
16,20
19,20
20,40
I
II
0,015
0,20
0,25
μR/hg
1,0
1,5
2,0
g/cm³
PA-2 (1346 G)
+ 23,71 m
m
2,0
5,2
8,1
12,4
14,4
16,5
0,01
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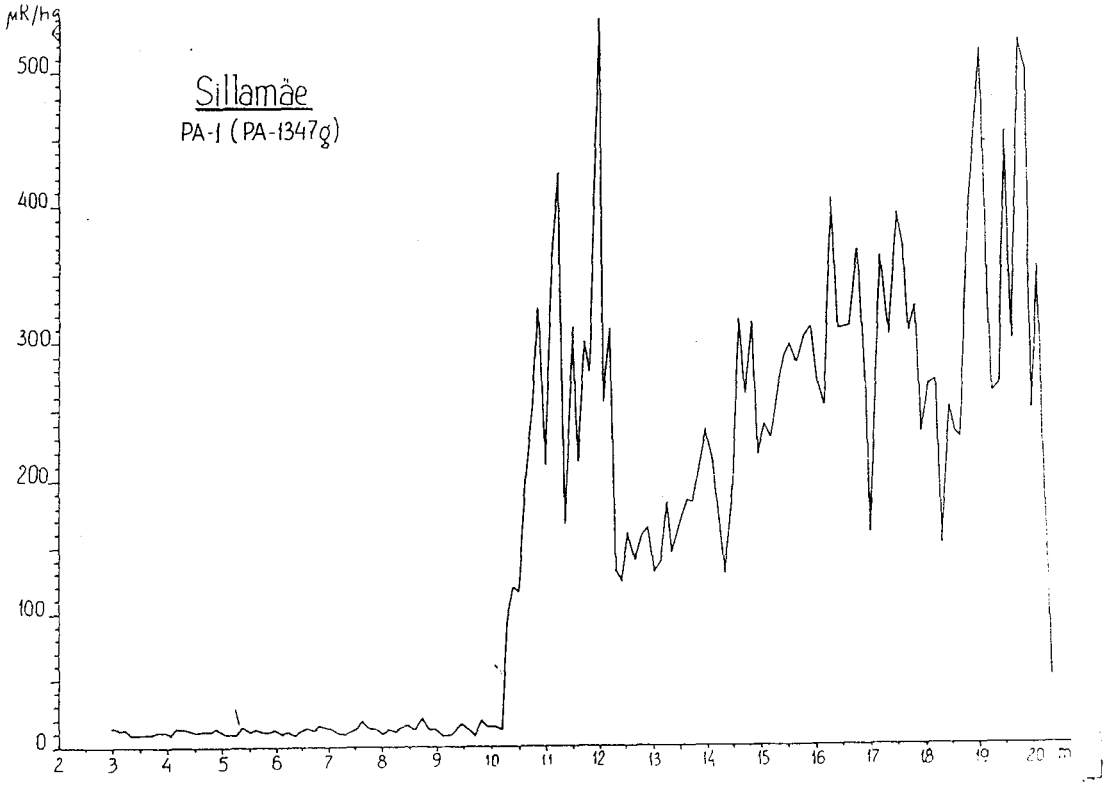
2,0
g/cm³
1
2
3
4

Fig. 6


μR/hg
500
400
300
200
100
0
Sillamäe
PA-1 (PA-1347g)
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 m

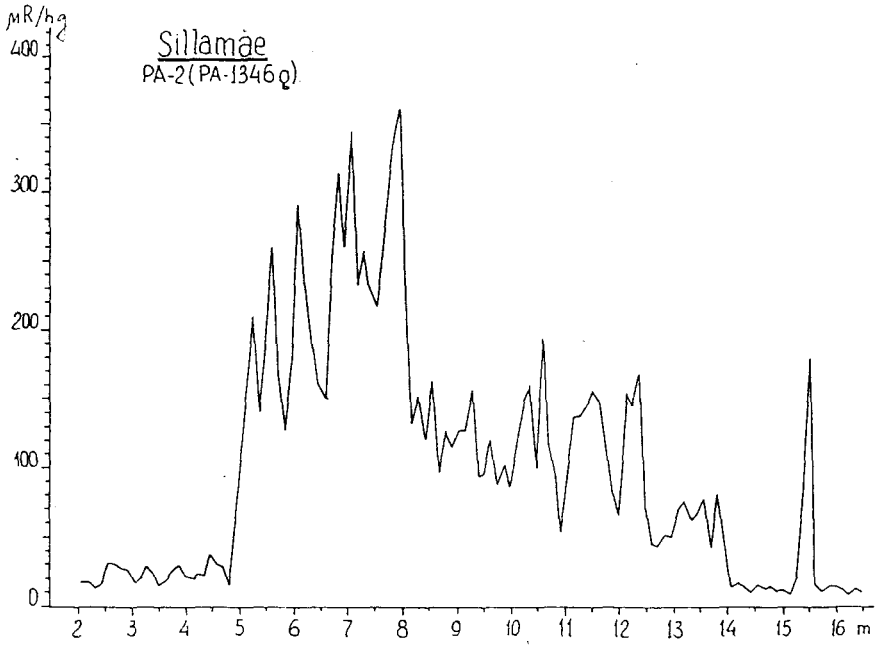

μR/hg
400
300
200
100
0
Sillamäe
PA-2(PA-1346g)
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 m

Fig. 7

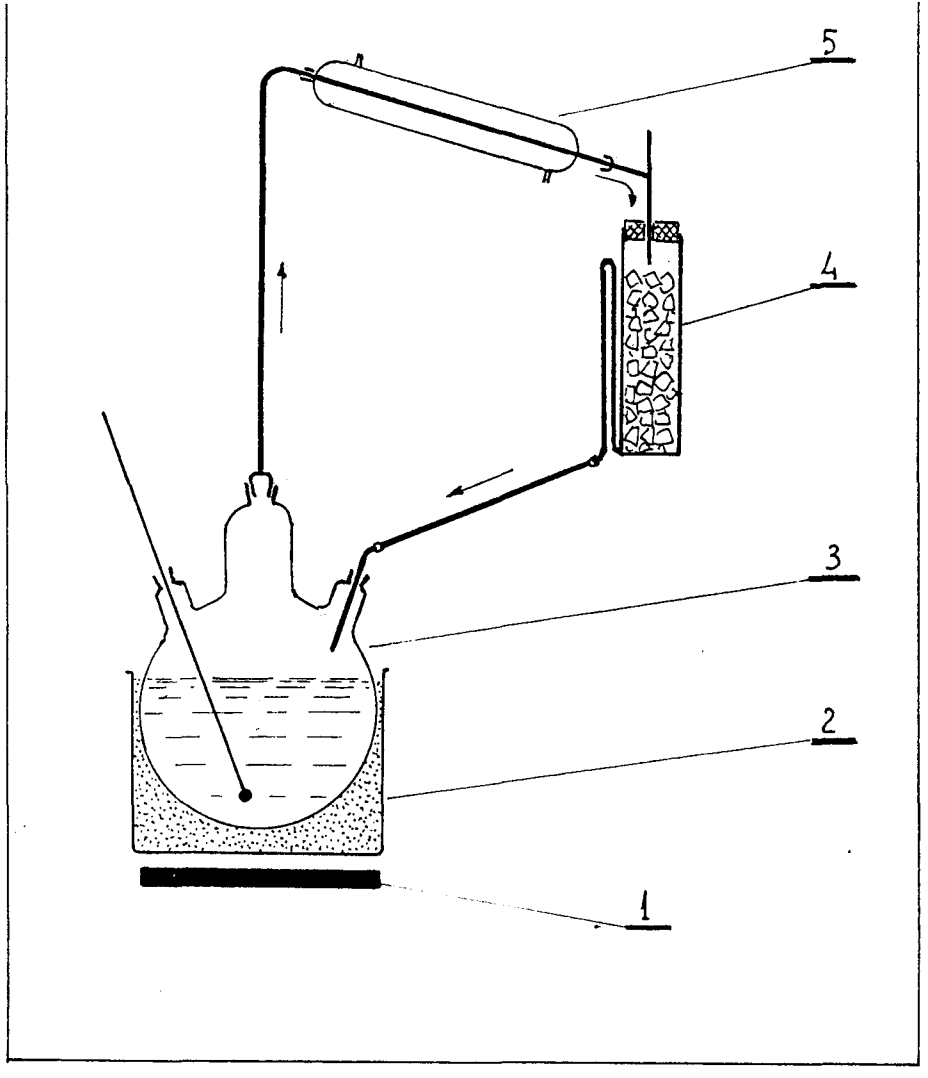


Fig. 8

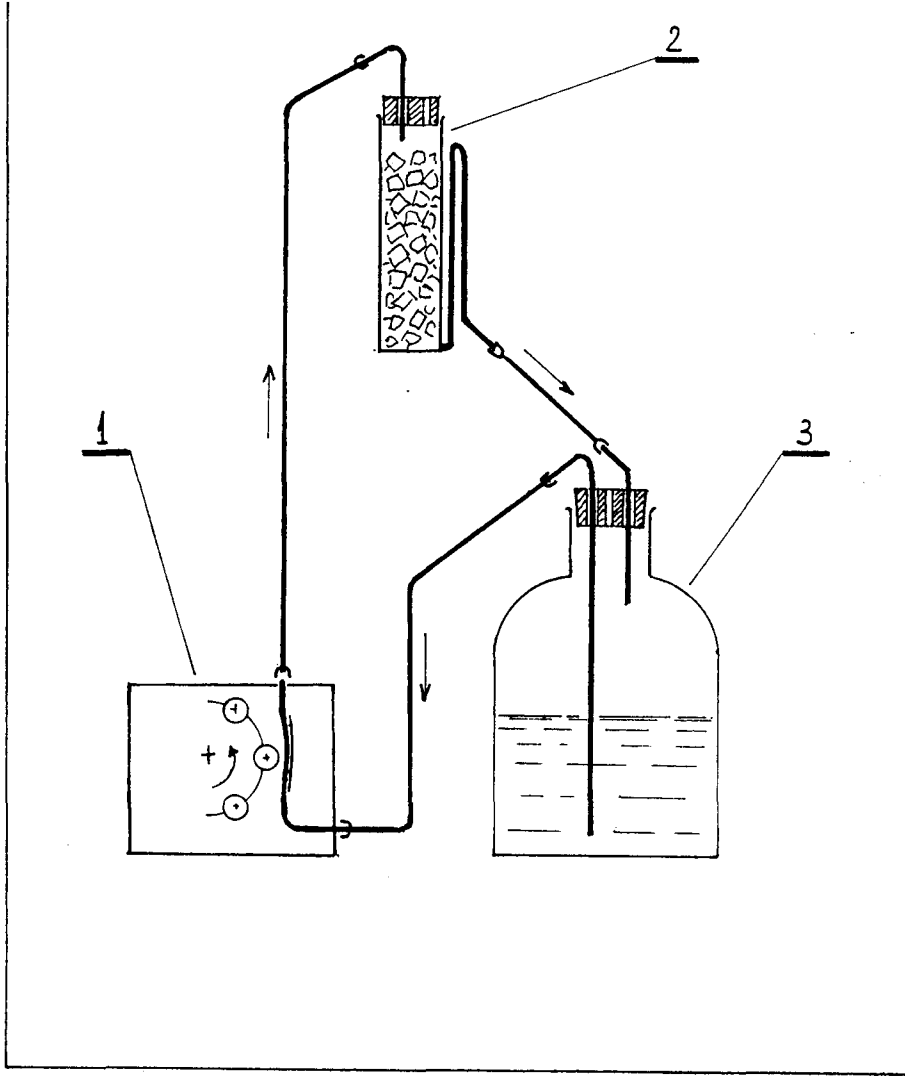


Fig. 9

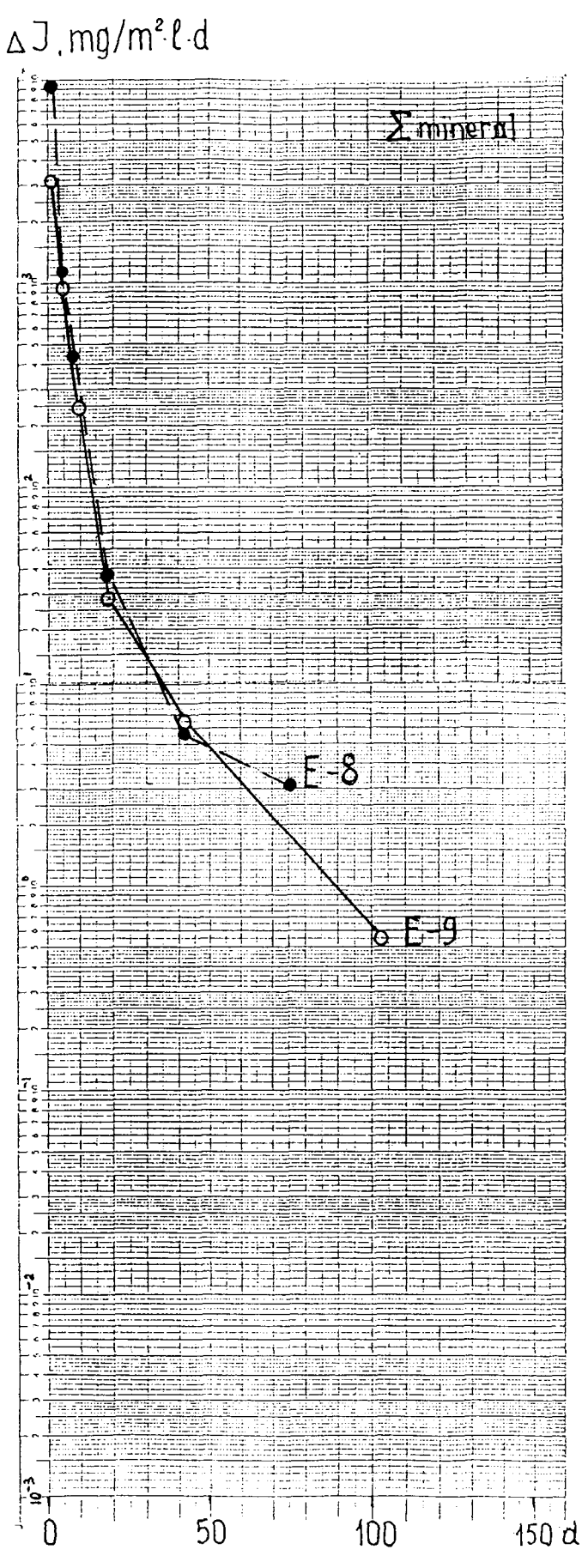


Fig. 10-1

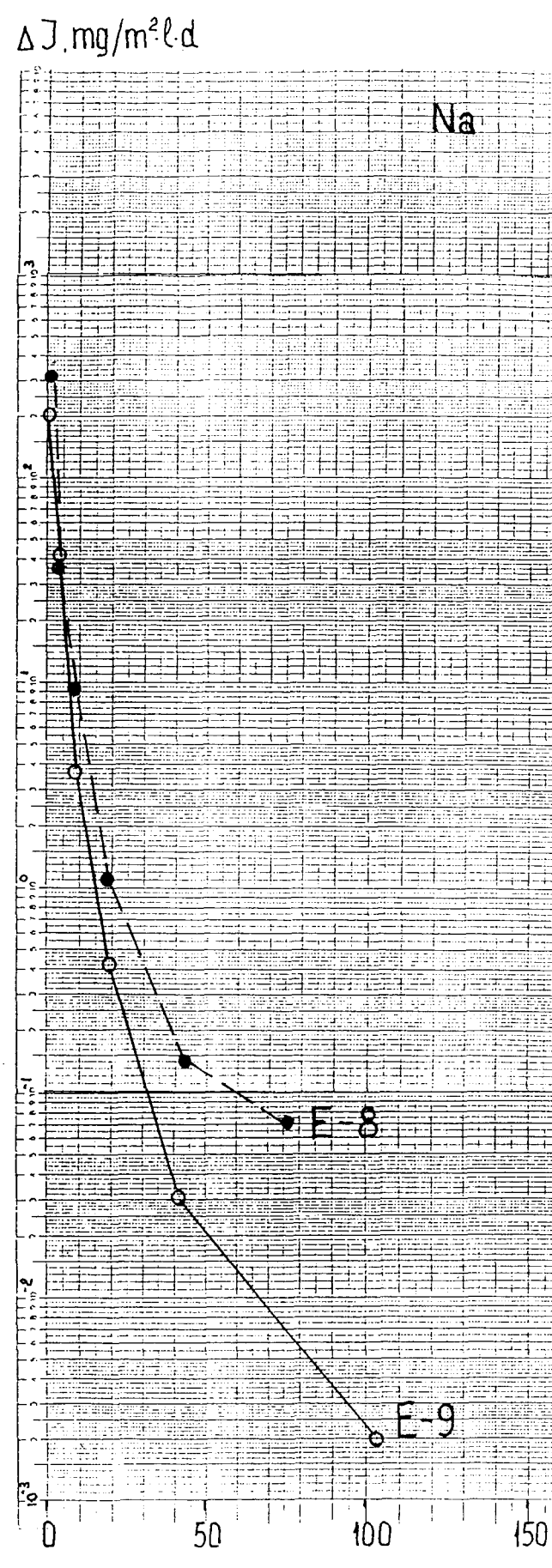


Fig. 10-2

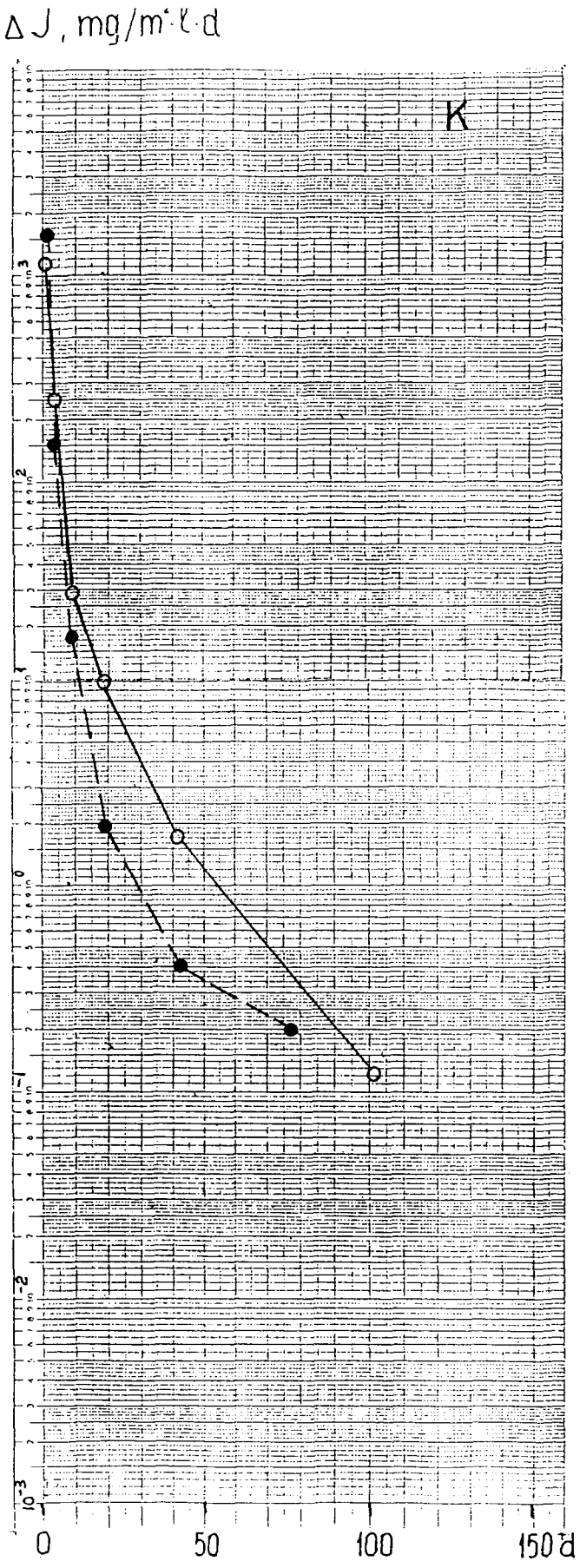


Fig. 10-3

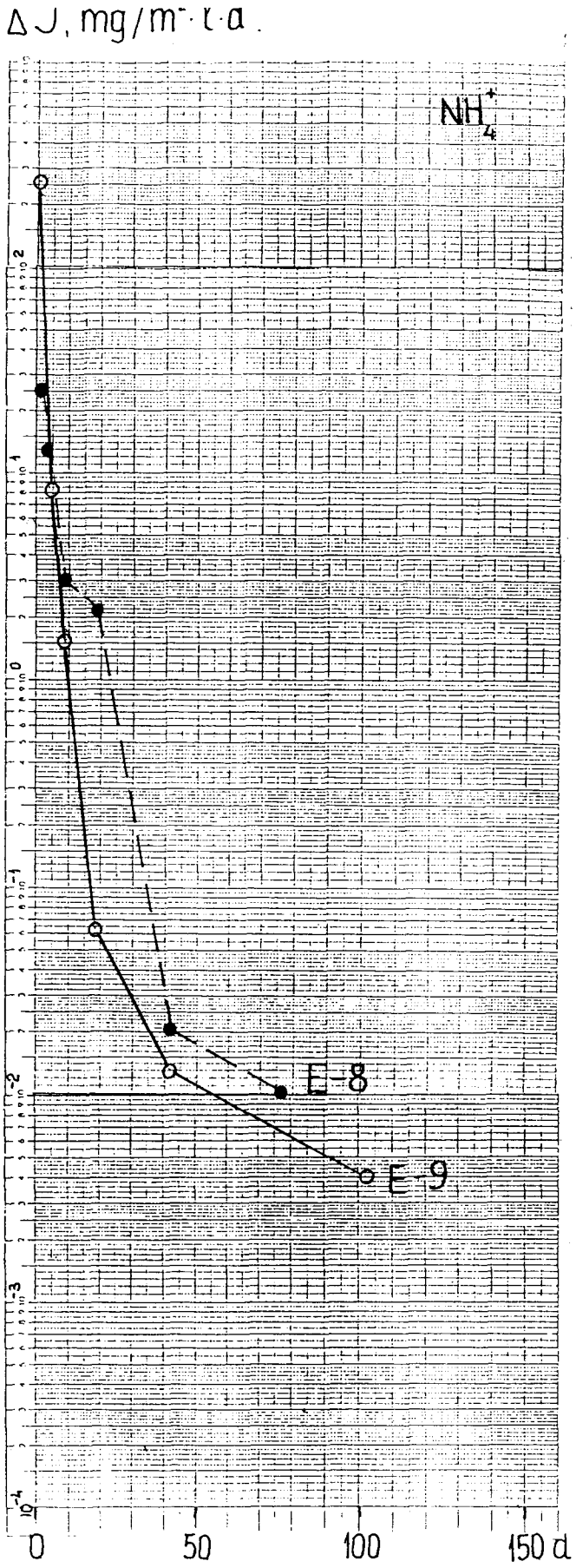


Fig. 10-4

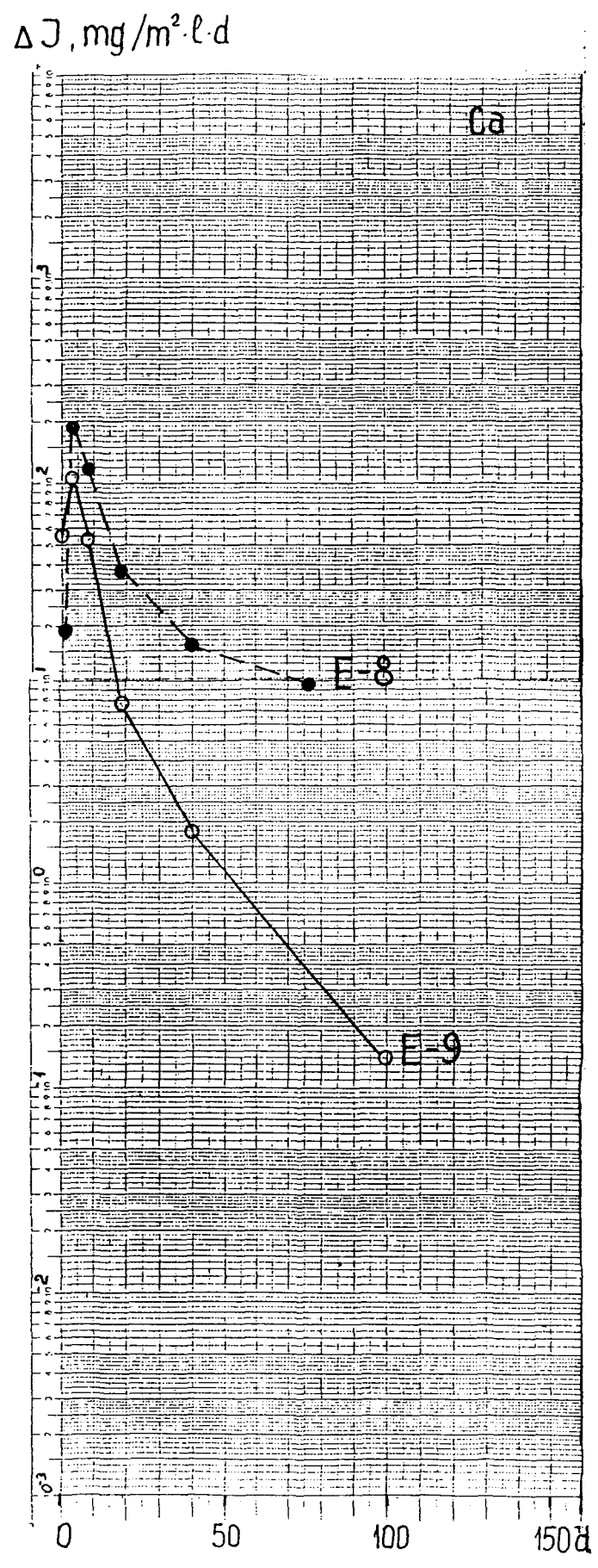


Fig. 10-5

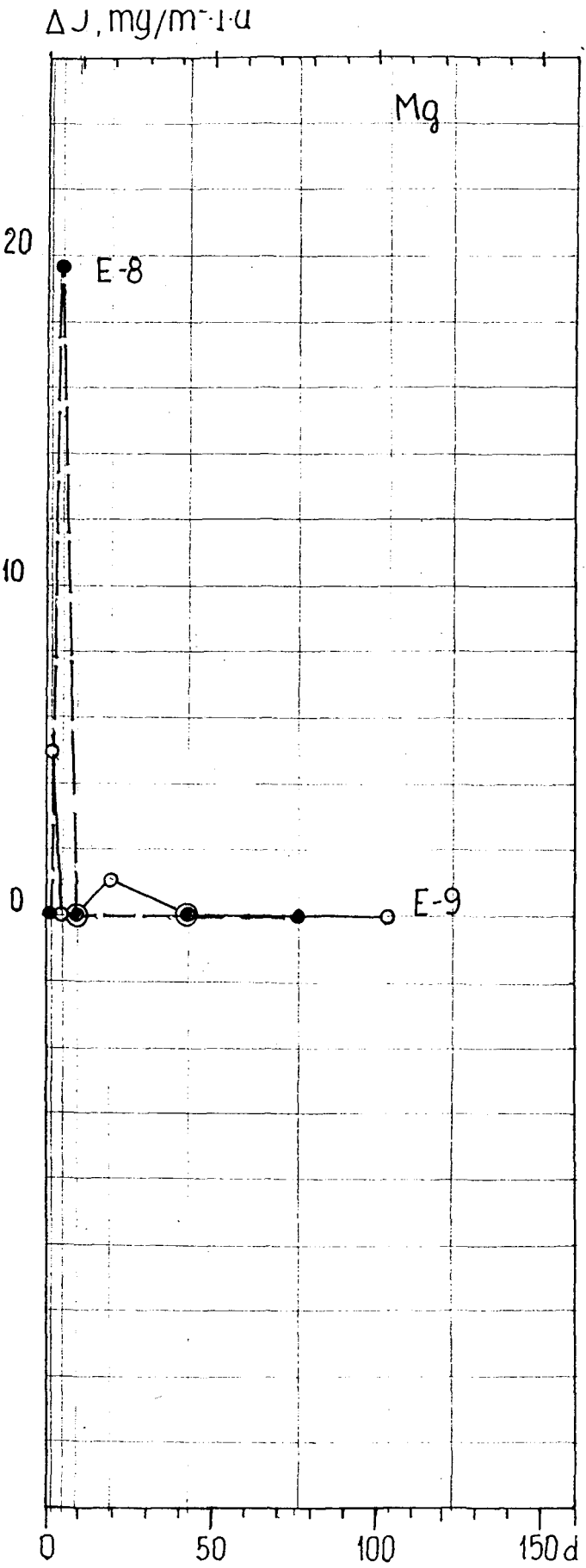
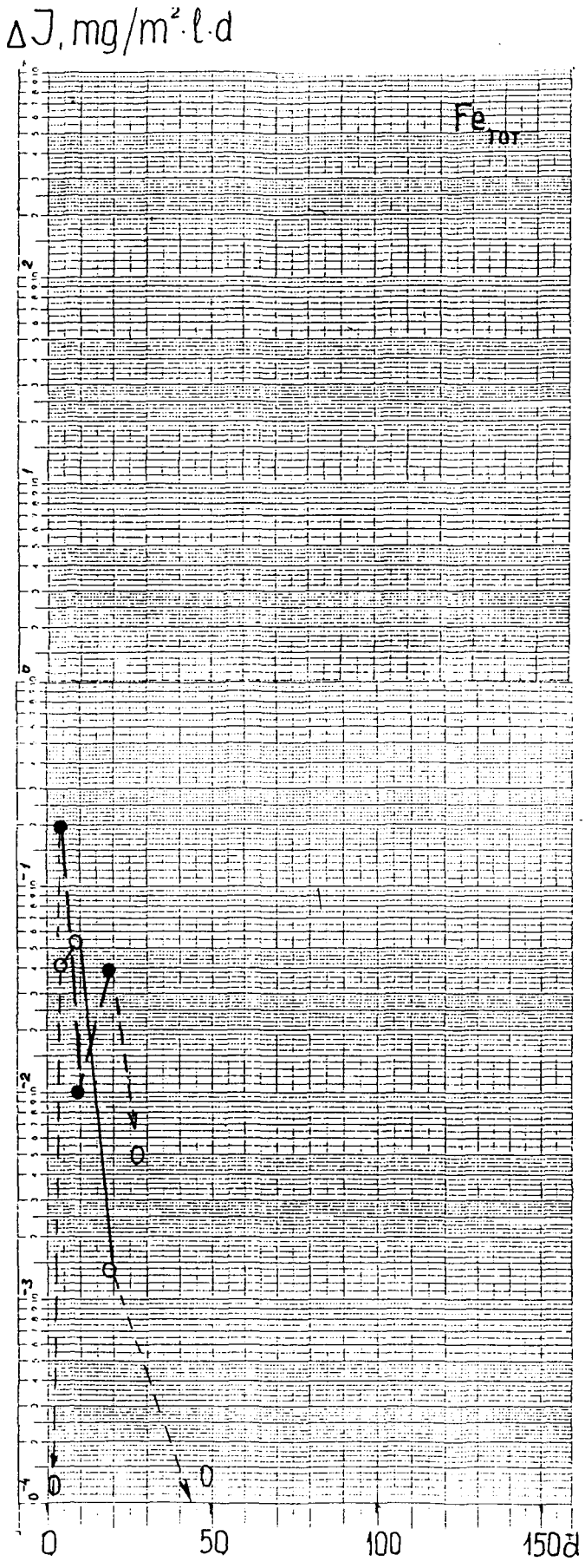


Fig. 10-6



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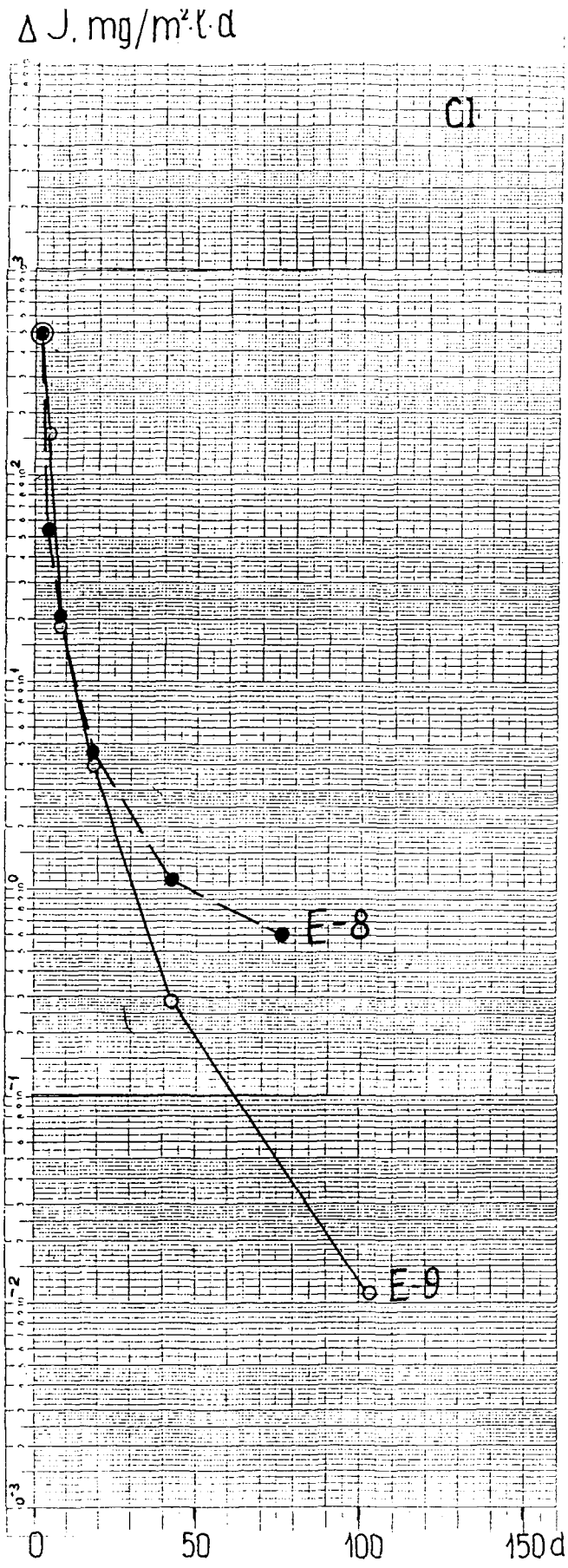

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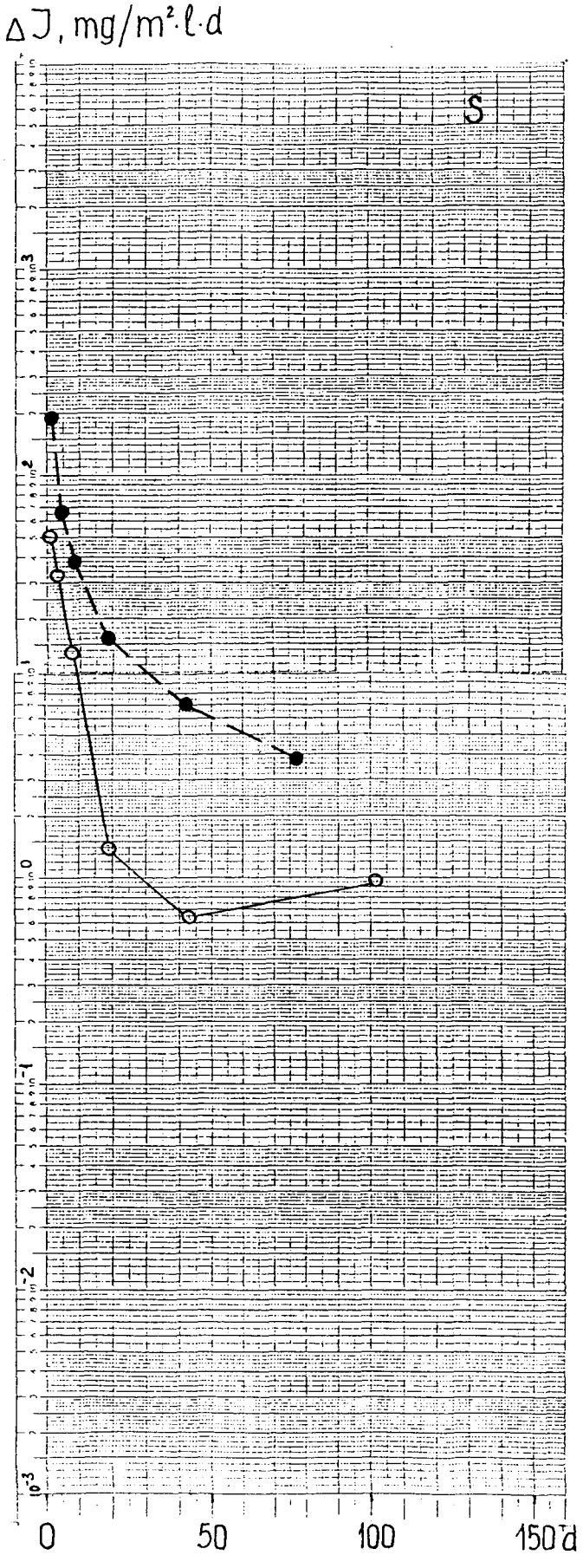
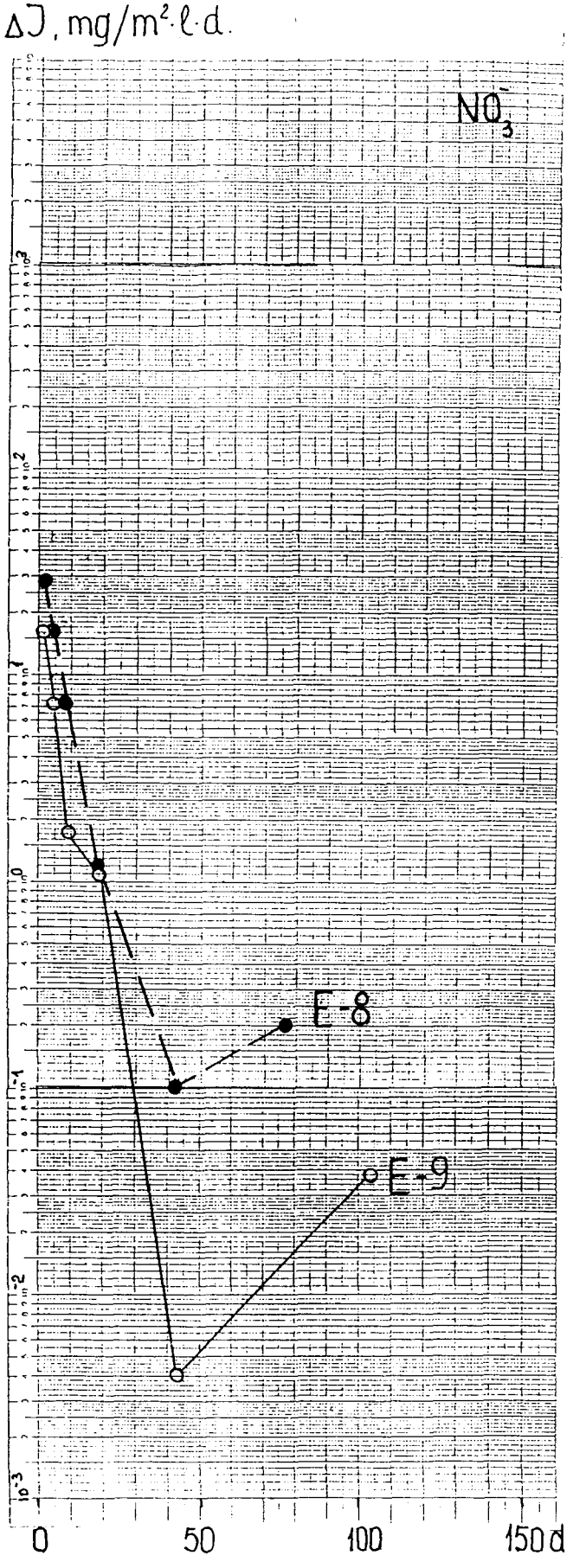


Fig. 10-9



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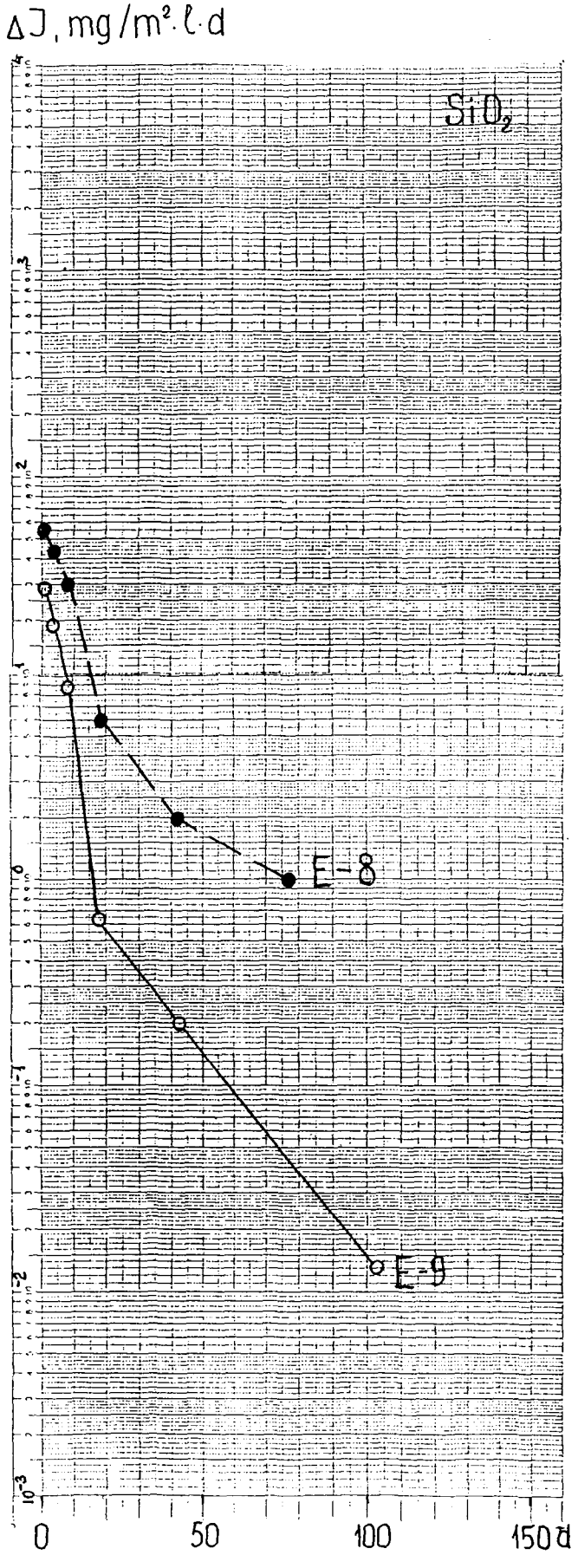

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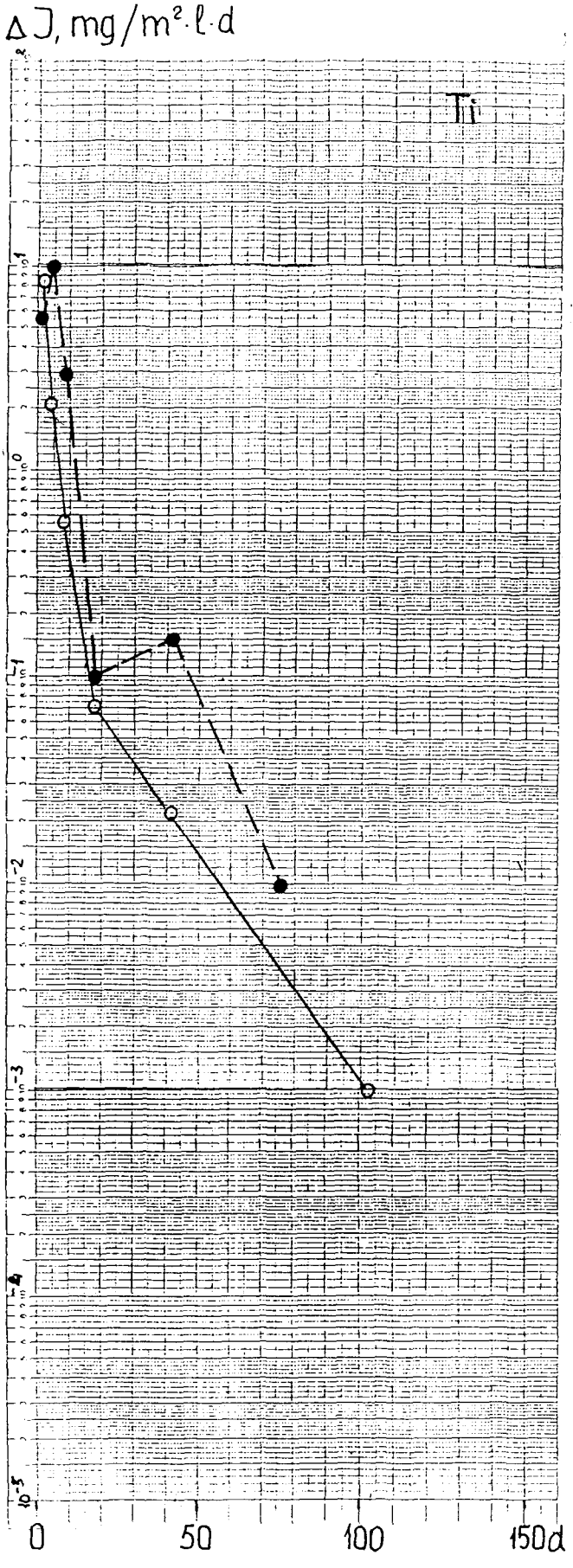

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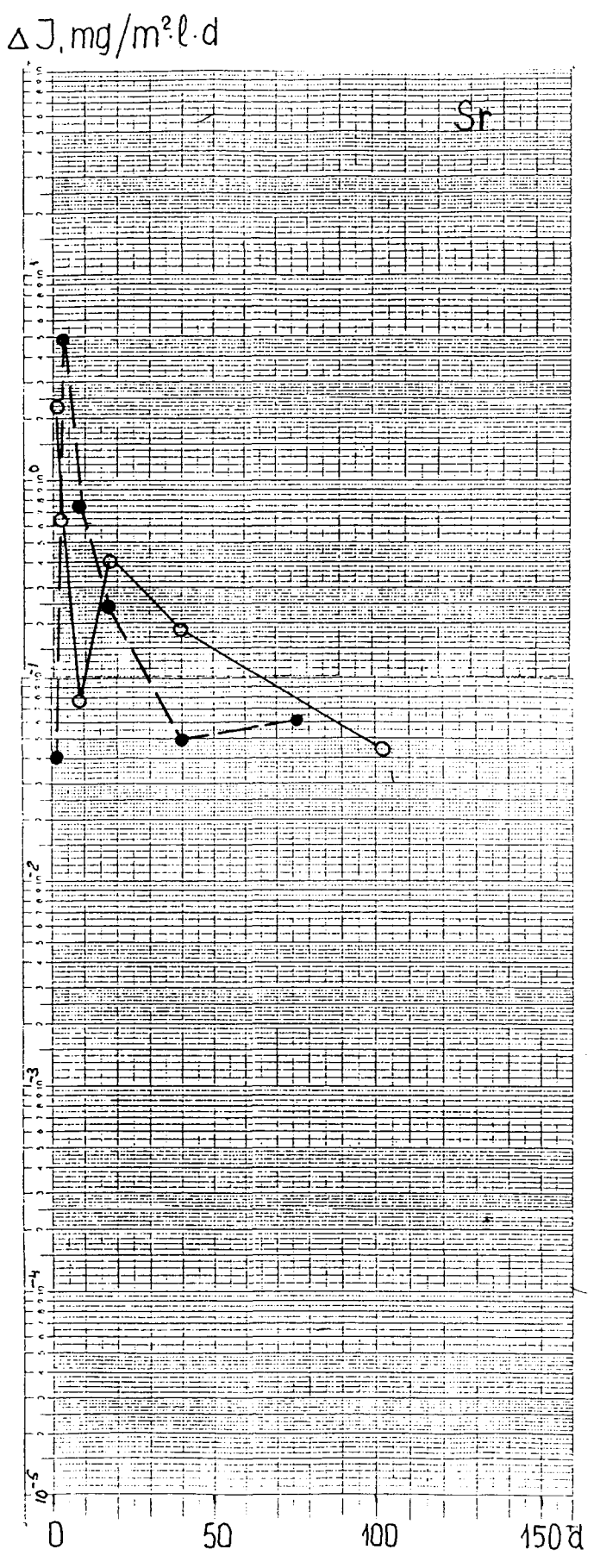

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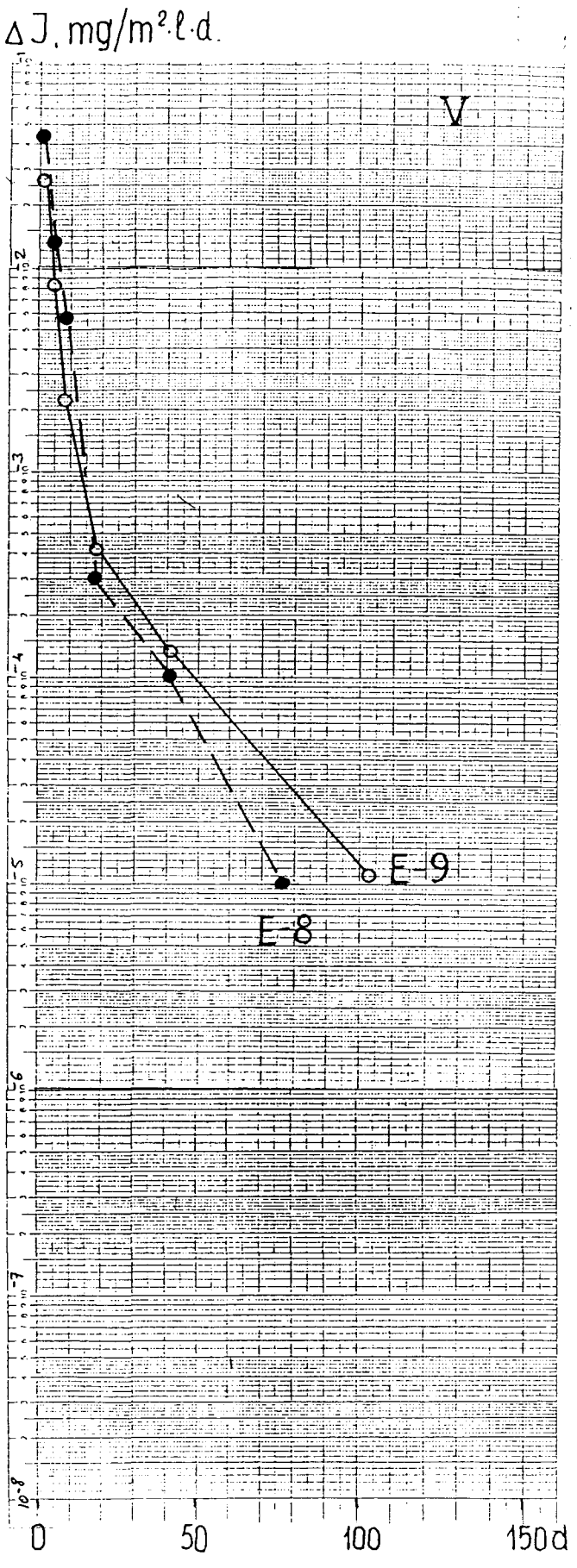

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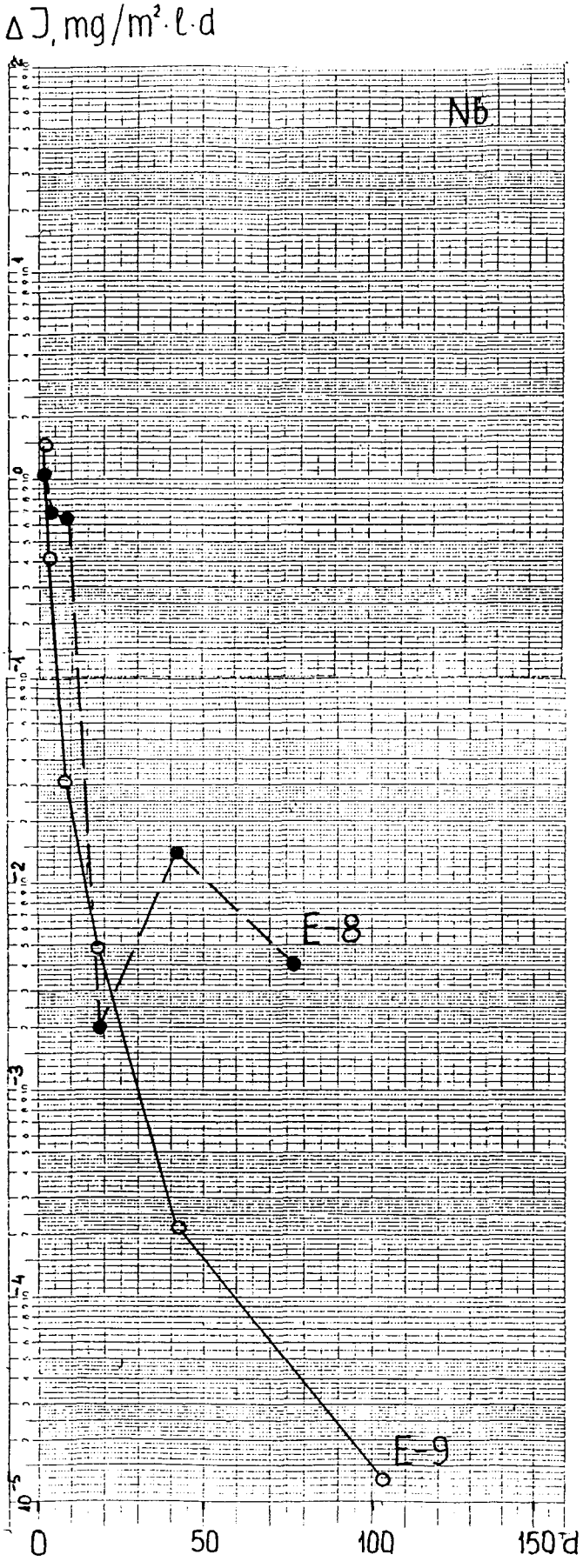

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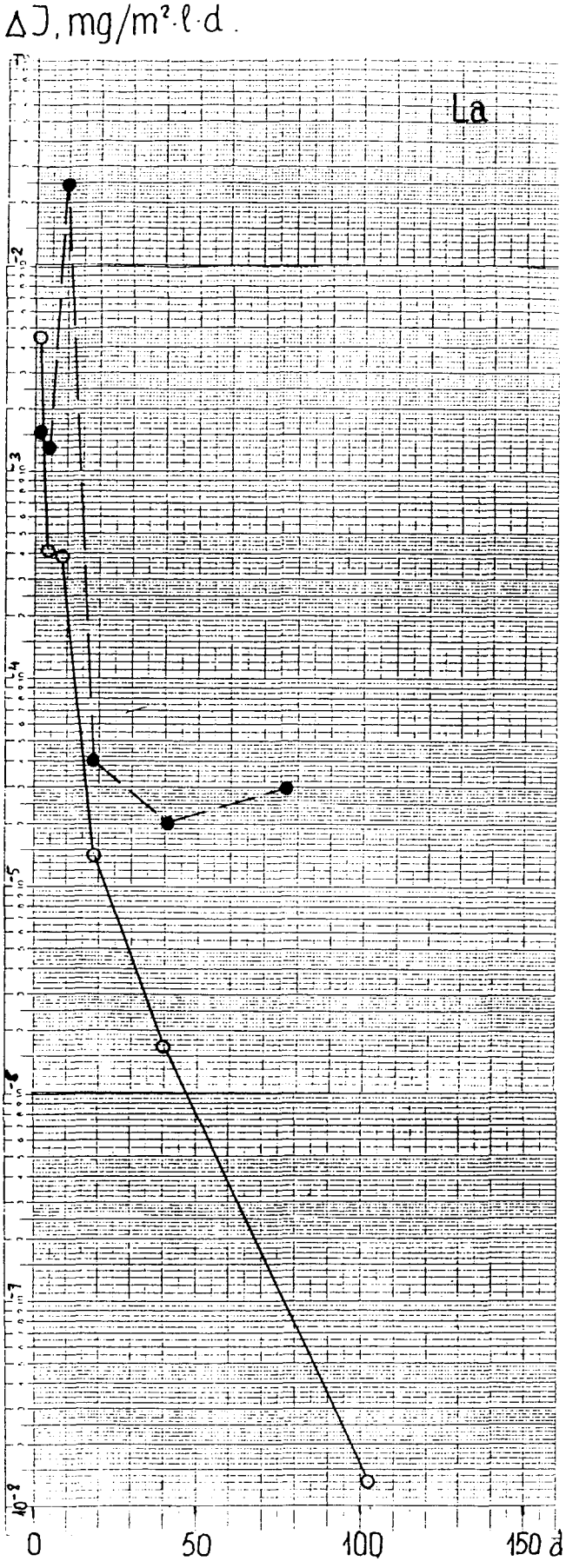


Fig. 10-16

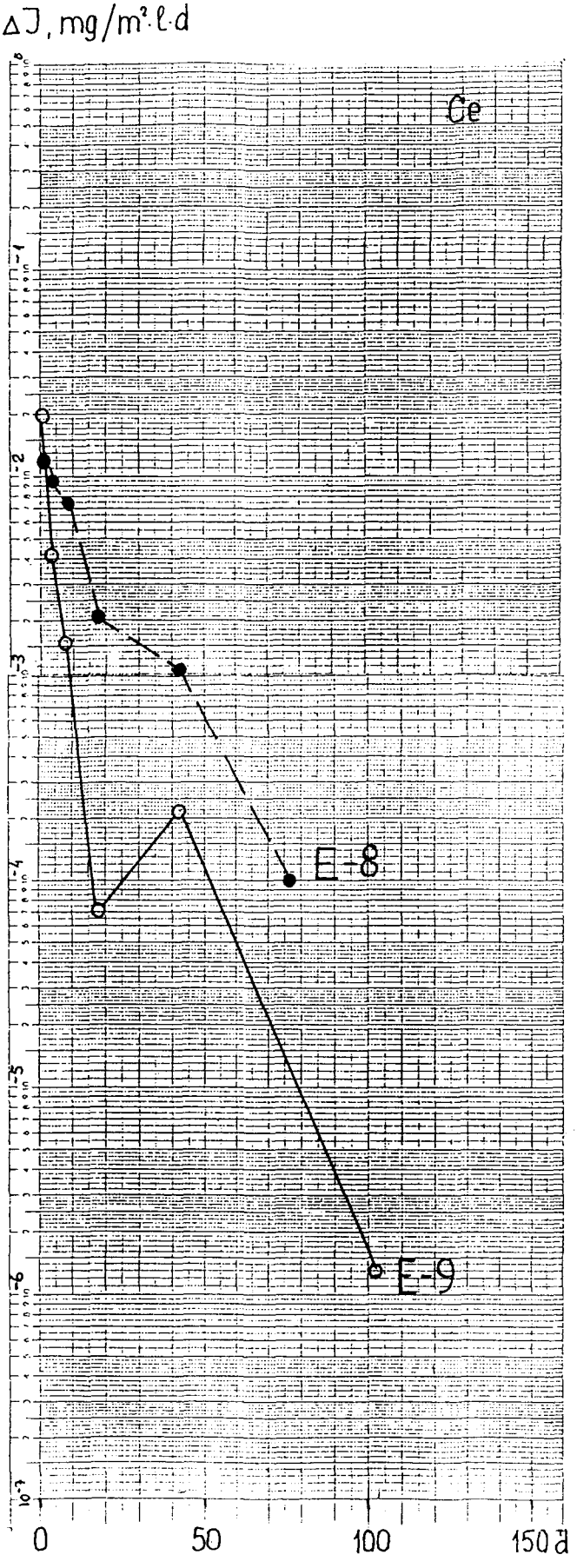
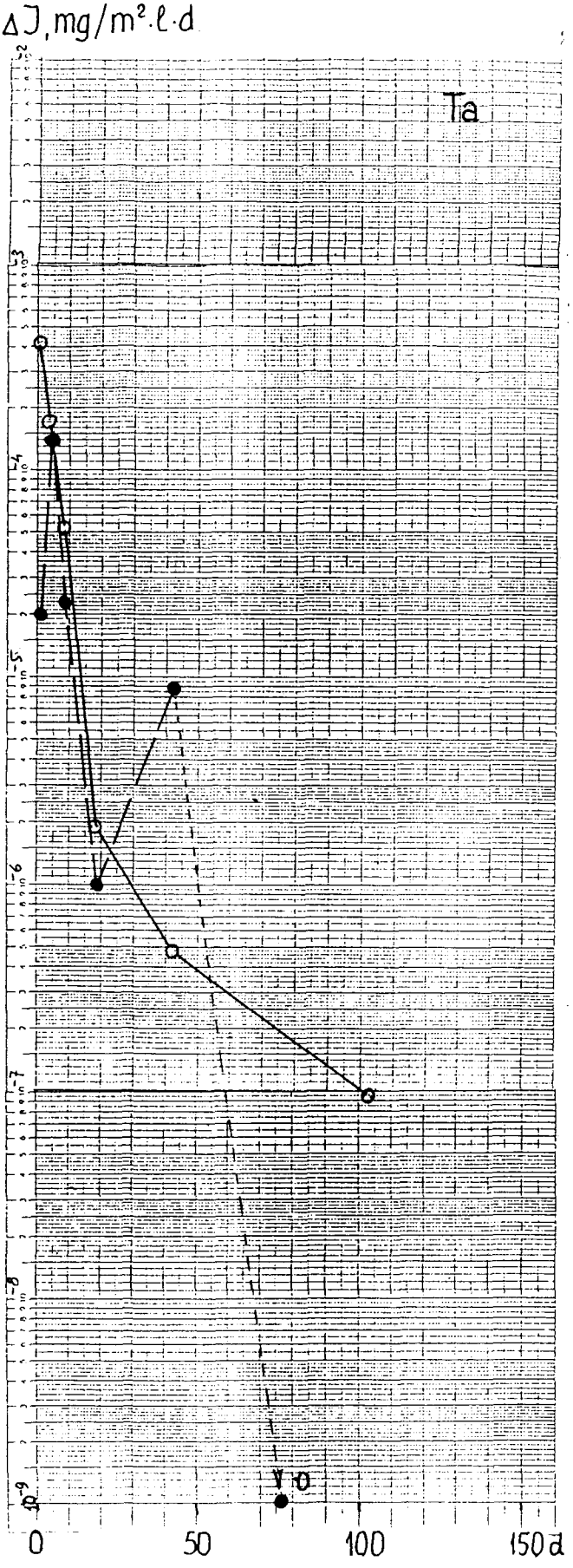


Fig. 10-17



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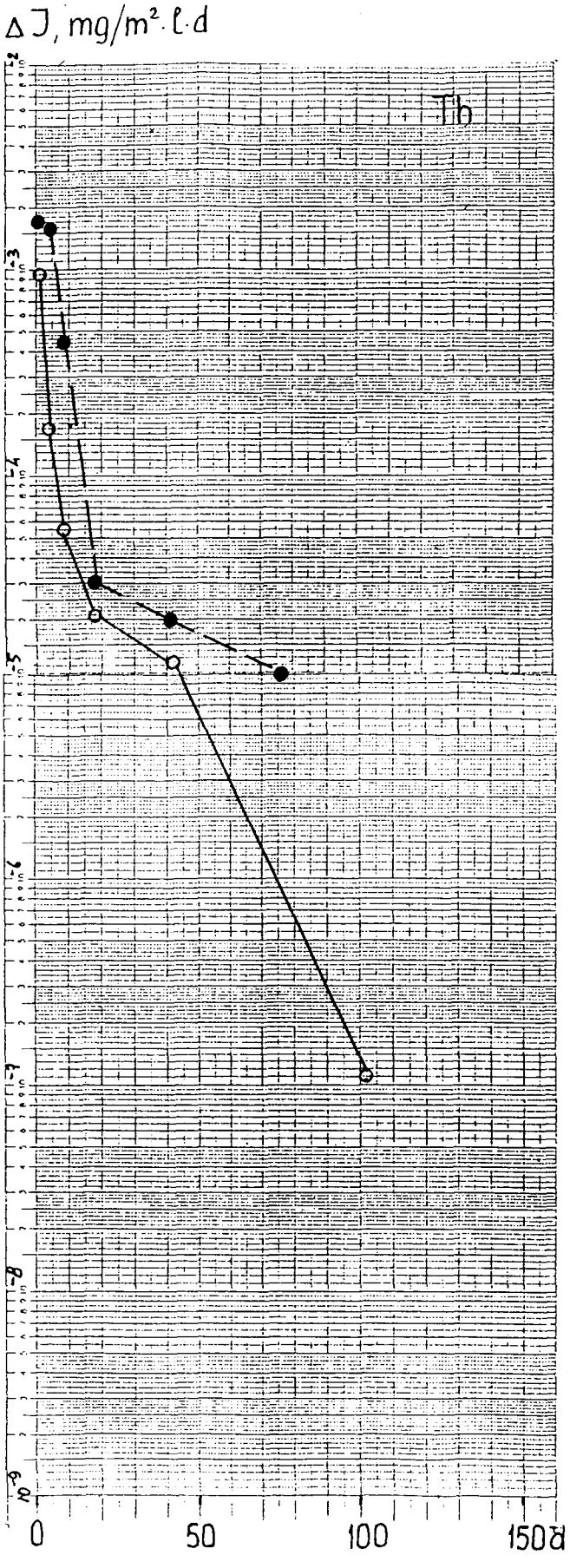

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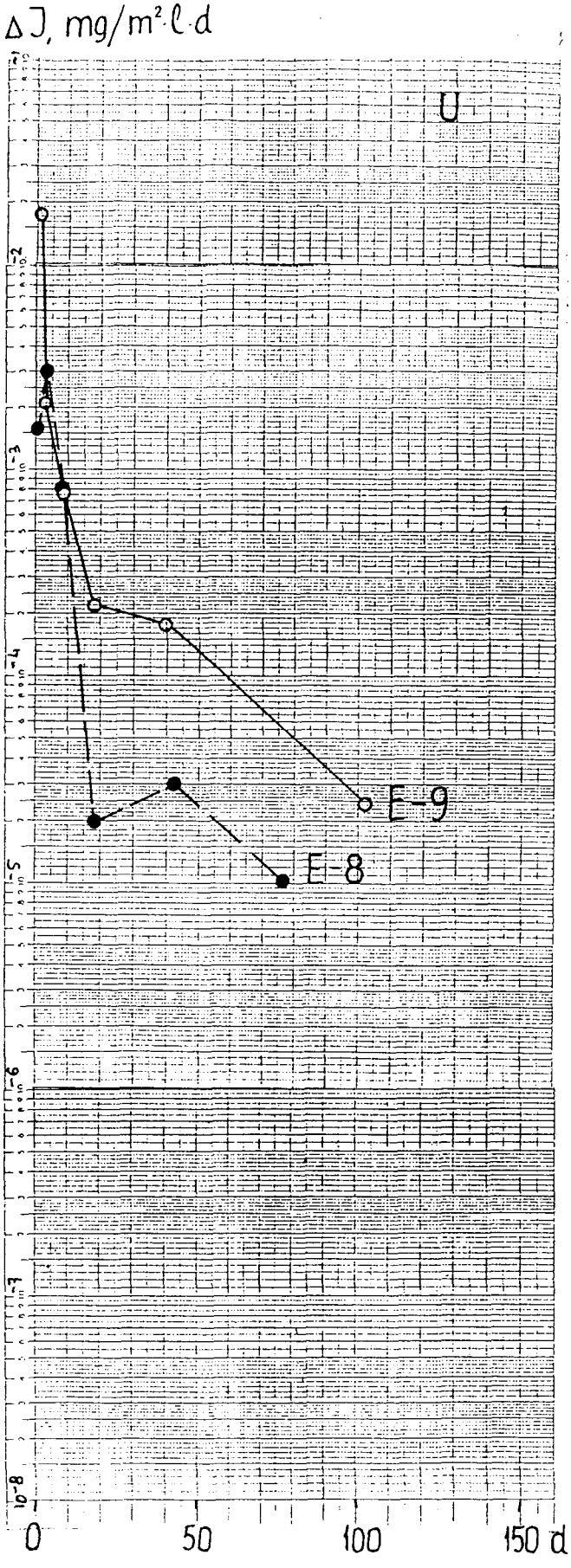


Fig. 10-20

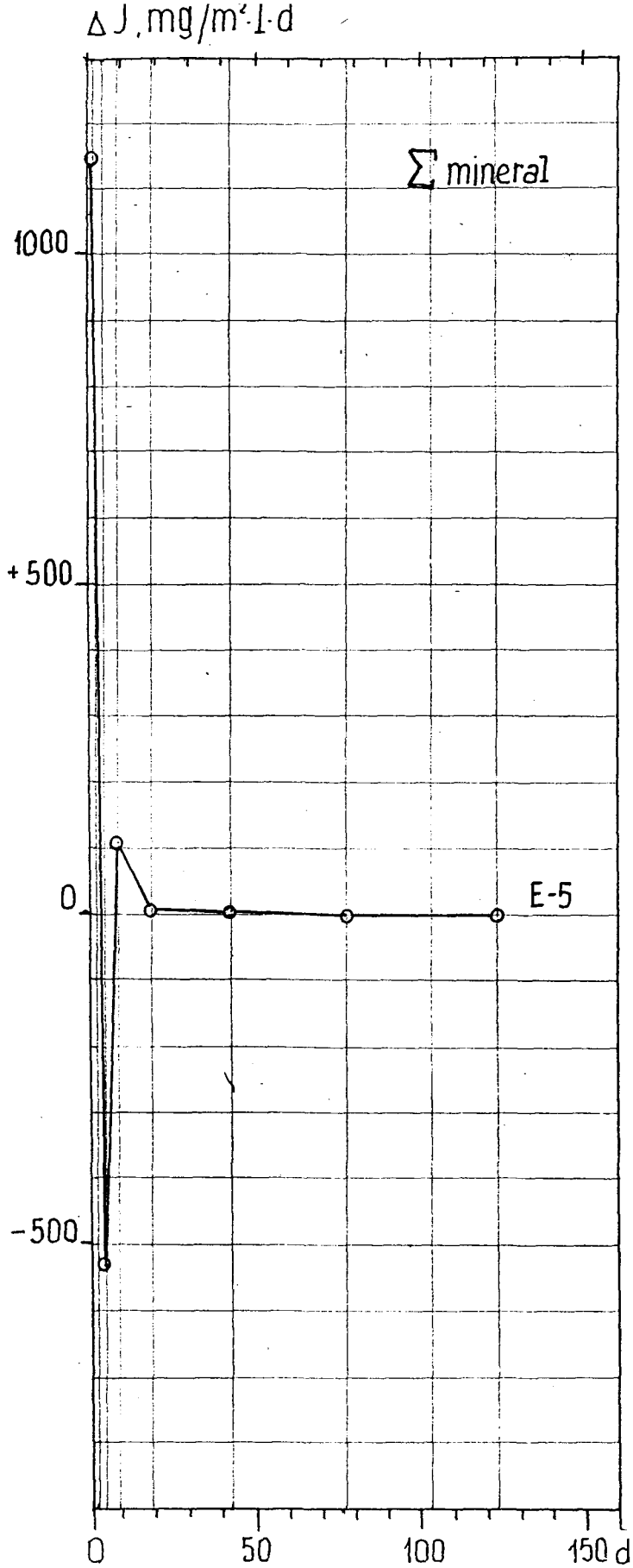


Fig. 11-1

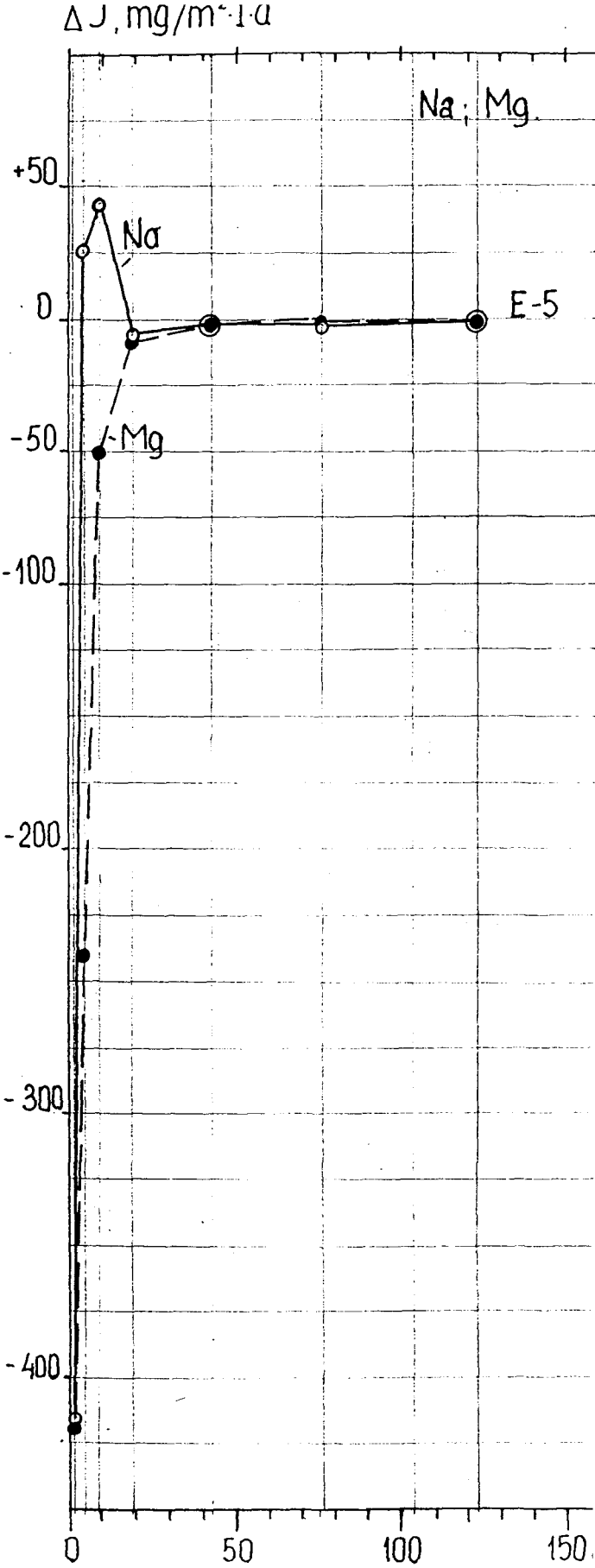


Fig. 11-2

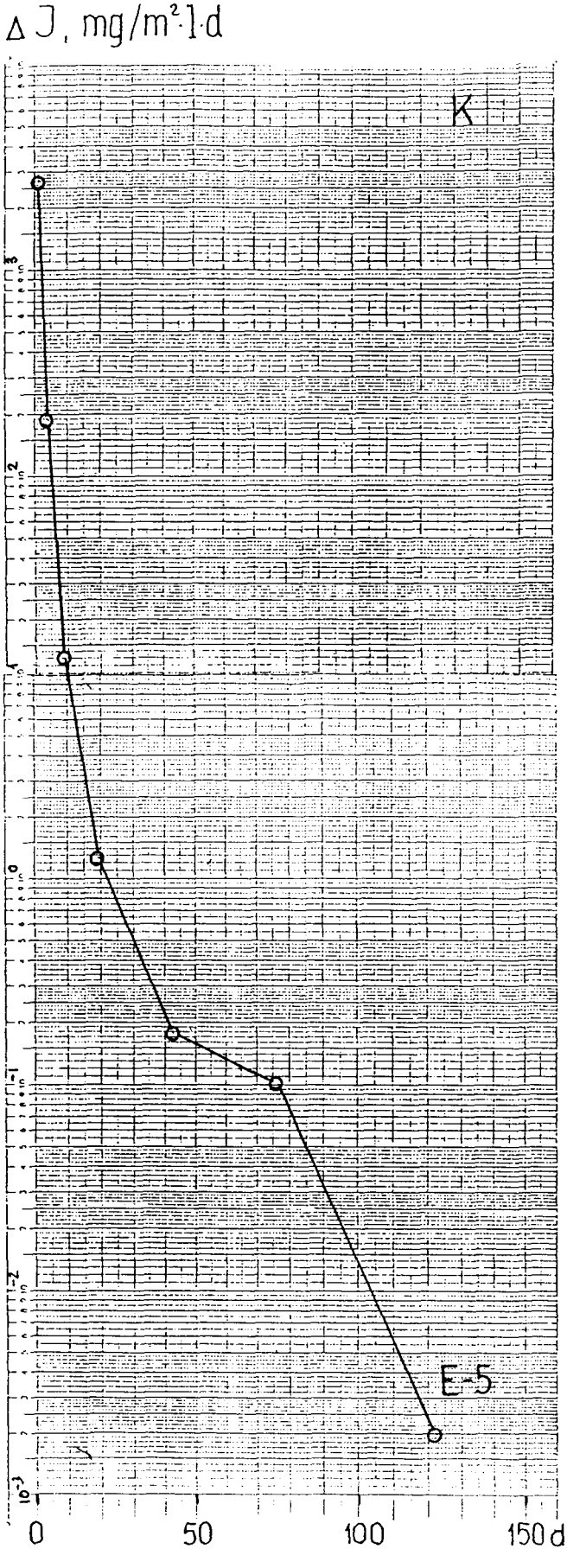
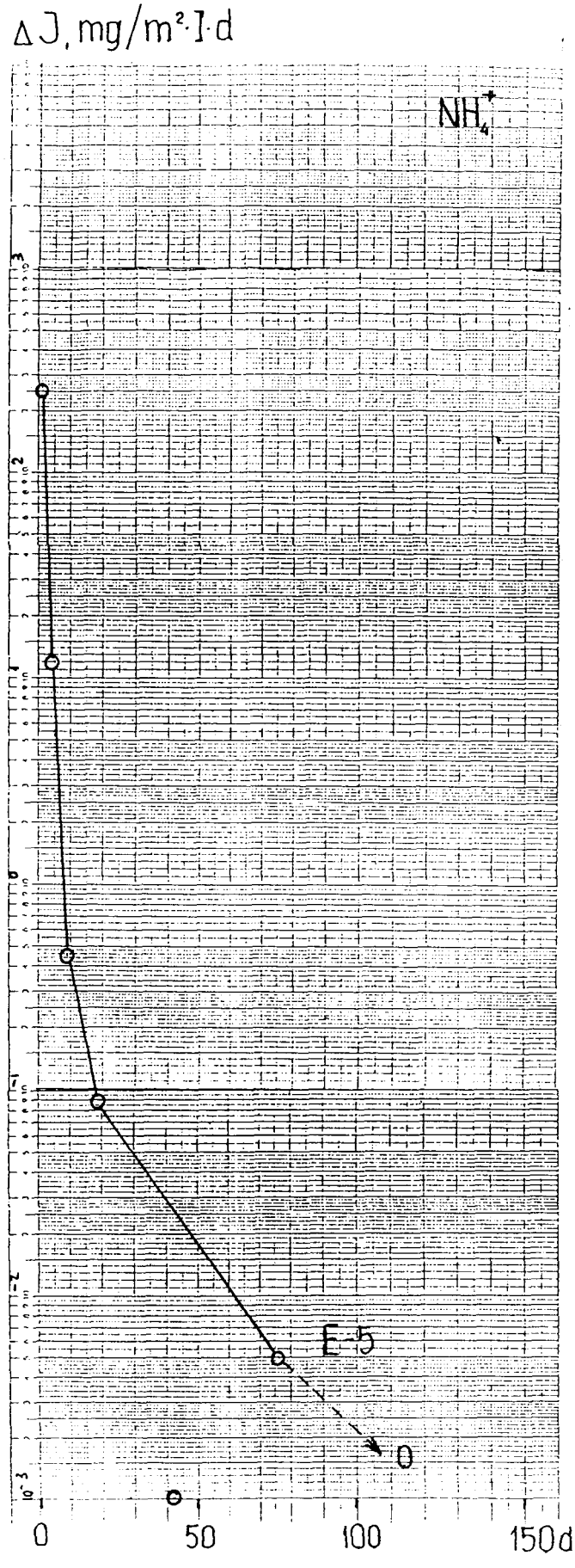


Fig. 11-3



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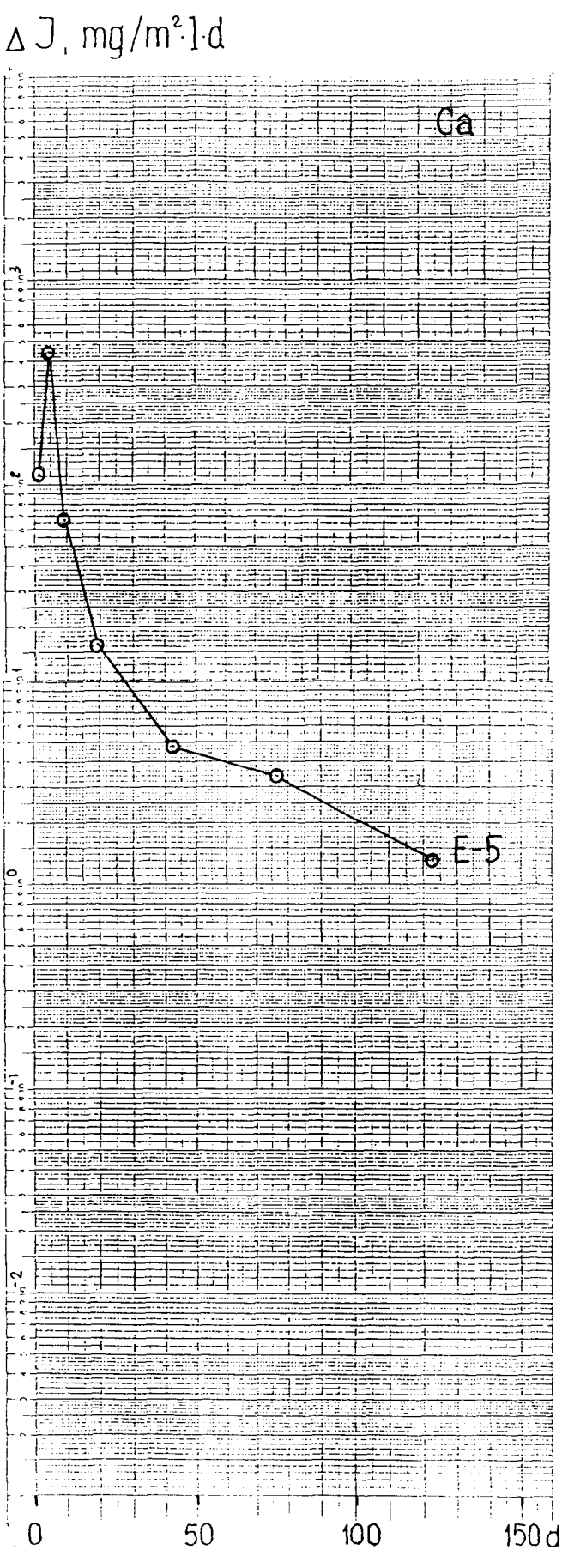


Fig. 11-5

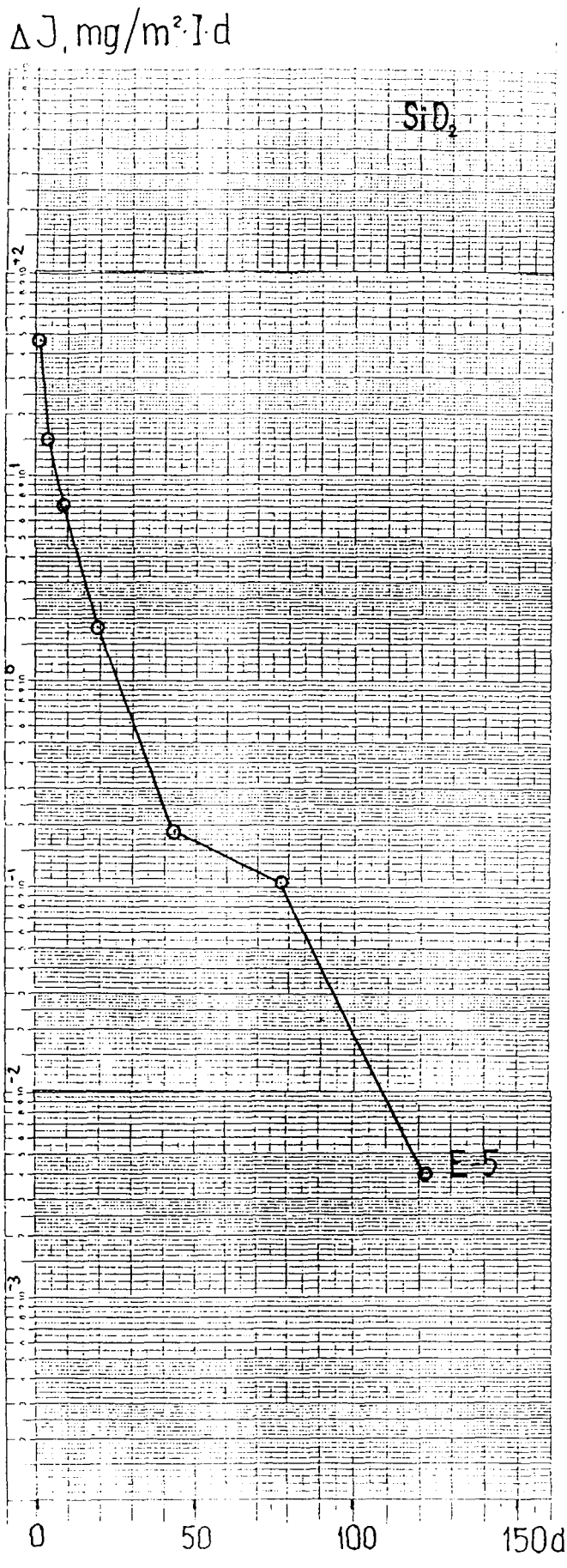


Fig. 11-6

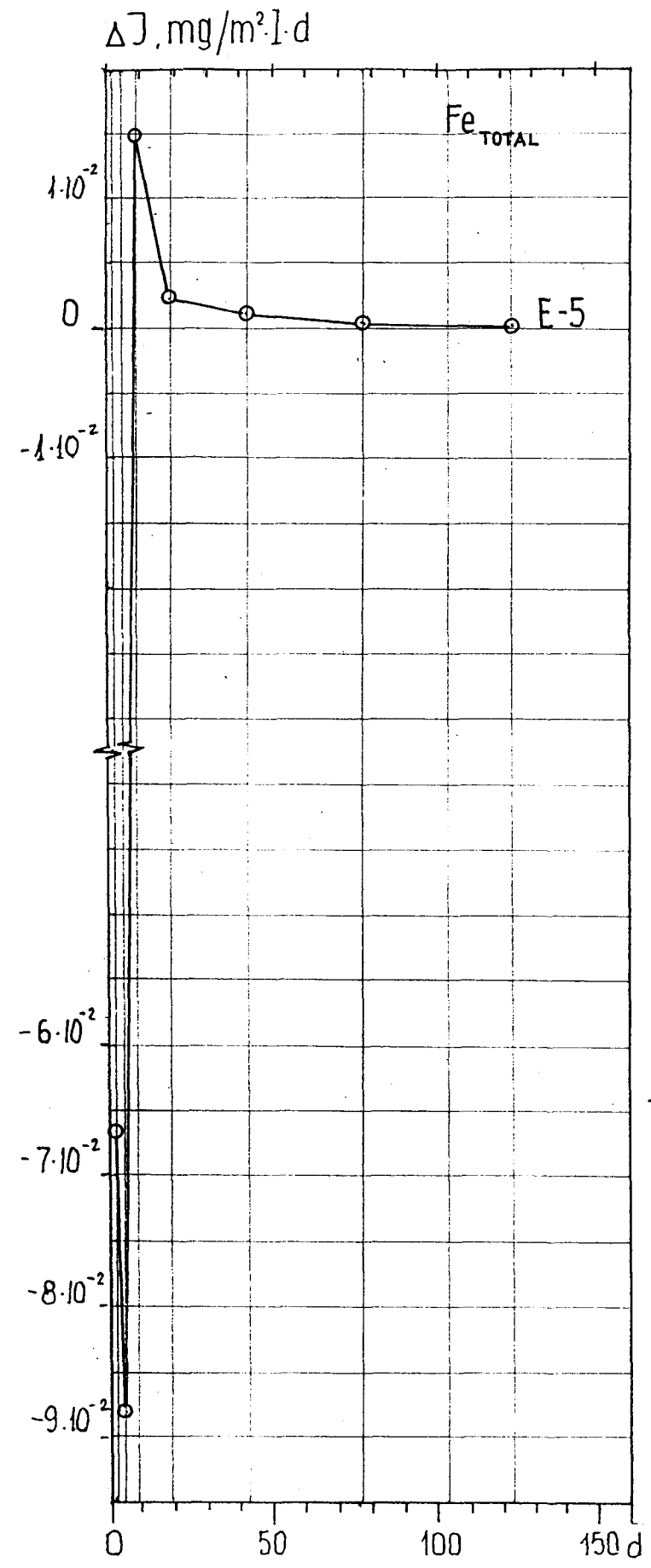


Fig. 11-7

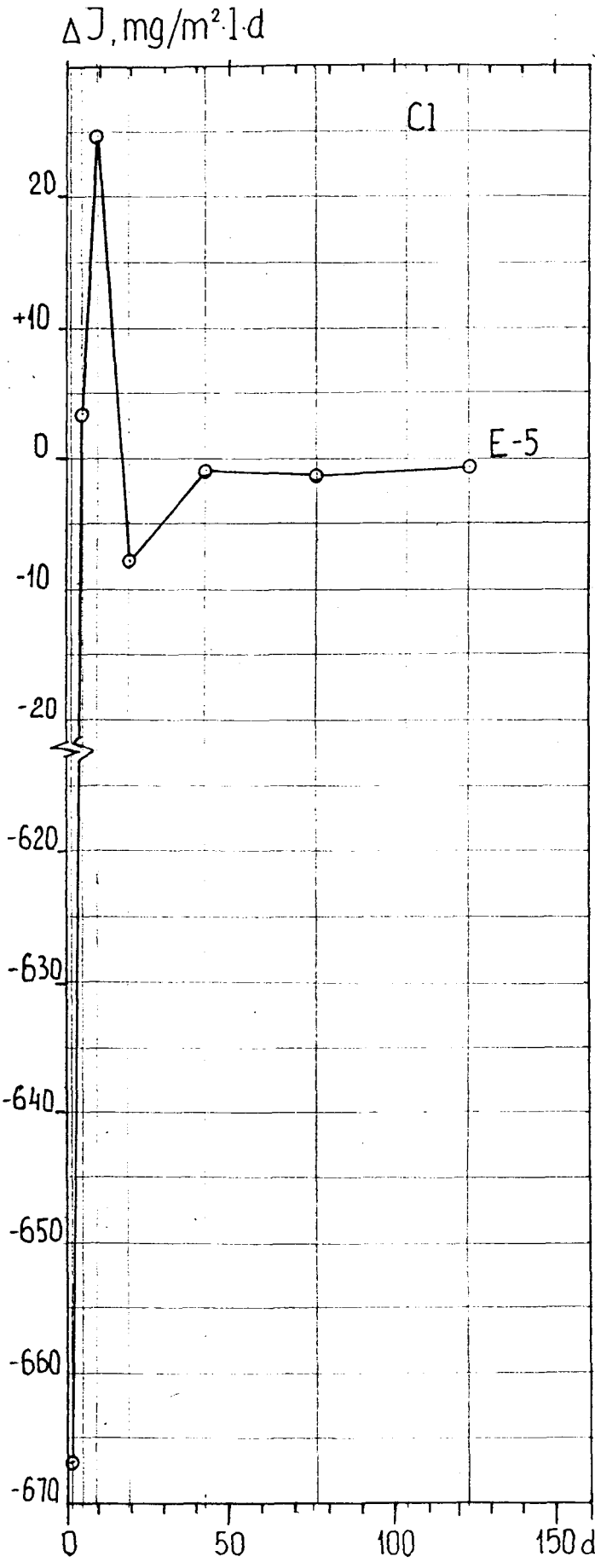


Fig. 11-8

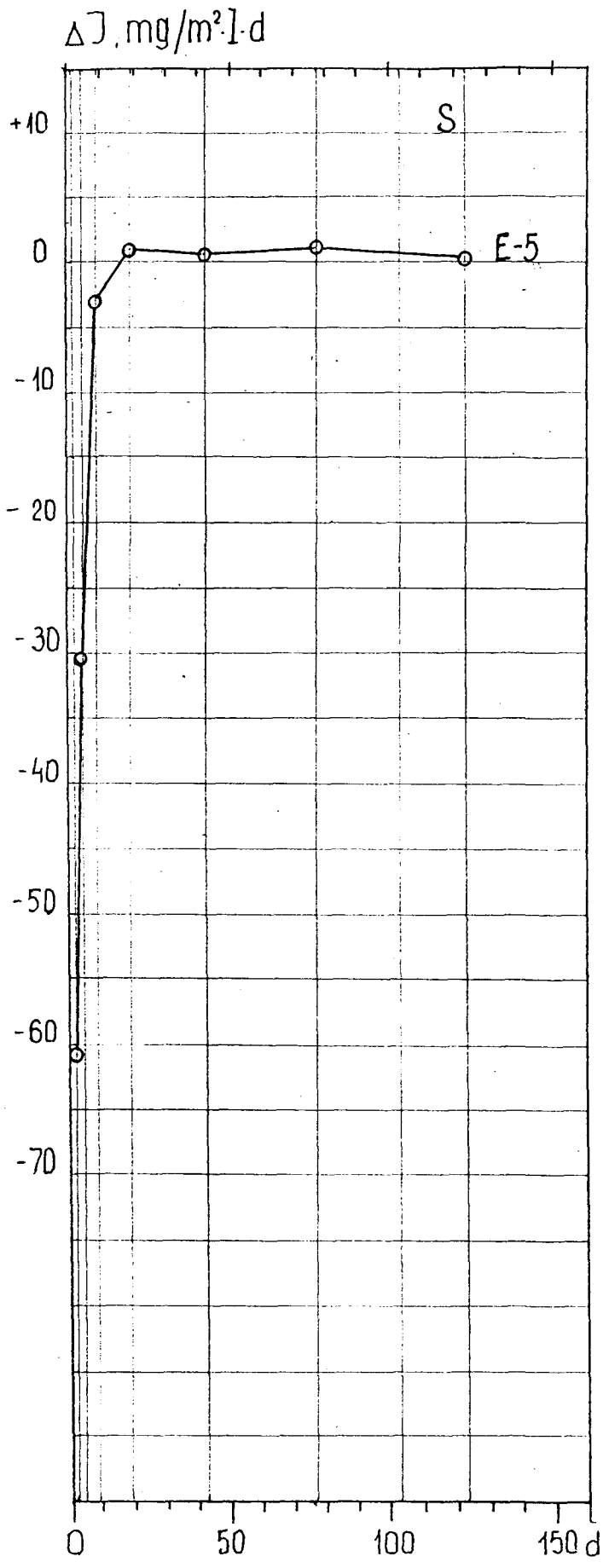
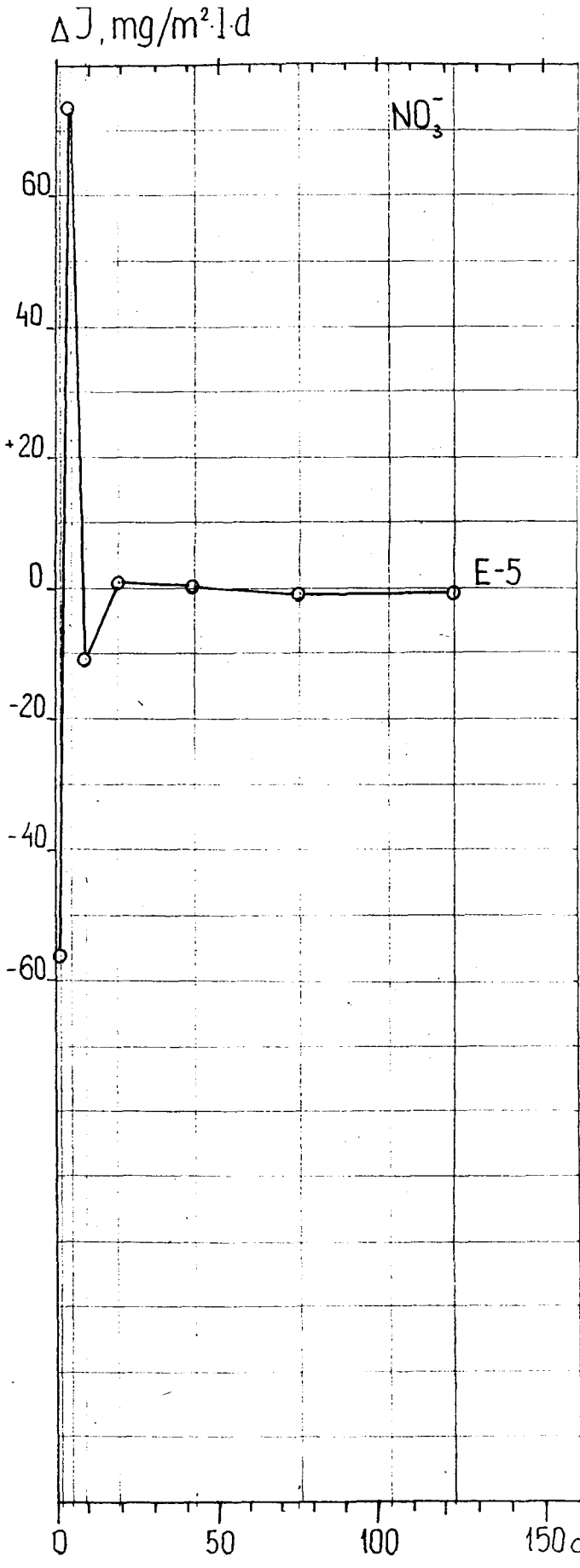


Fig. 11-9



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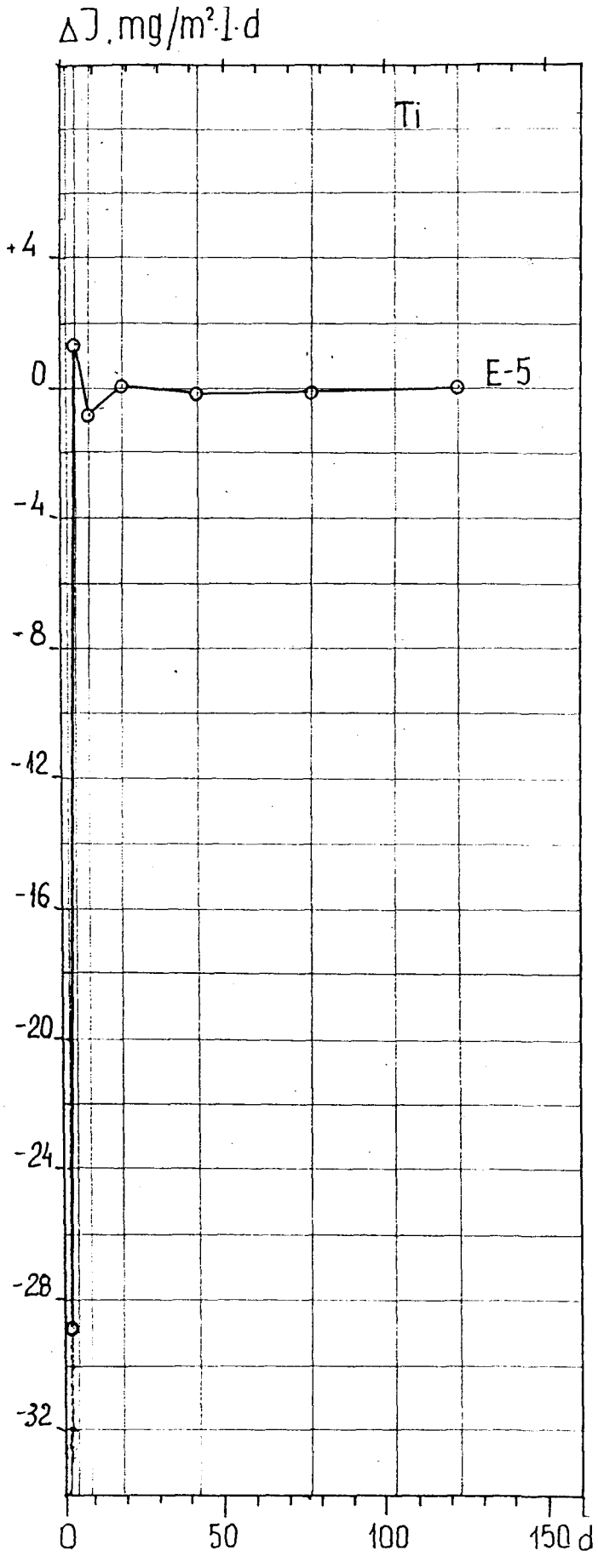


Fig. 11-11

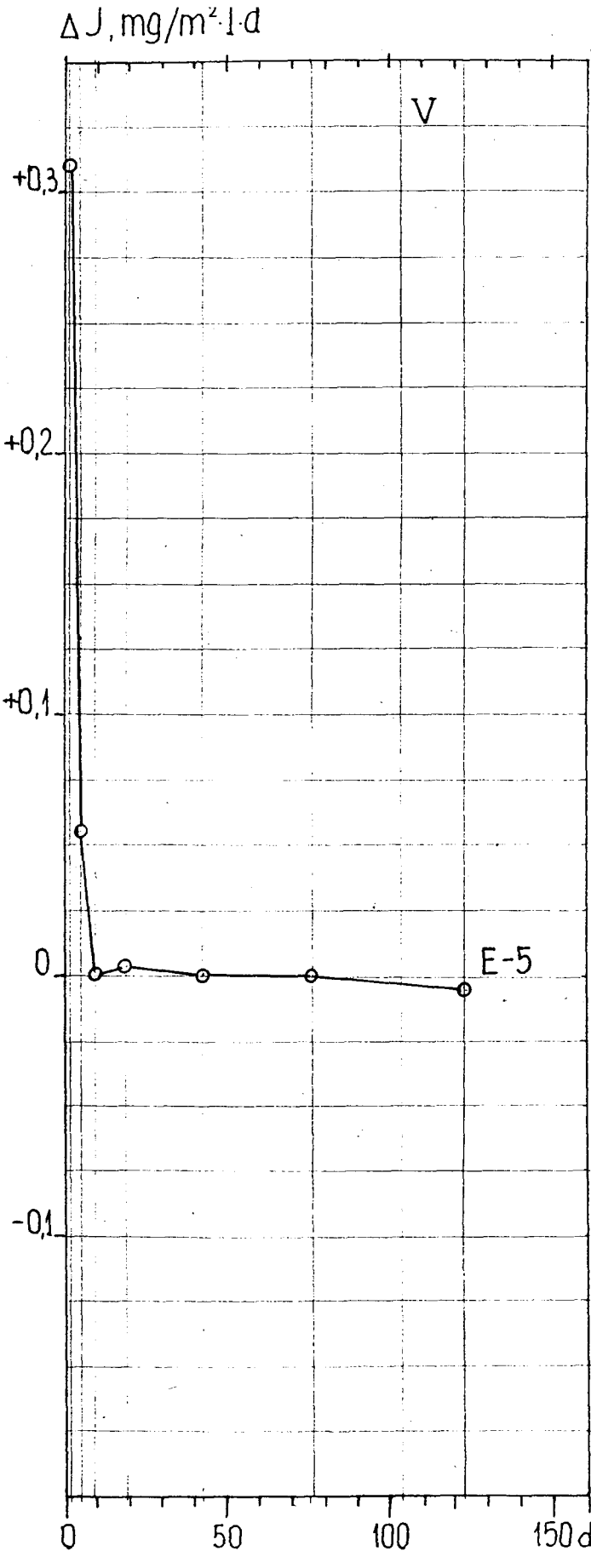


Fig. 11-12

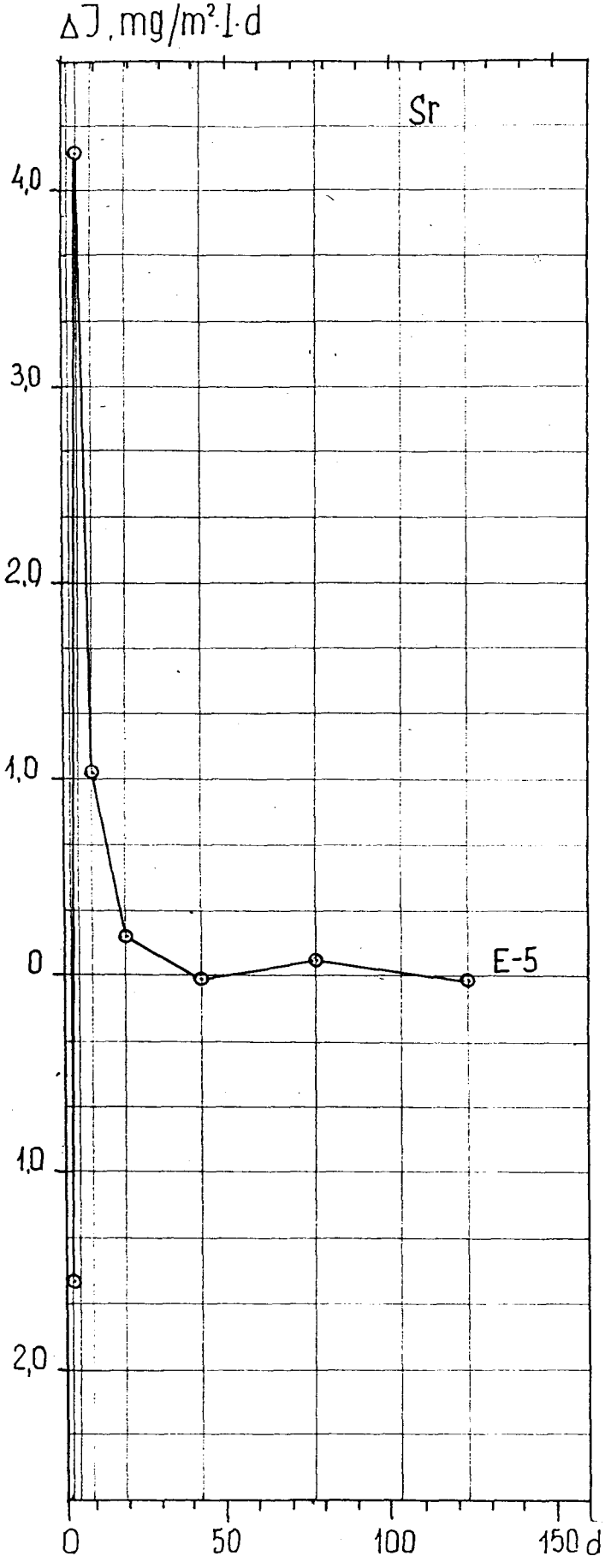


Fig. 11-13

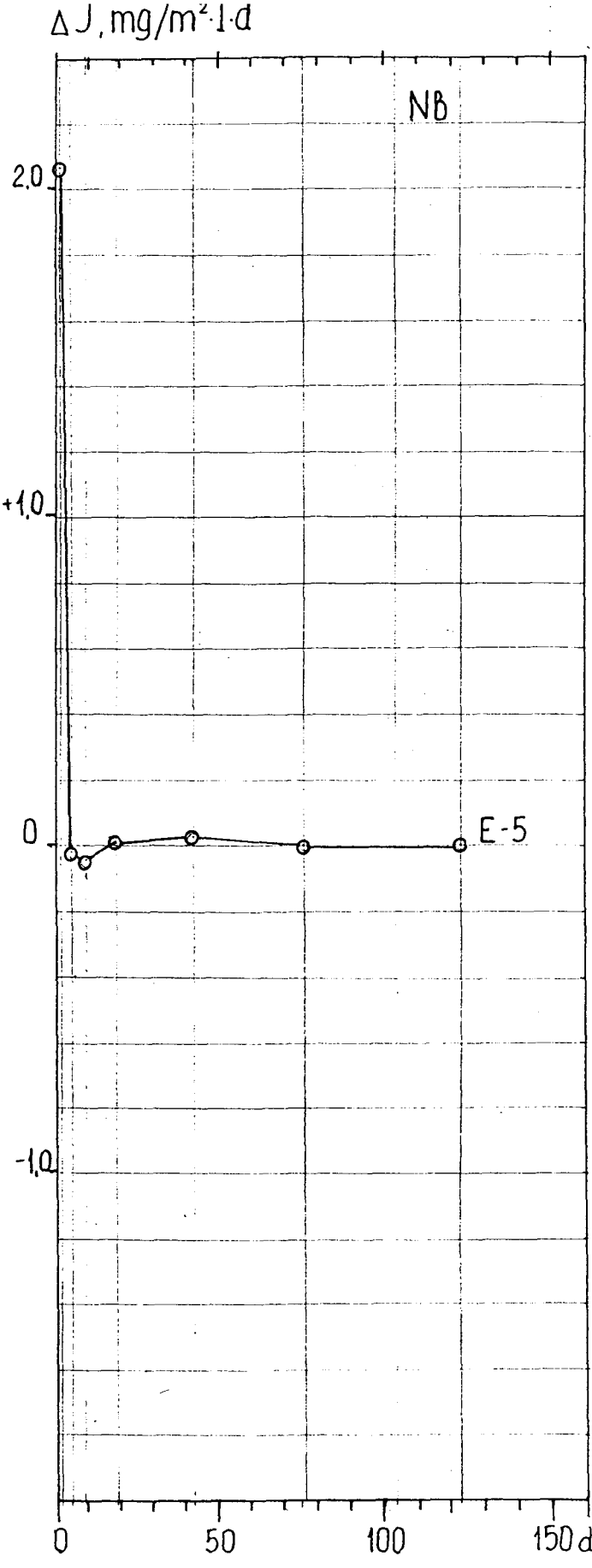
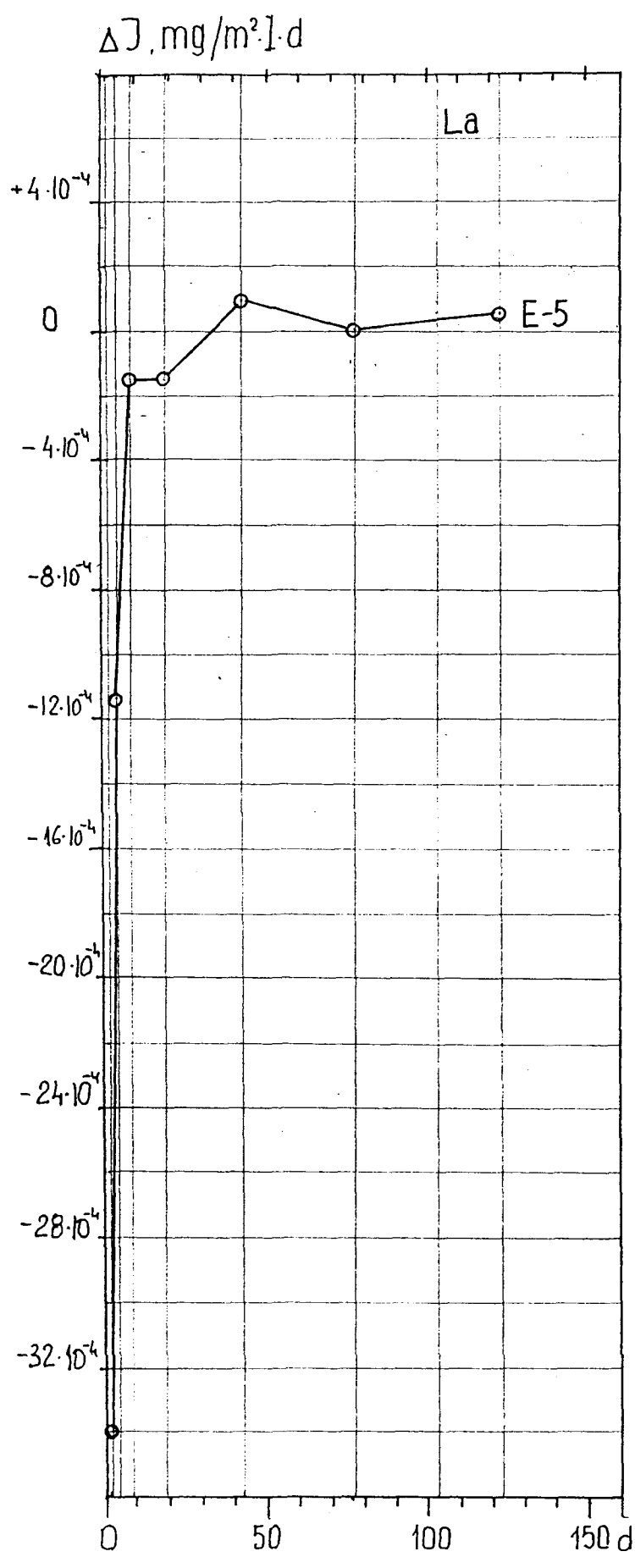


Fig. 11-14



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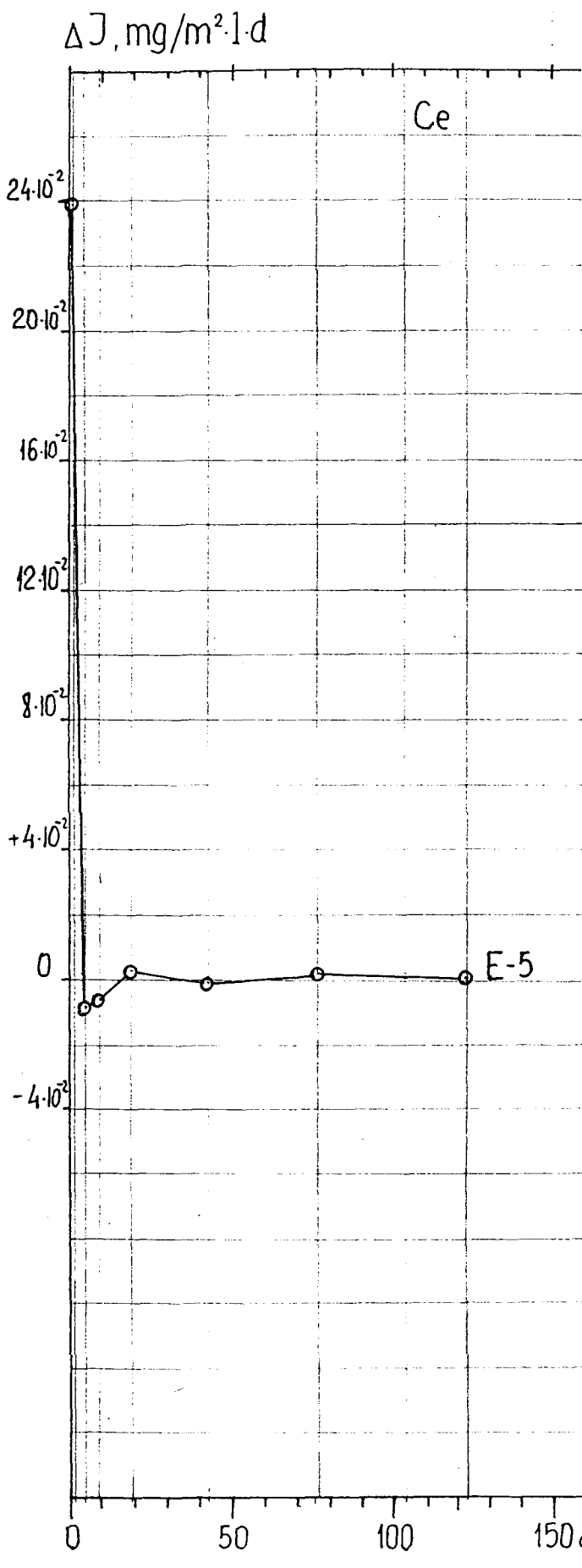


Fig. 11-16

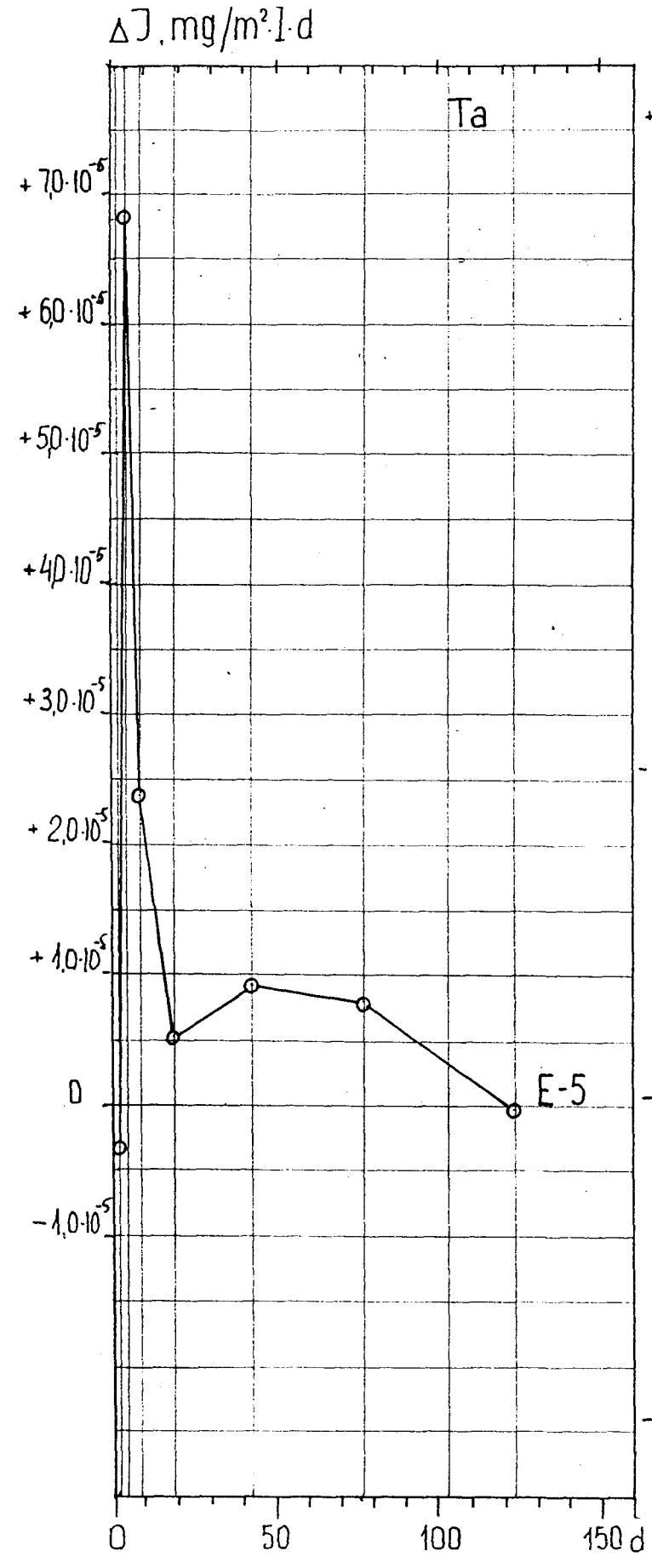


Fig. 11-17

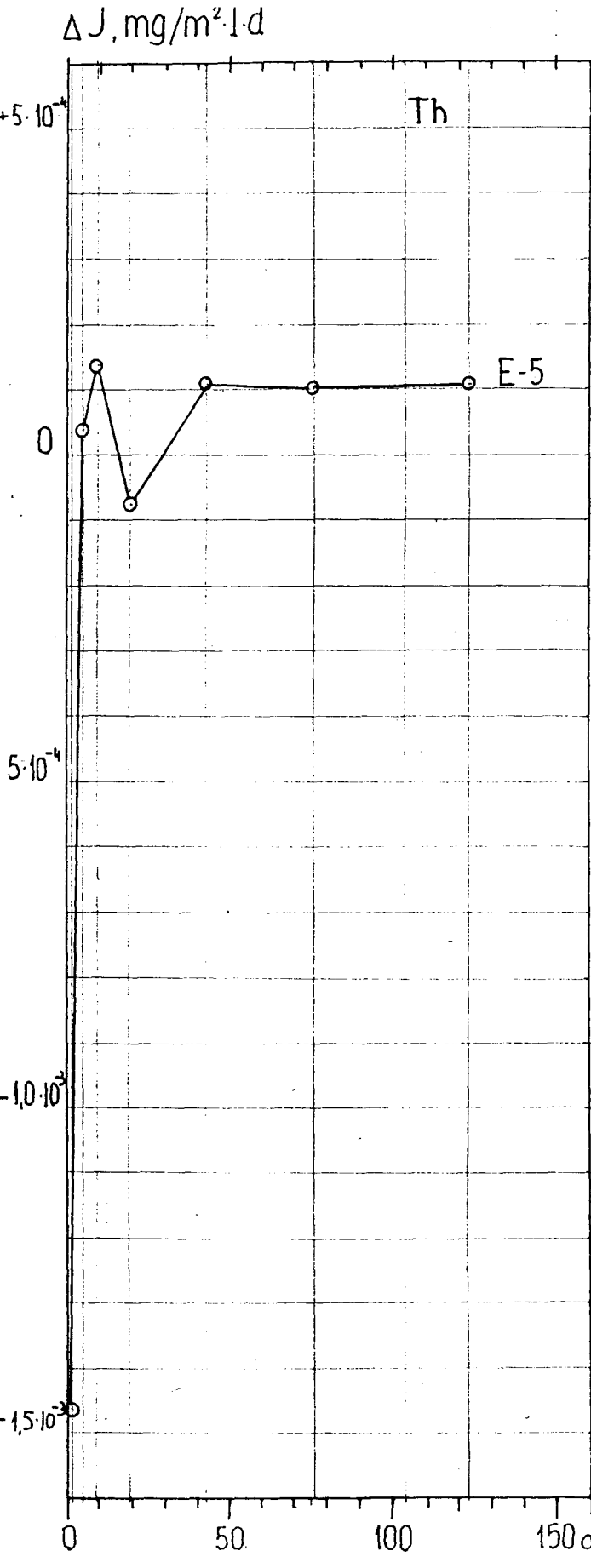


Fig. 11-18

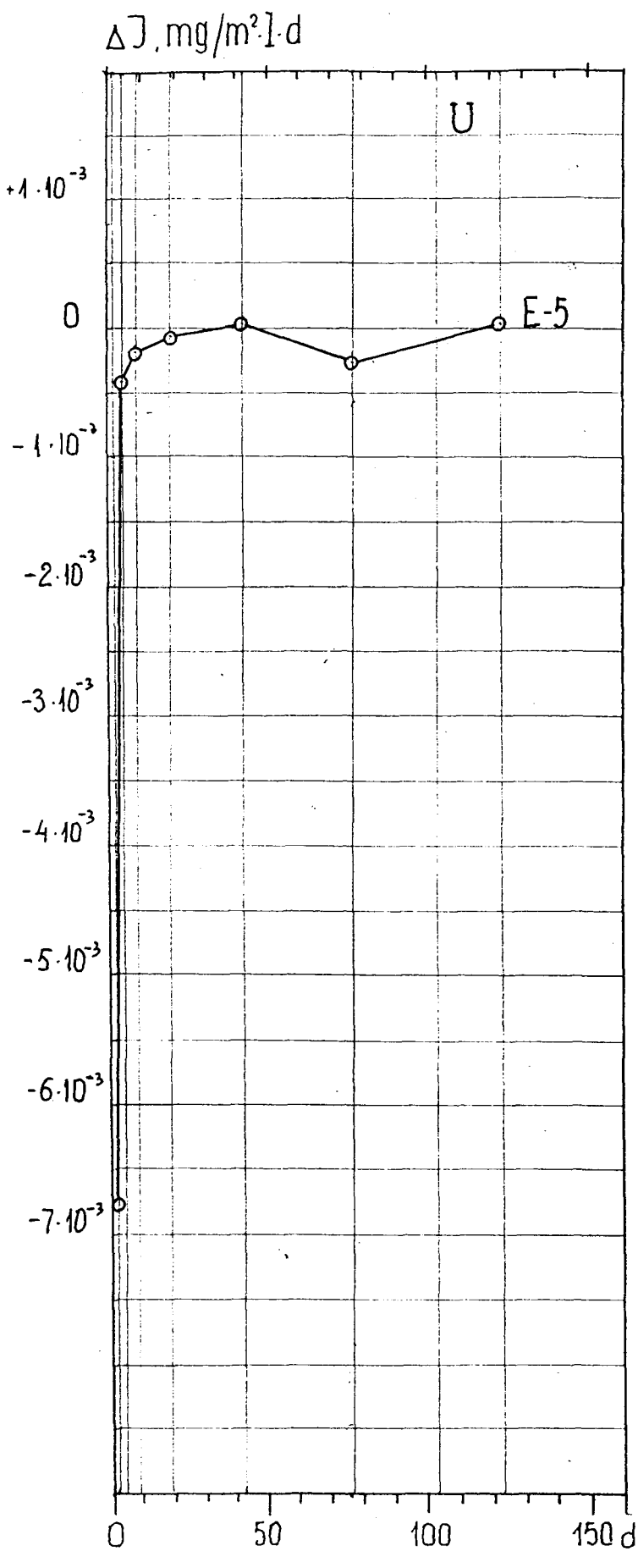


Fig. 11-19

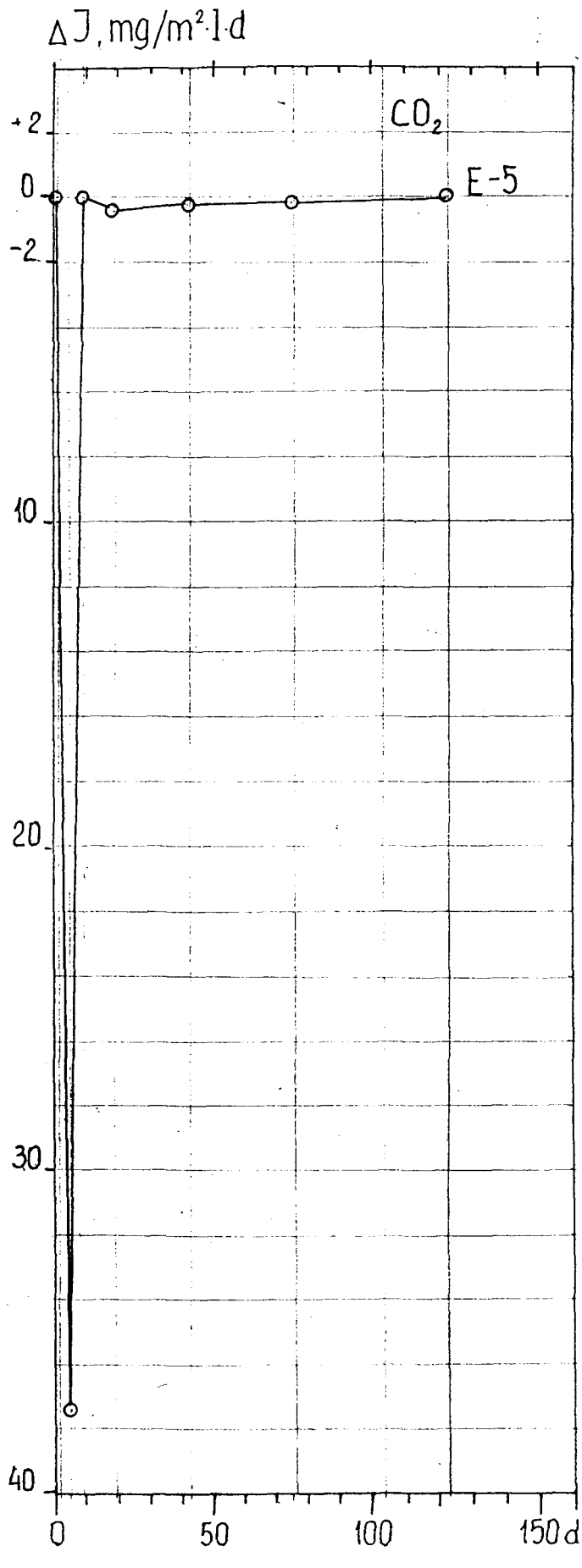


Fig. 11-20

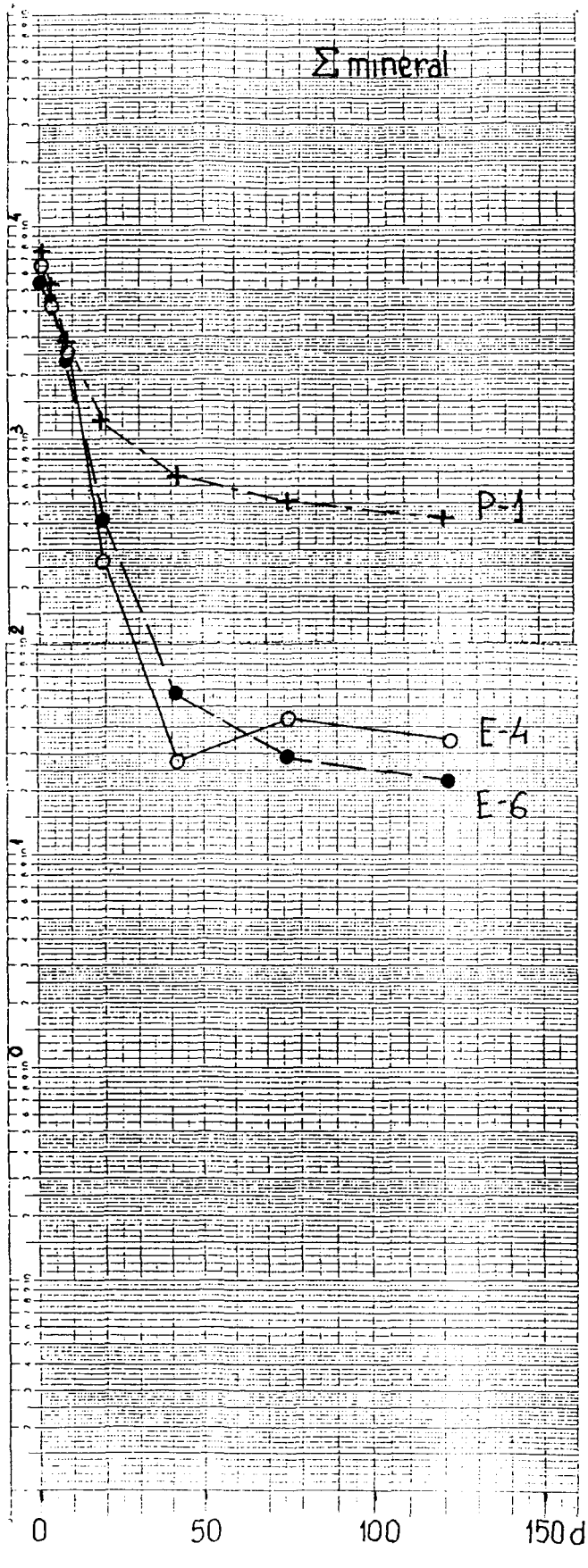


Fig. 12-1

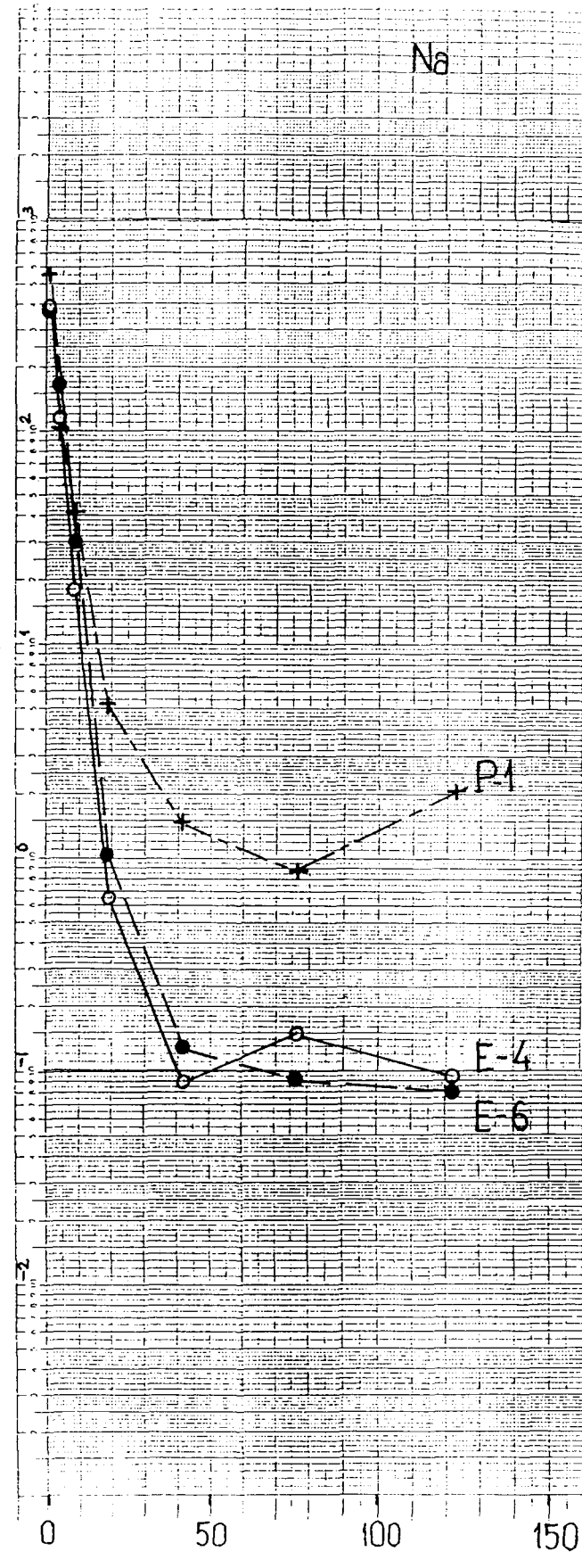


Fig. 12-2

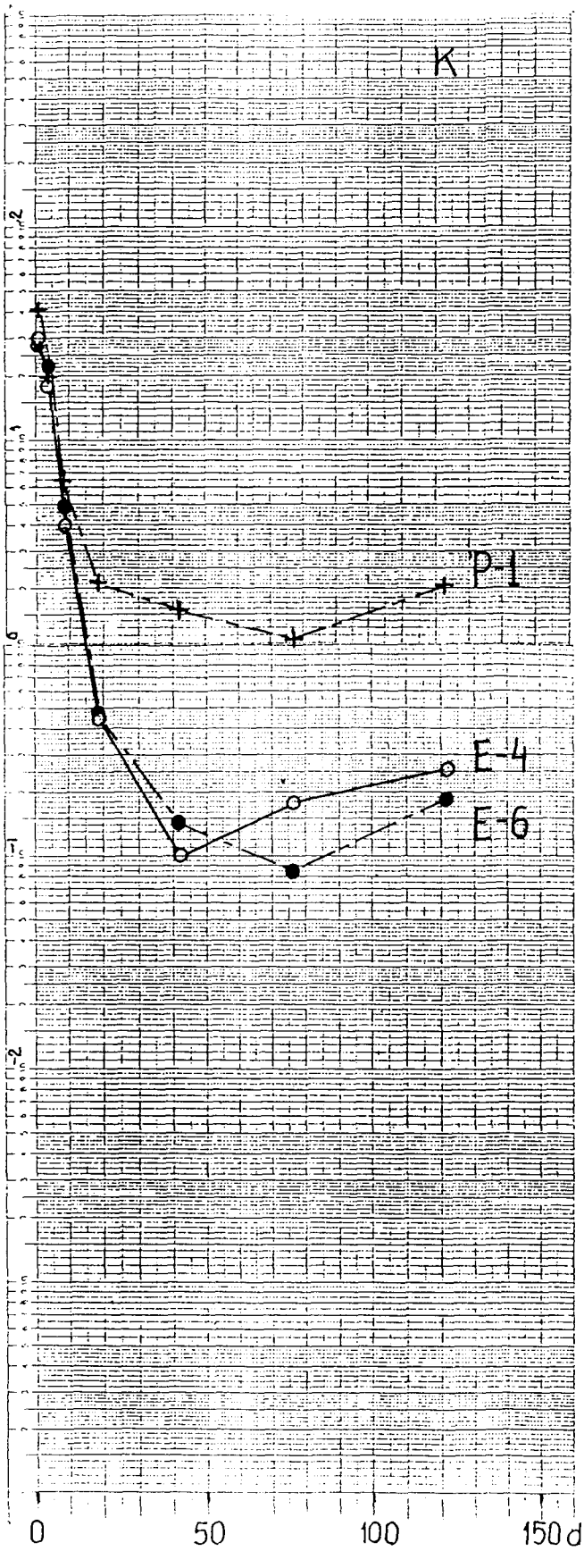
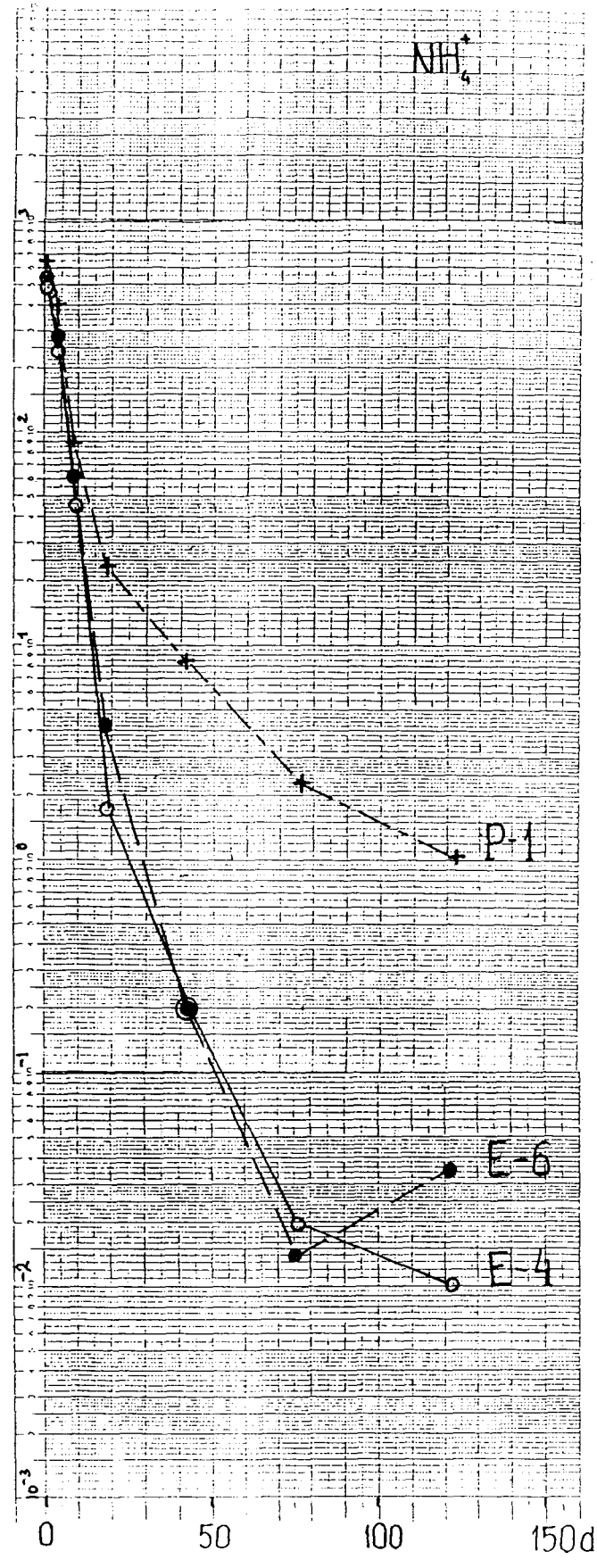


Fig. 12-3



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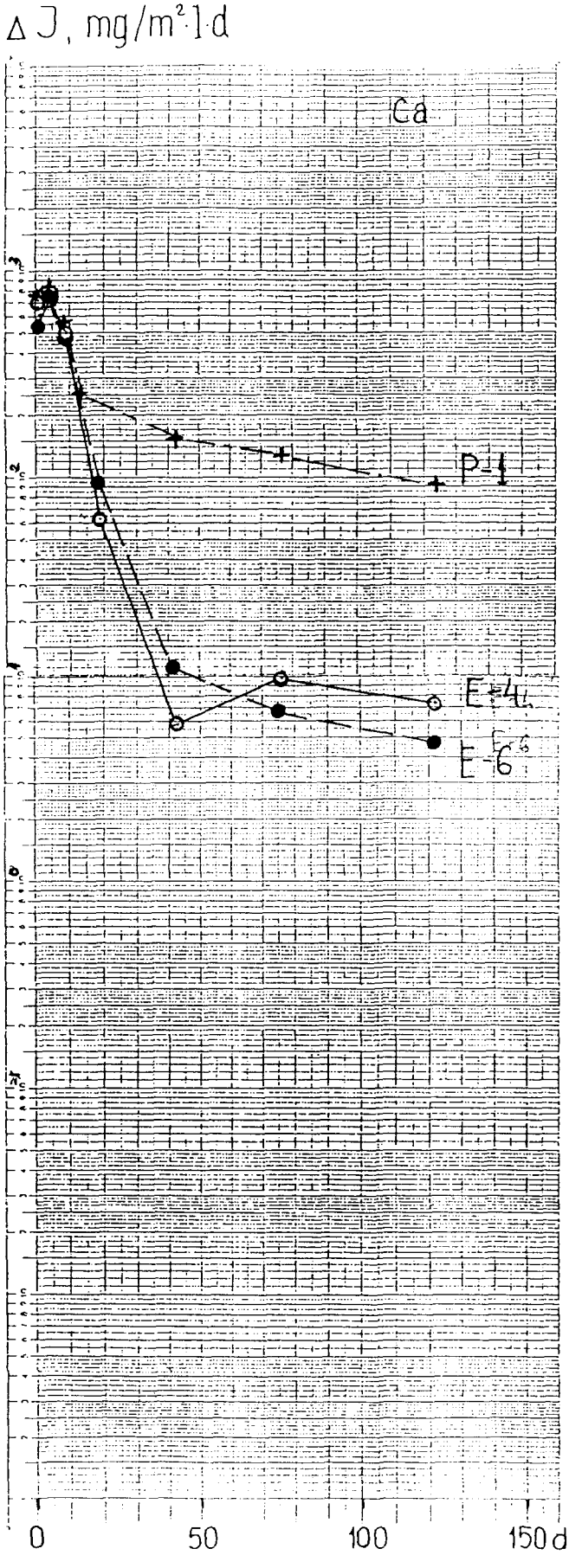


Fig. 12-5

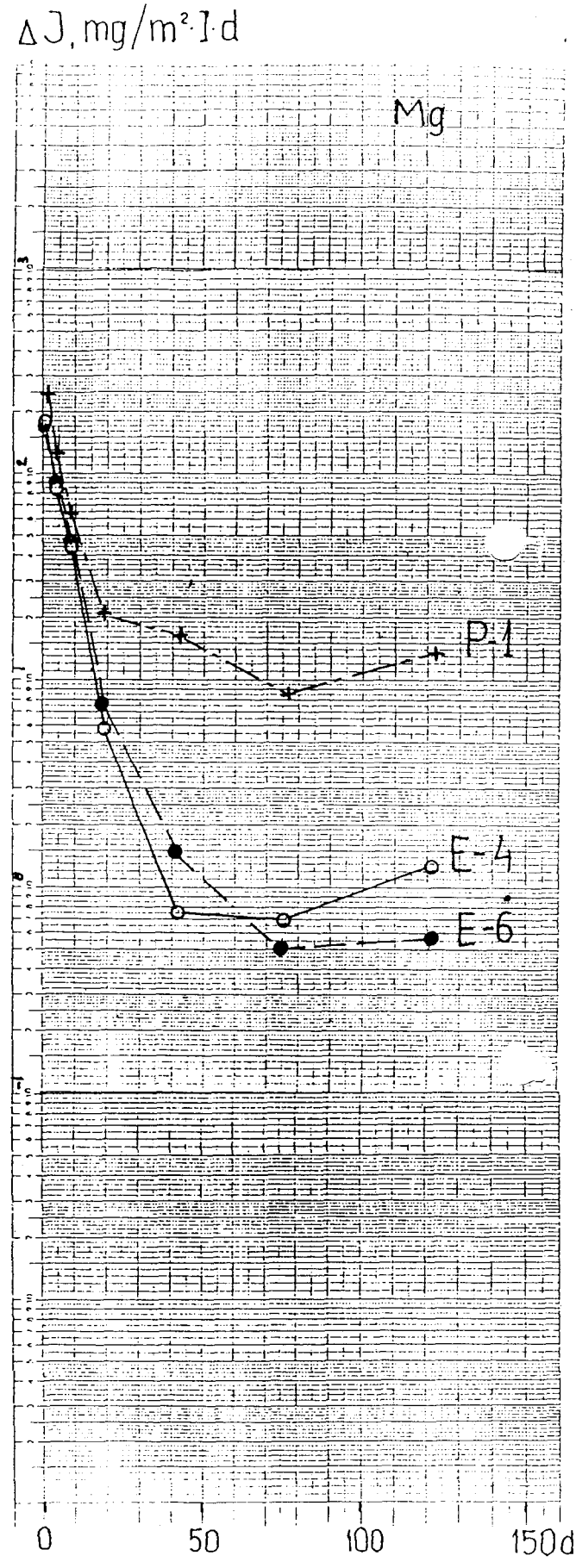
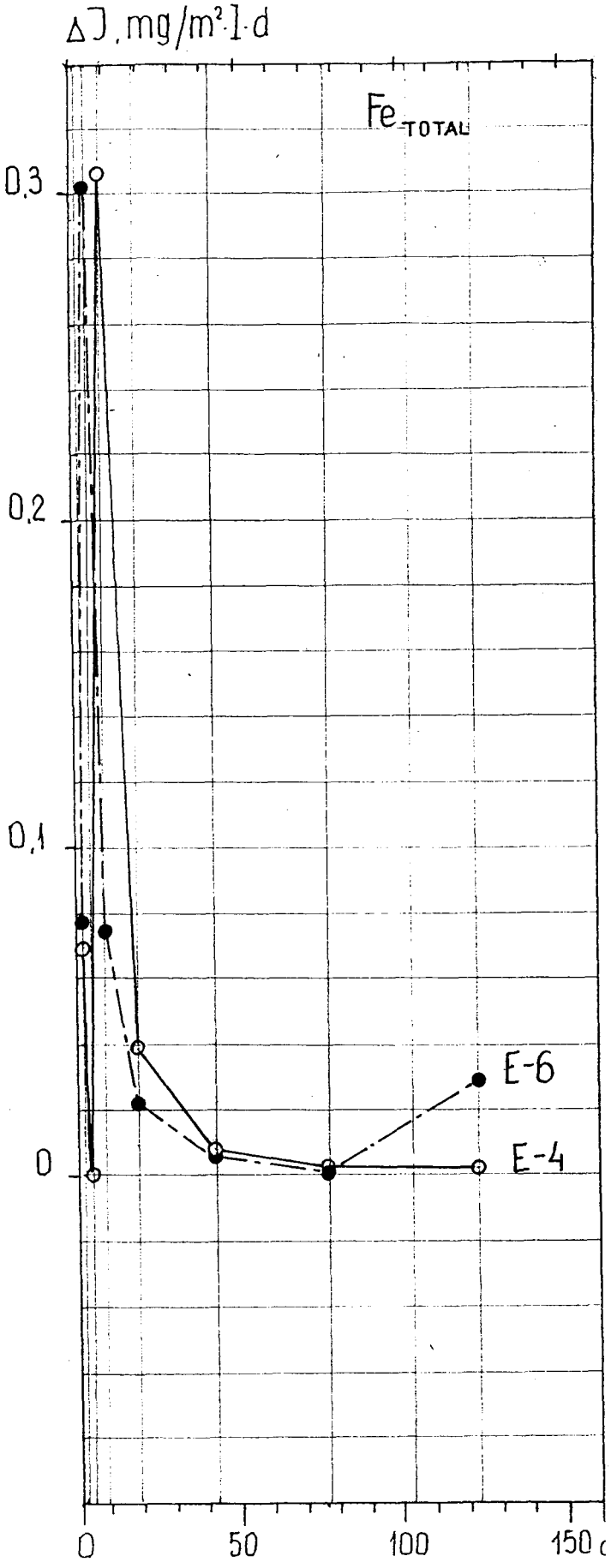


Fig. 12-6



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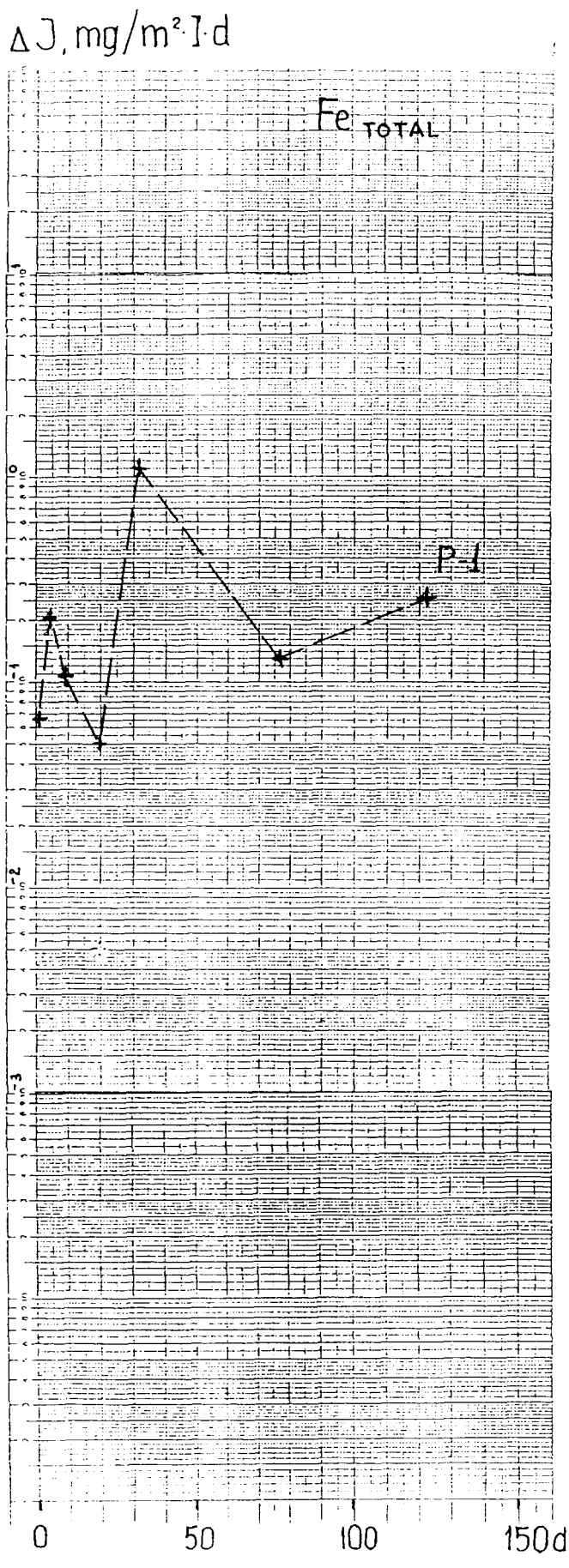

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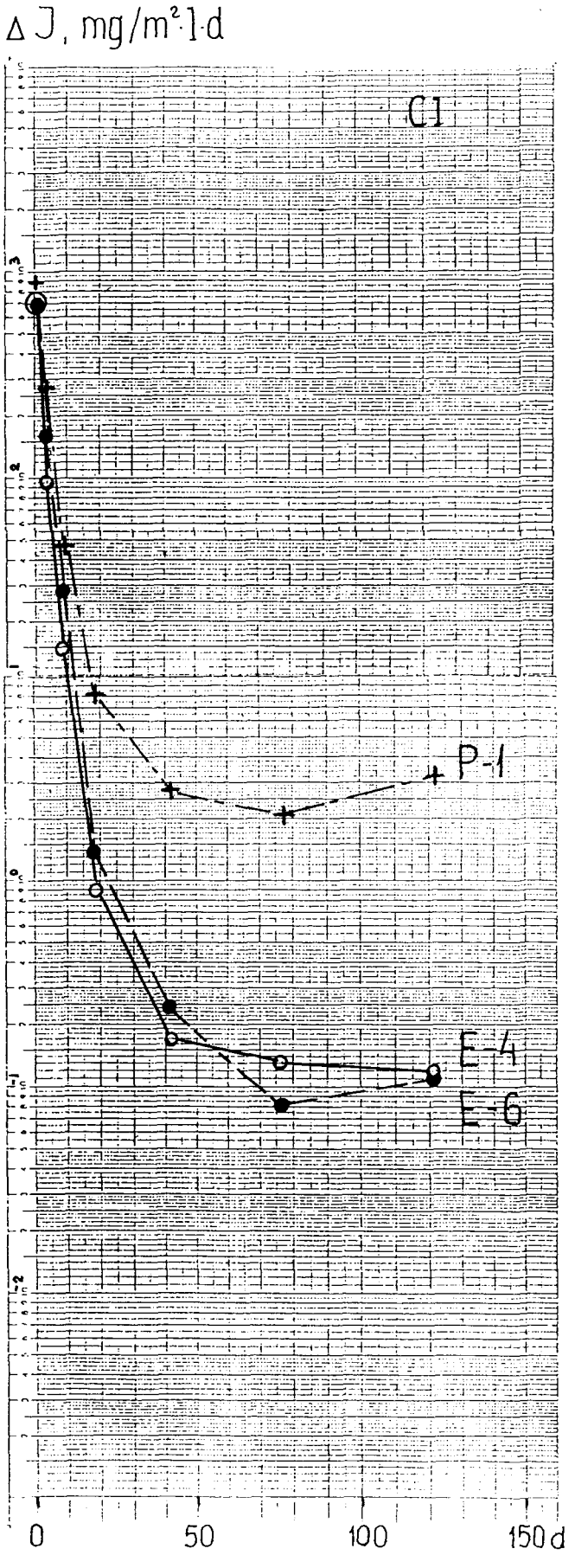

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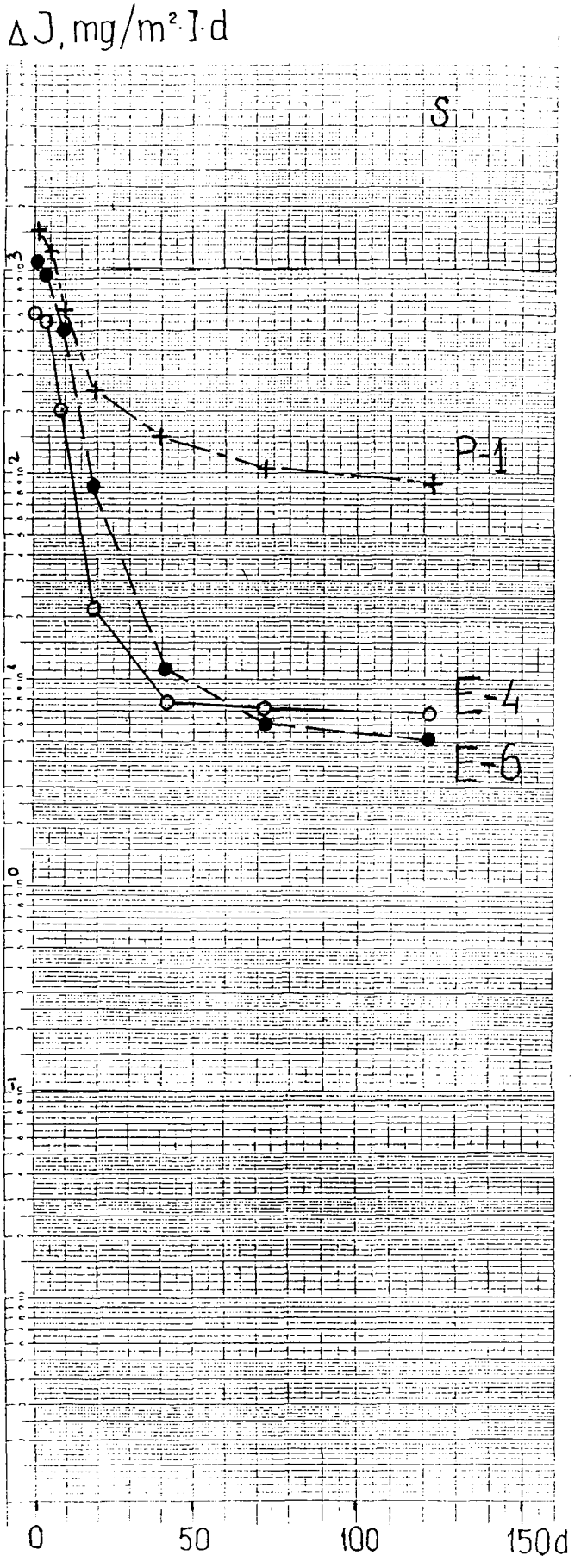


Fig. 12-10

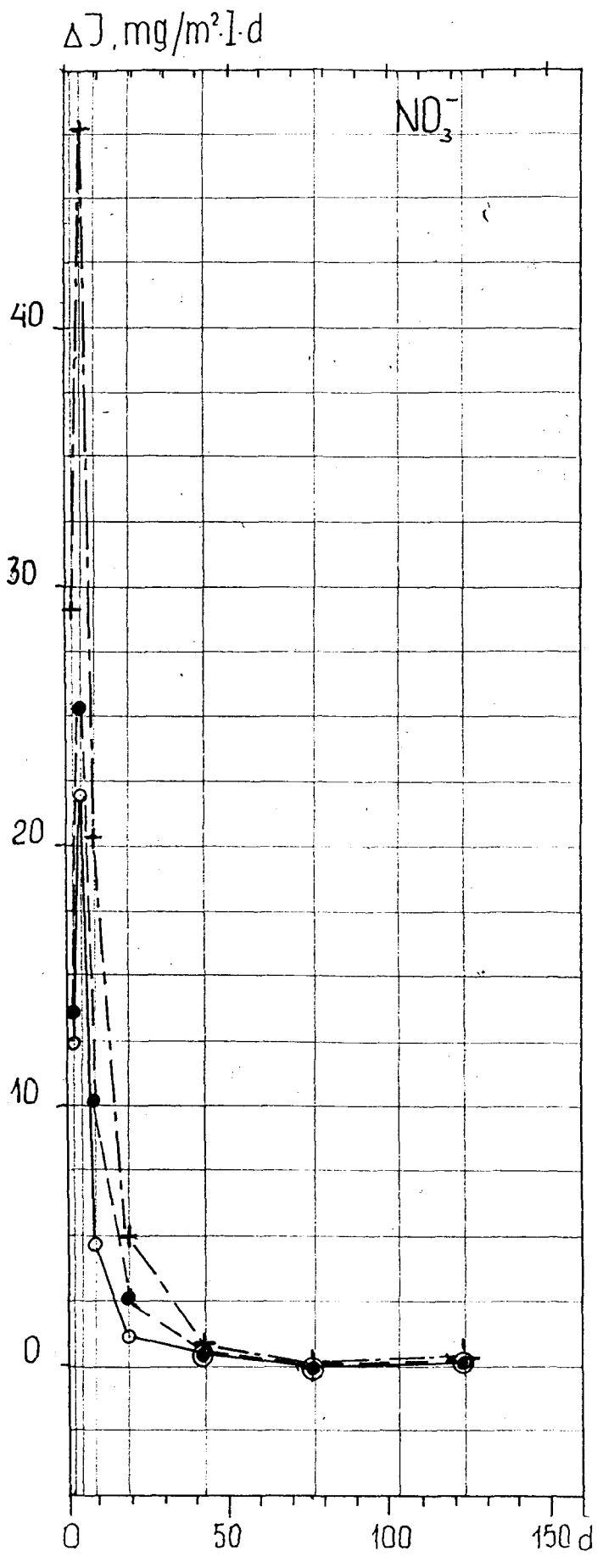


Fig. 12-11

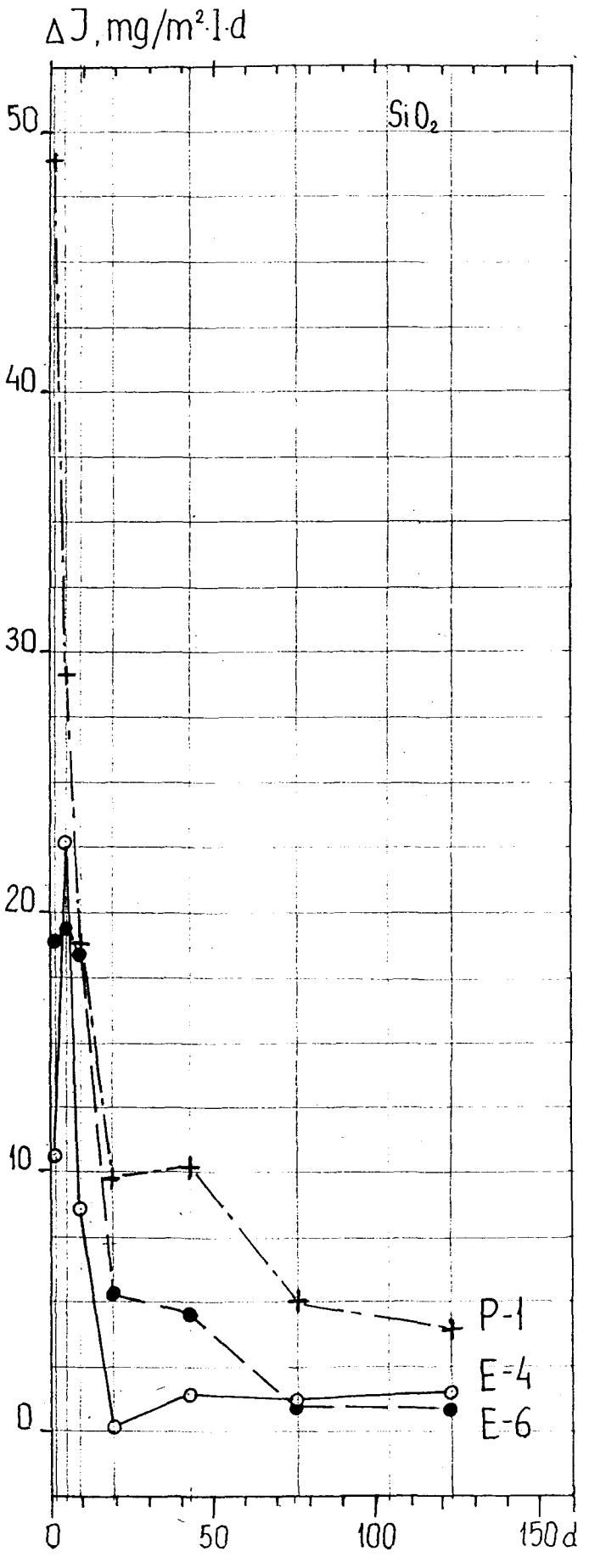


Fig. 12-12

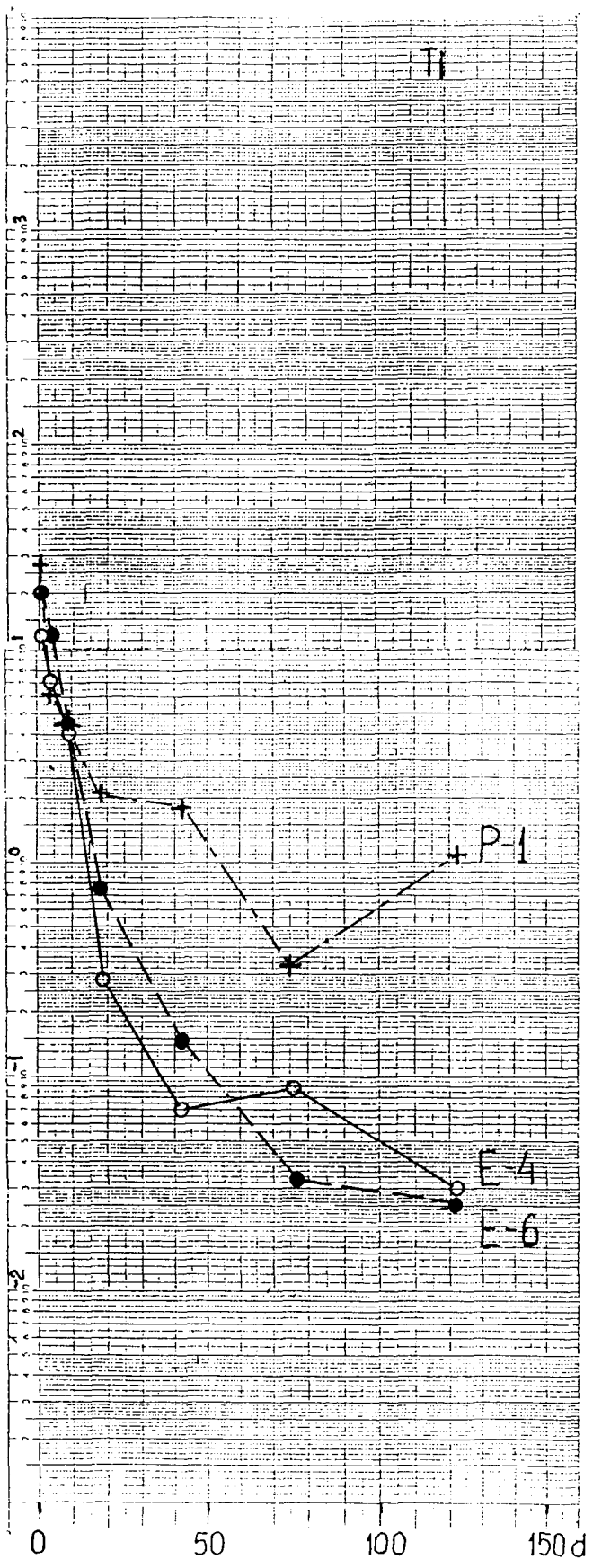


Fig. 12-13

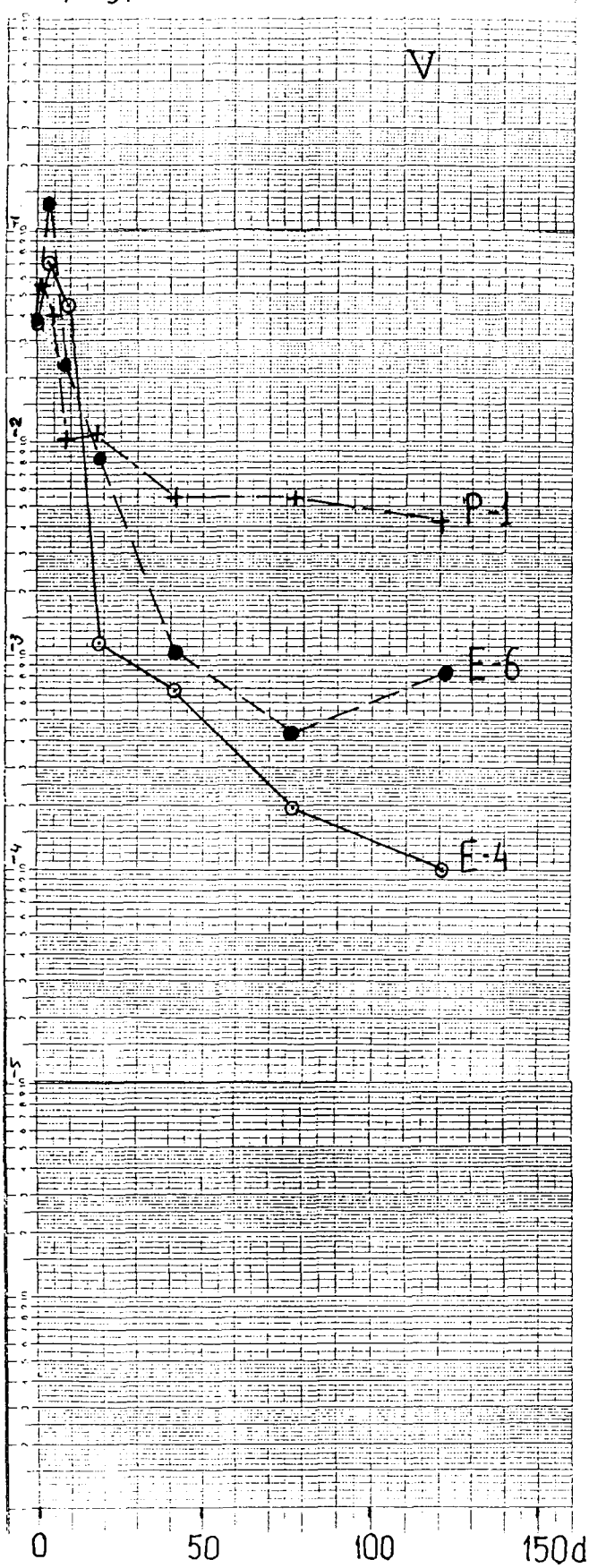


Fig.12-14

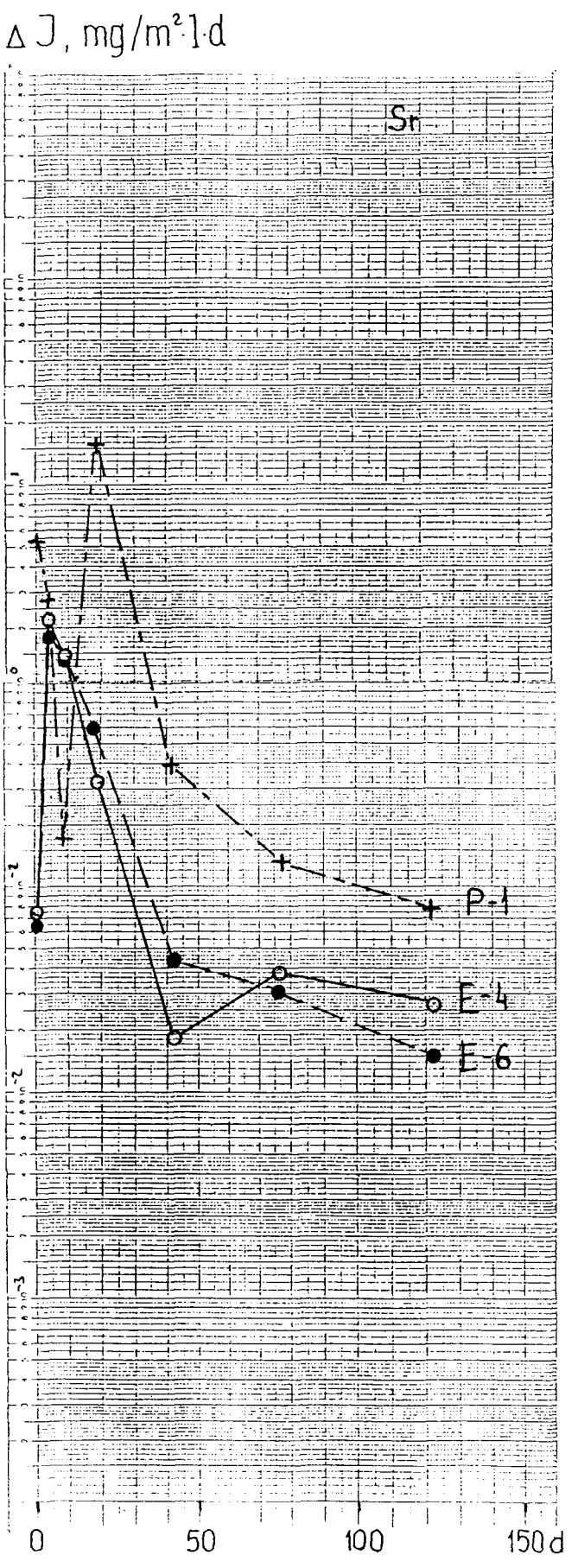


Fig. 12-15

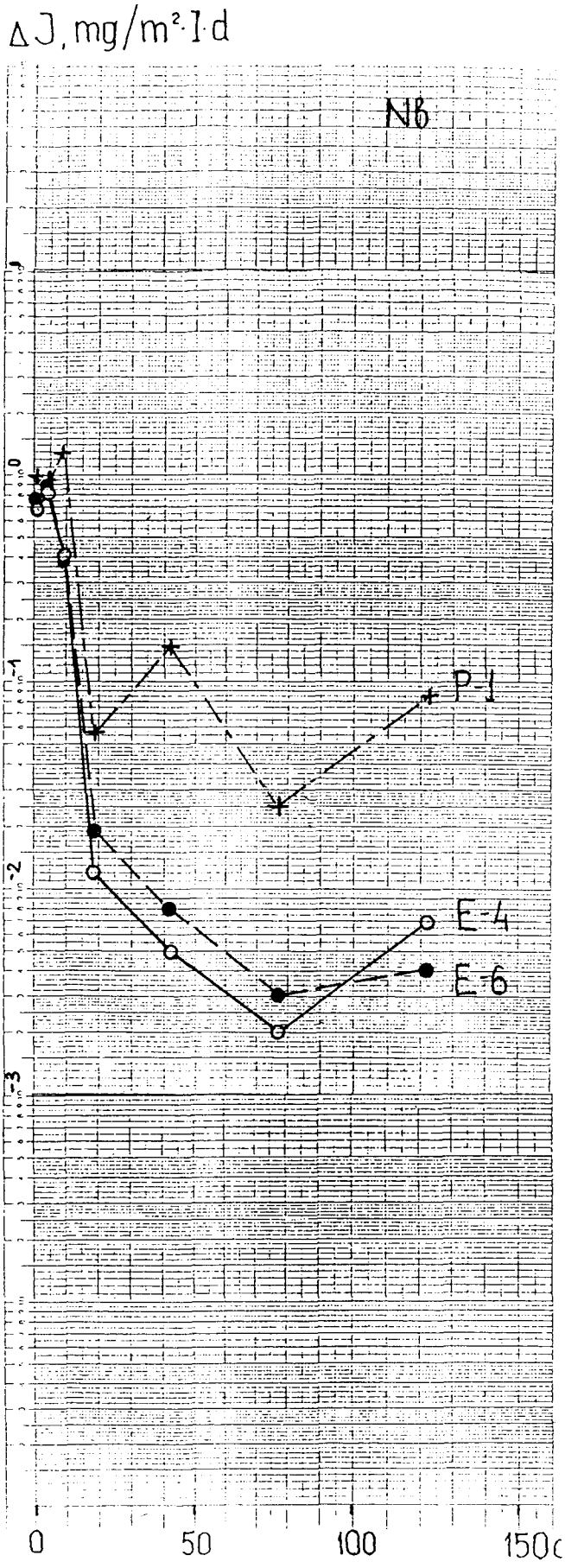
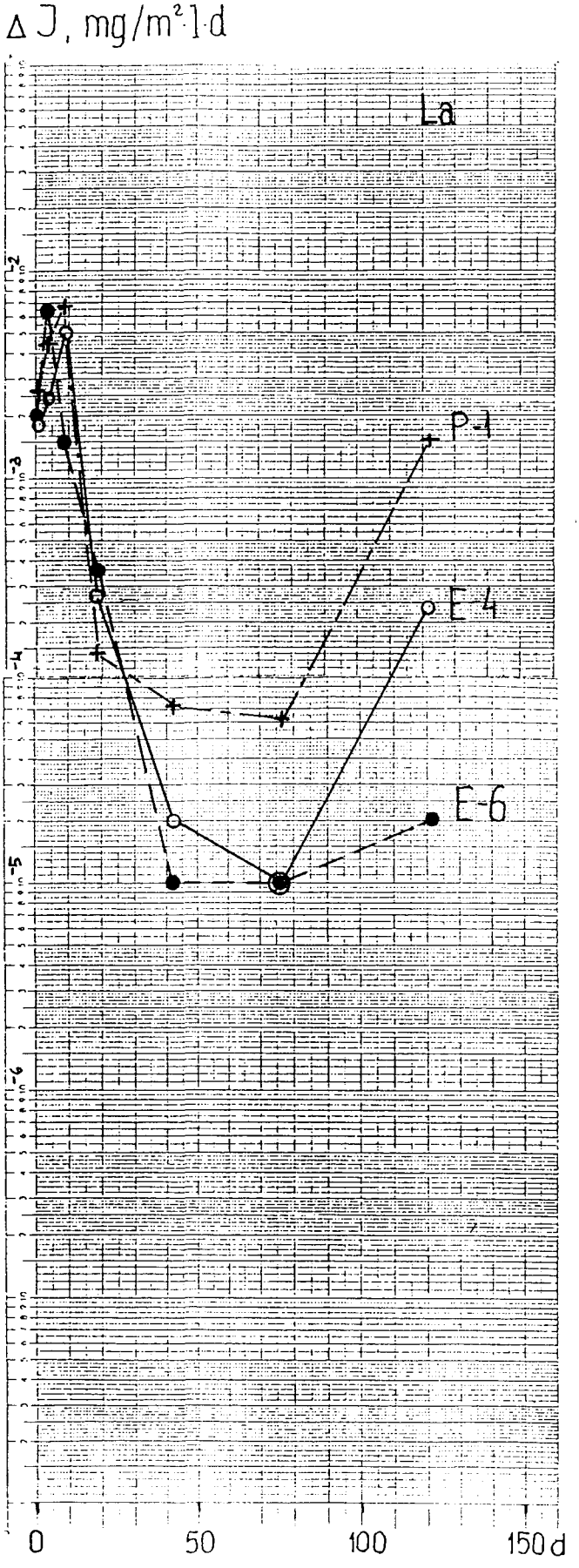


Fig. 12-16



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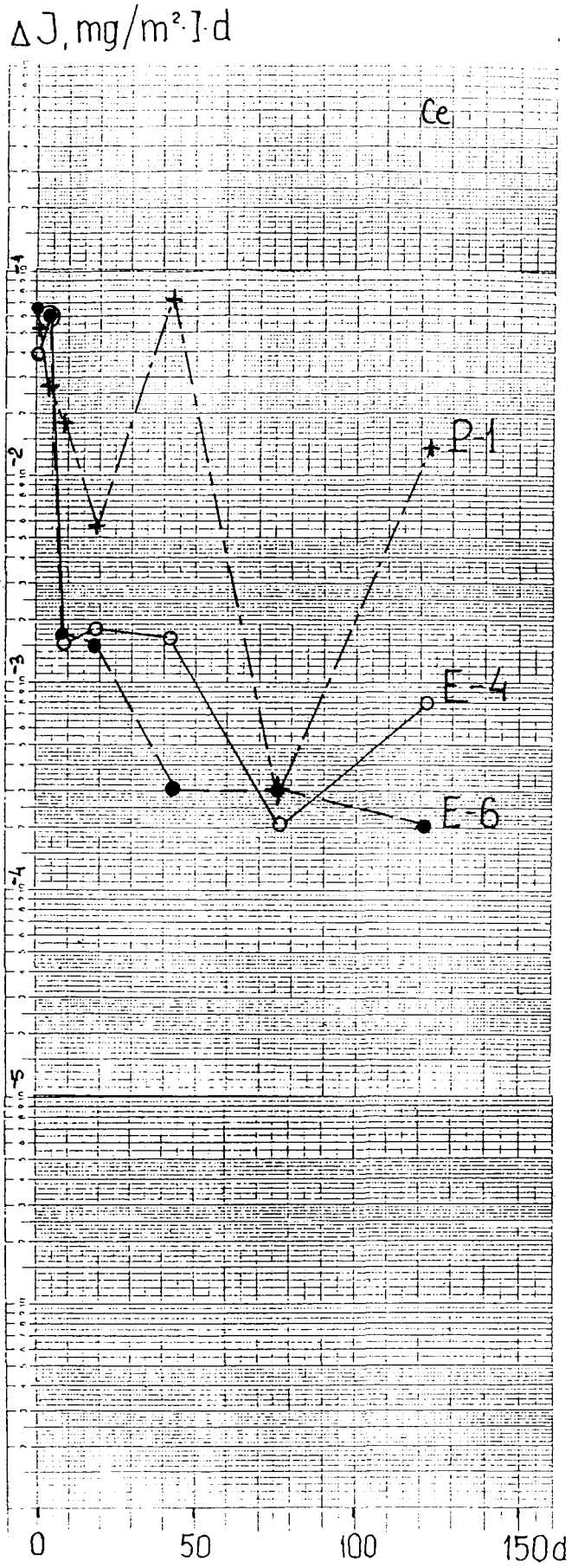

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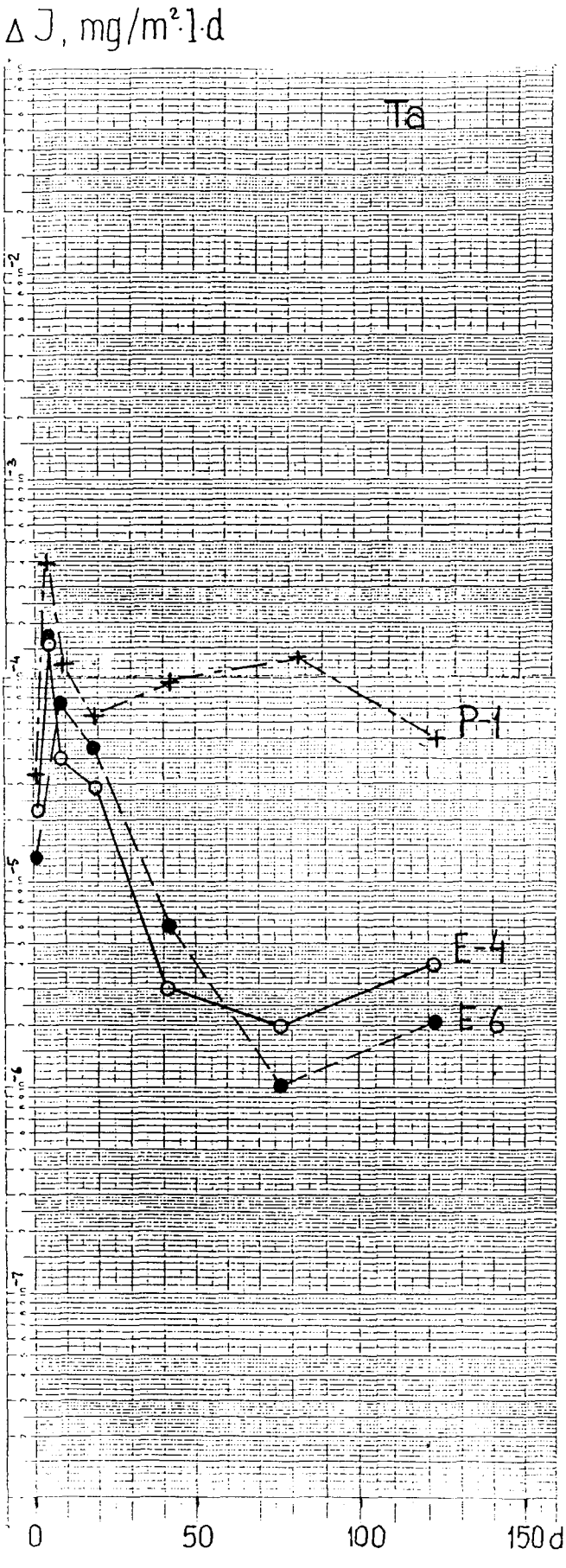

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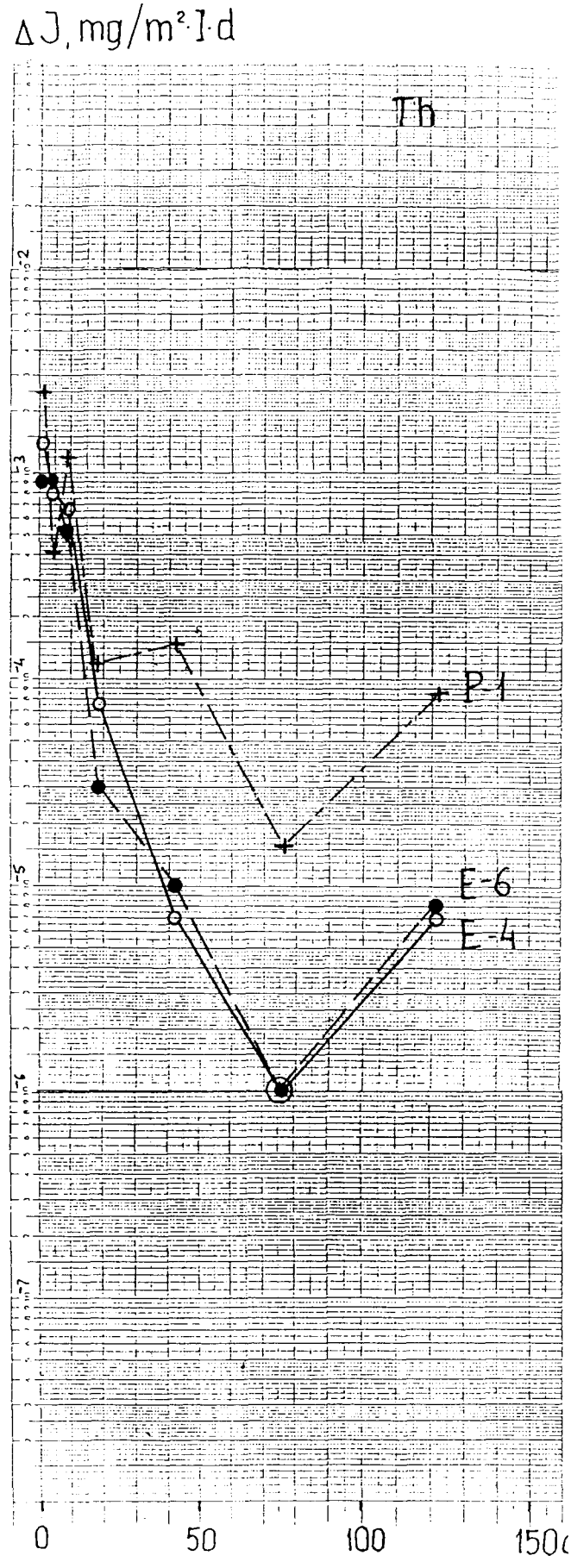

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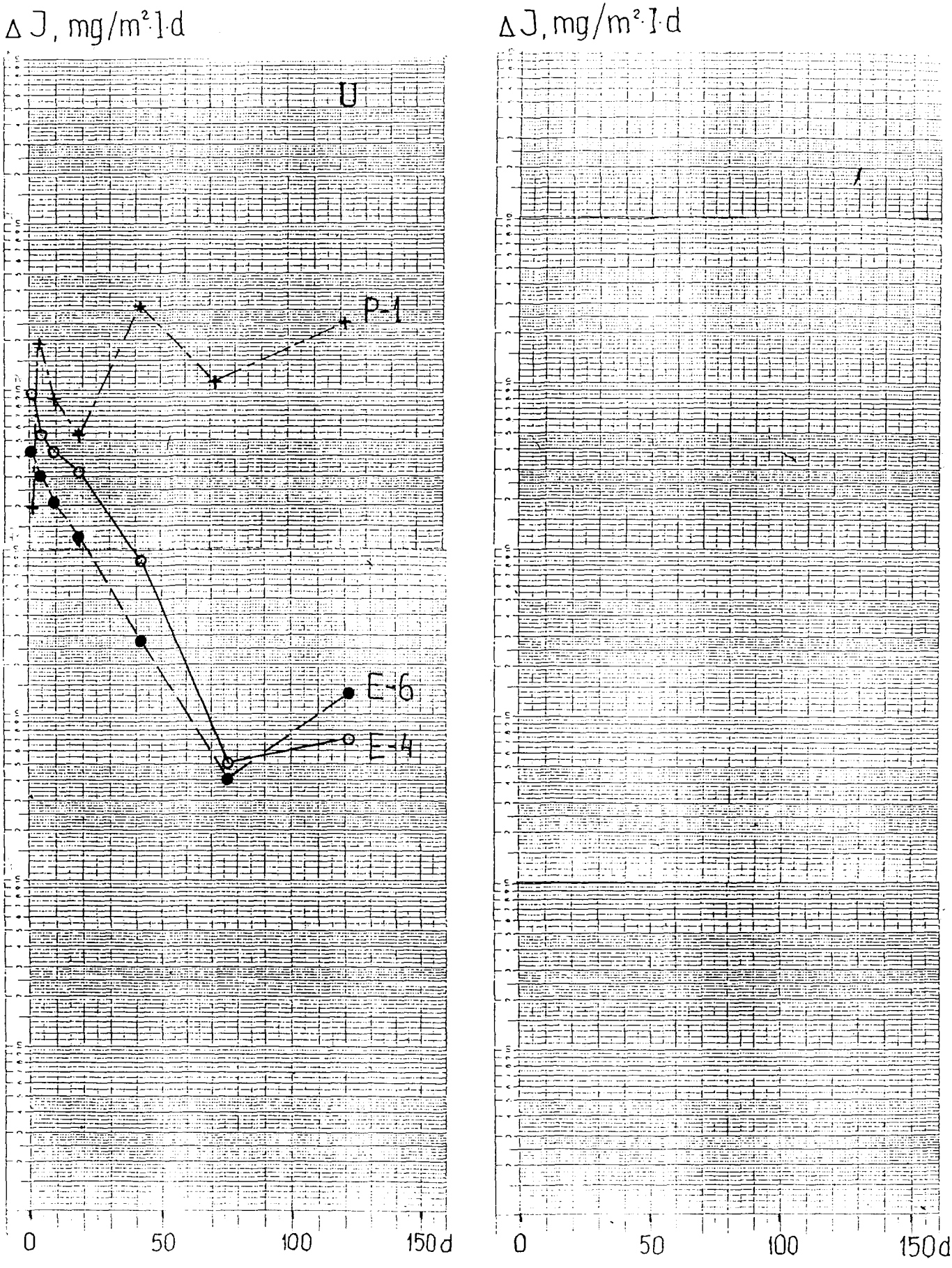

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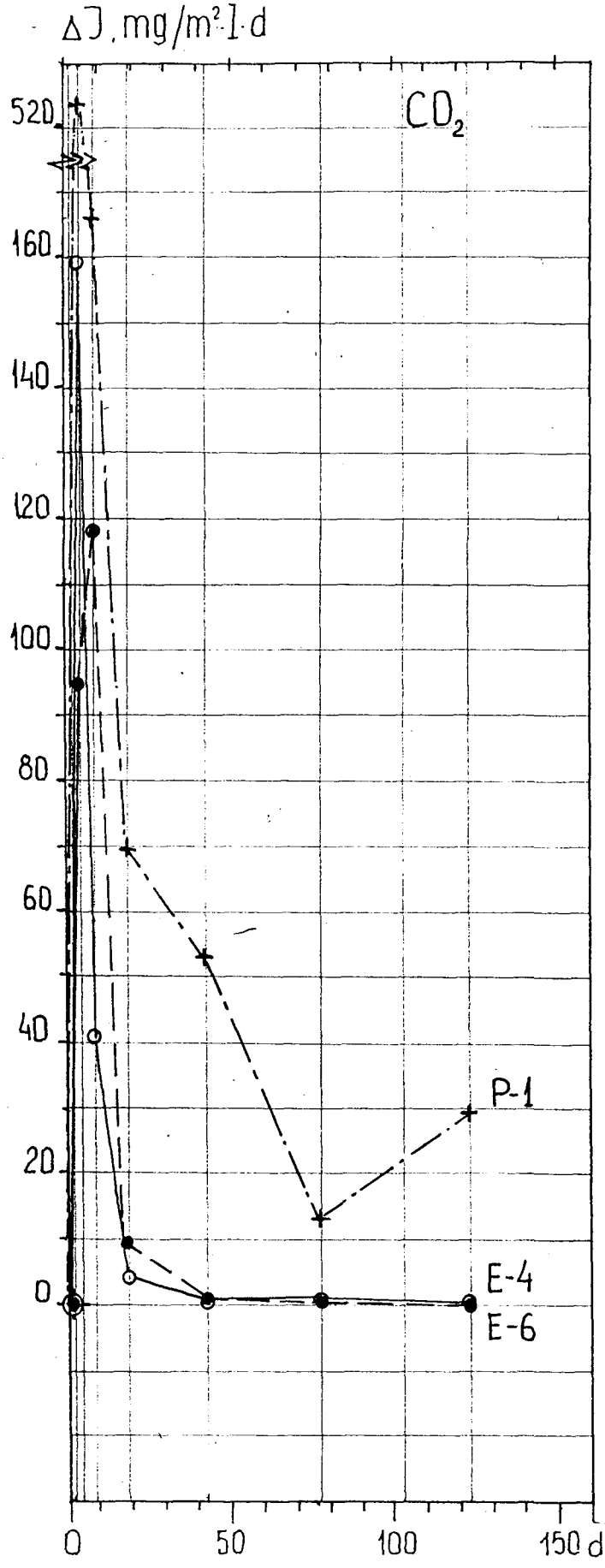

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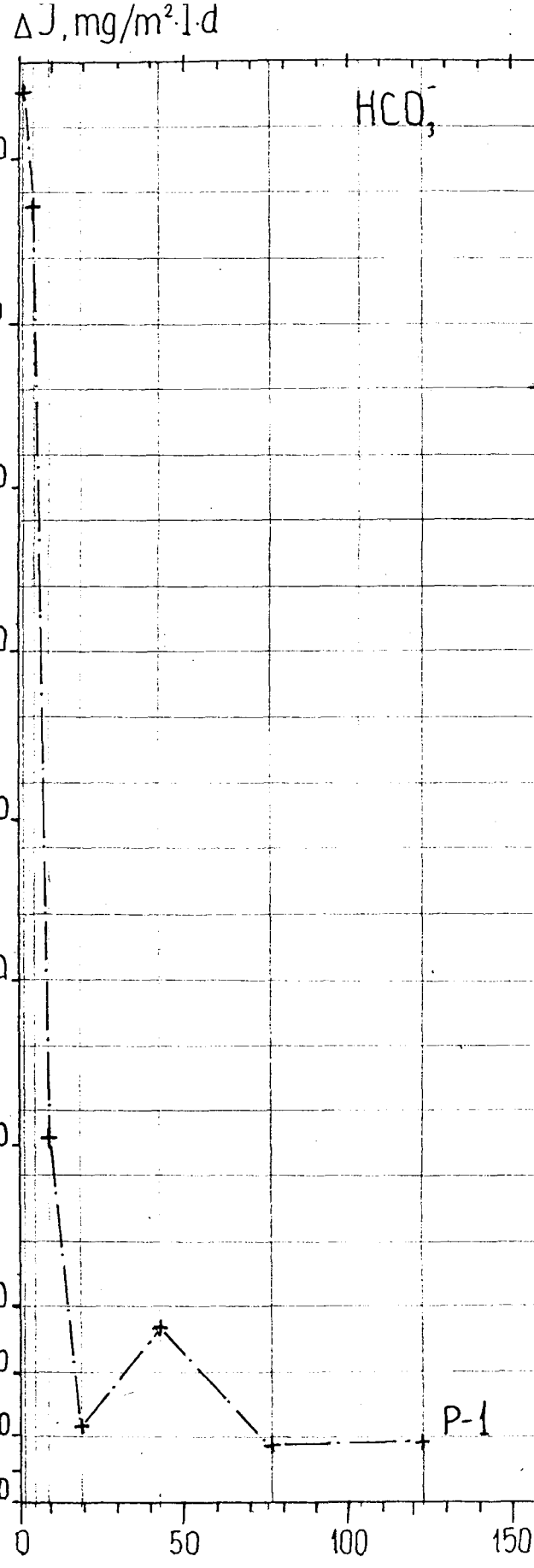

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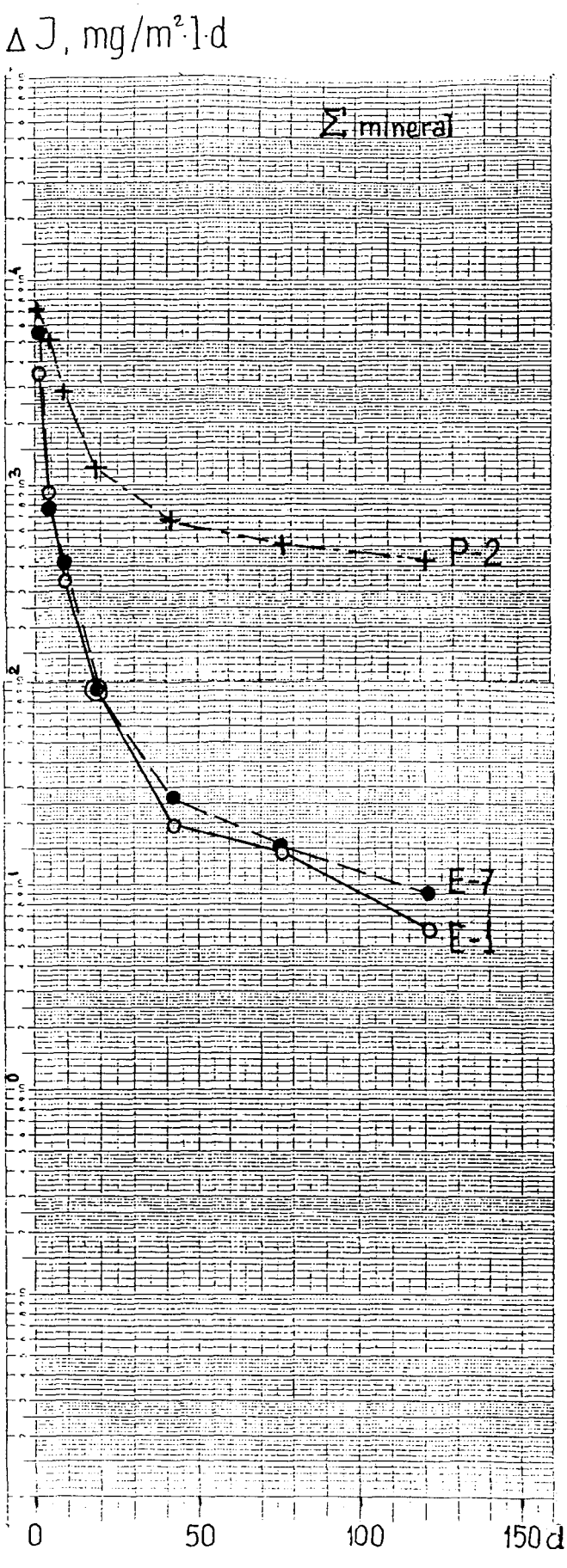

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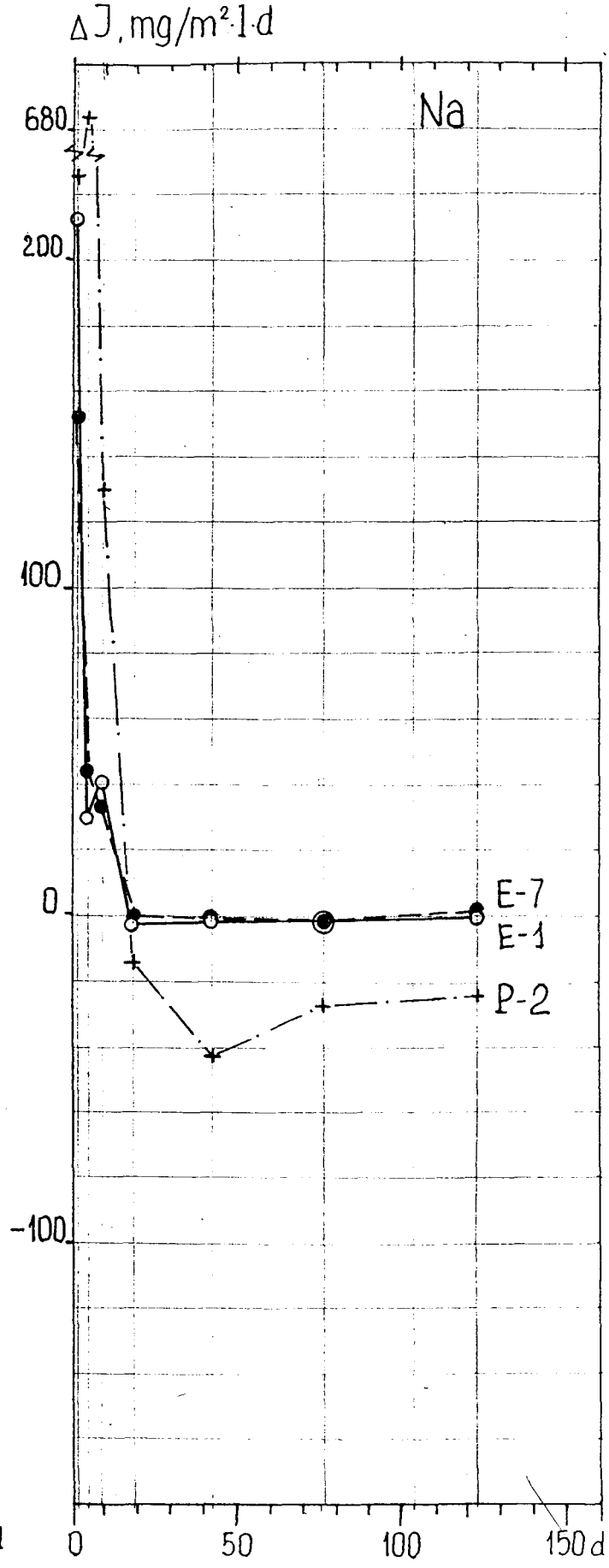

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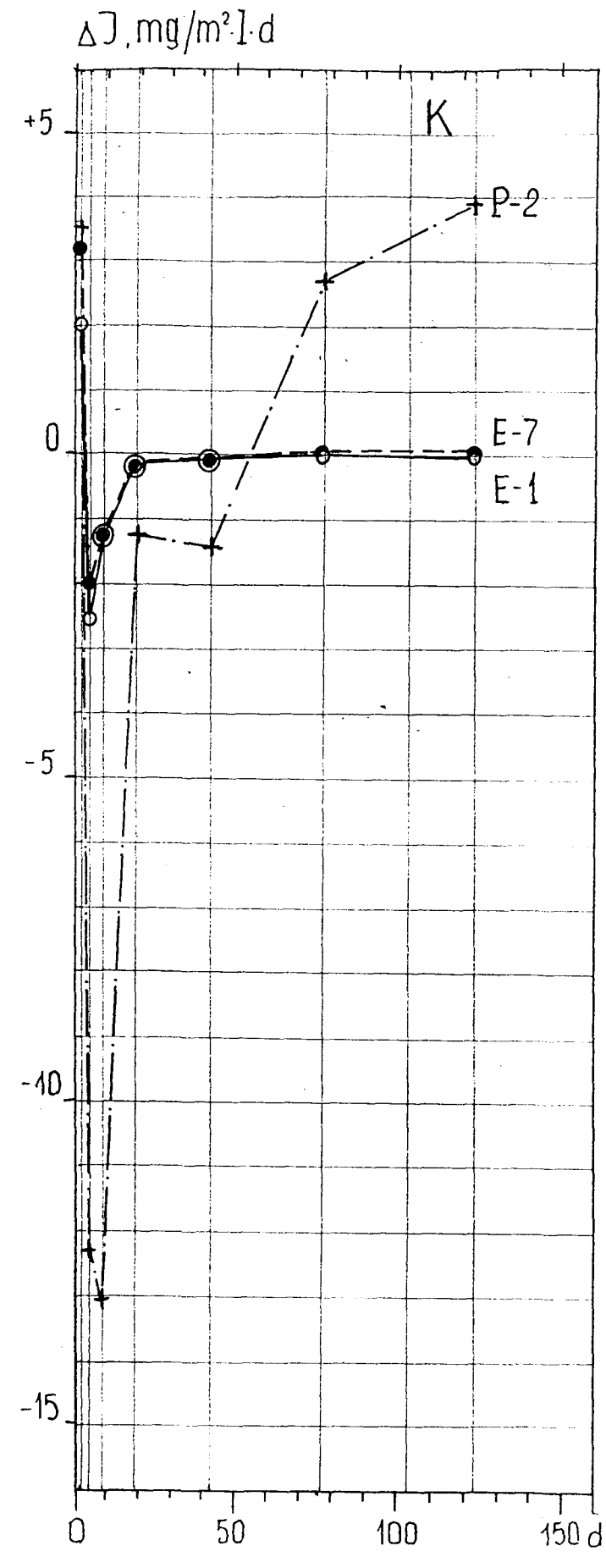

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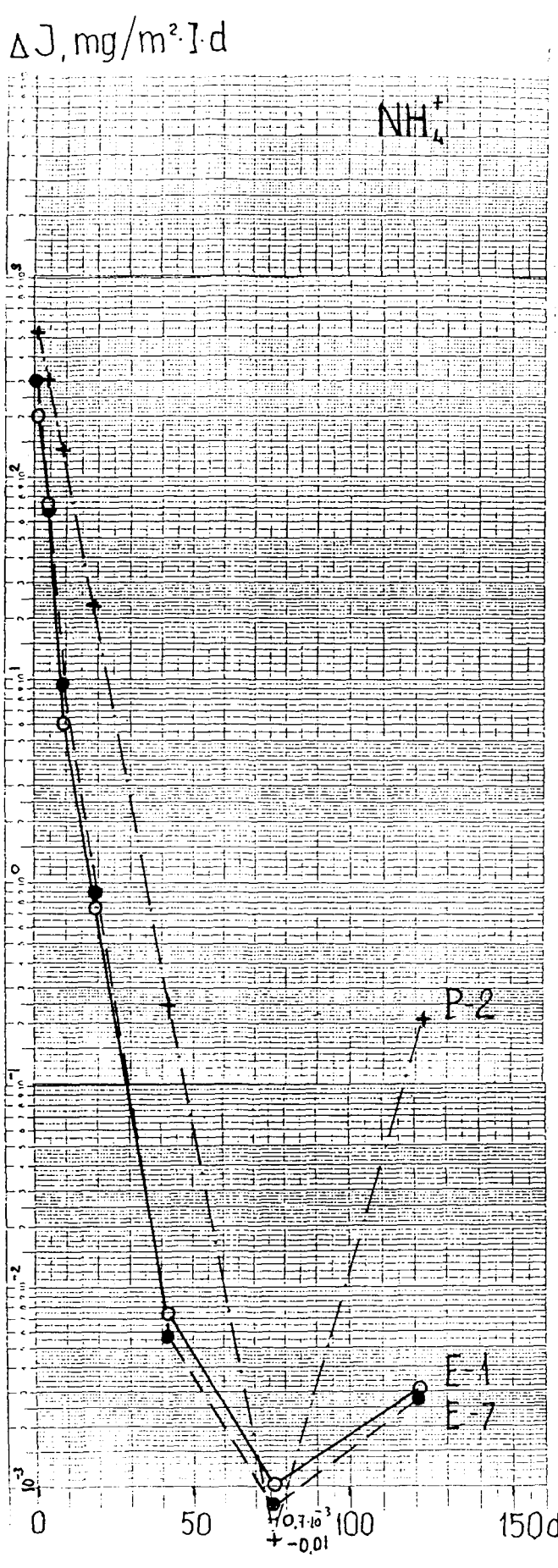

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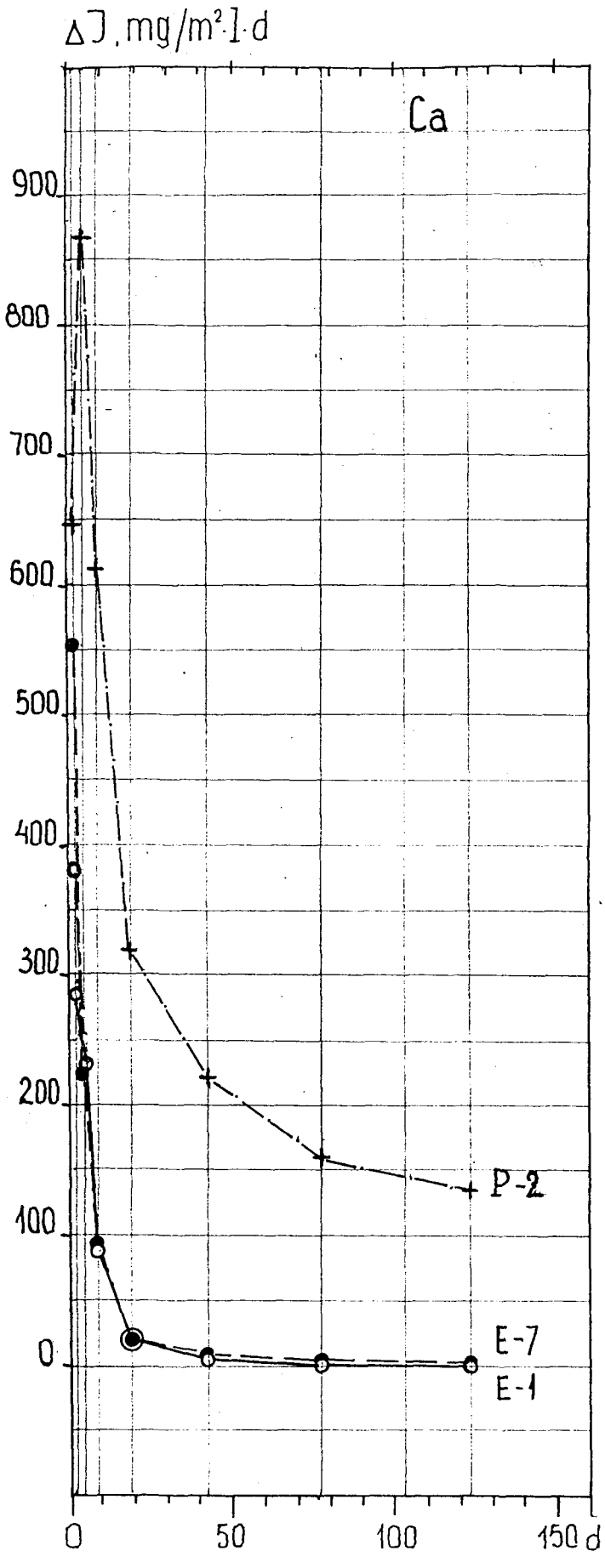

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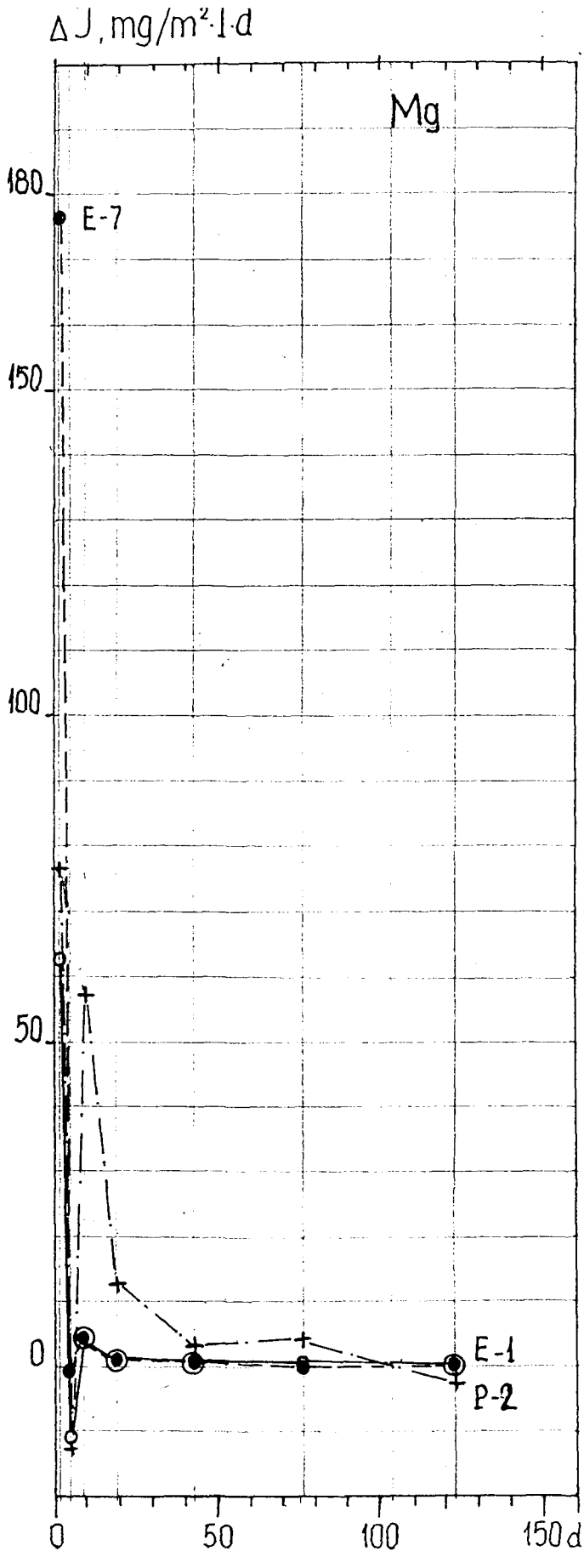

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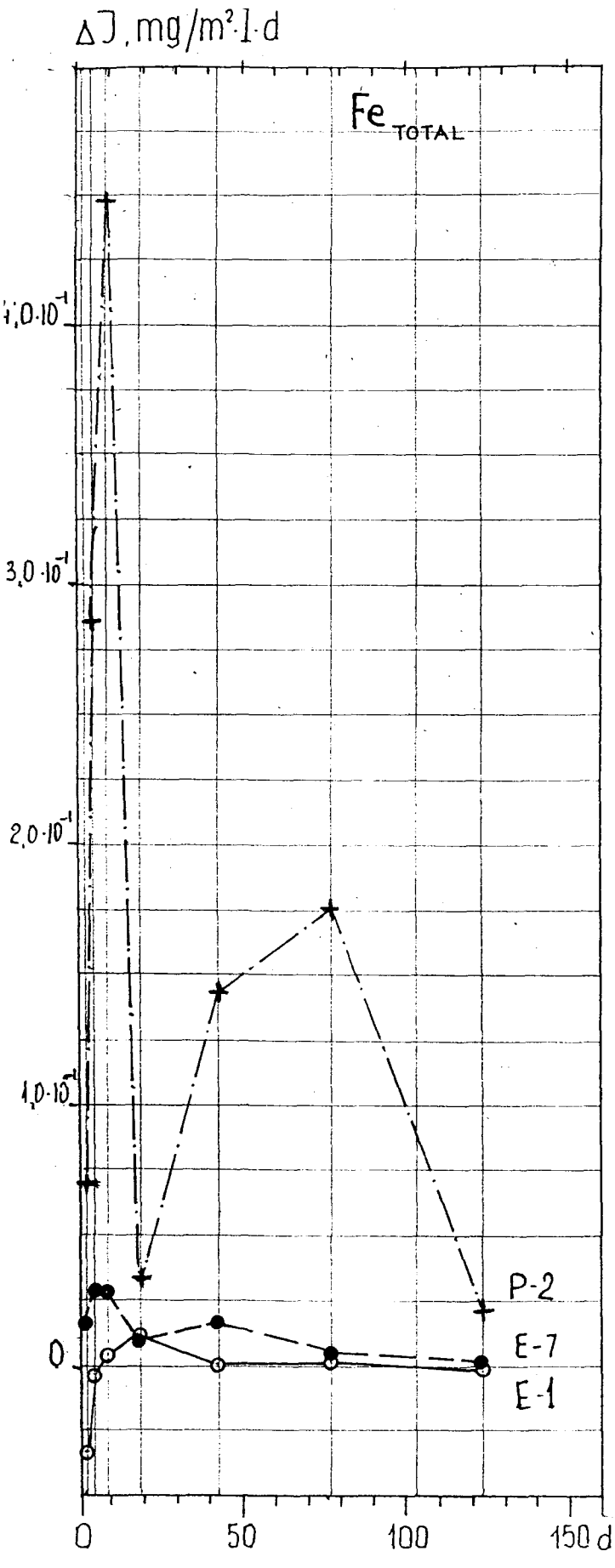

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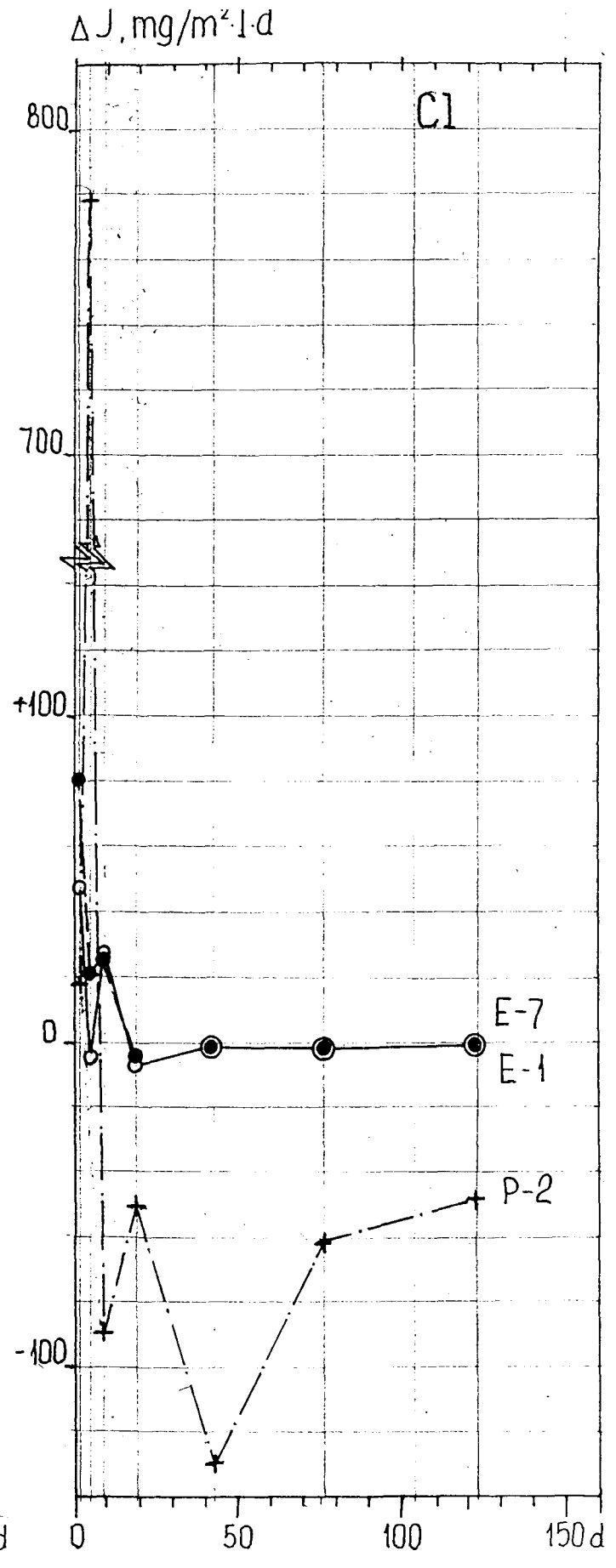

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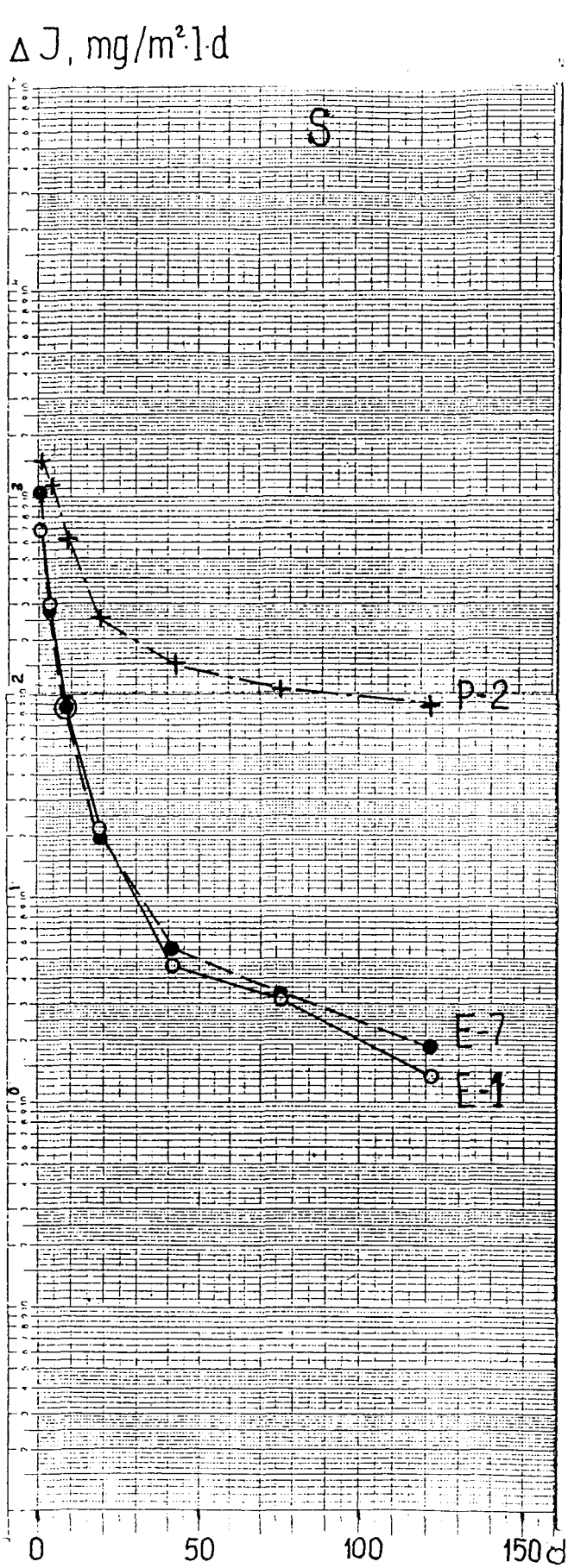
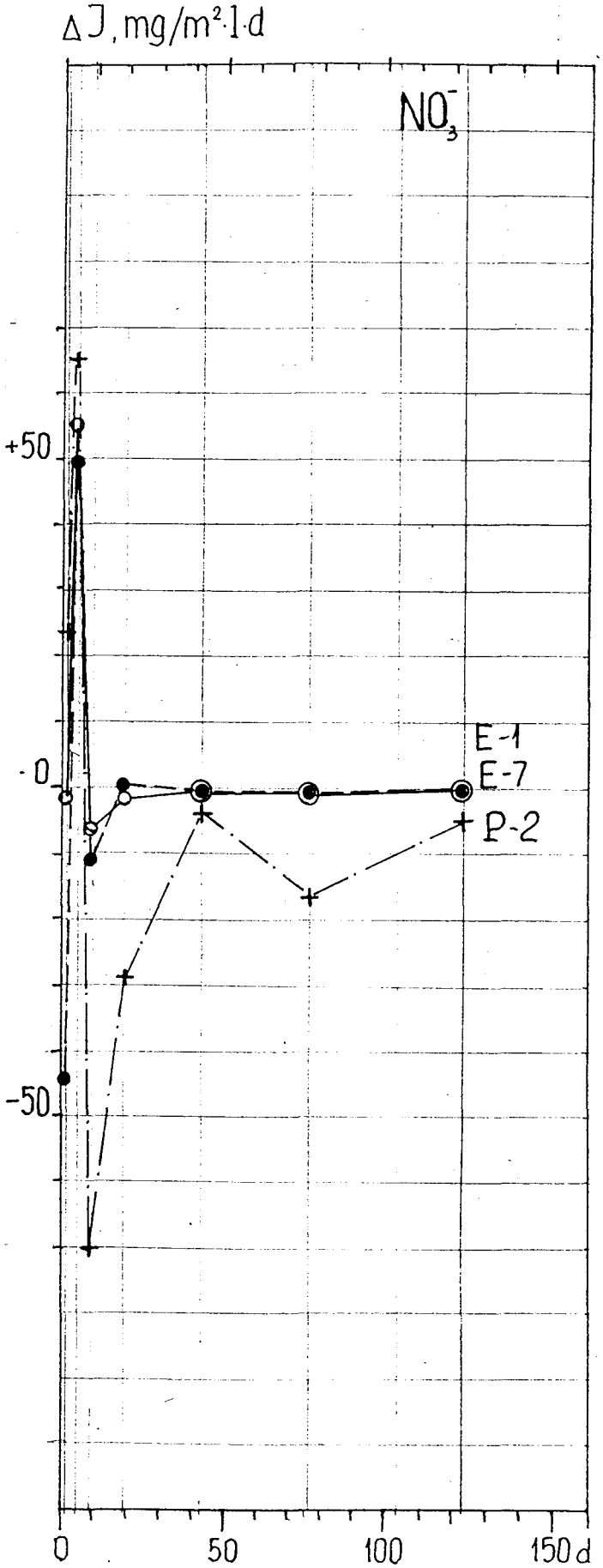


Fig. 13-9



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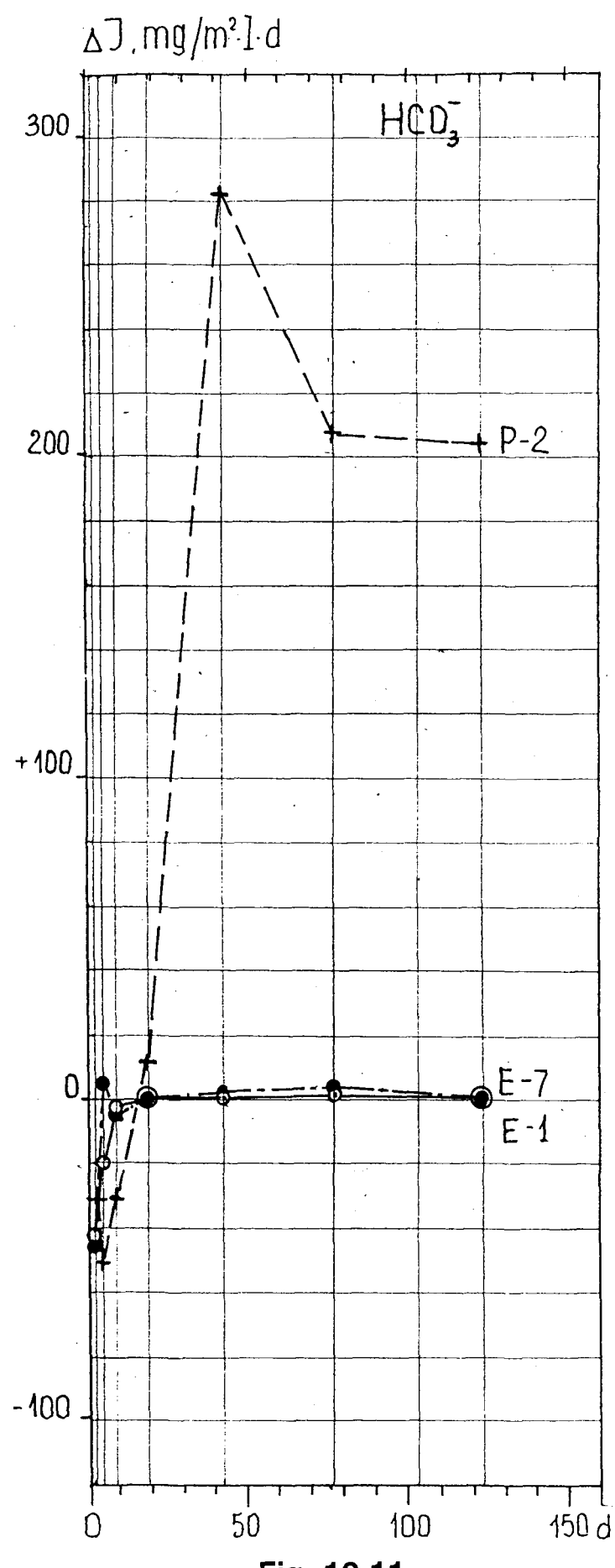

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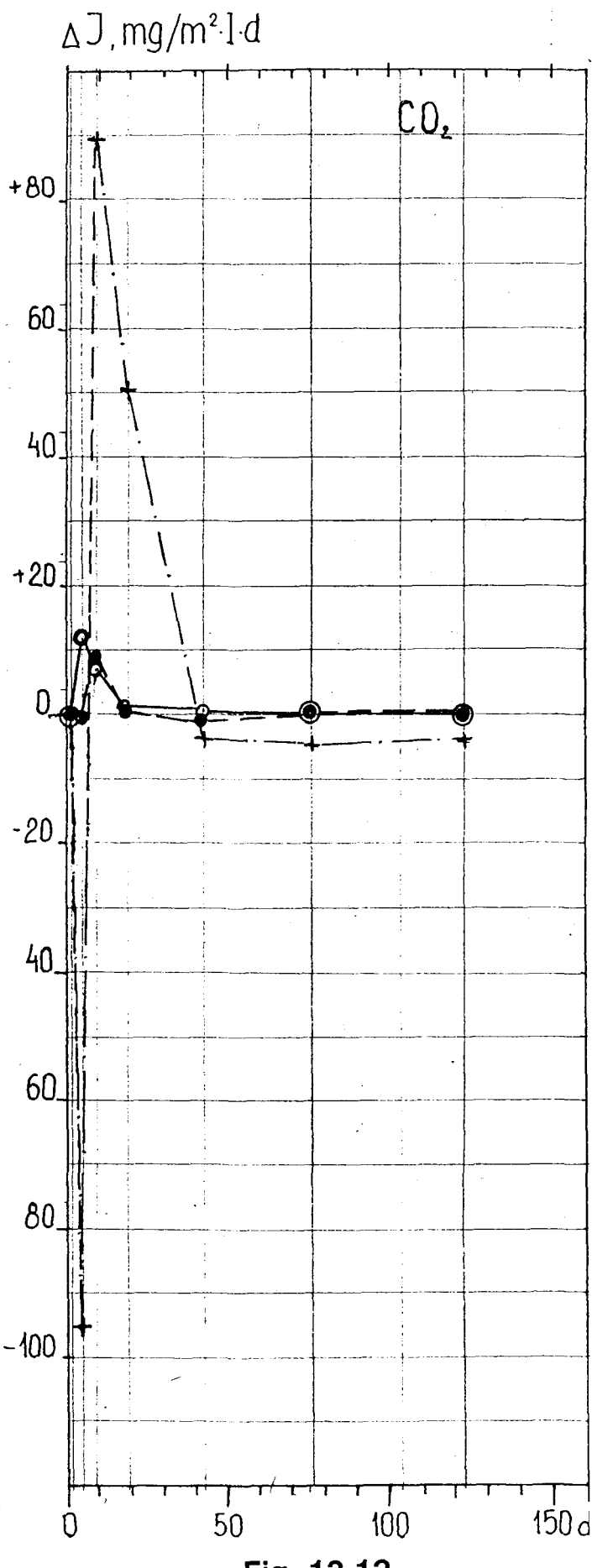

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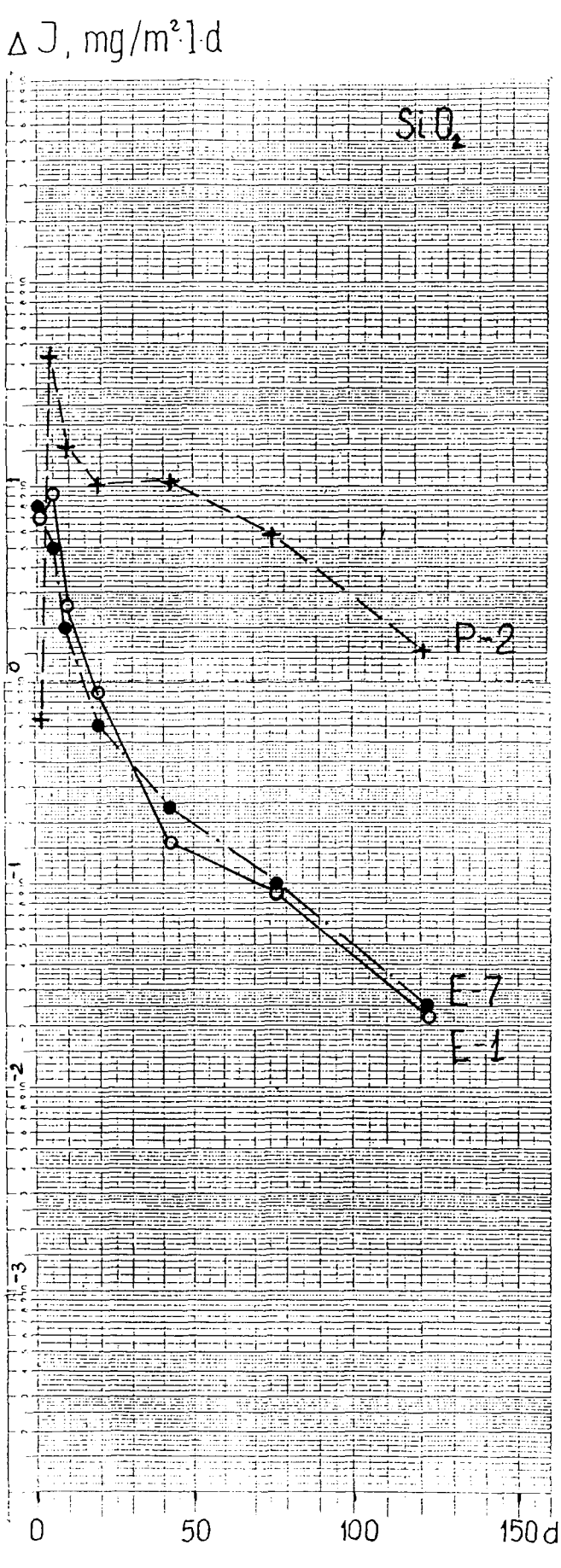
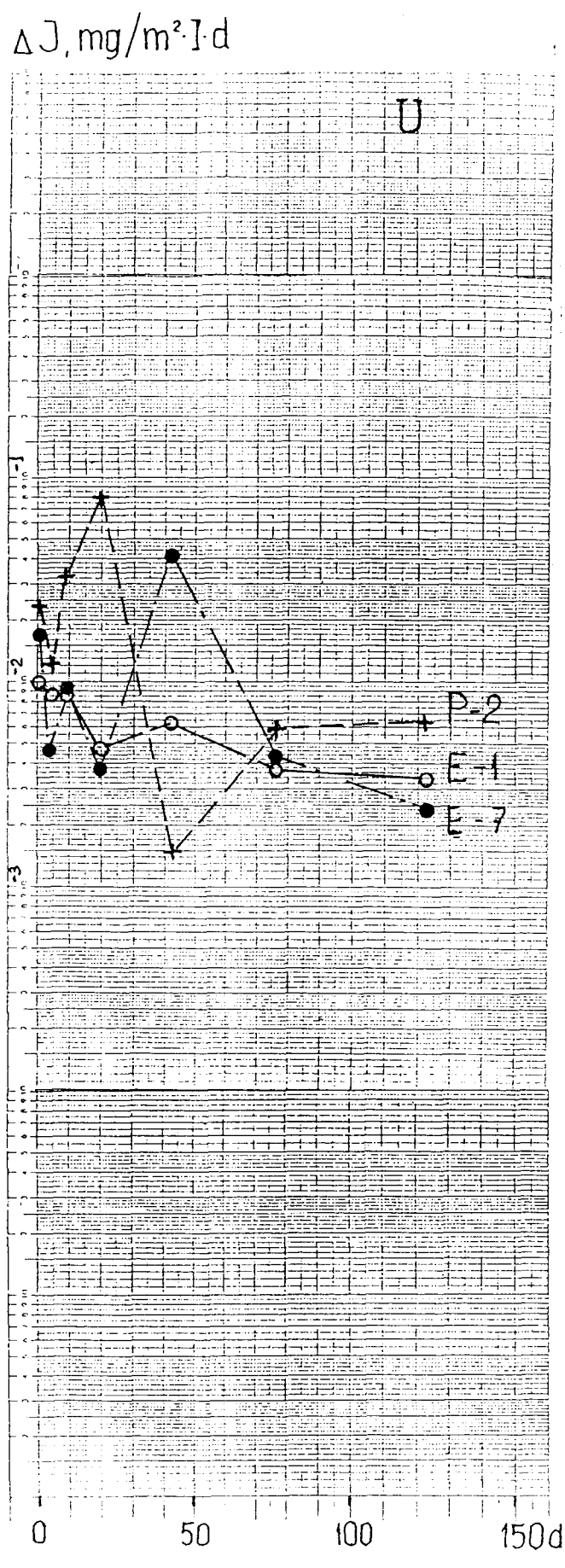


Fig. 13-13



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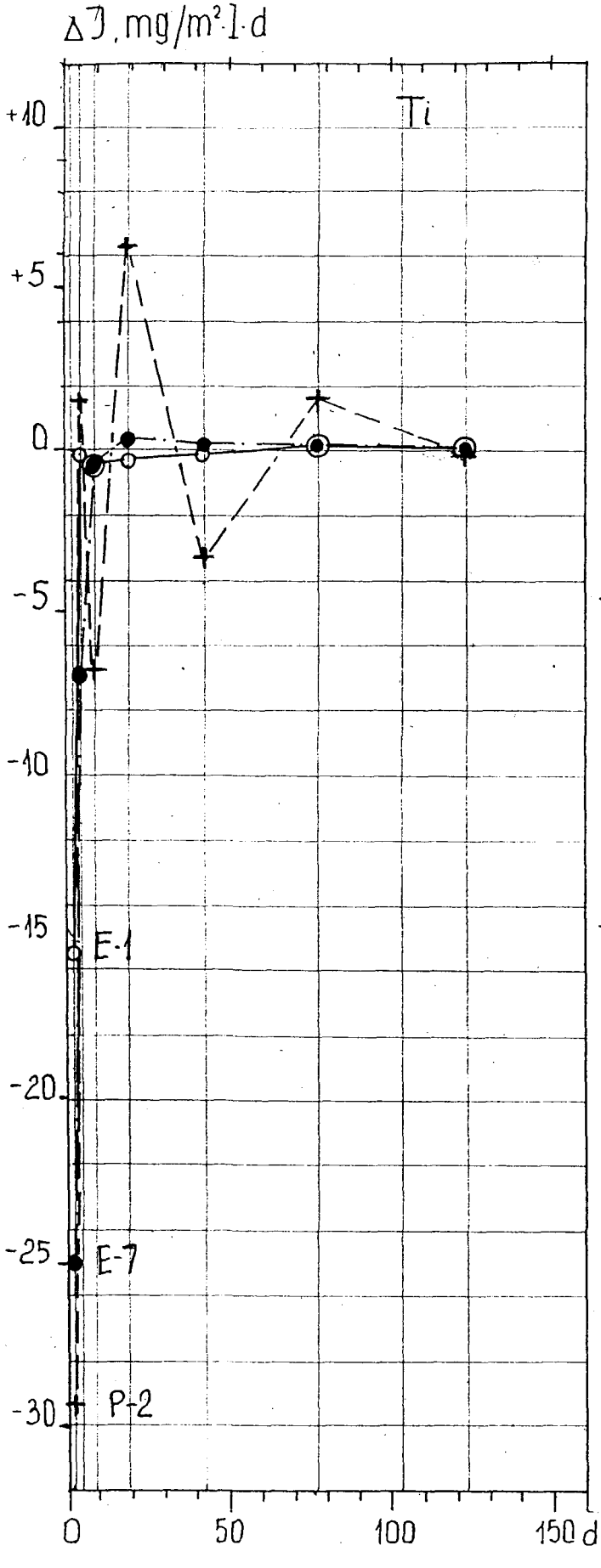

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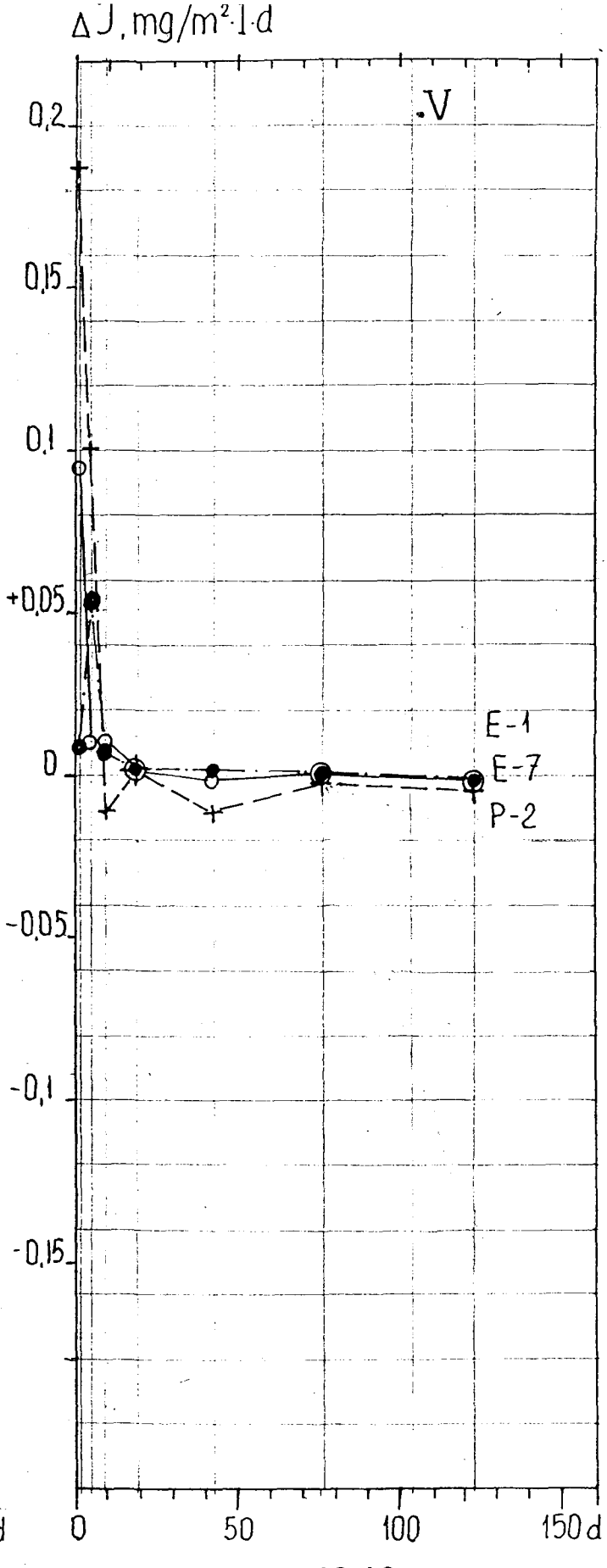

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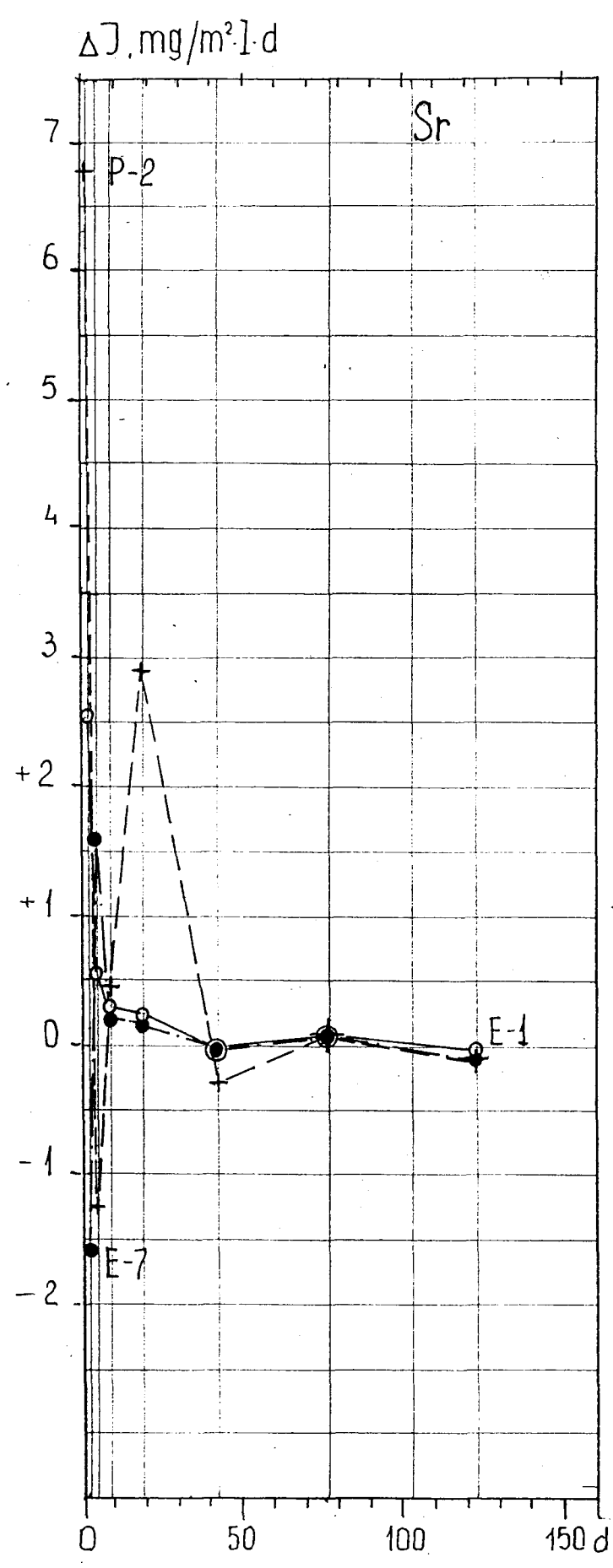

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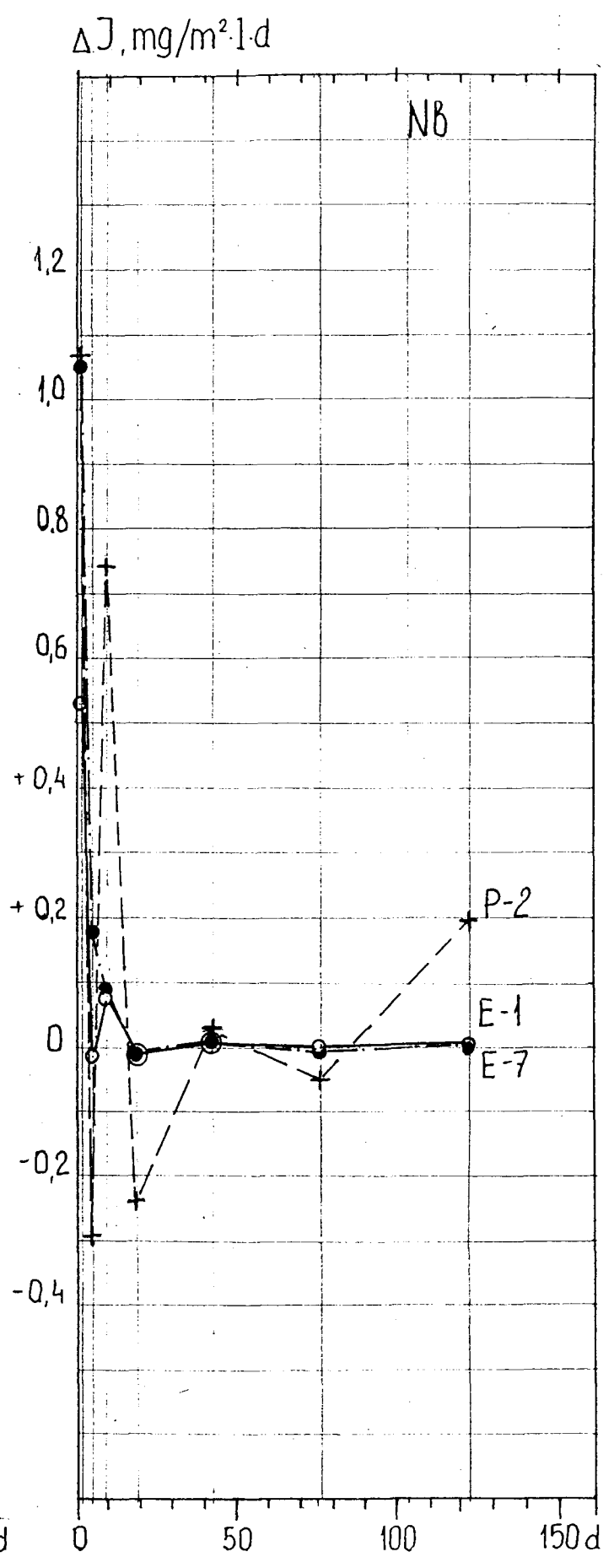

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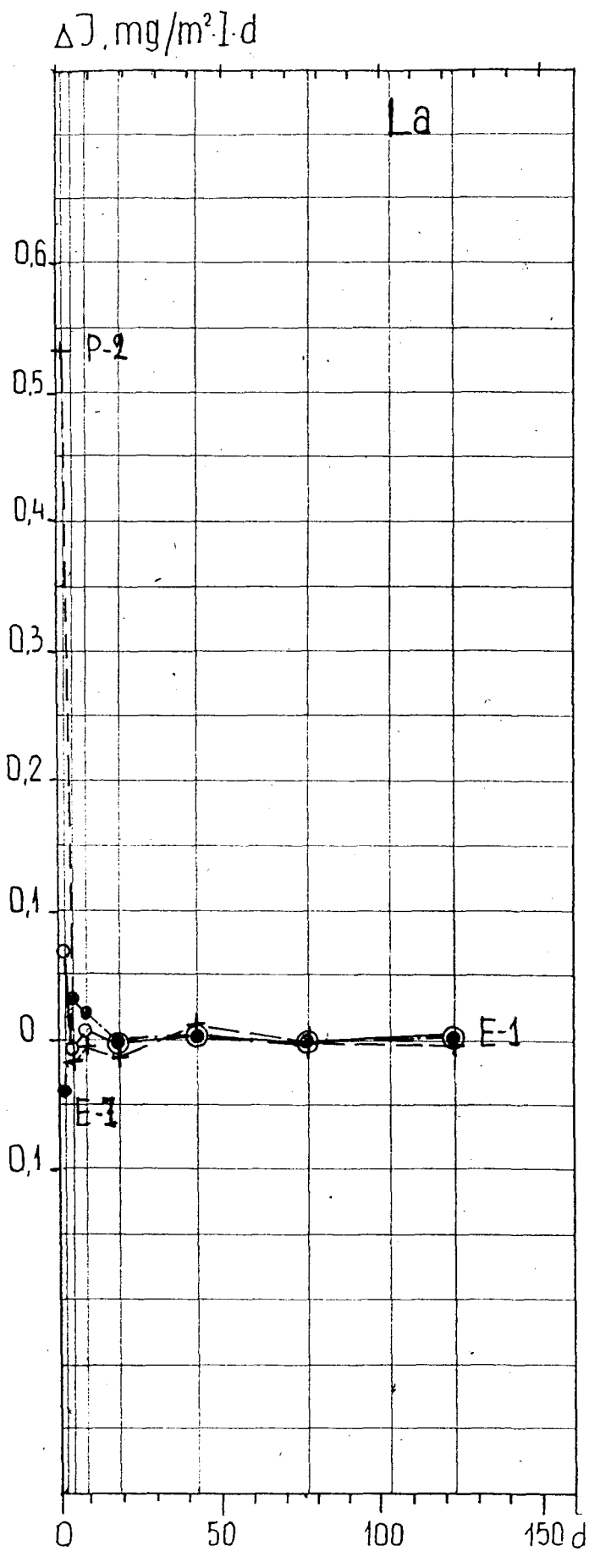

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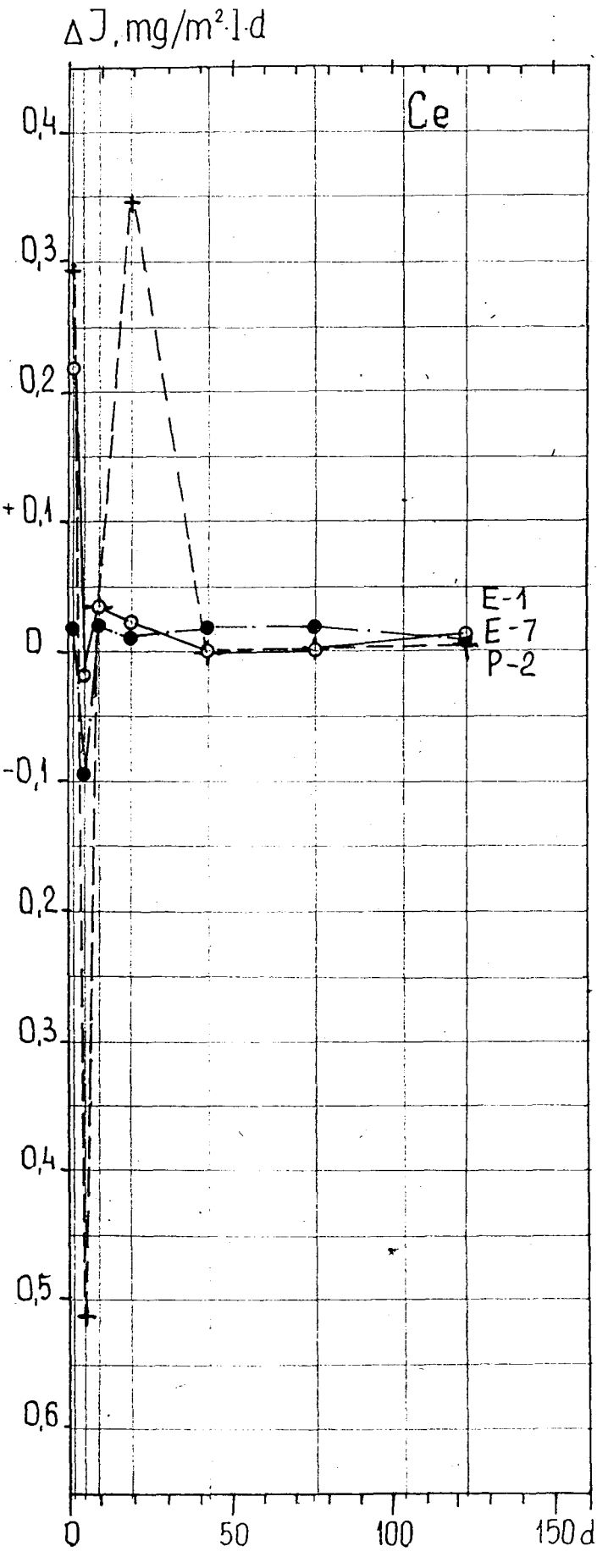
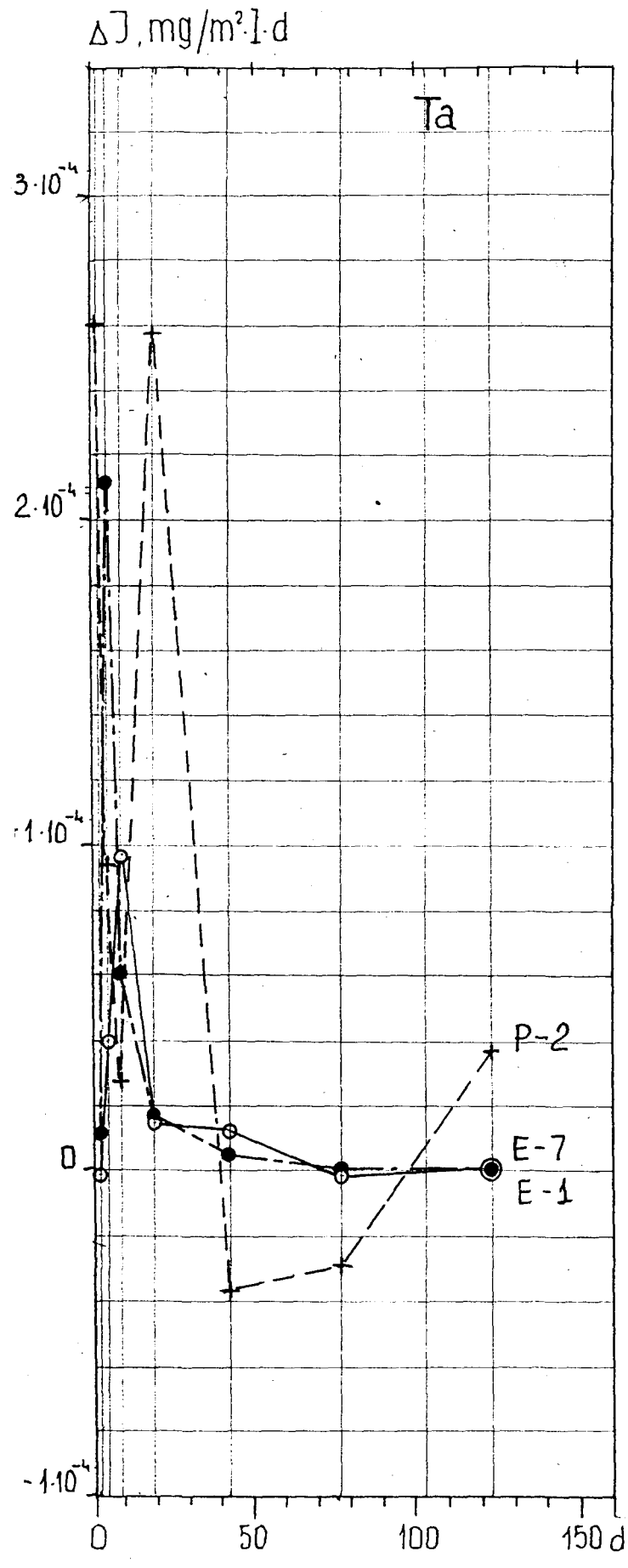


Fig. 13-20



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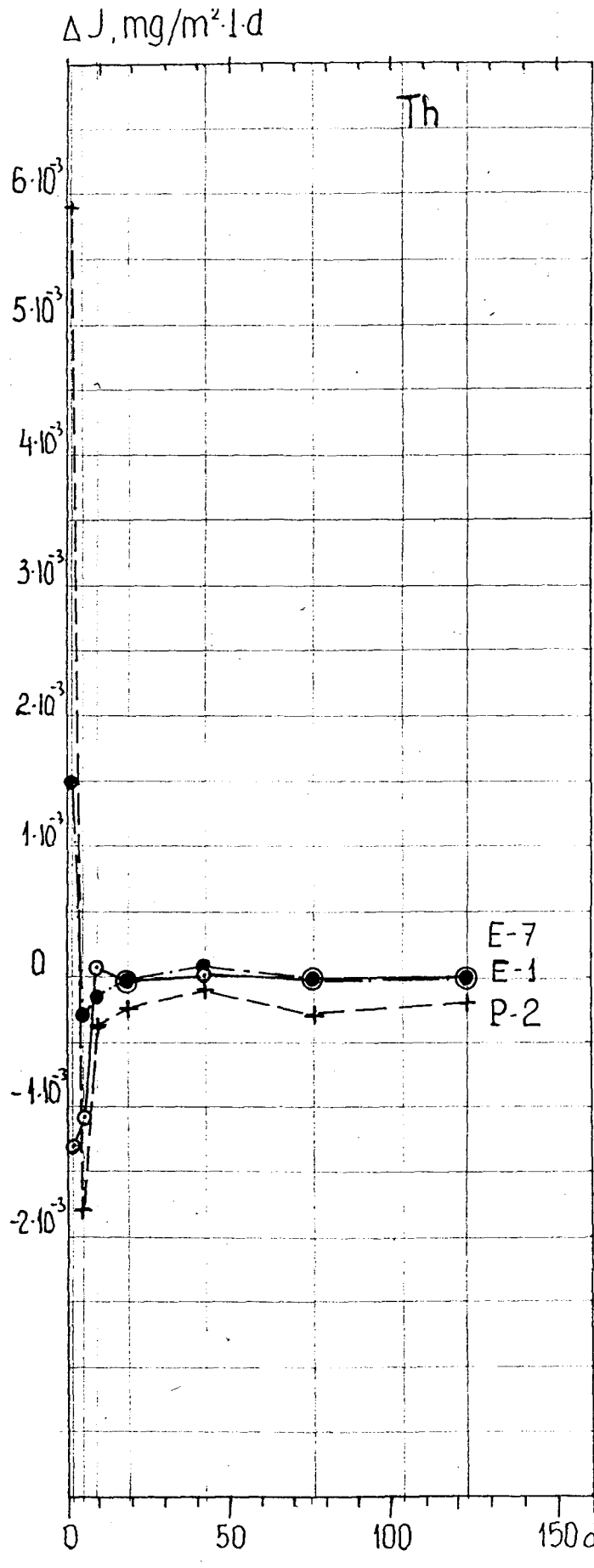

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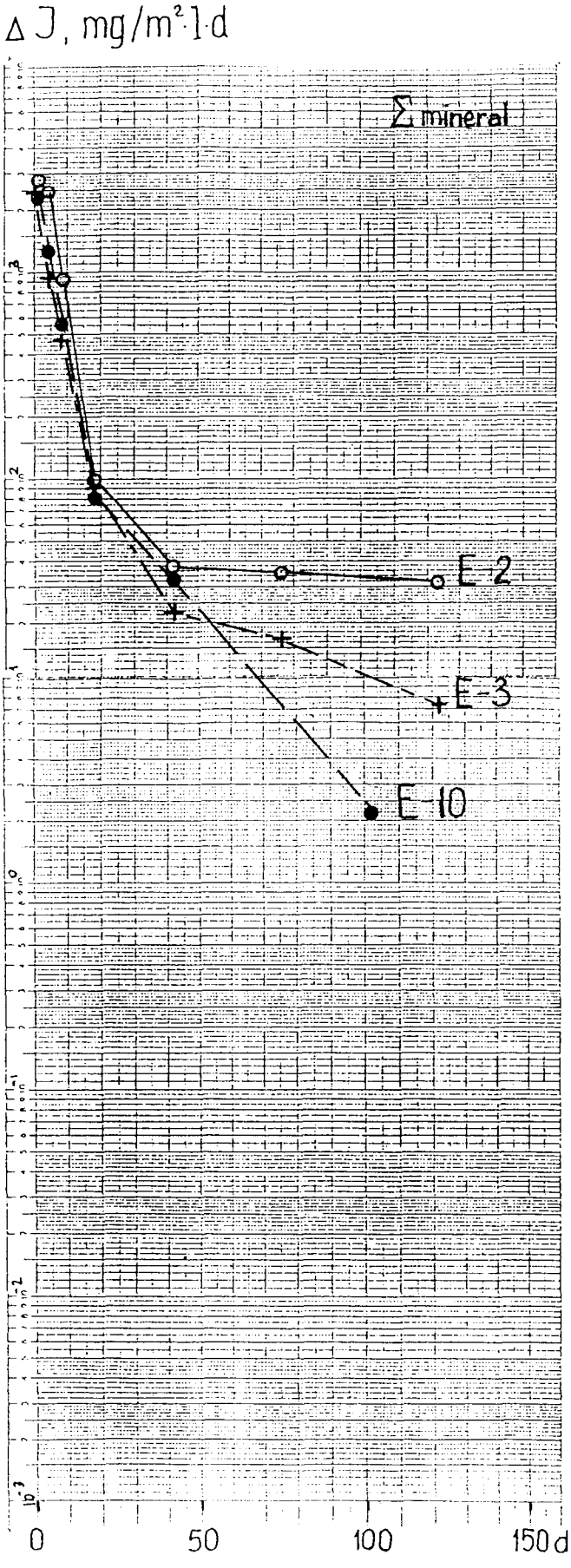

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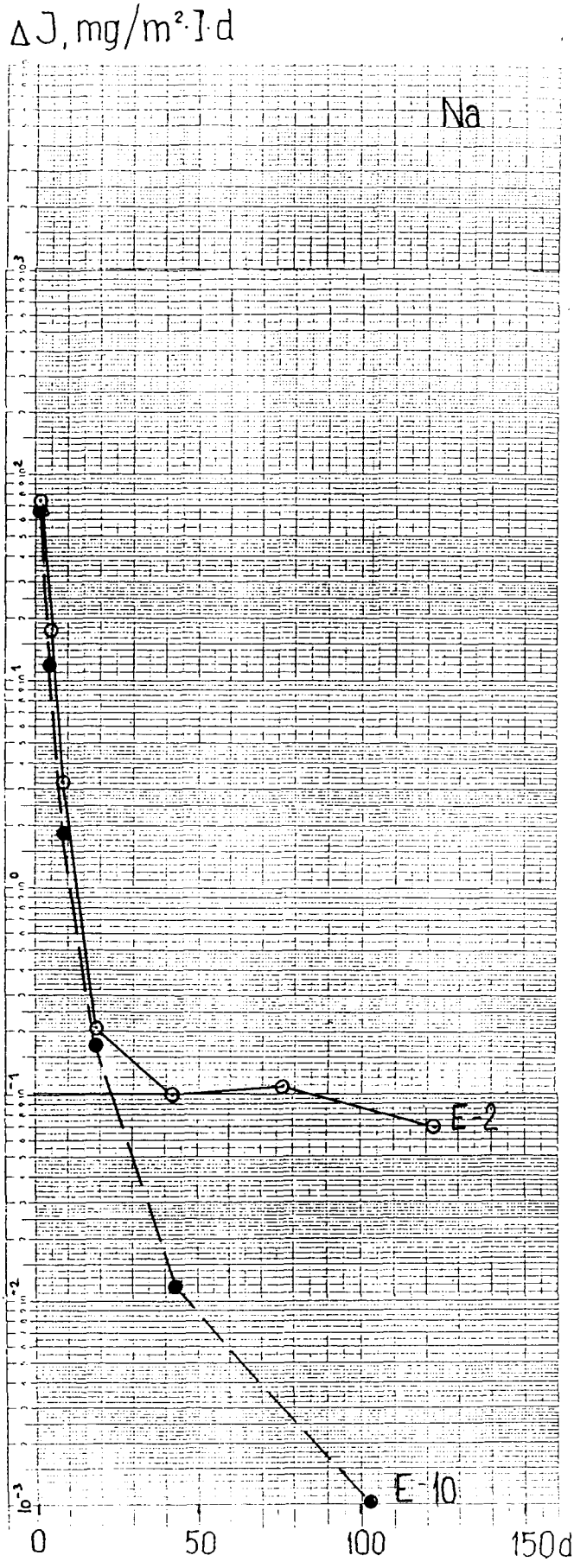
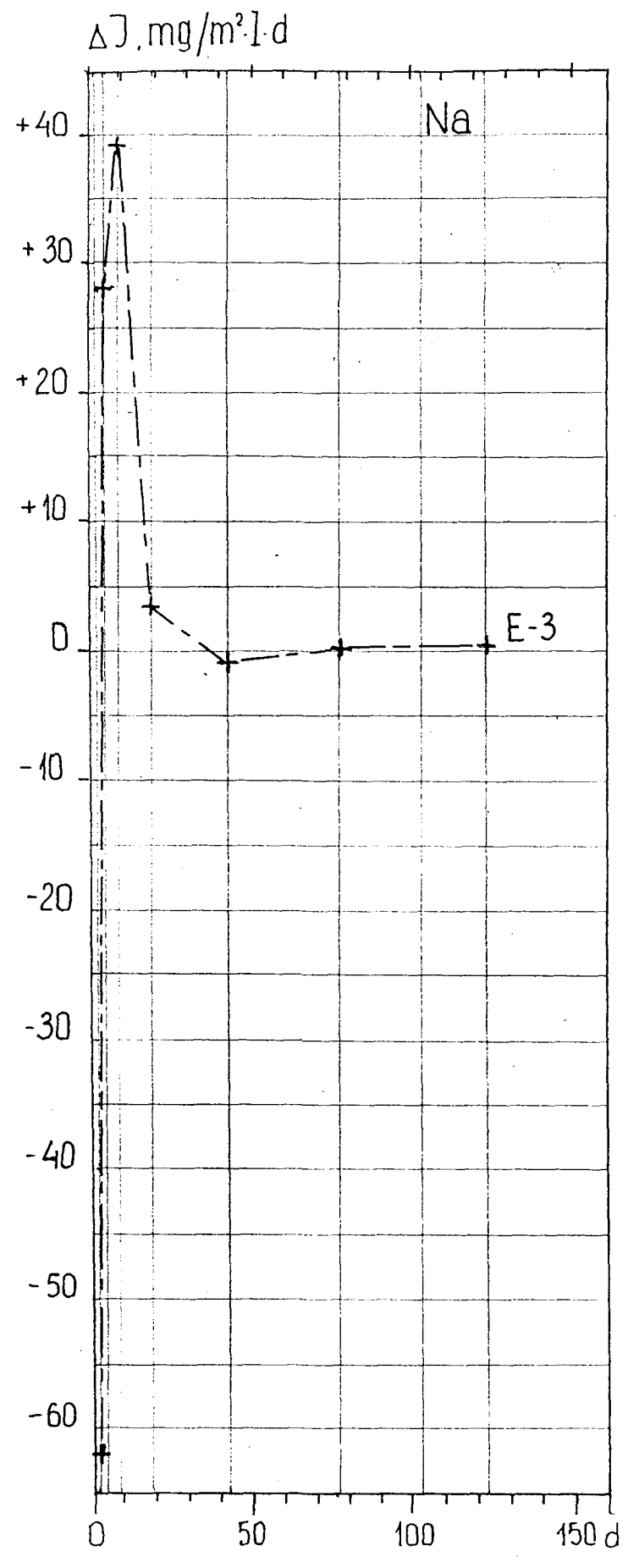


Fig. 14-2



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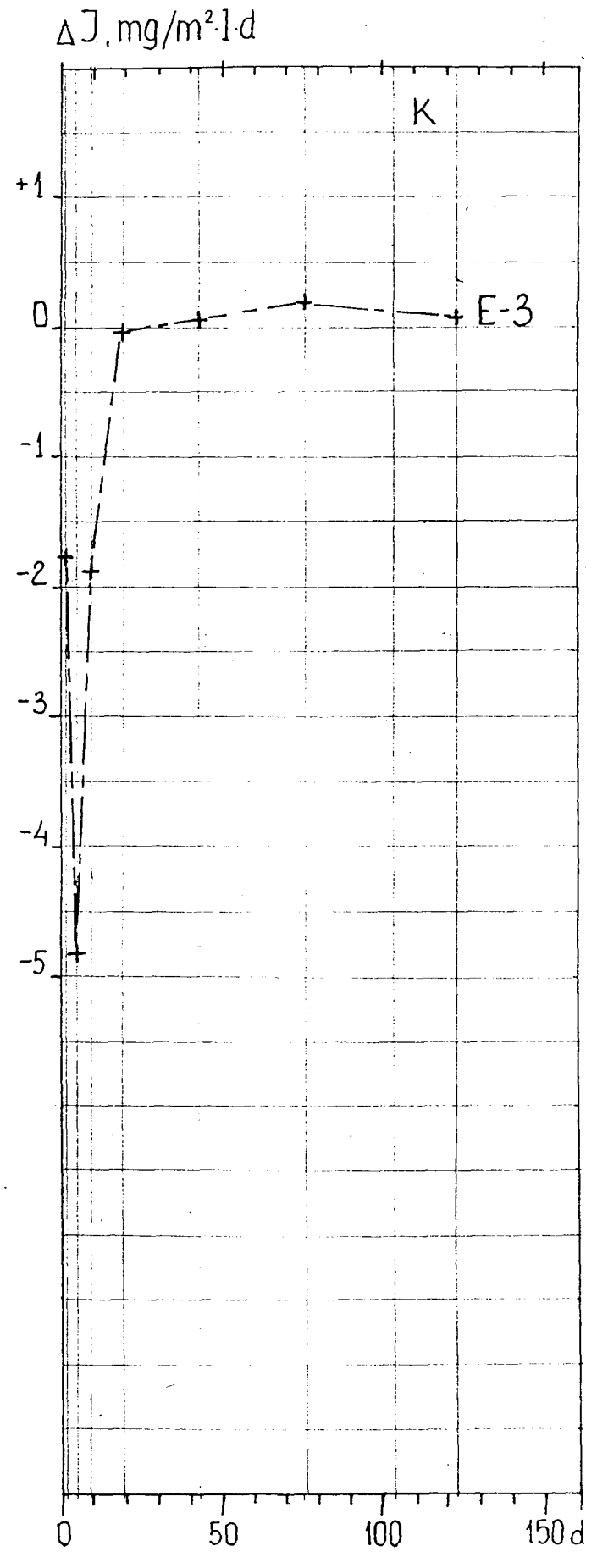

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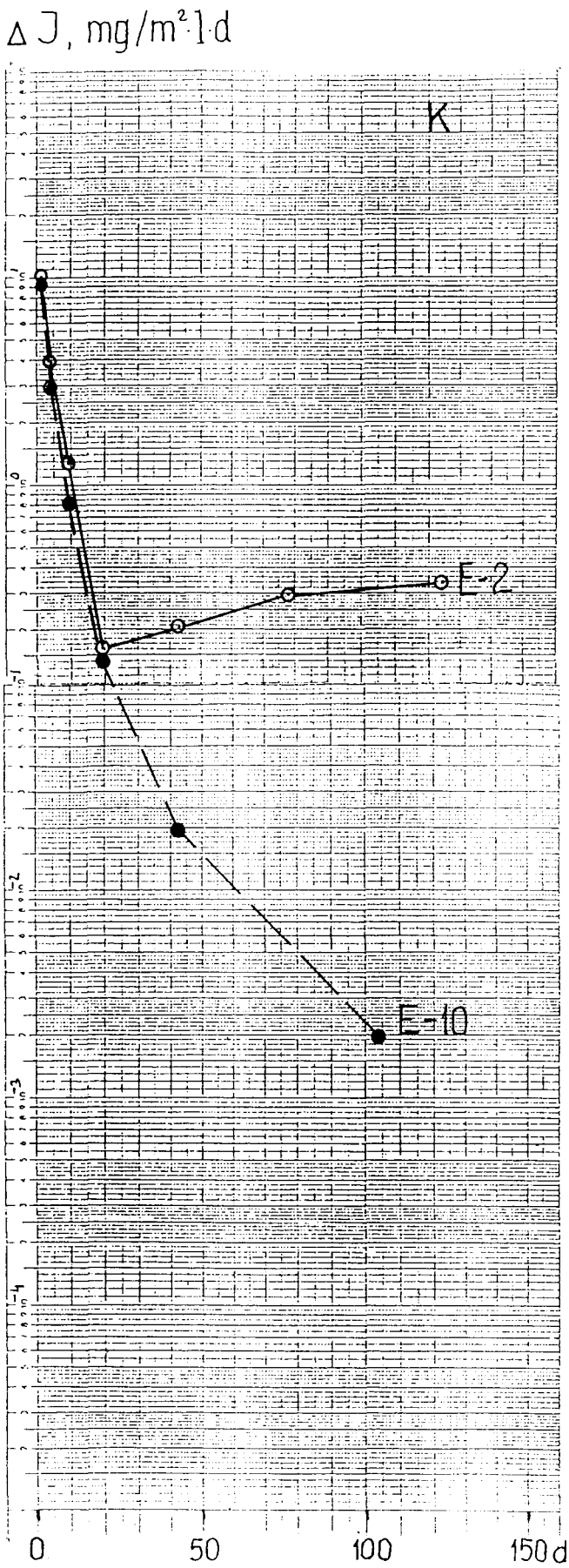
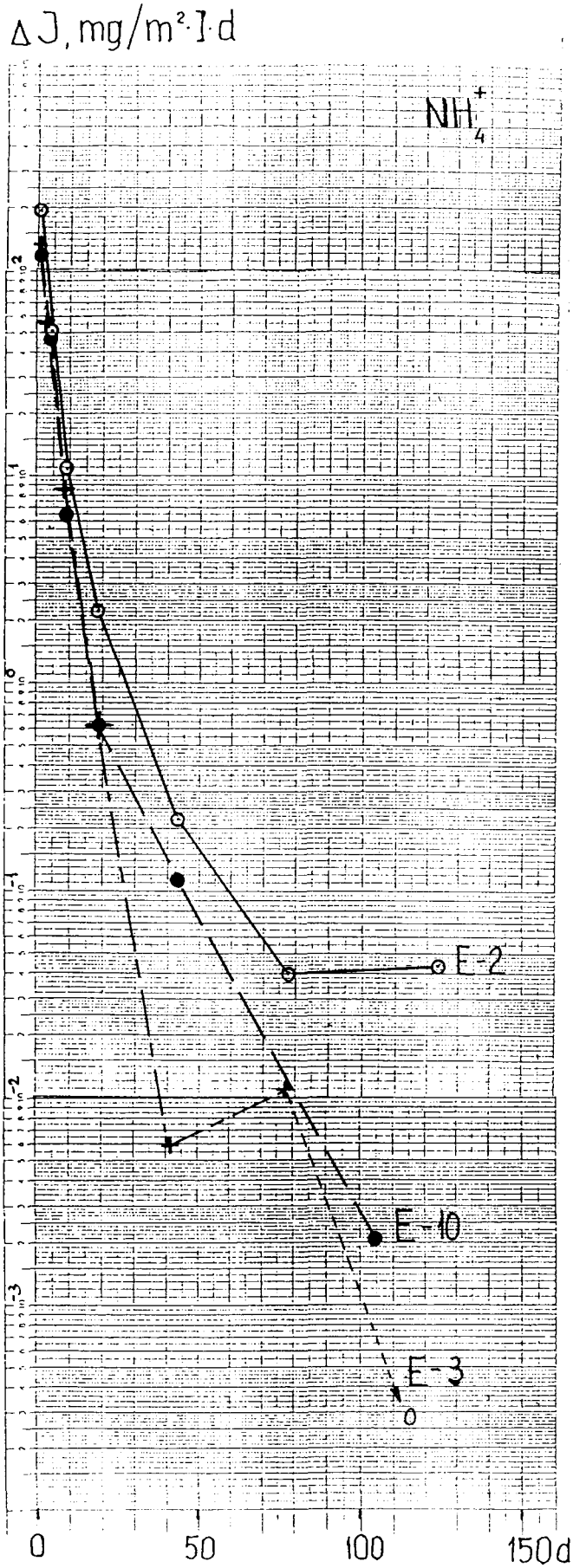


Fig. 14-5



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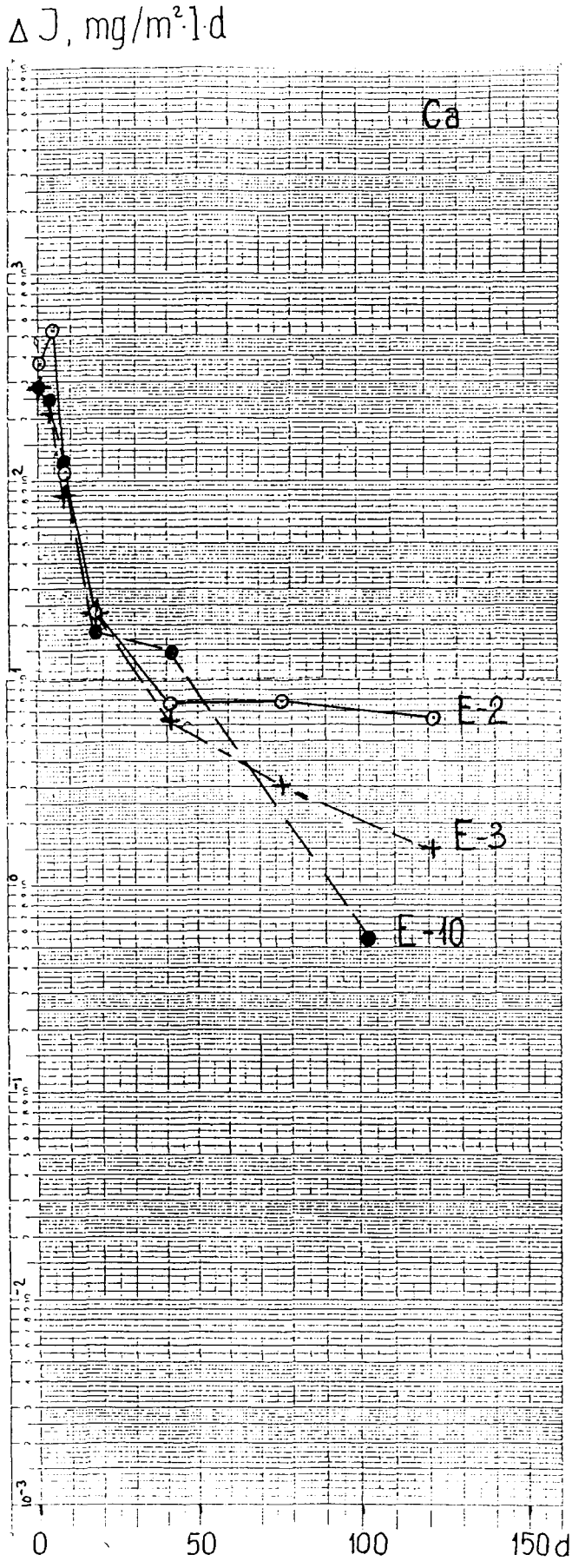

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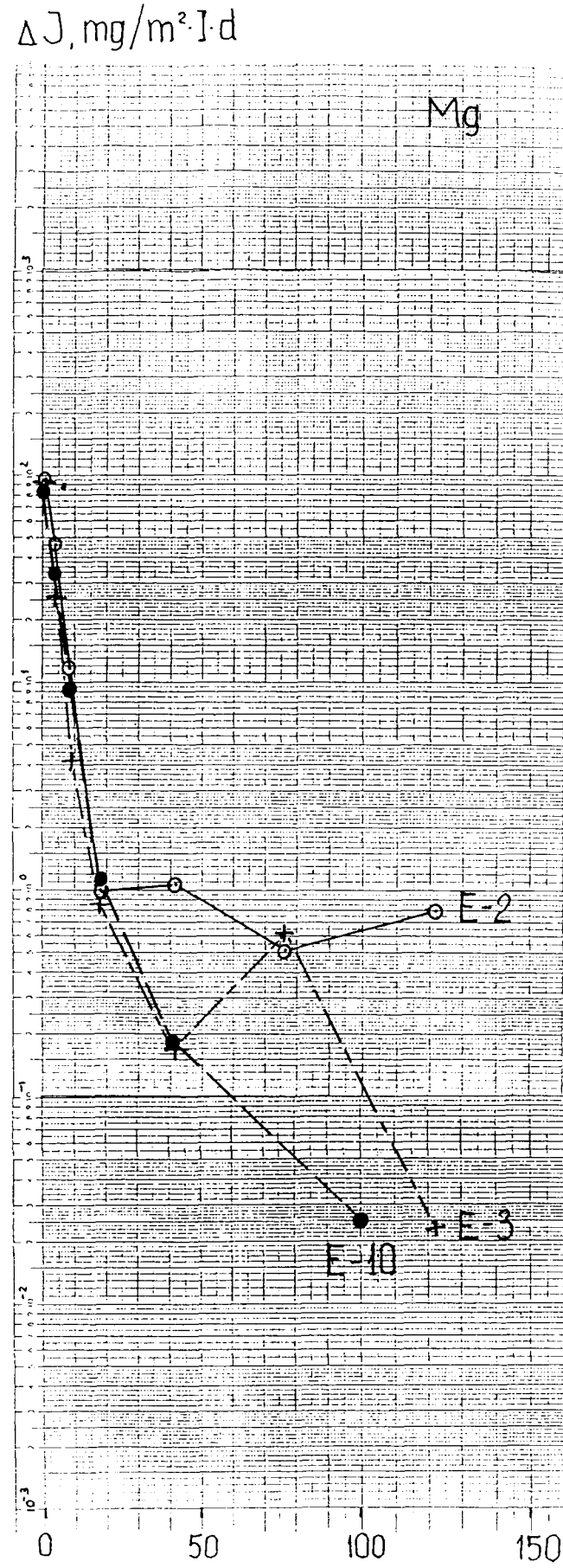

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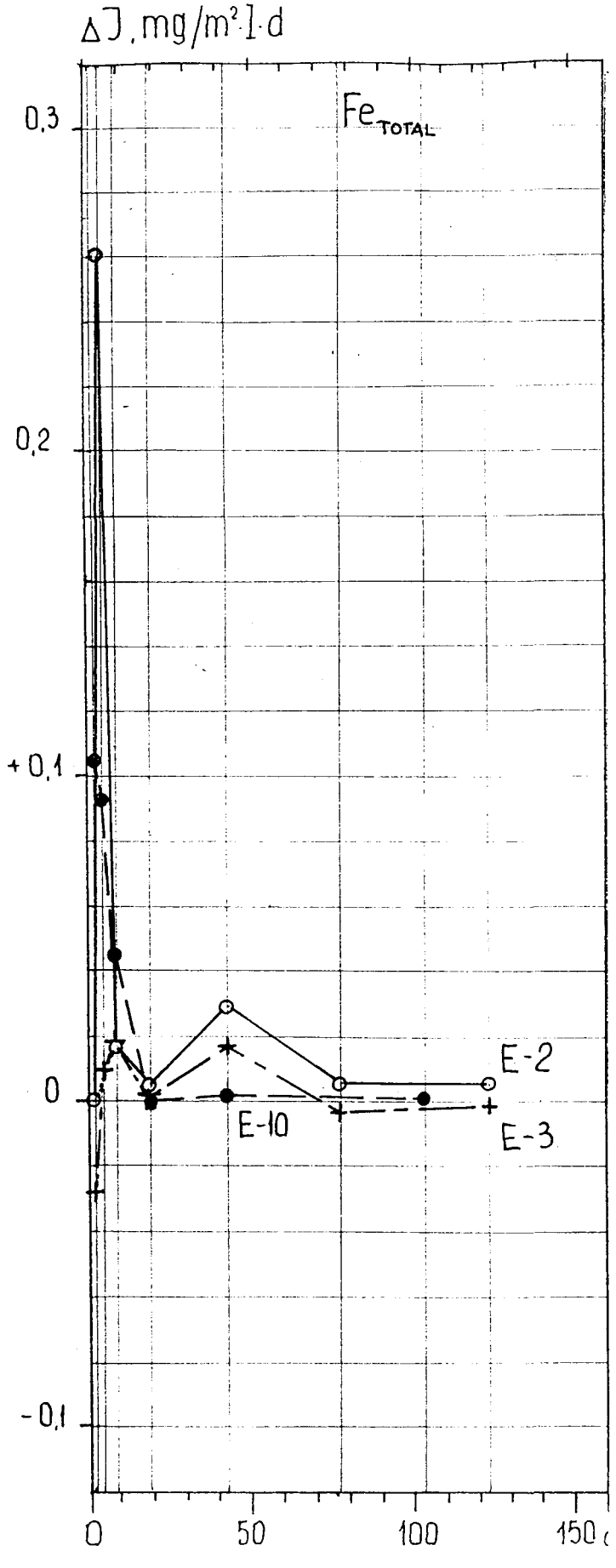

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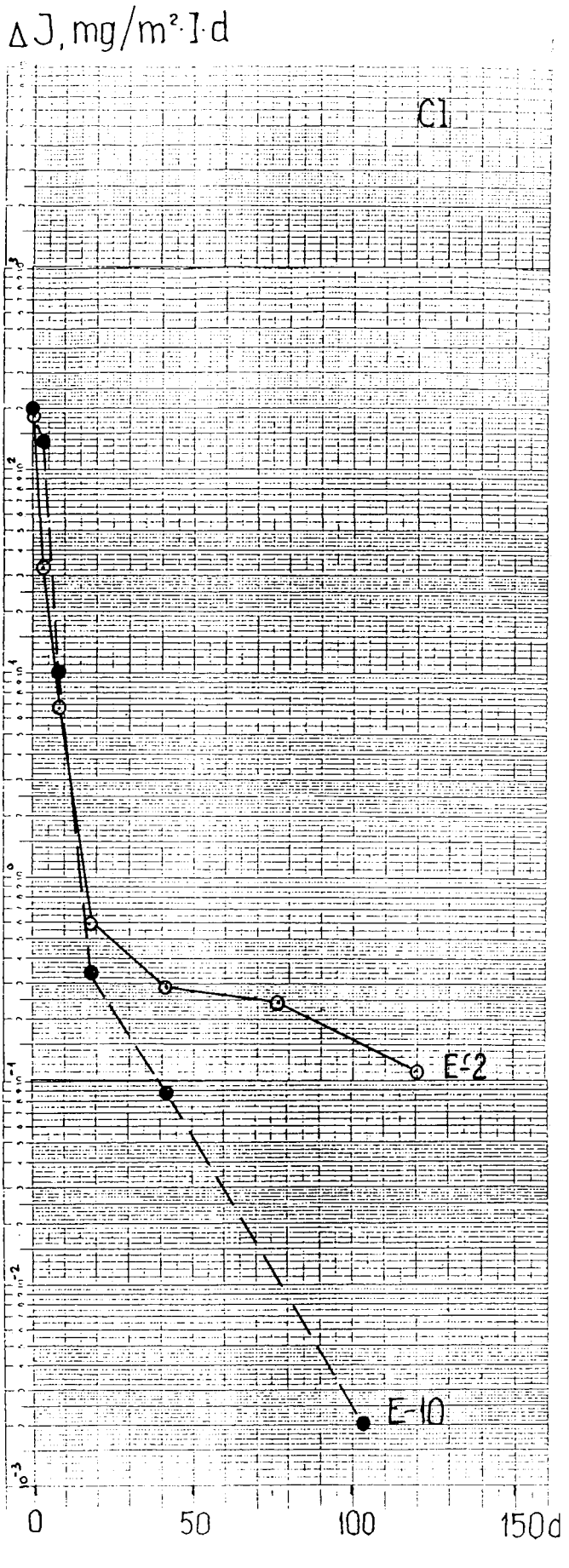

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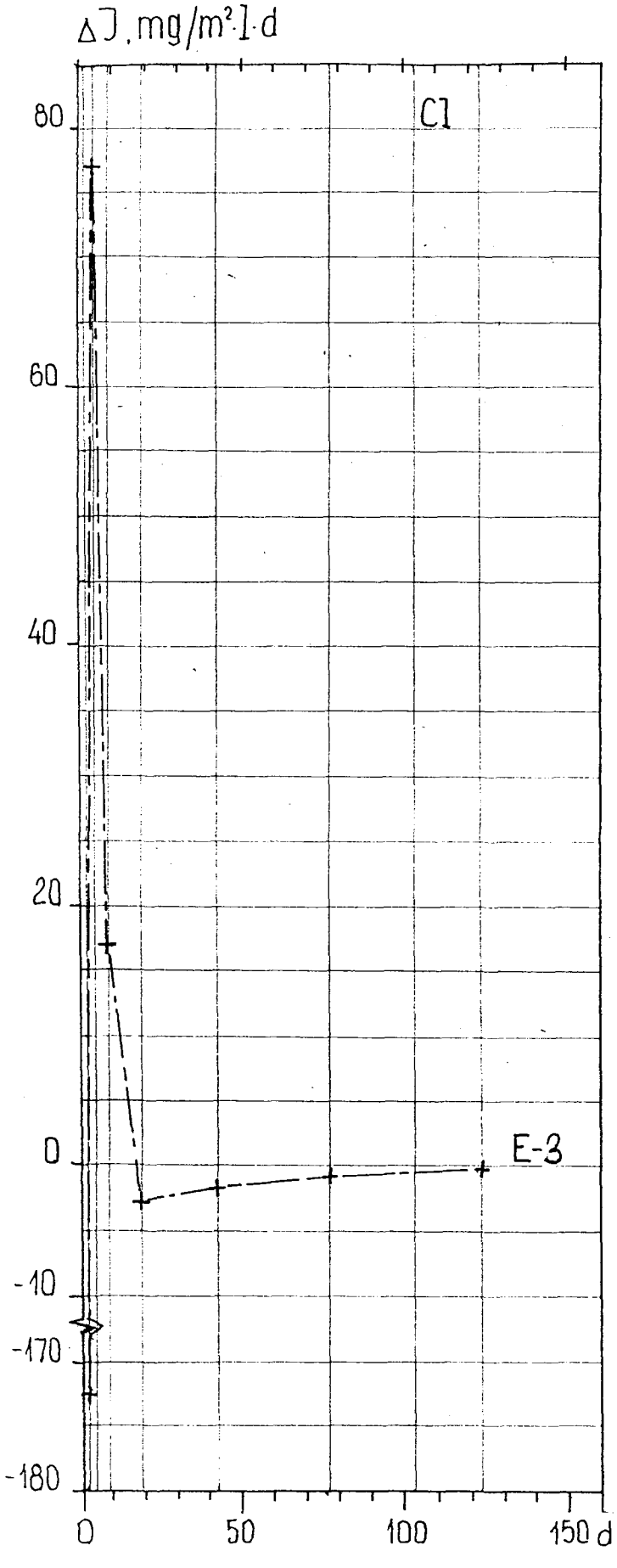

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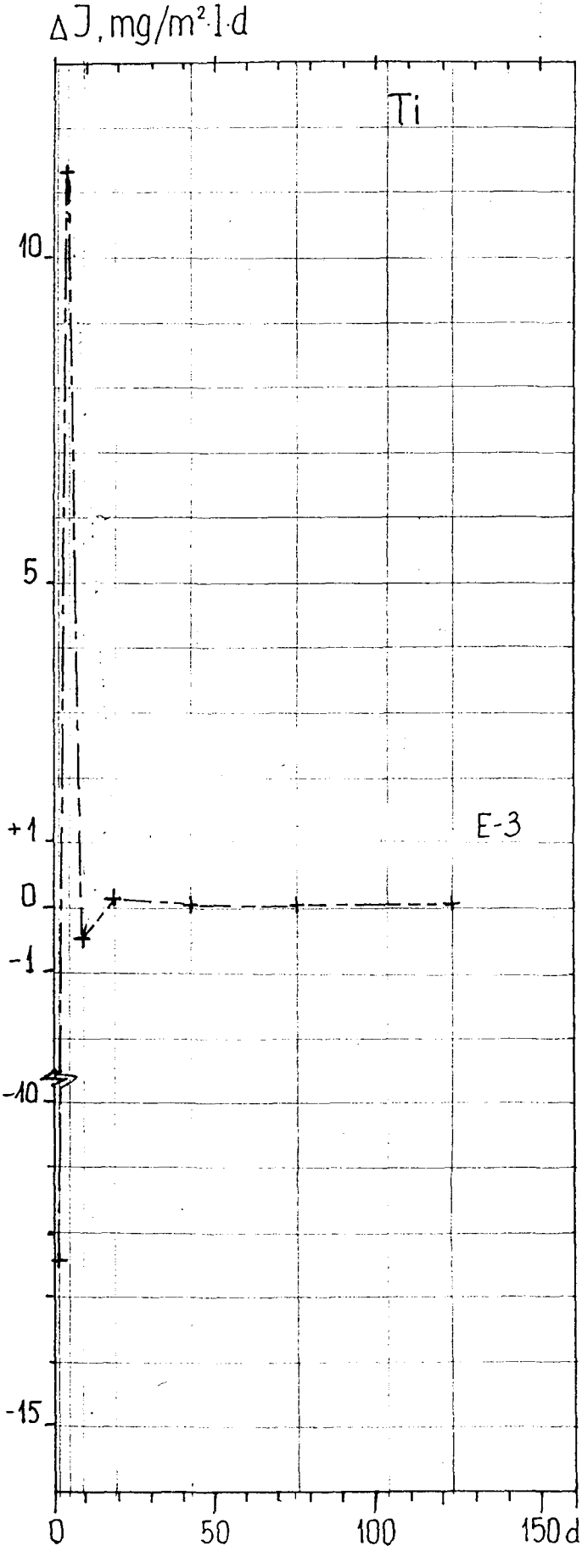

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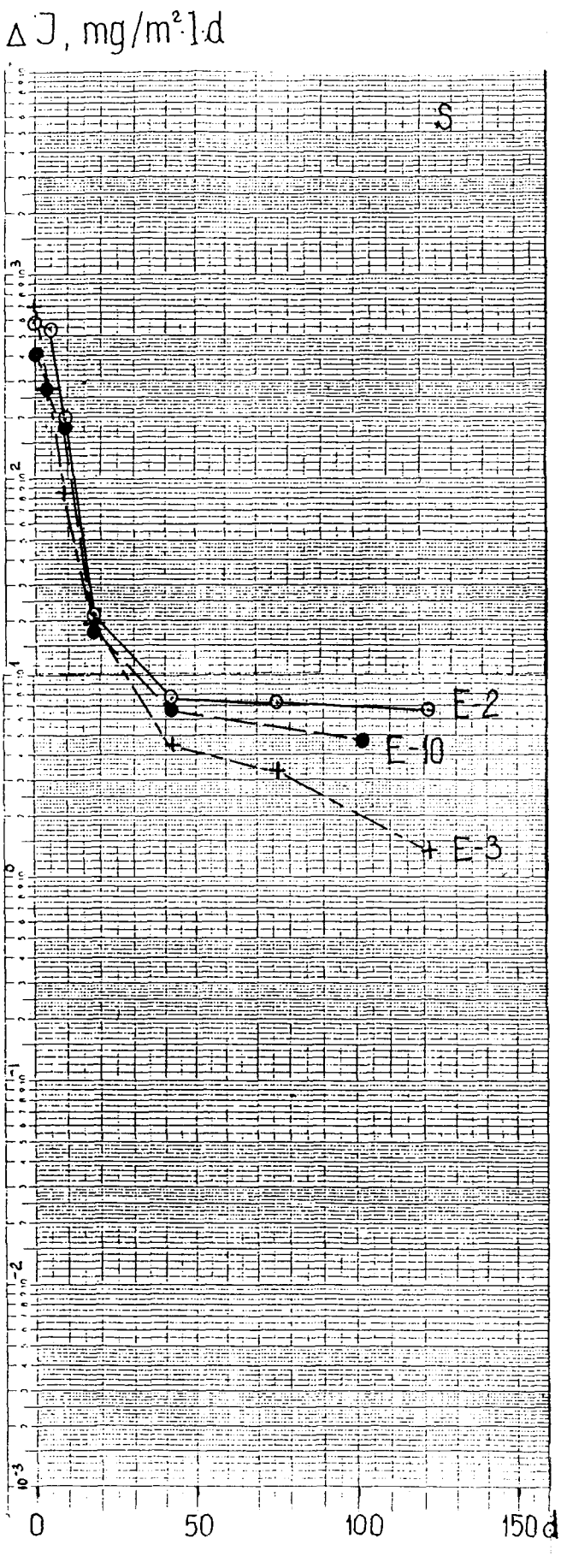

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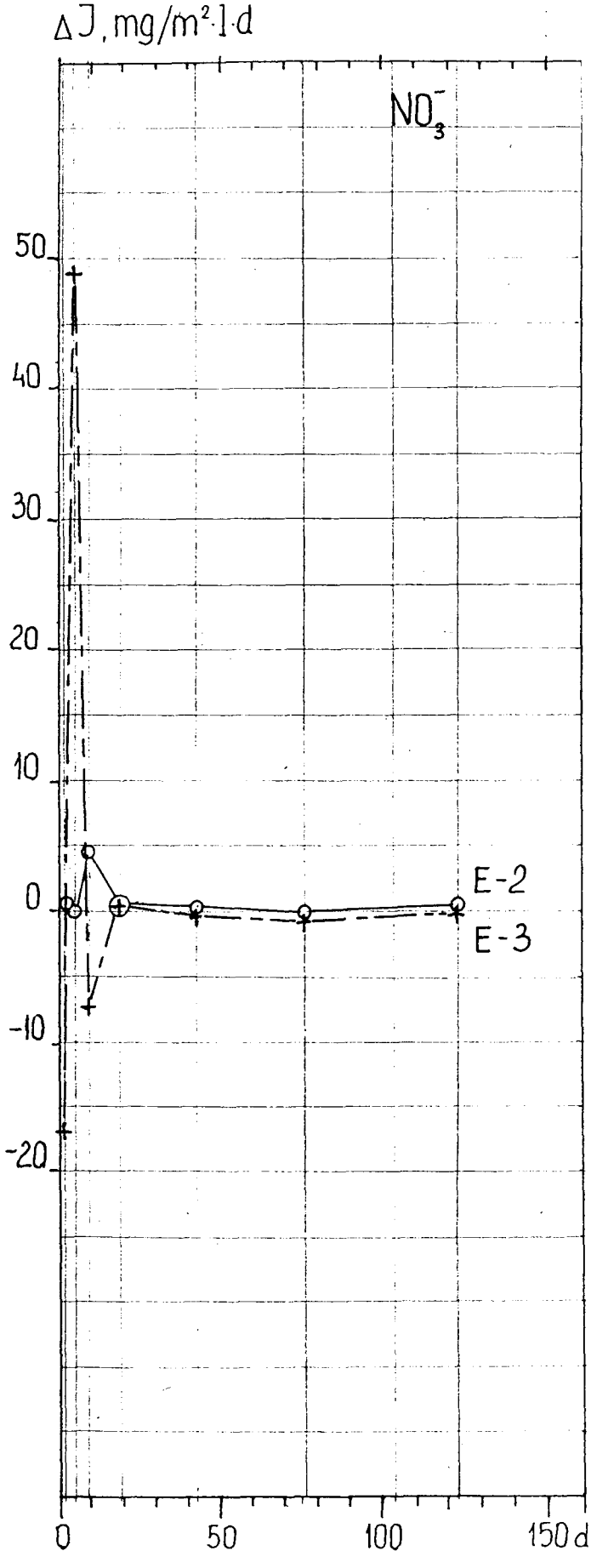

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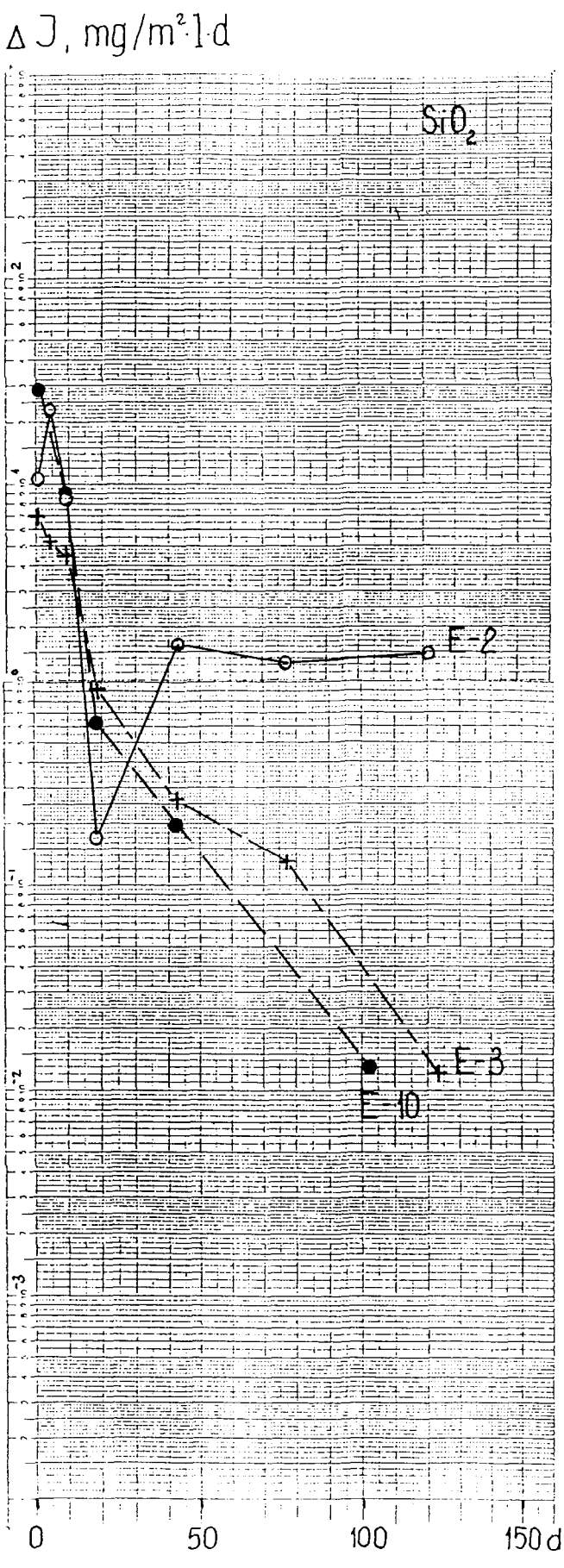

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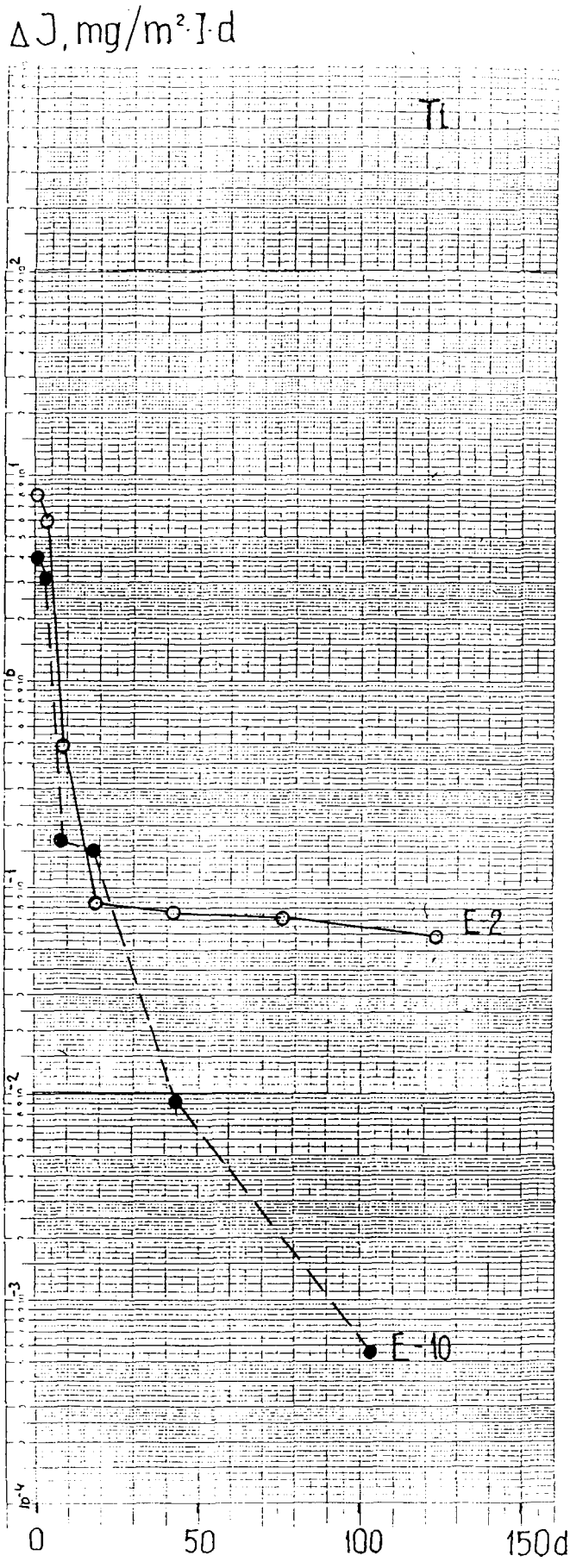
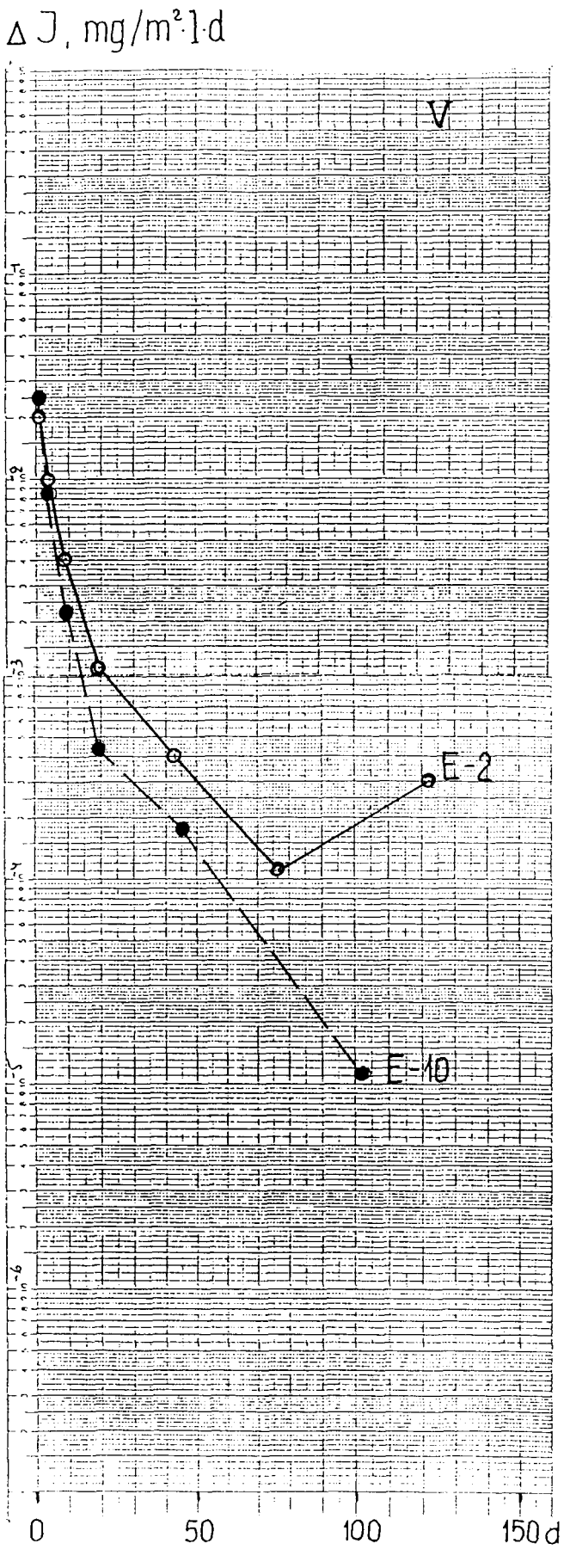


Fig. 14-16



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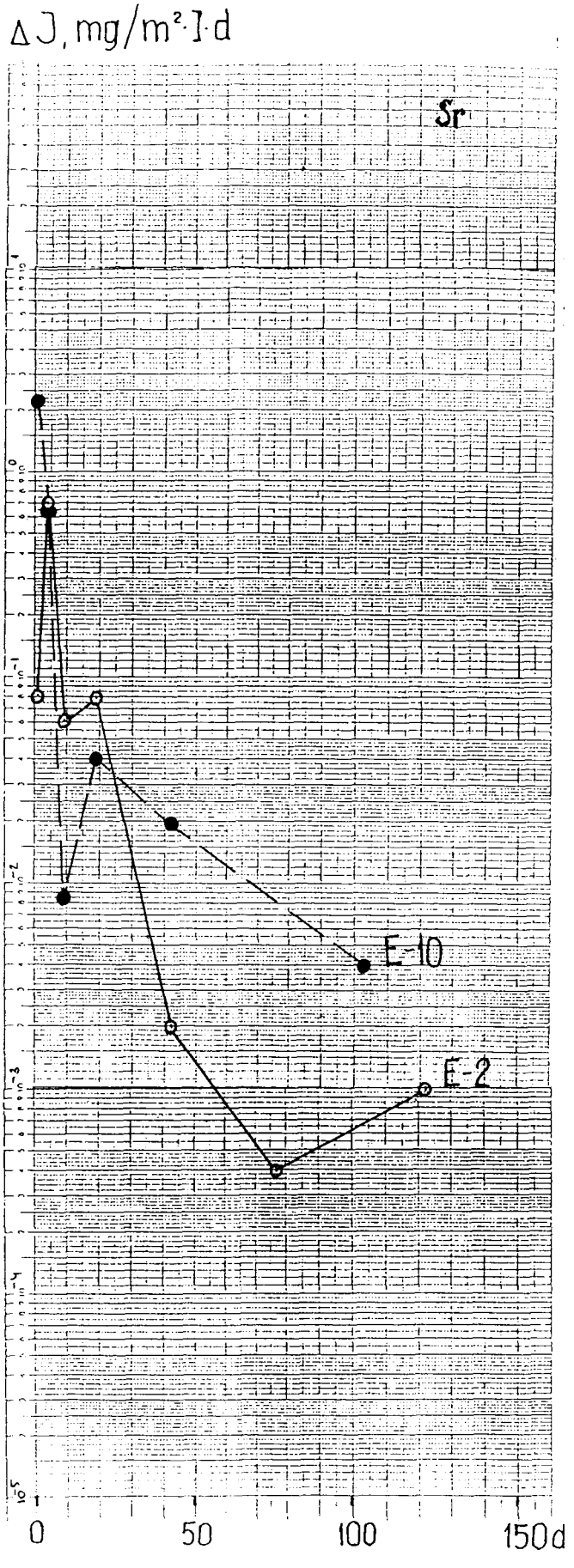

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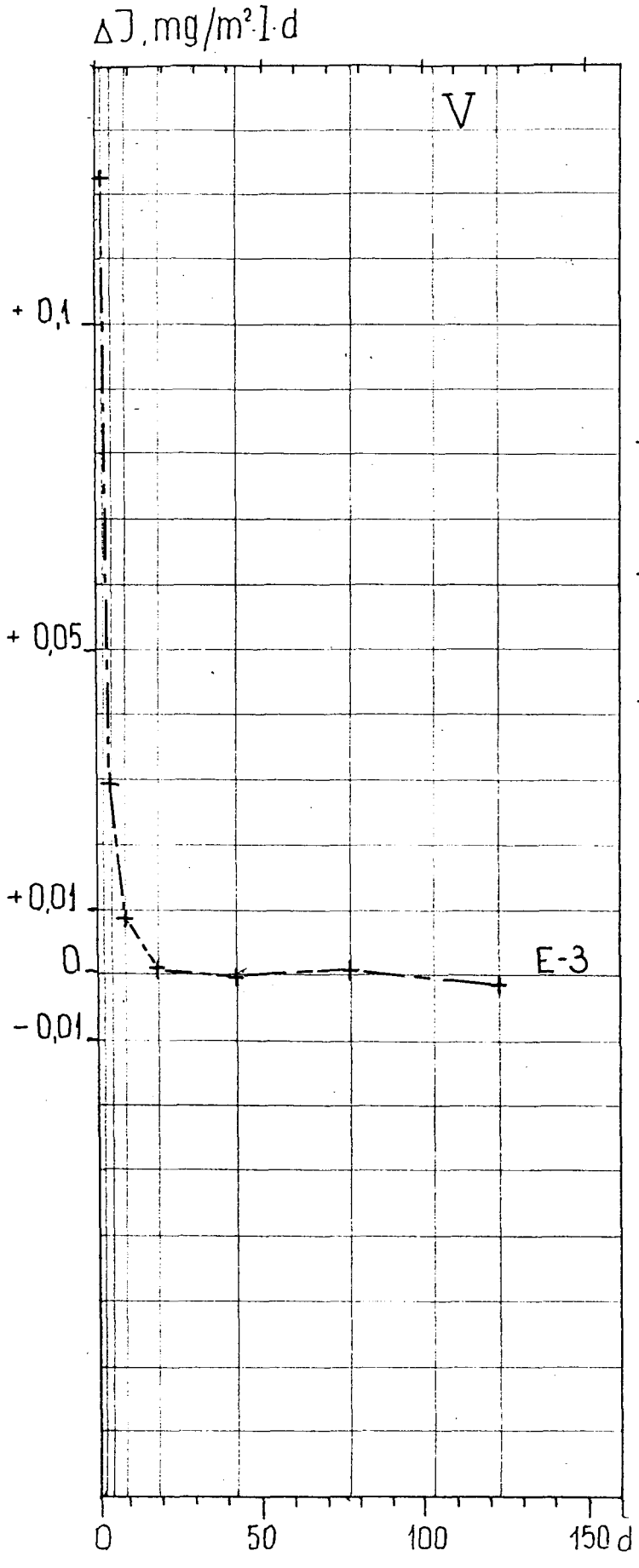

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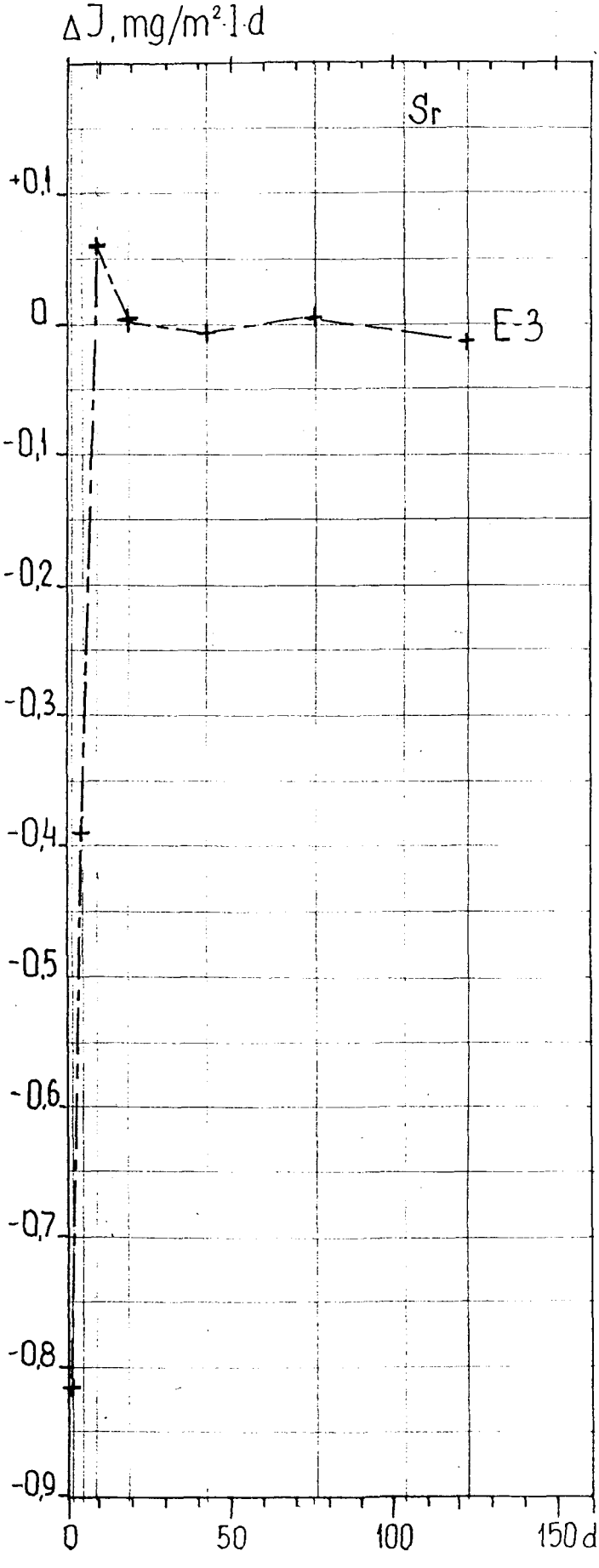

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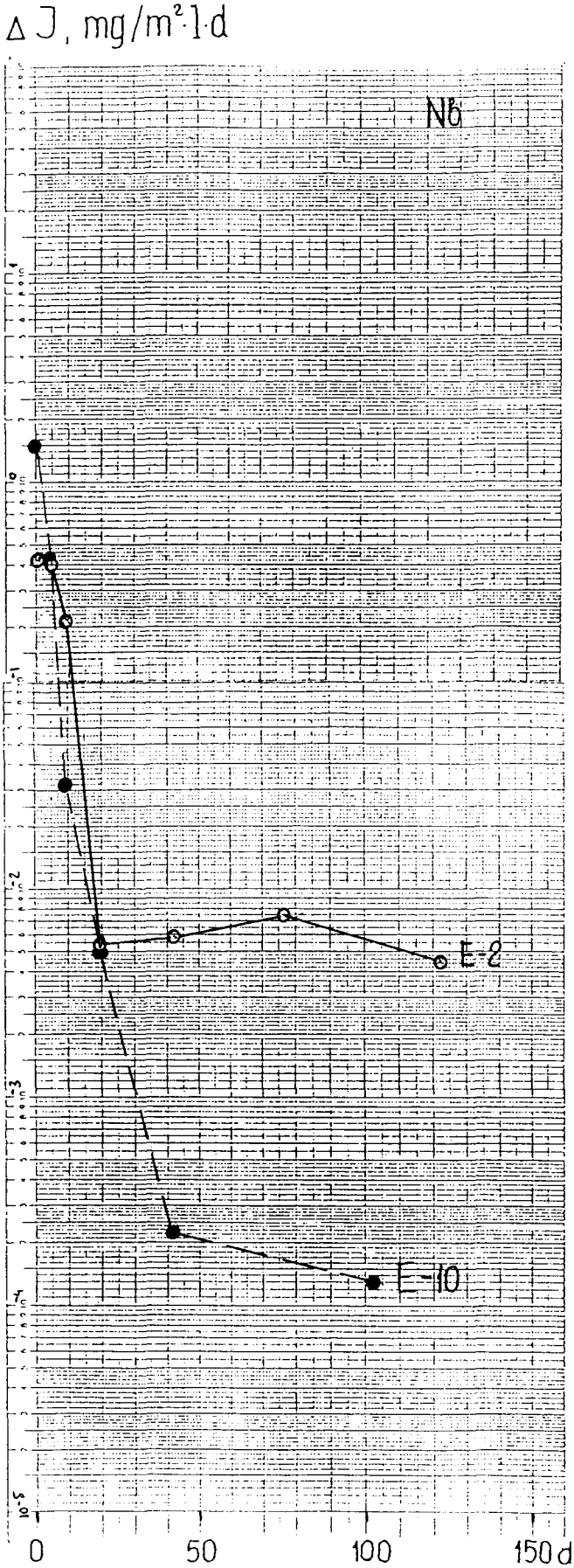

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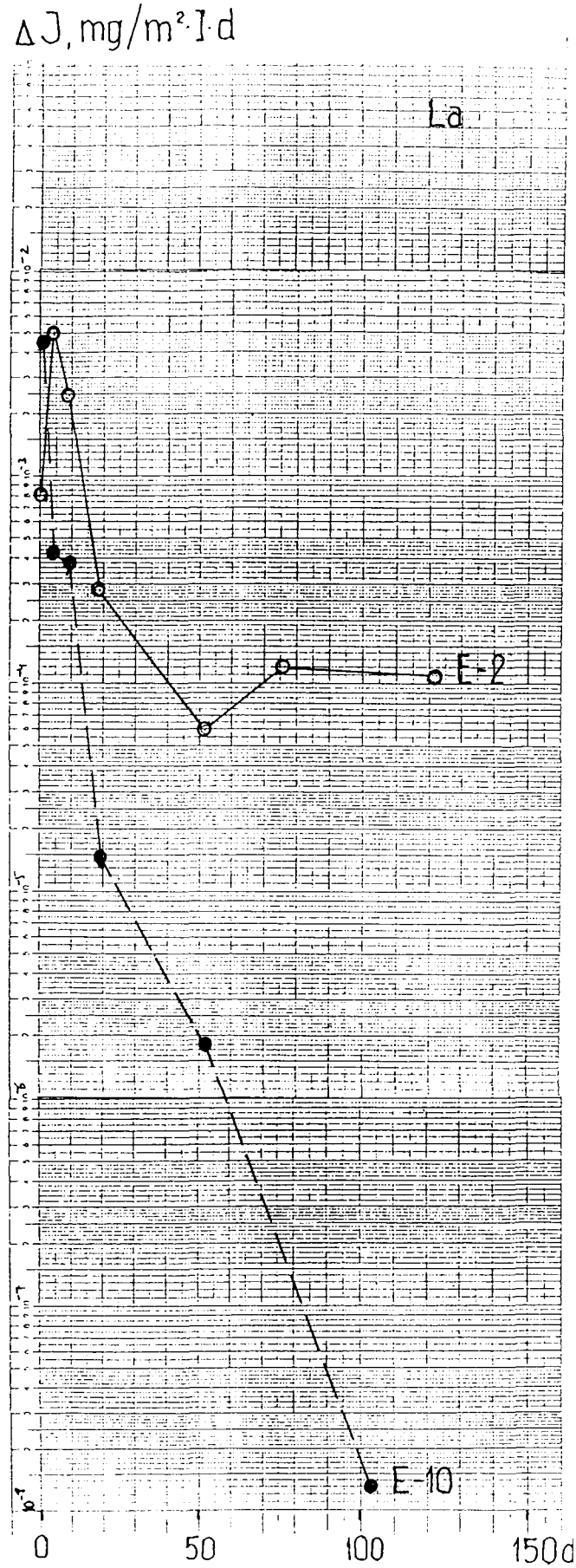

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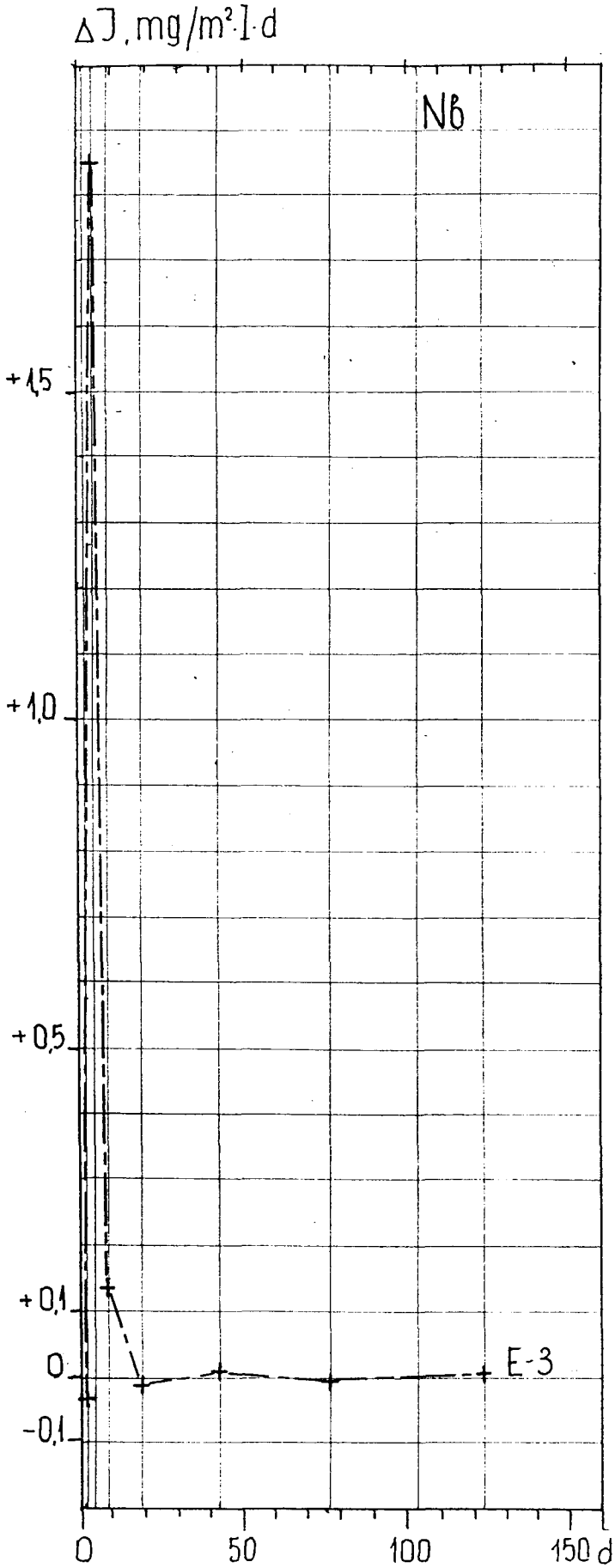

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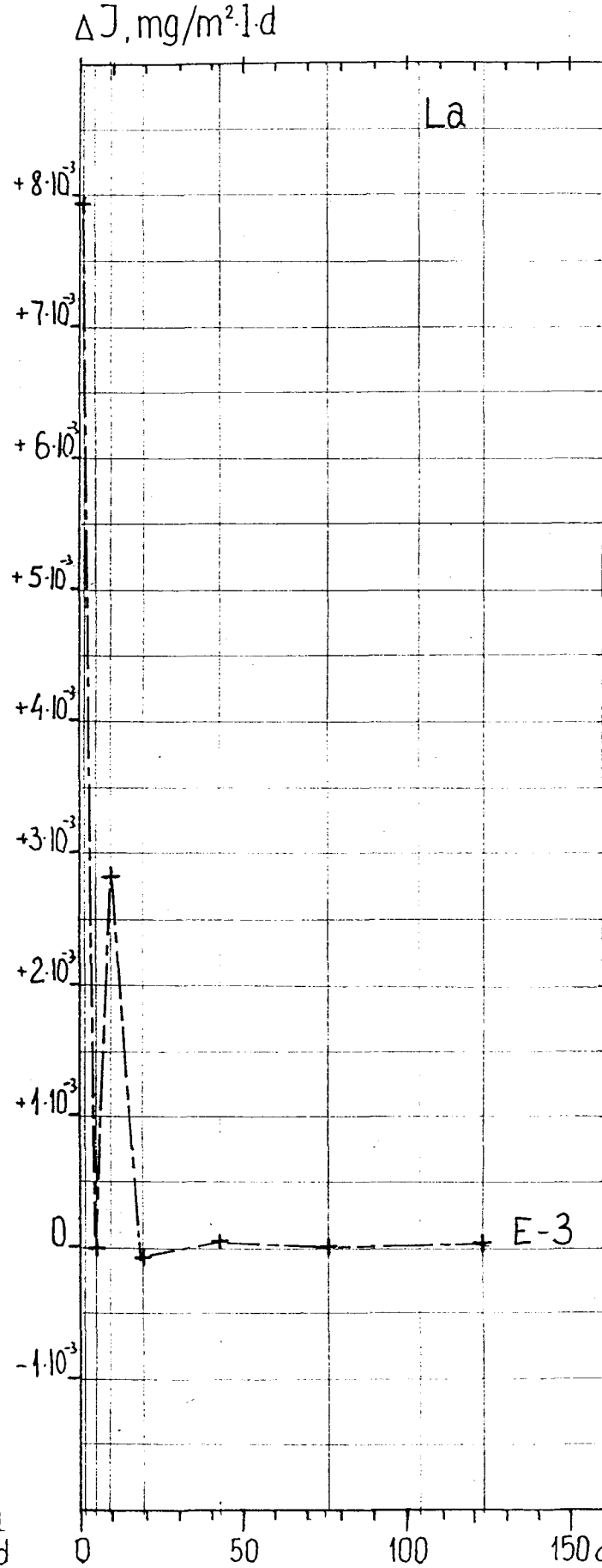

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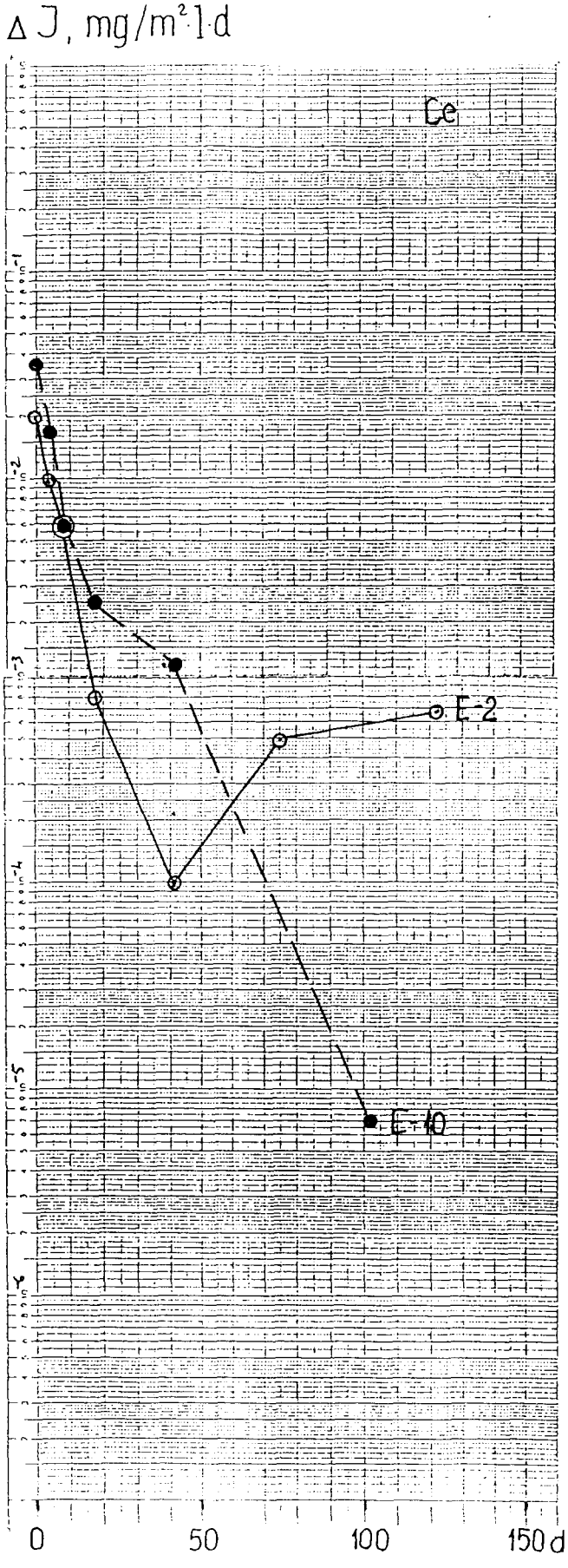

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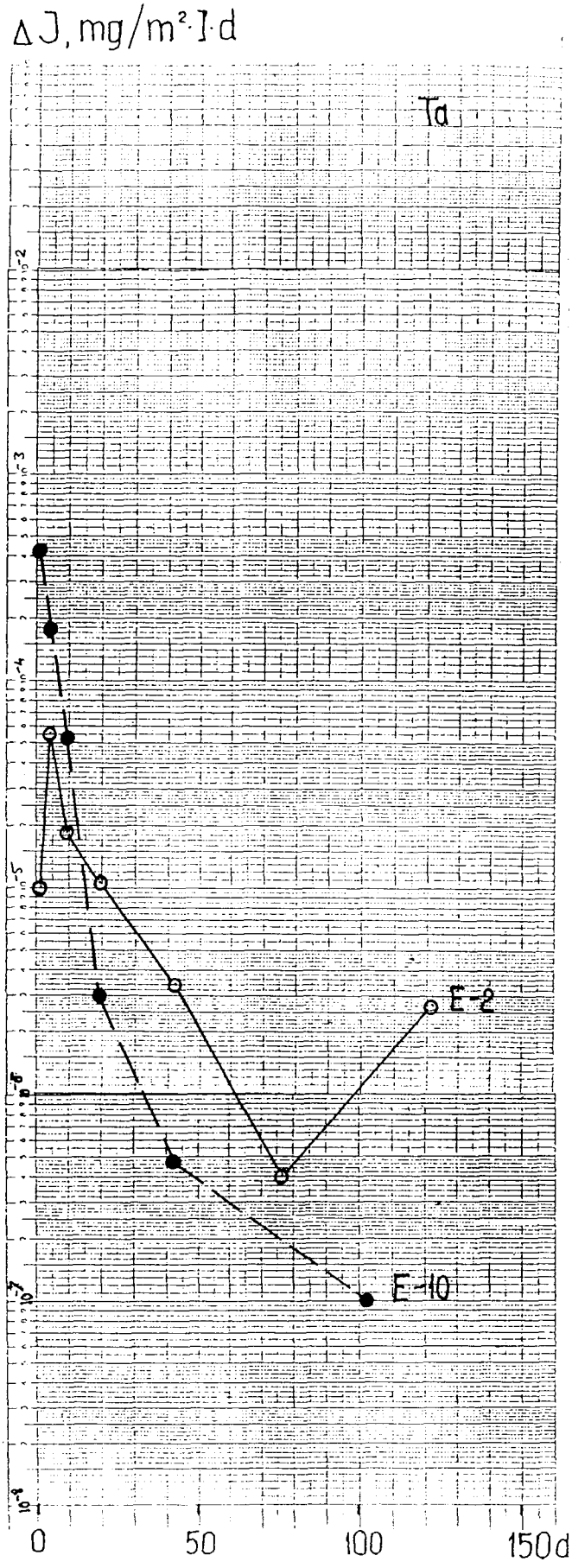

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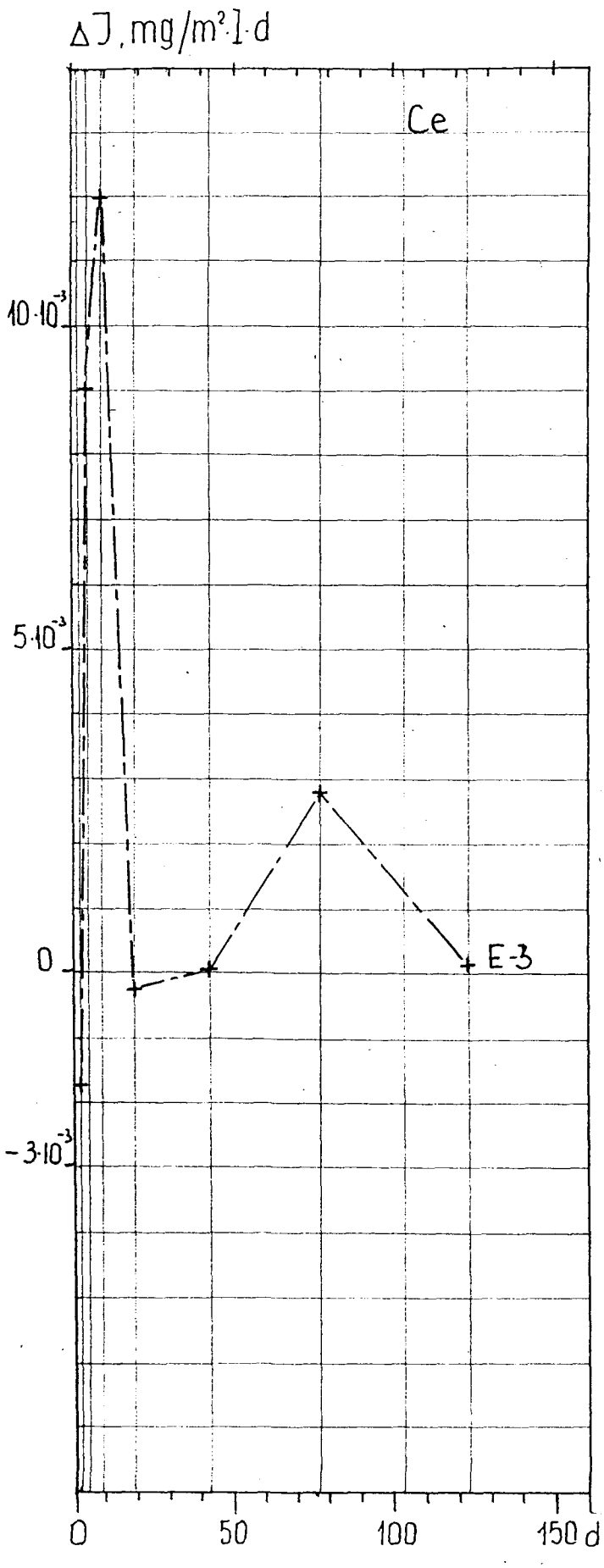

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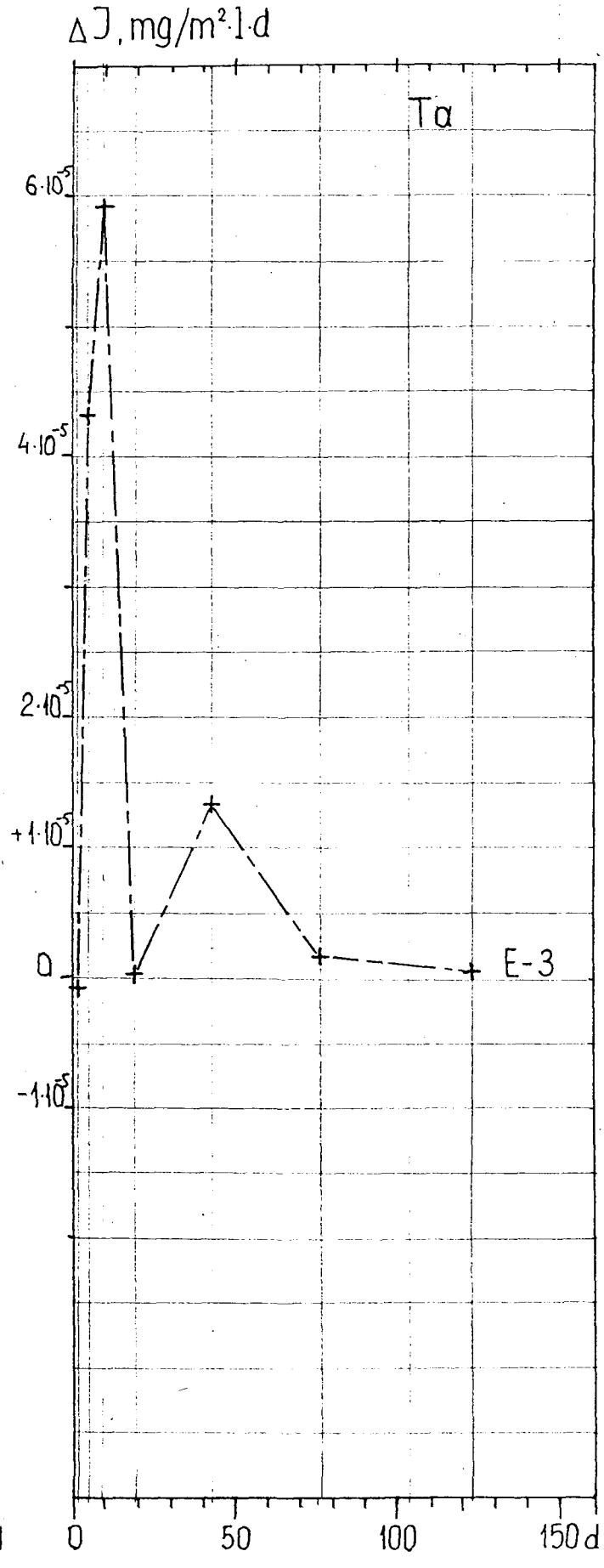

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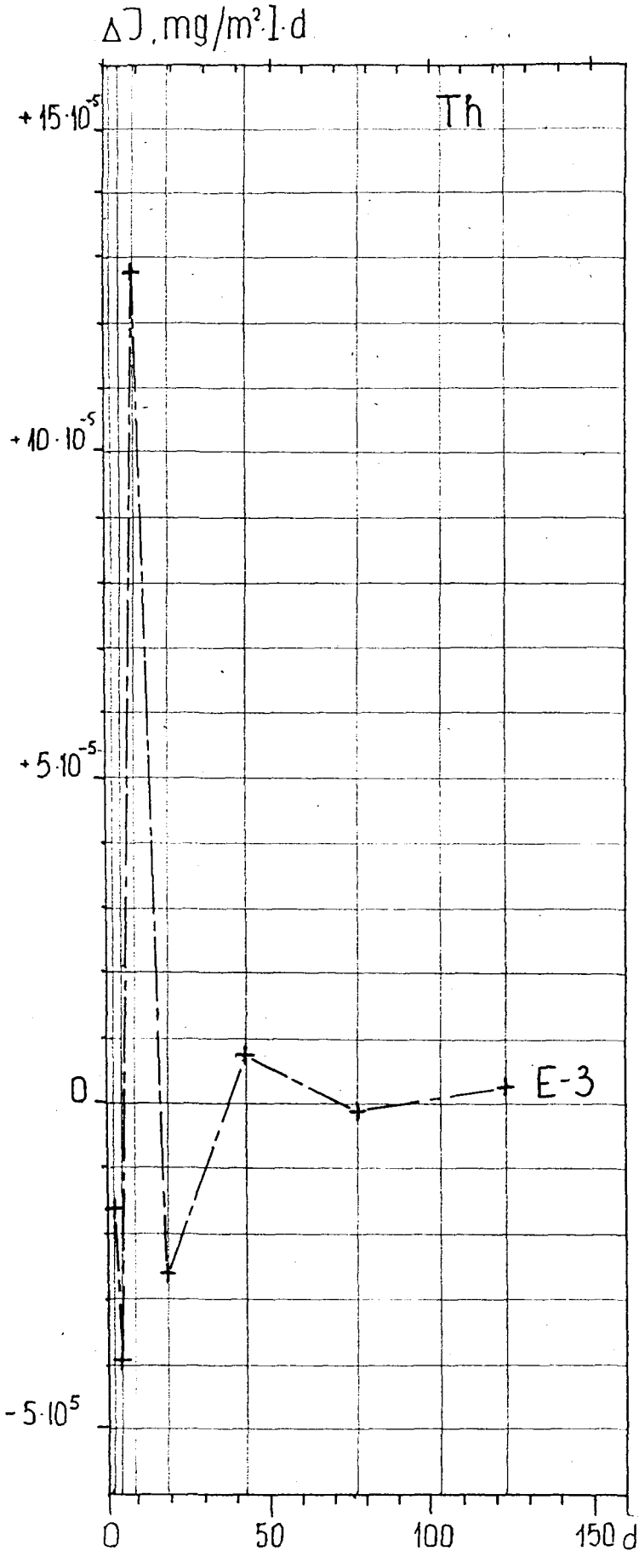

Fig. 14-29

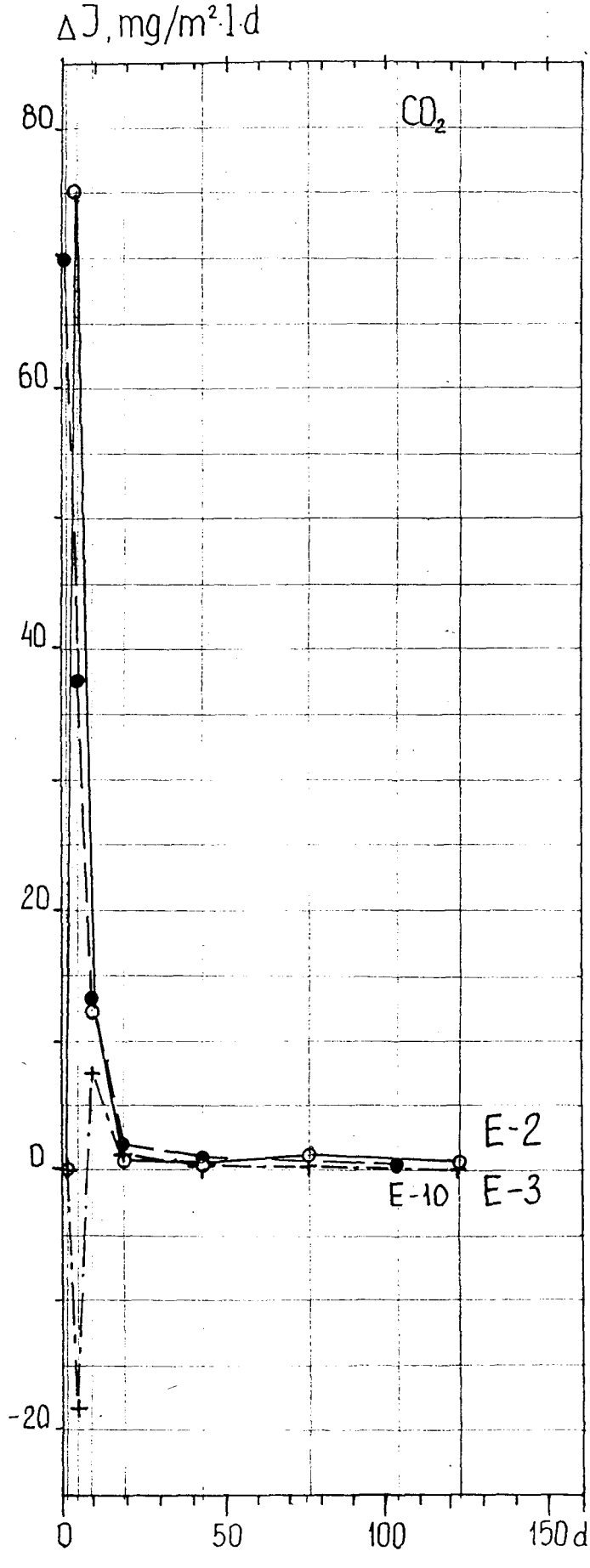

Fig. 14-30

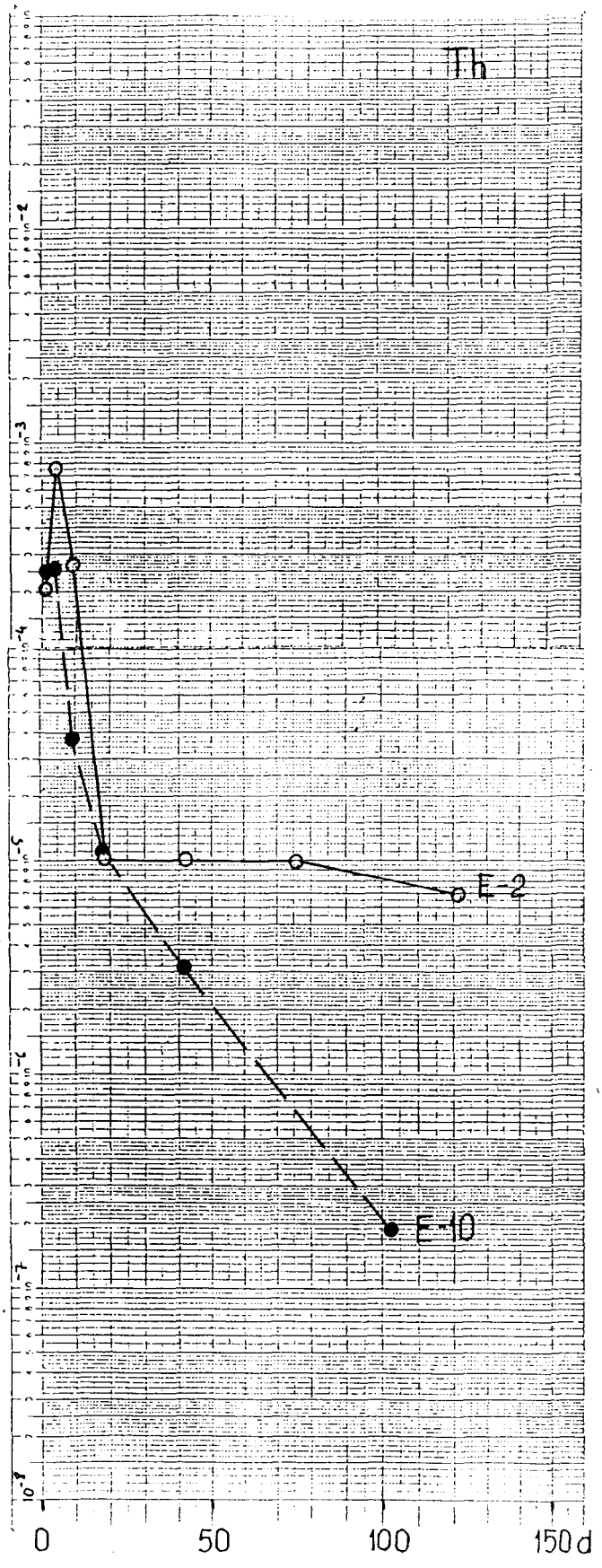

Fig. 14-31

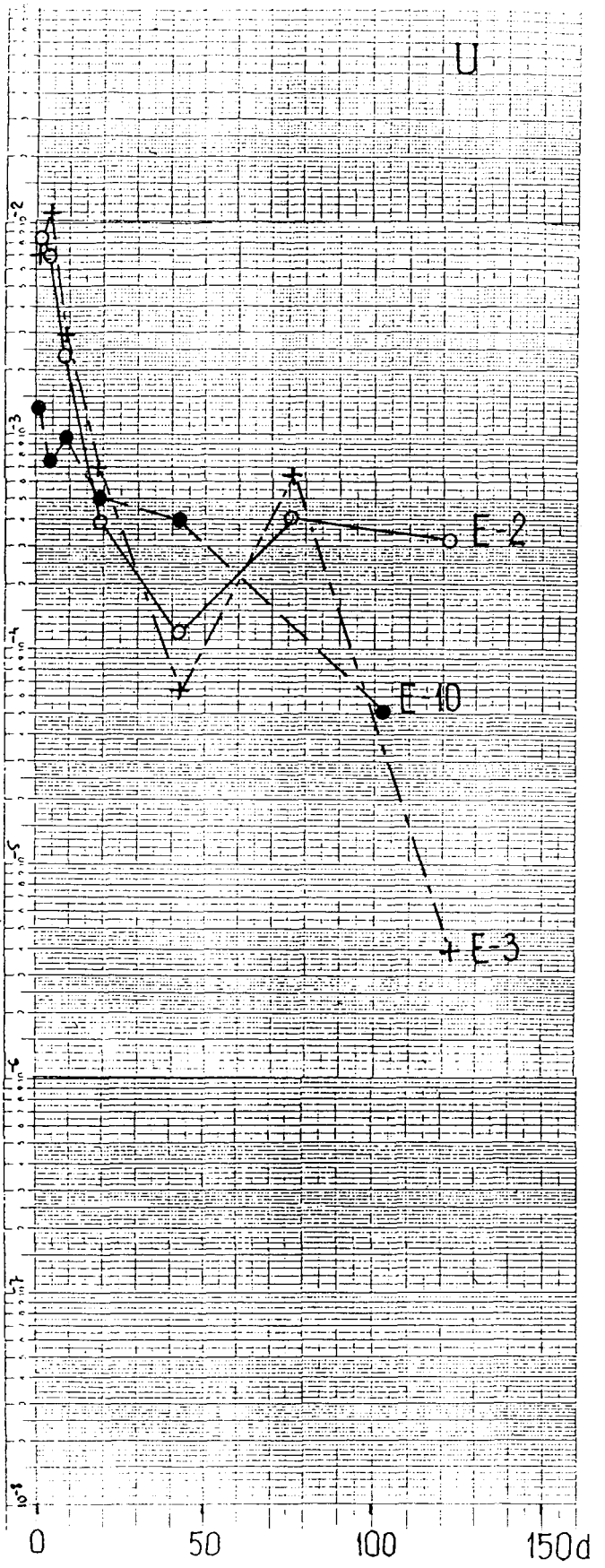

Fig. 14-32

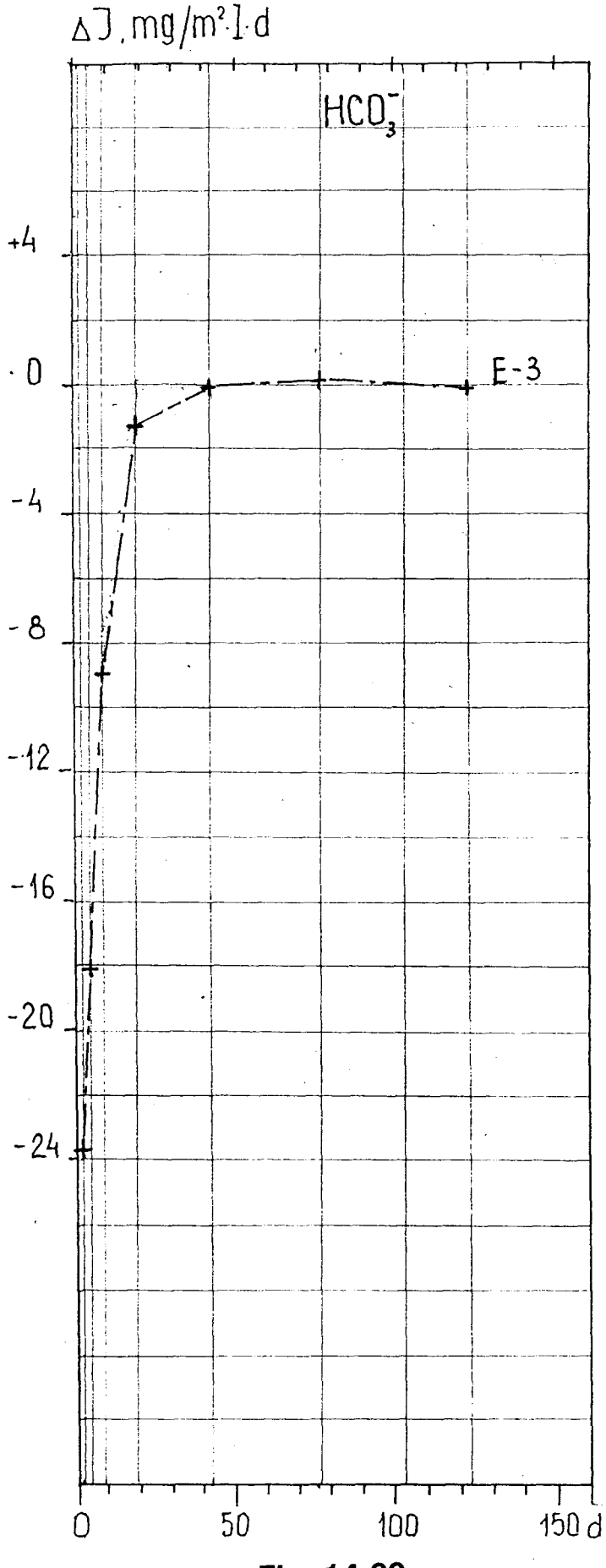

Fig. 14-33

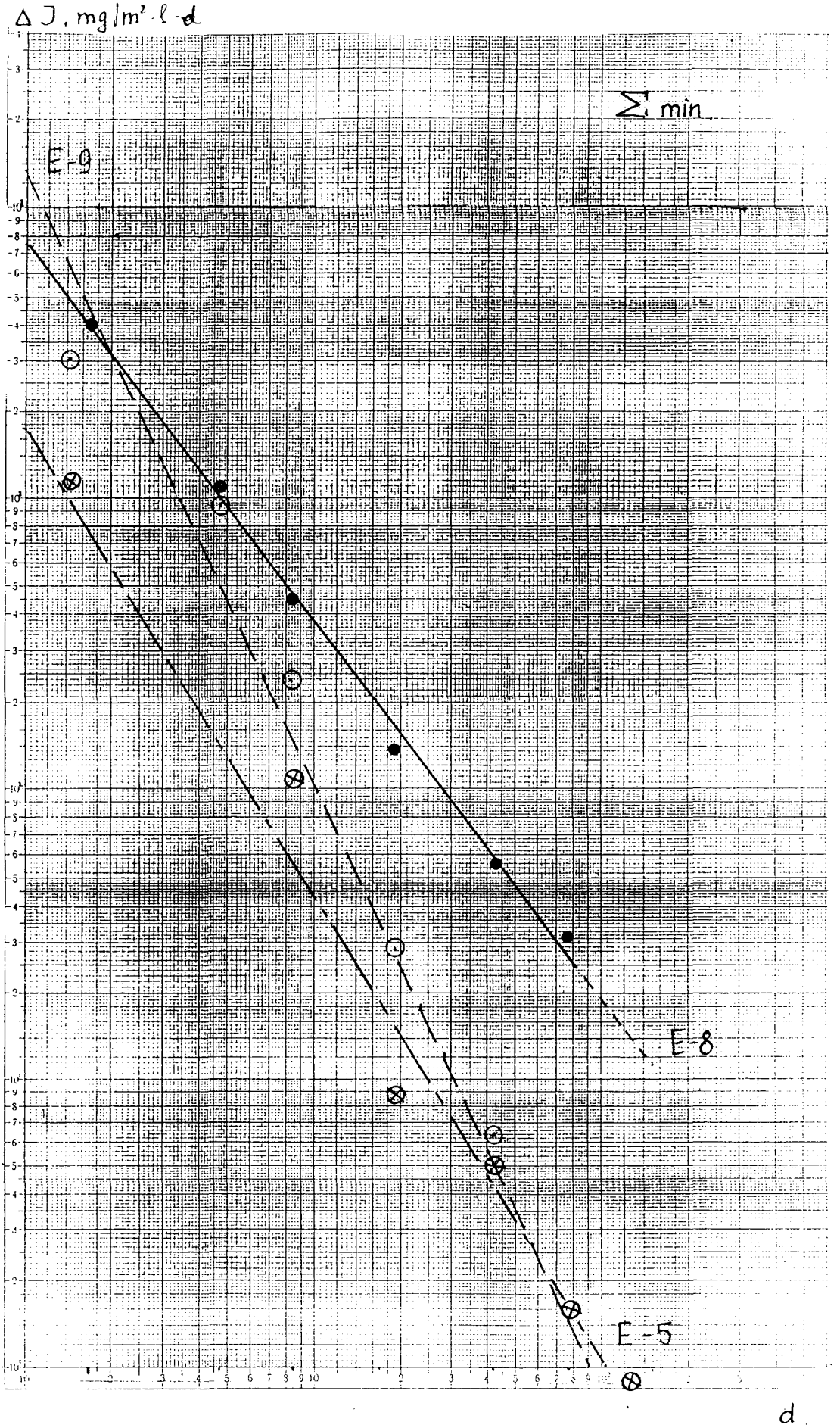

Fig. 15-1

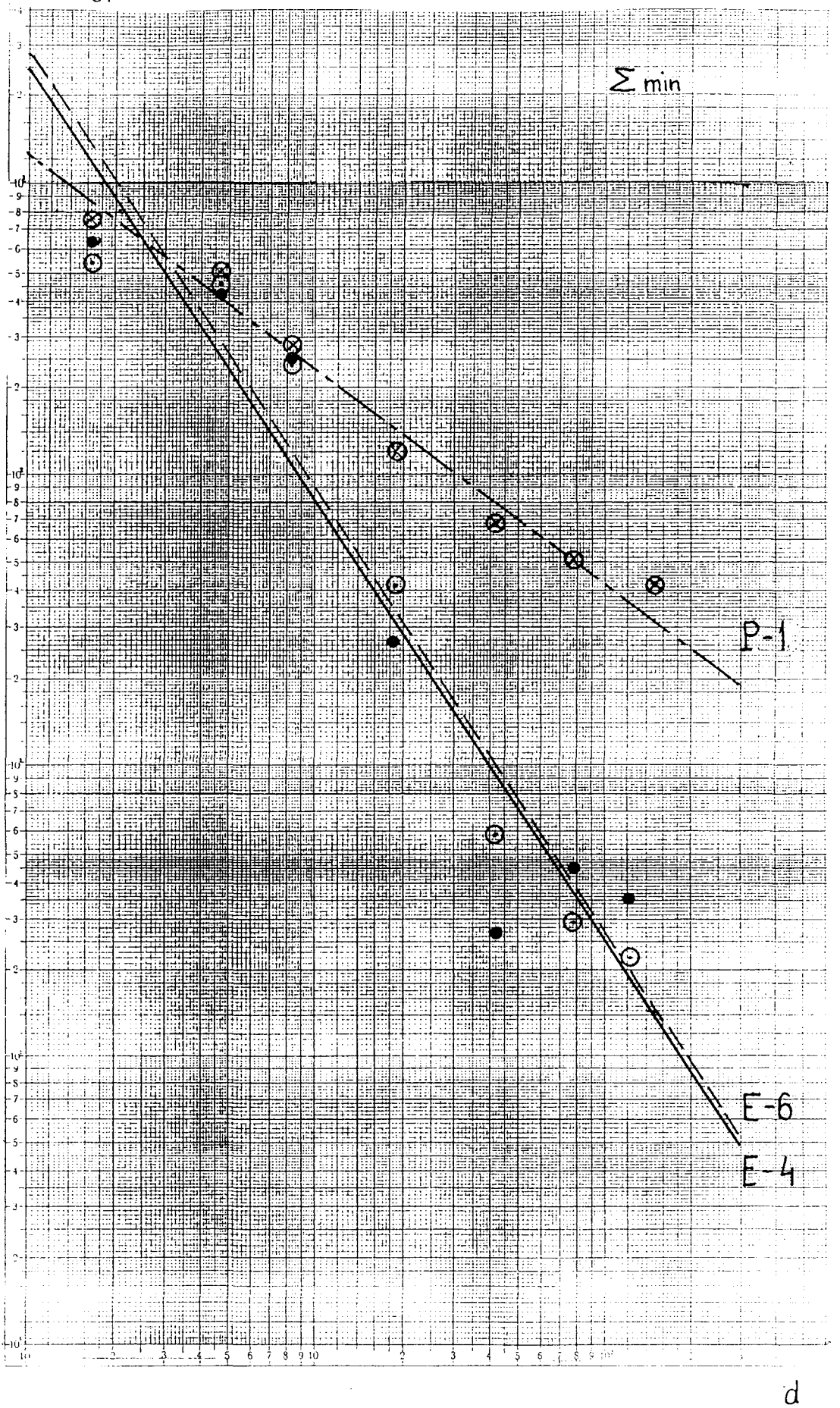

Fig. 15-2

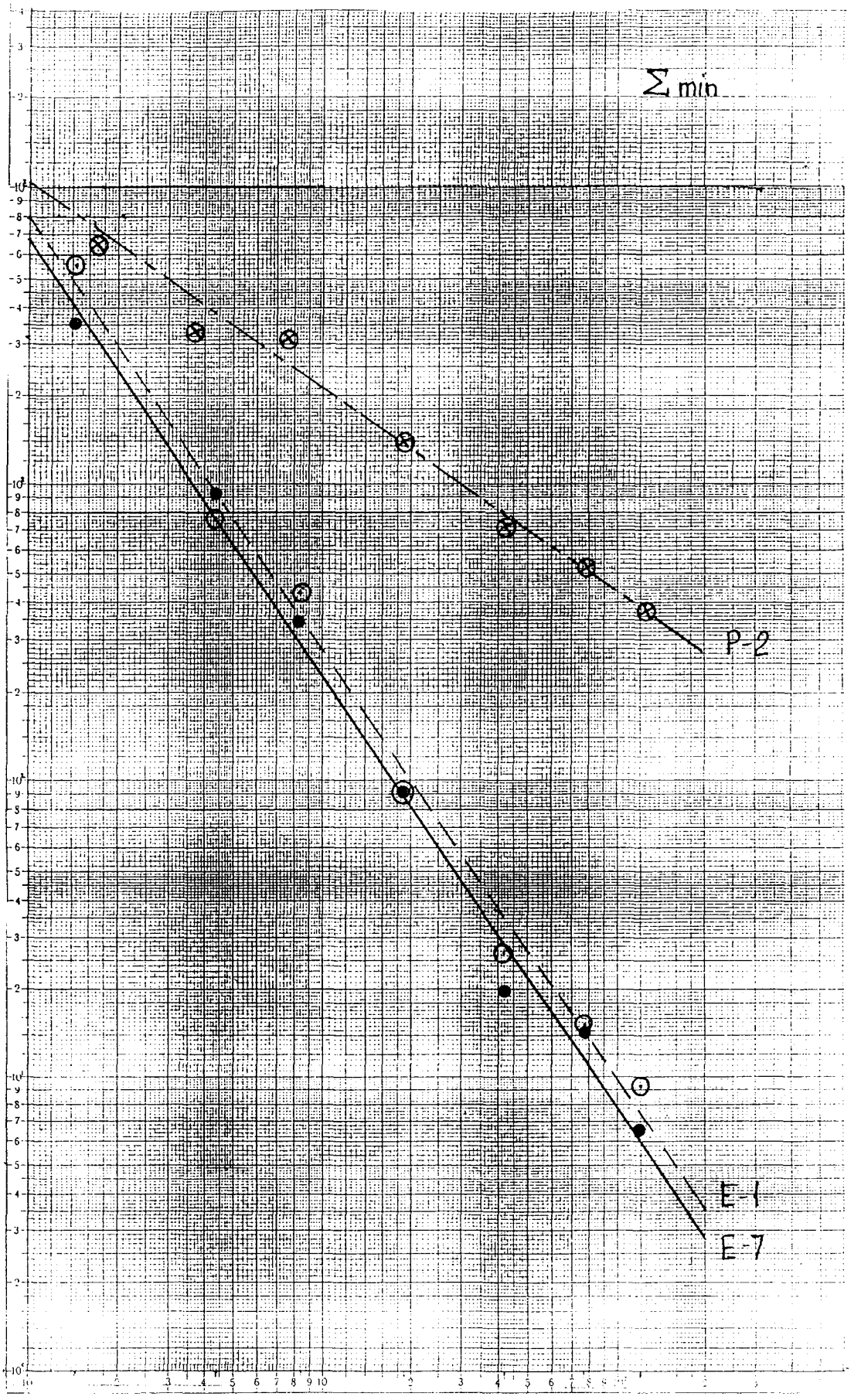

Fig. 15-3

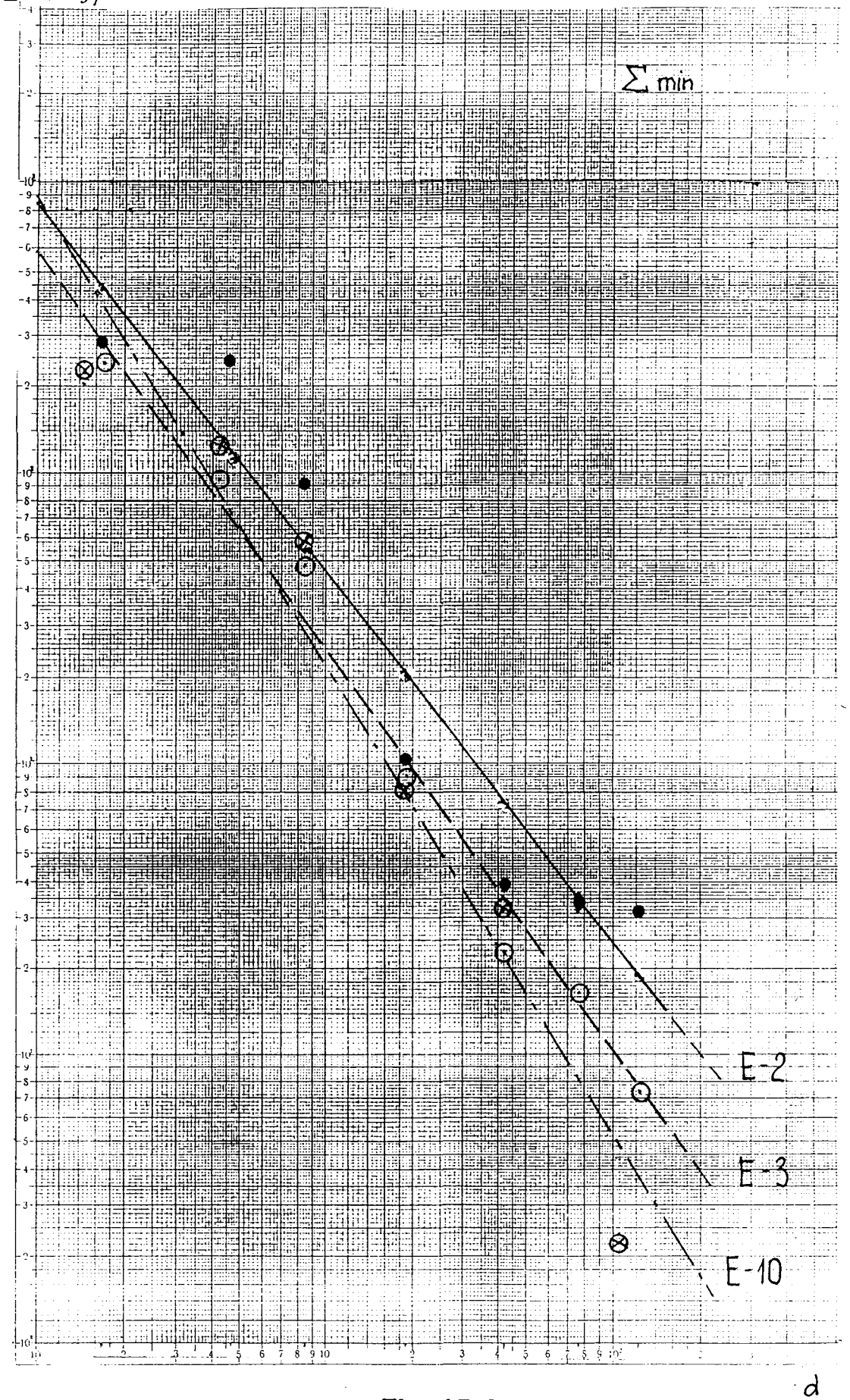

Fig. 15-4

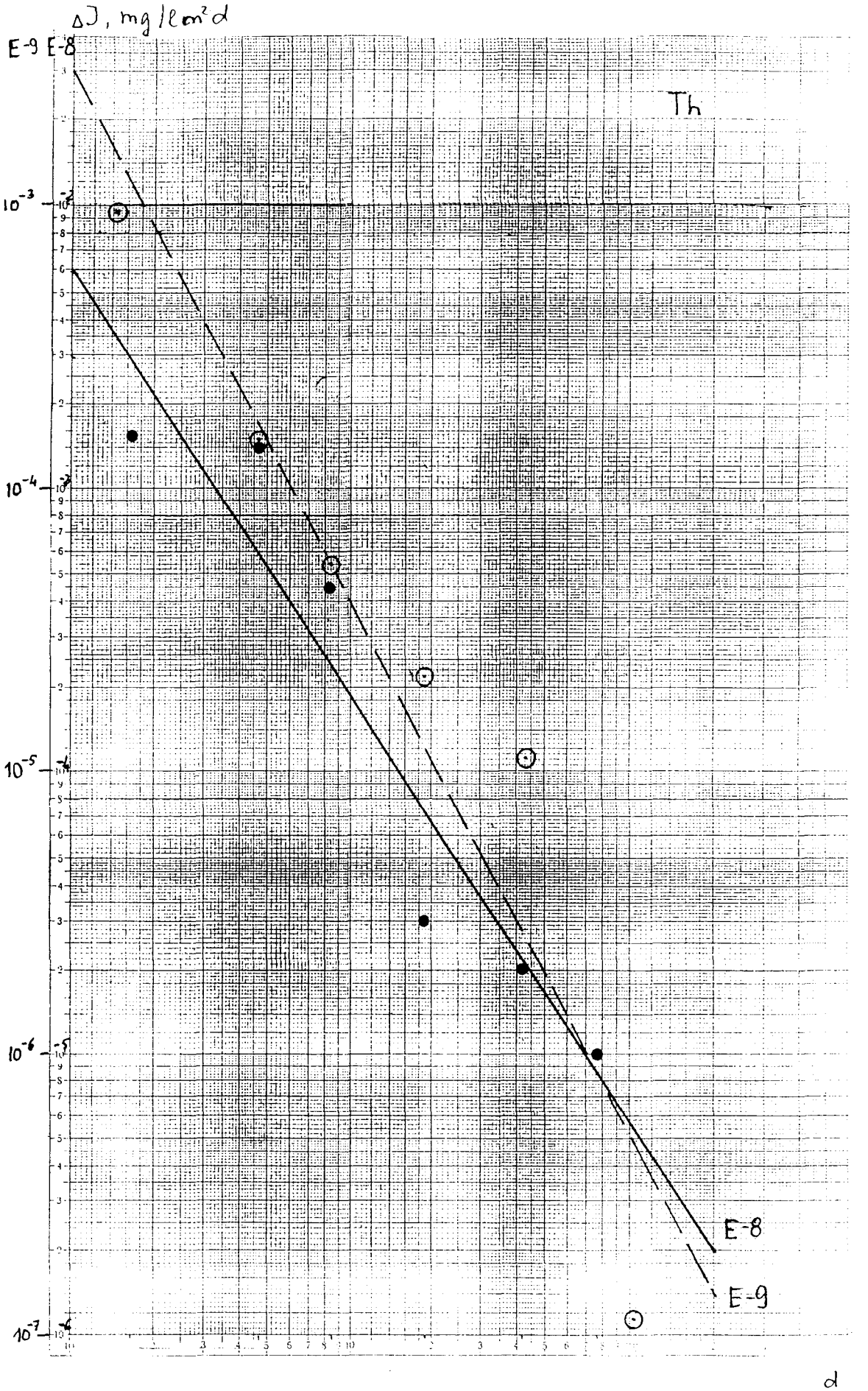

Fig. 16-1

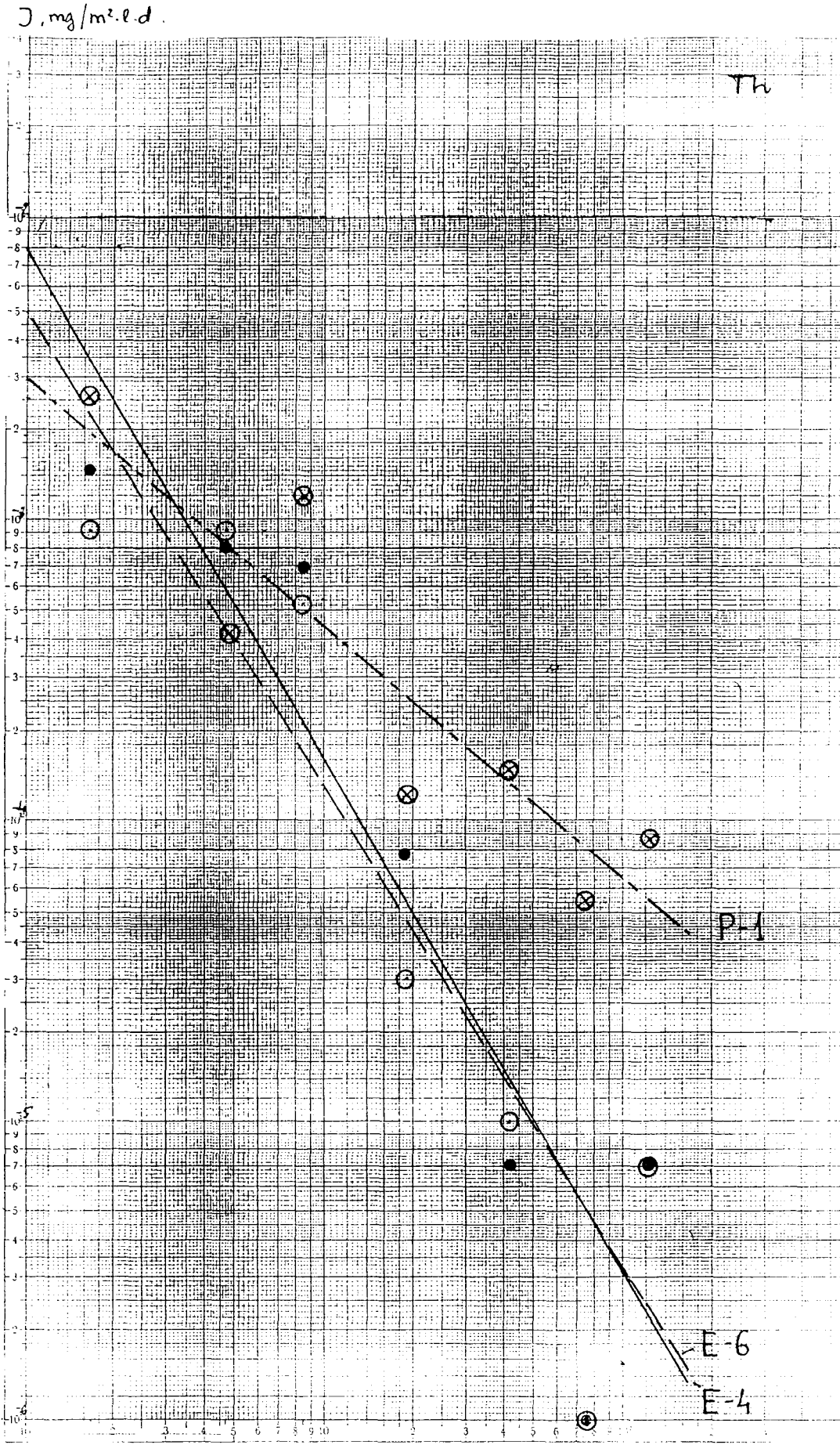

Fig. 16-2

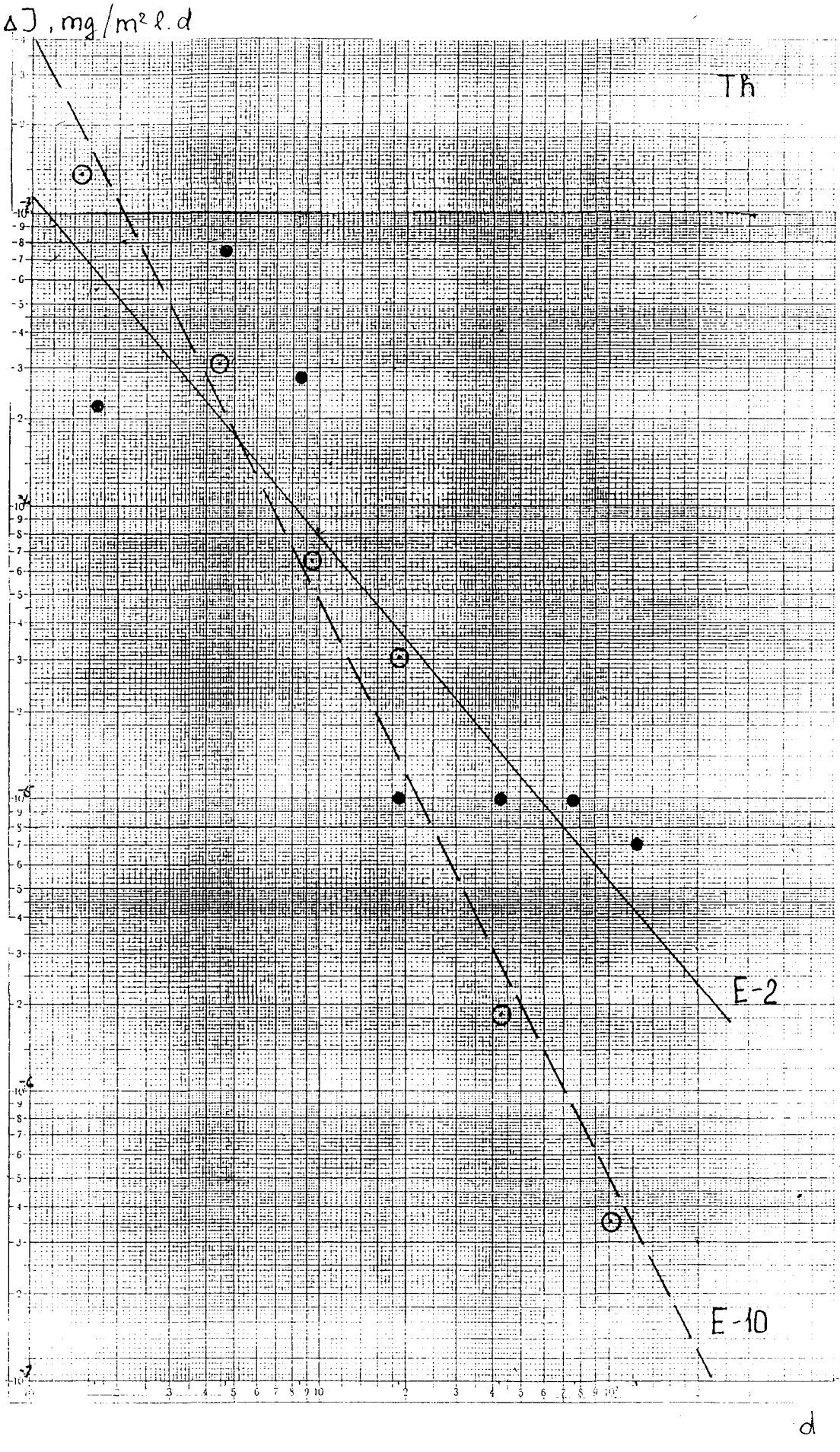

Fig. 16-3

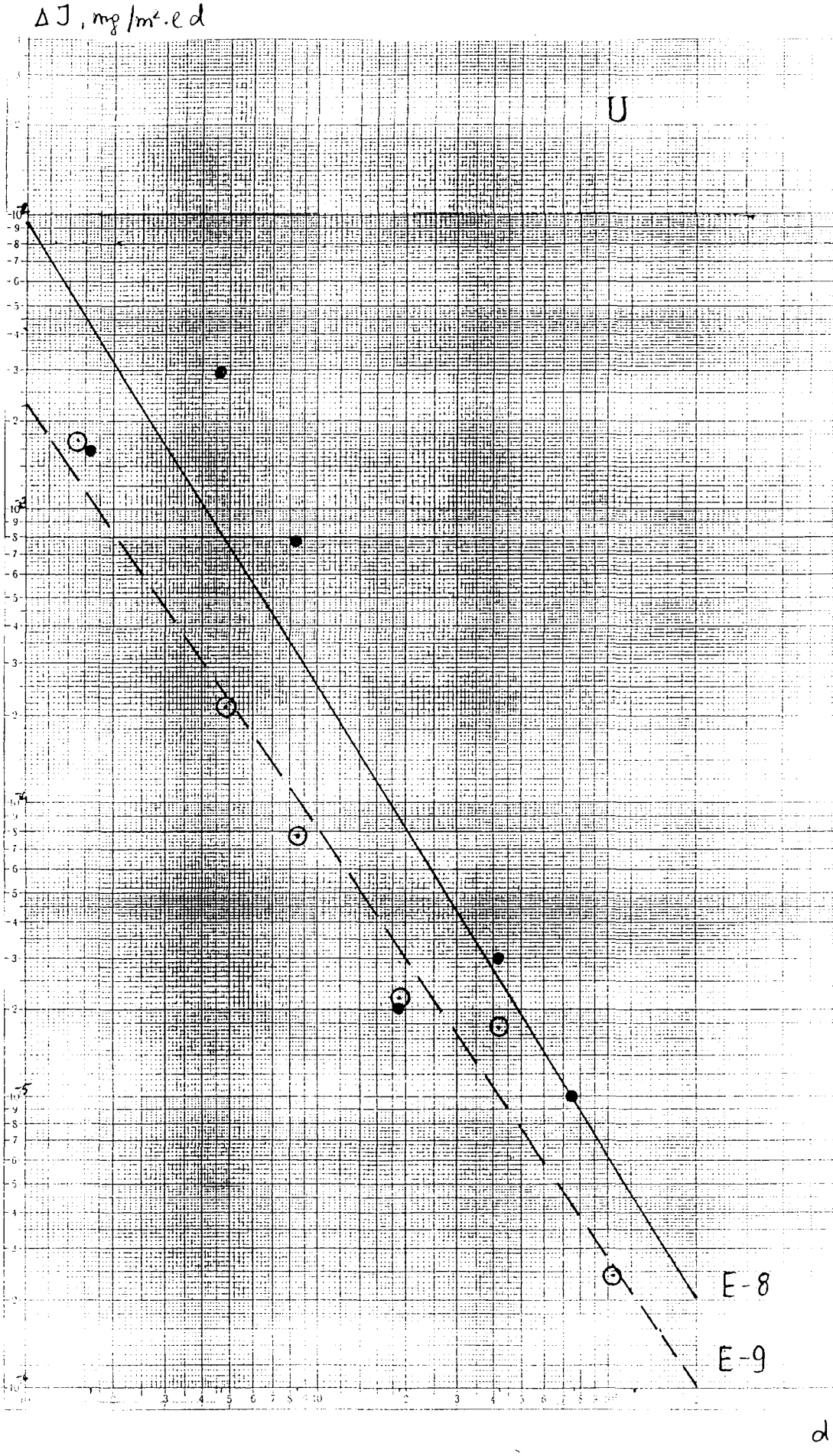

Fig. 17-1

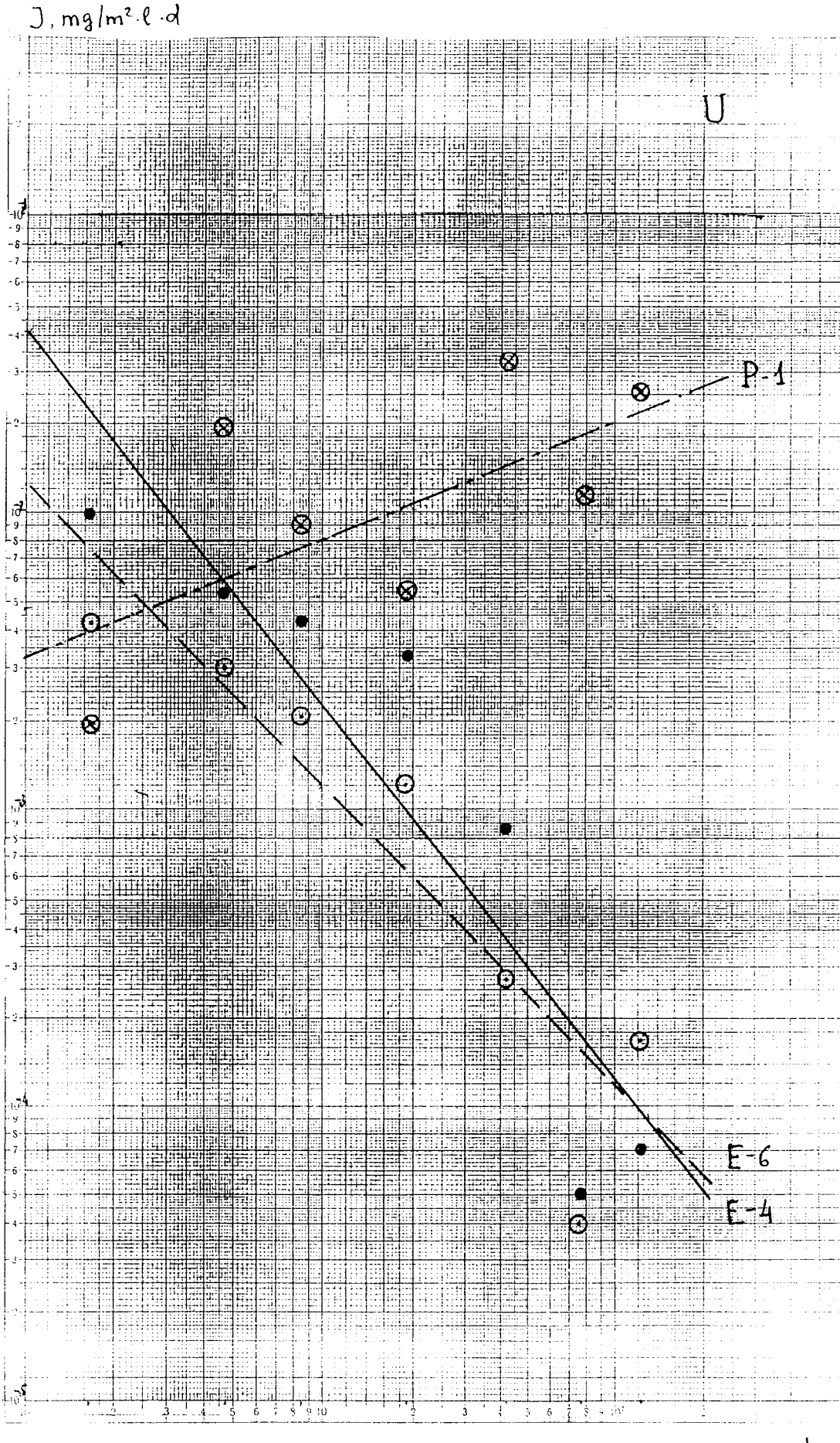

Fig. 17-2

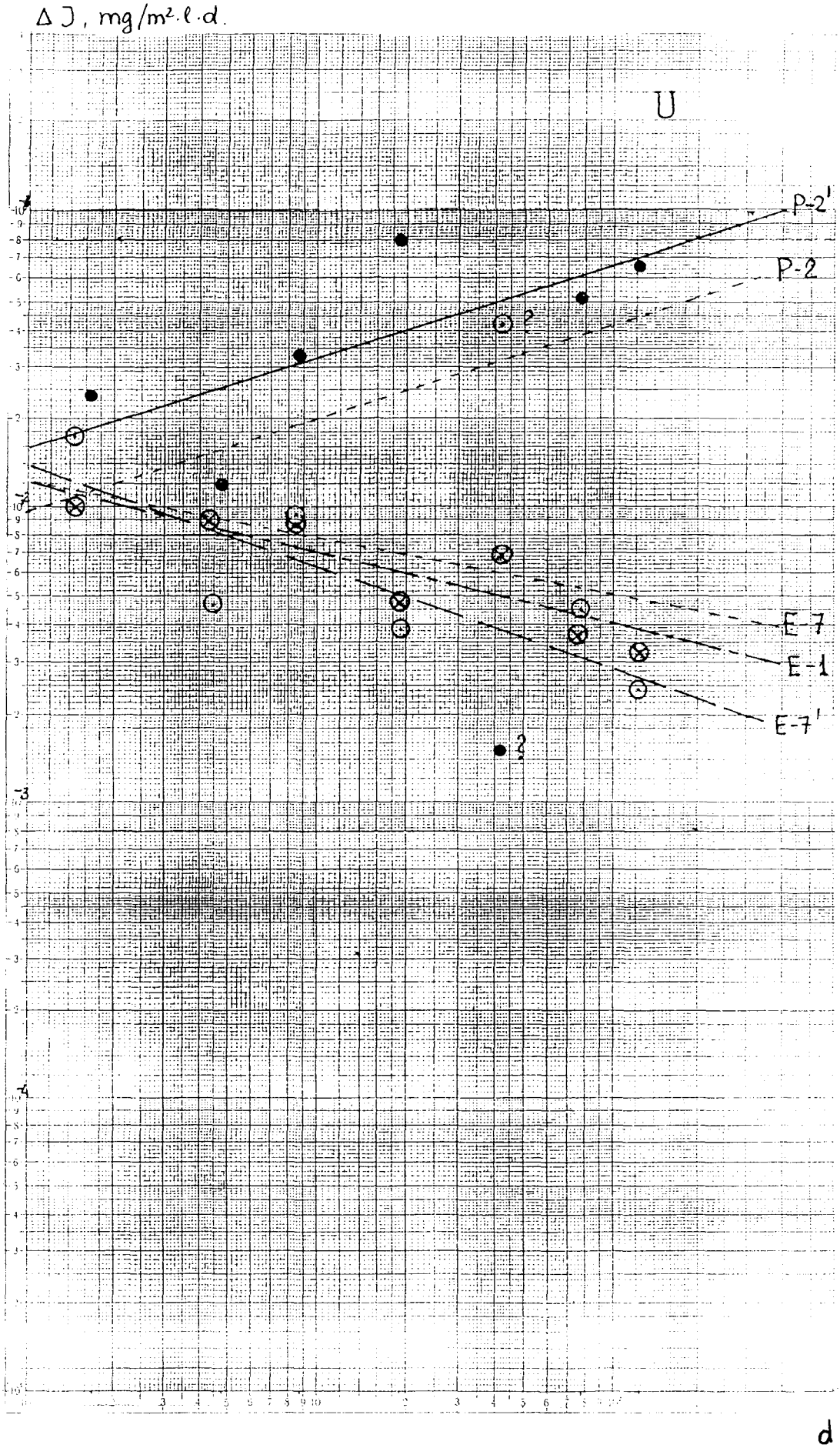

Fig. 17-3

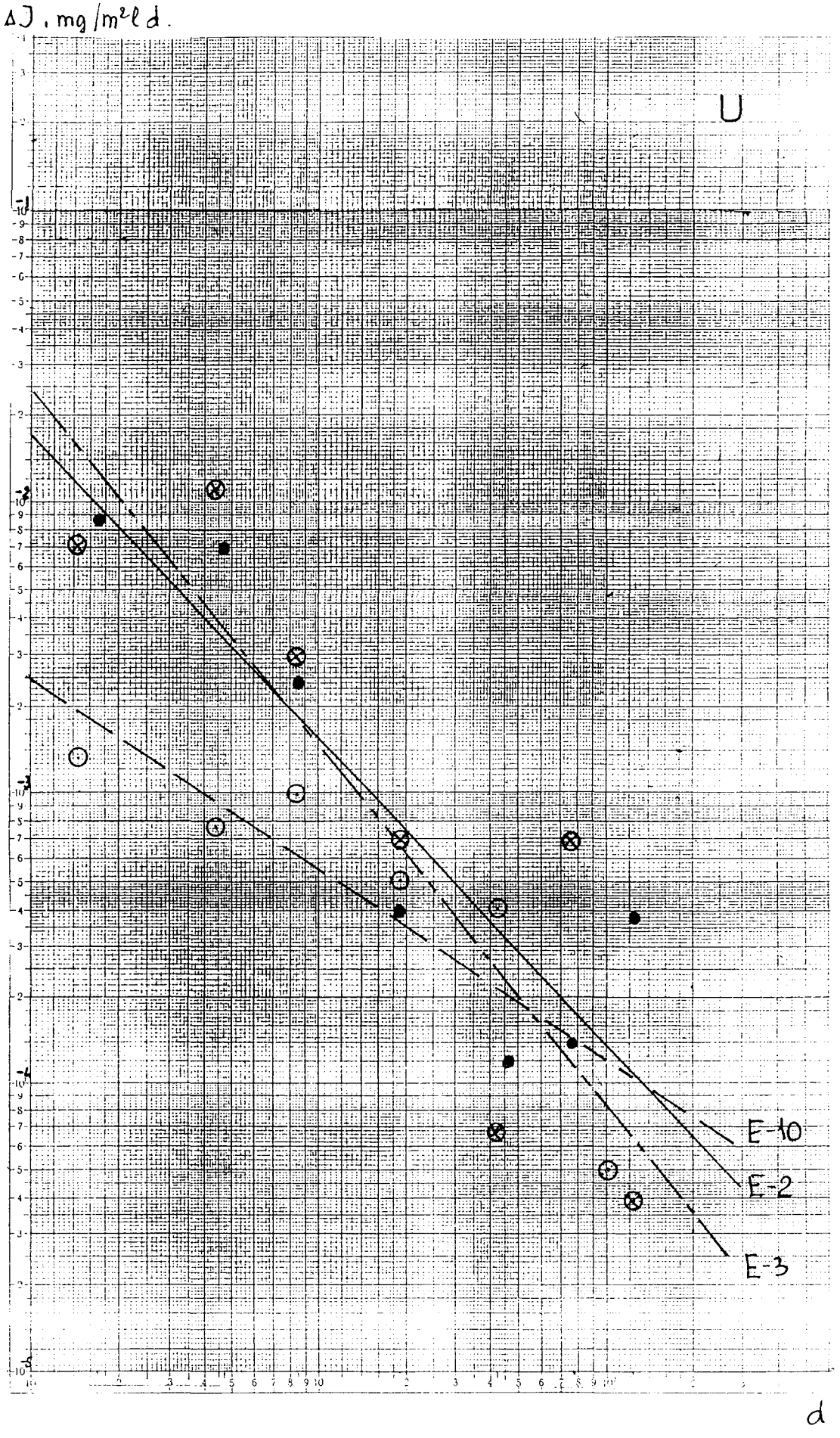

Fig. 17-4

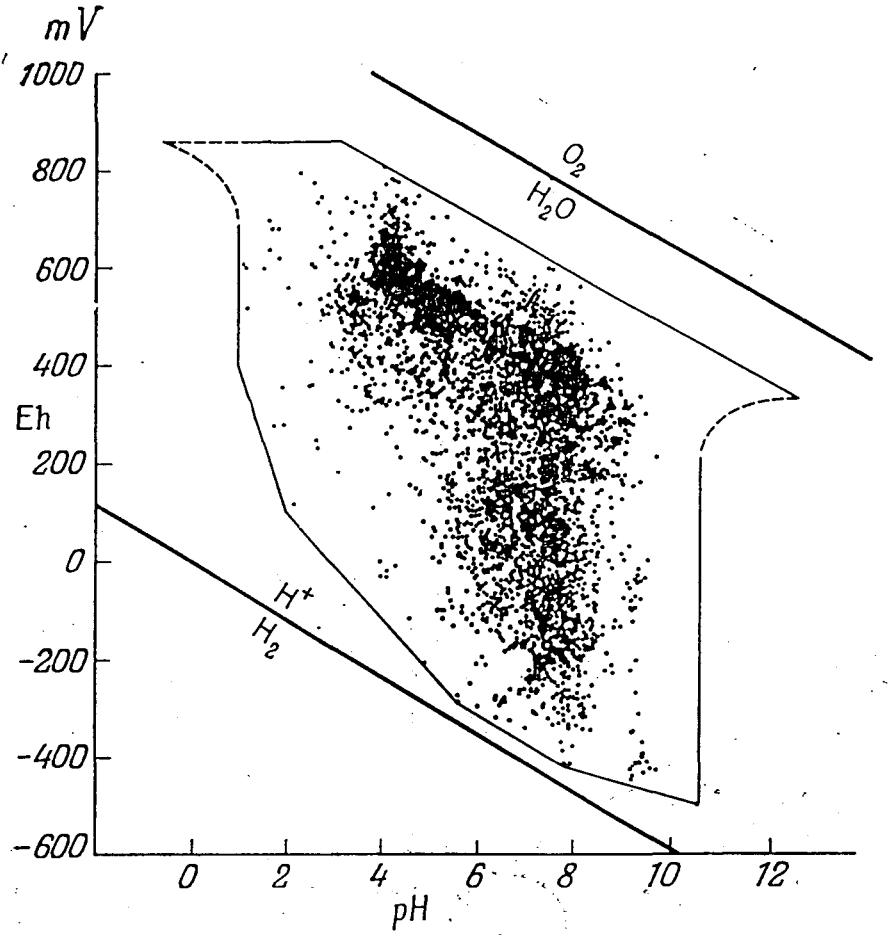

Fig. 18

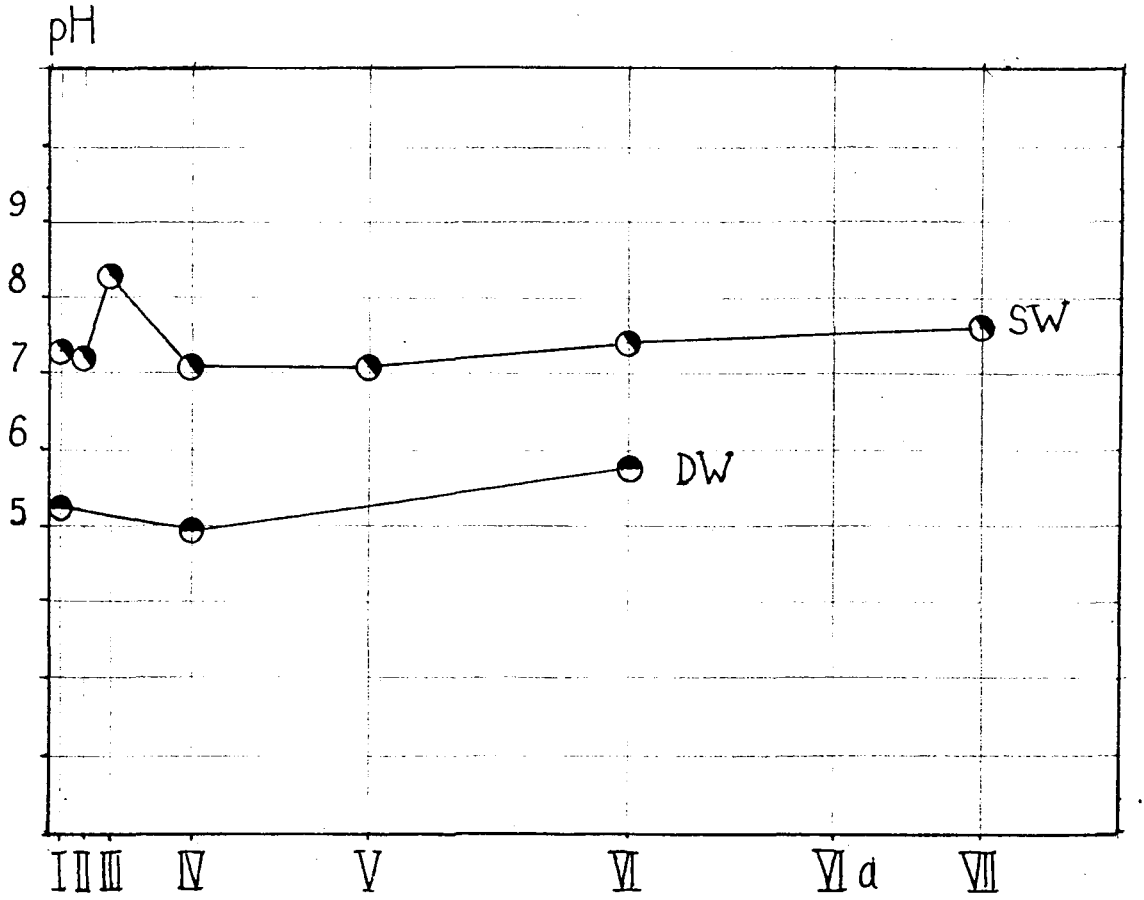

Fig. 19-1

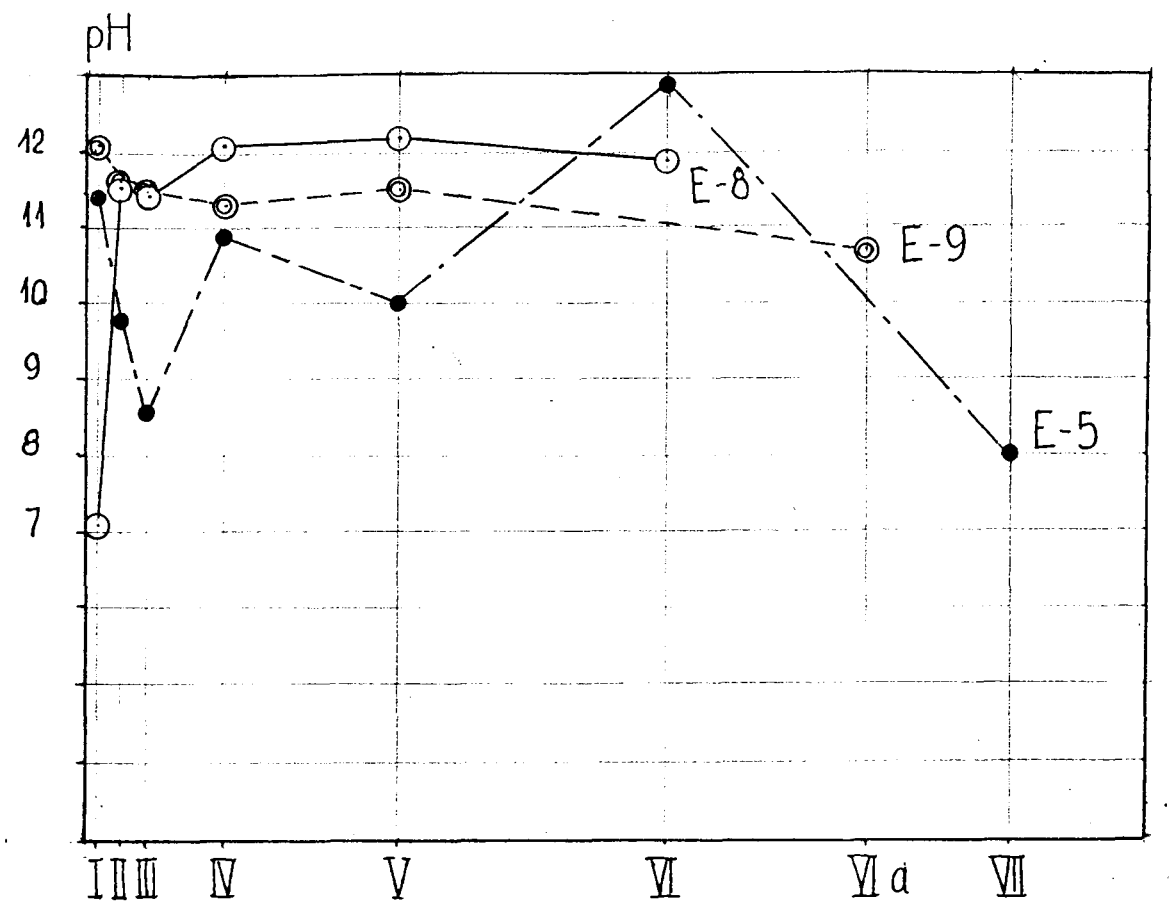

Fig. 19-2

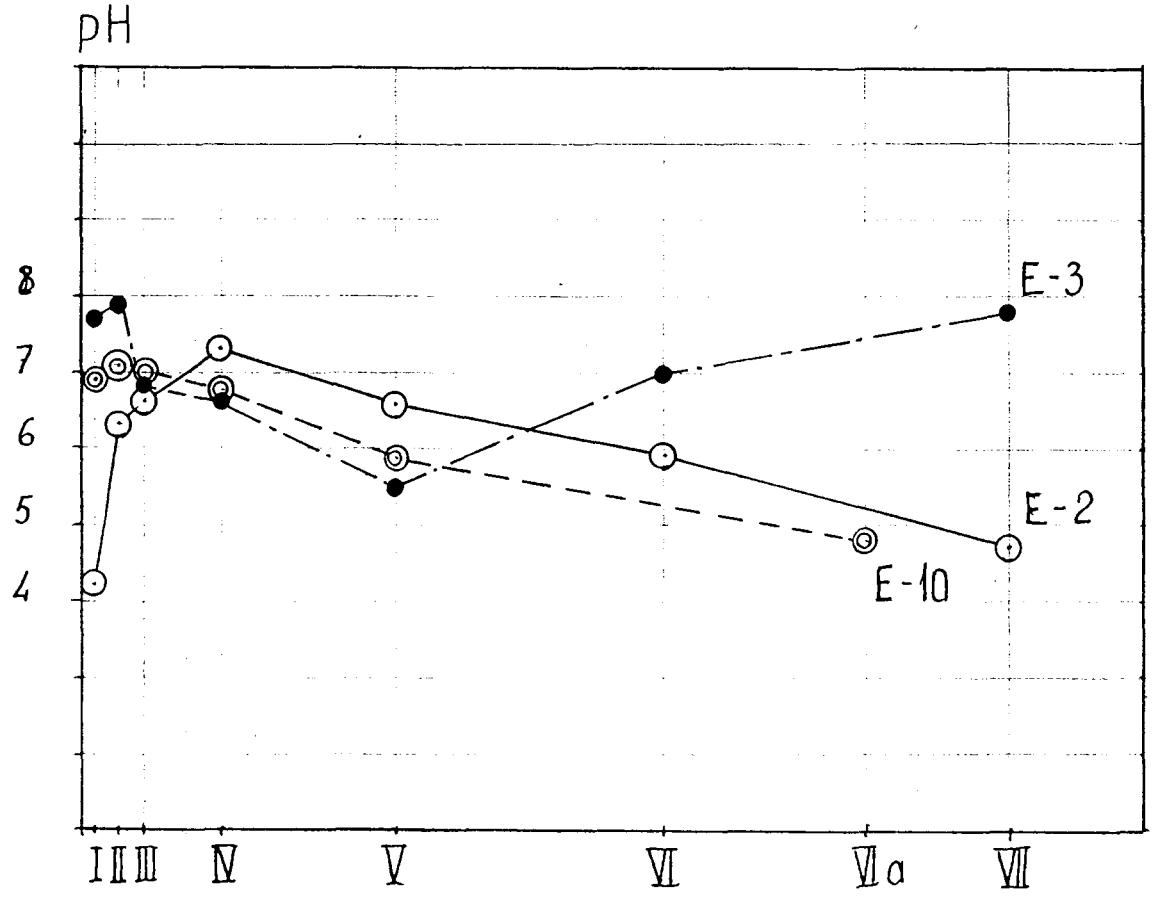

Fig. 19-3

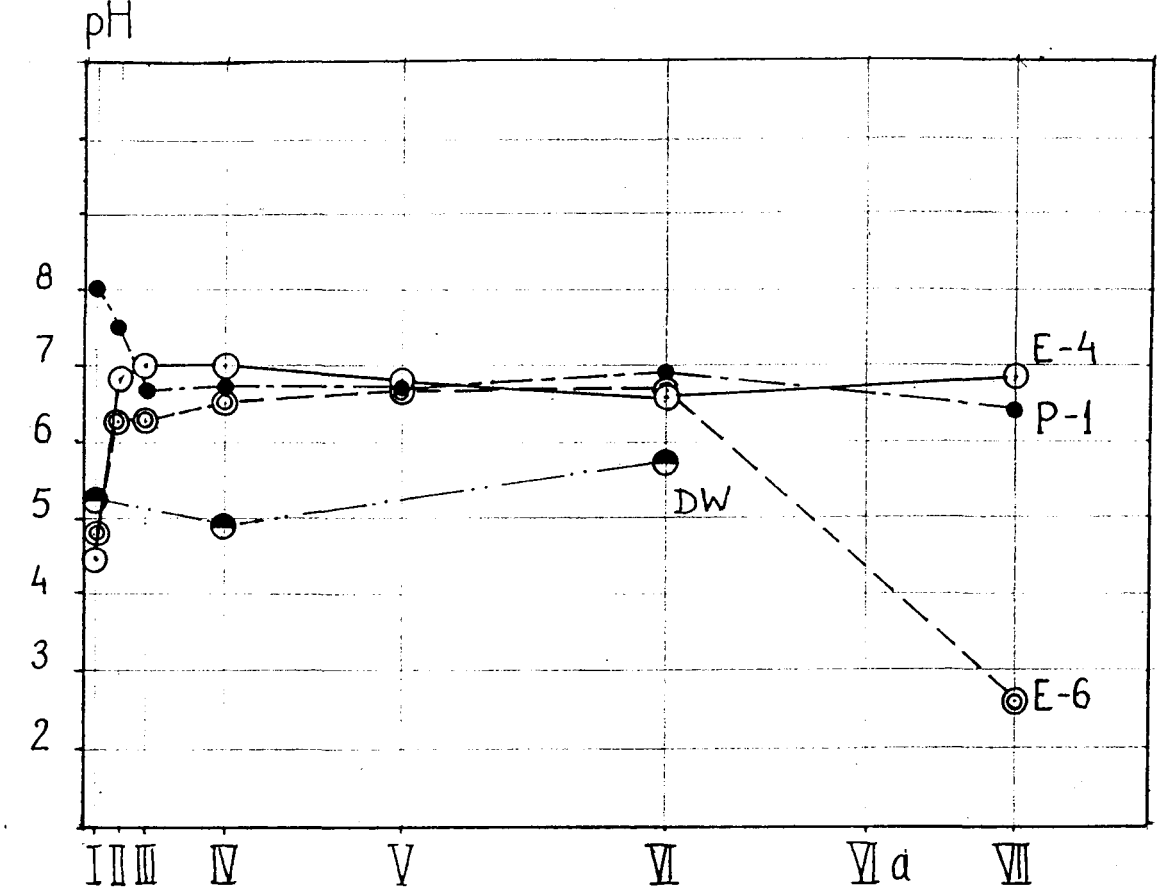

Fig. 19-4

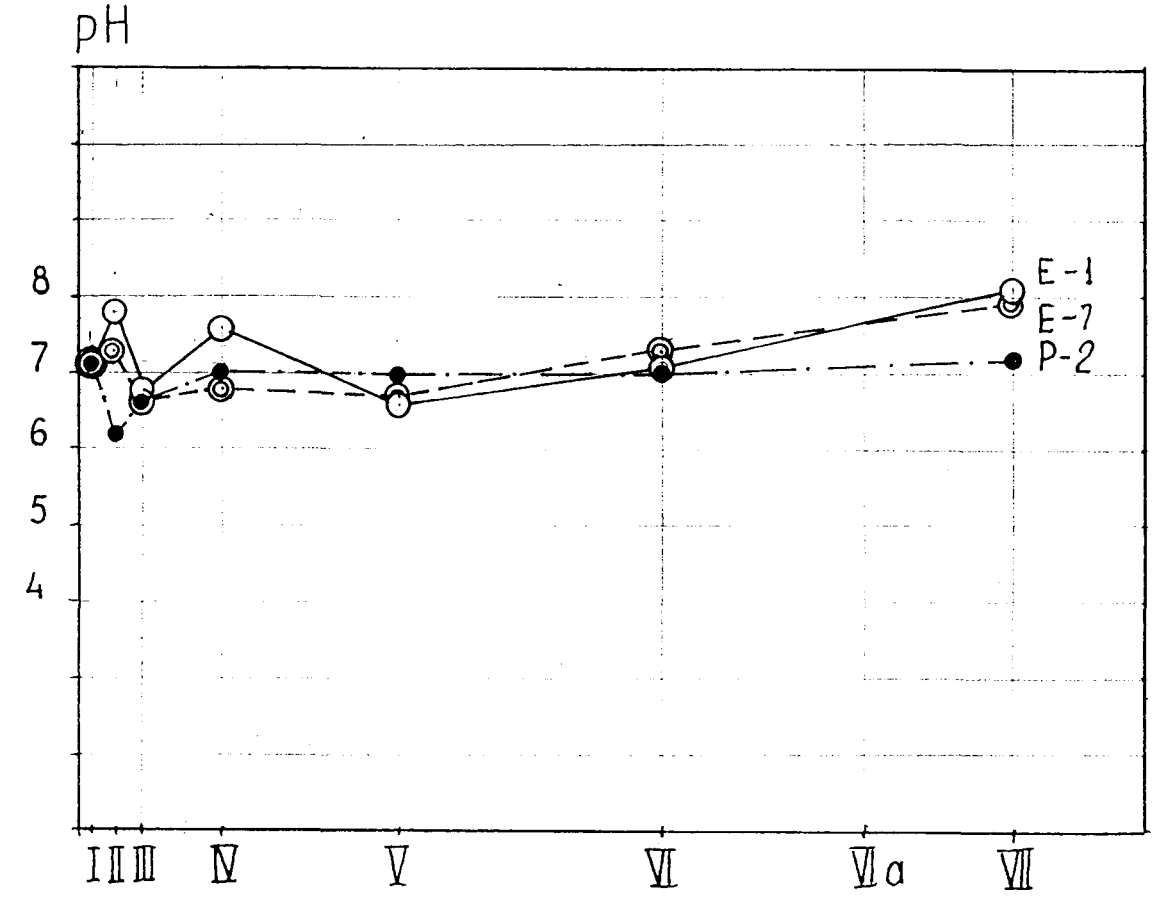

Fig. 19-5

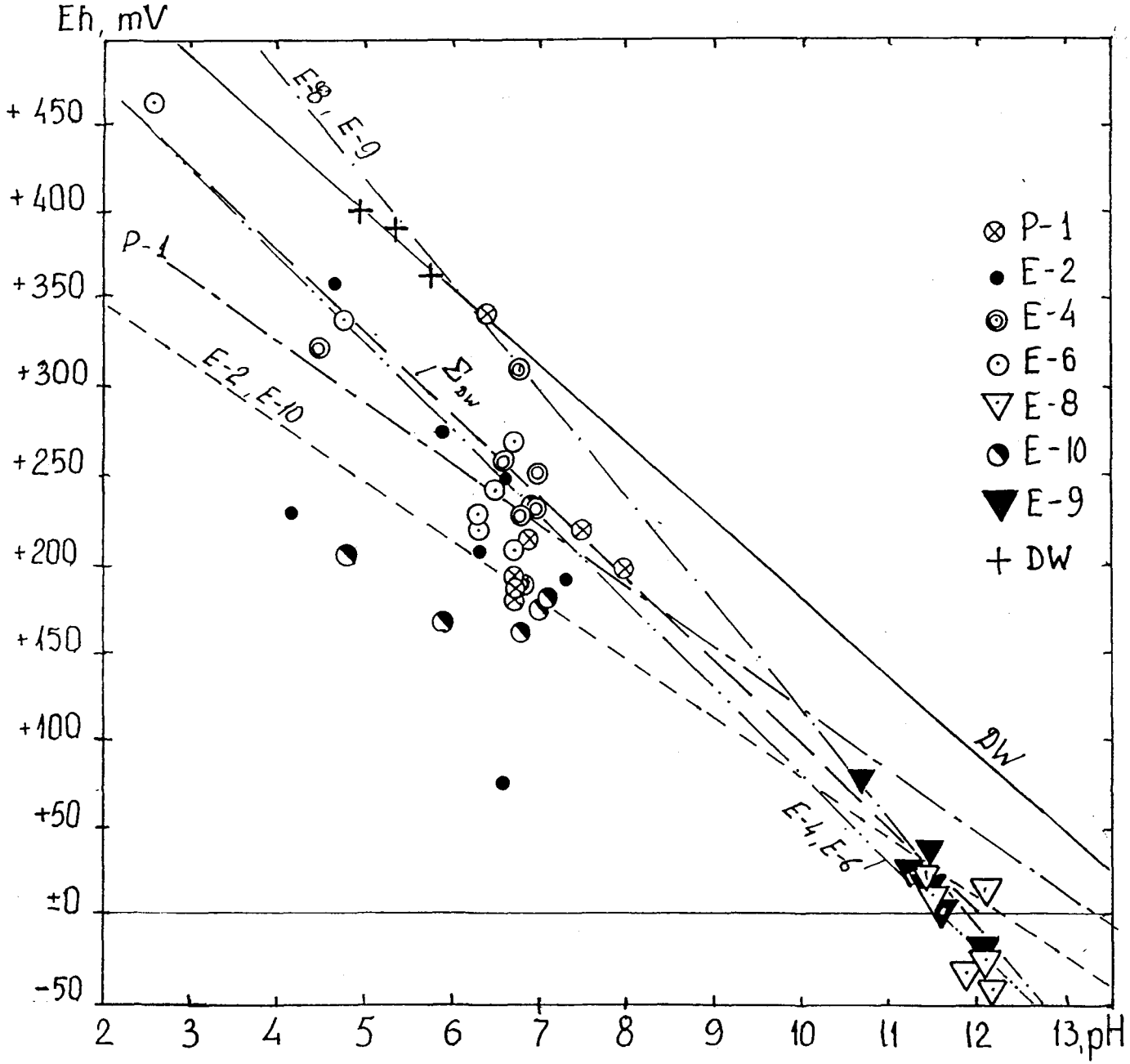
Eh, mV
+450
+400
+350
+300
+250
+200
+150
+100
+50
±0
-50
2
3
4
5
6
7
8
9
10
11
12
13, pH
E-8, E-9
P-1
E-2, E-10
Σ DW
DW
E-4, E-6
P-1
E-2
E-4
E-6
E-8
E-10
E-9
DW

Fig. 20

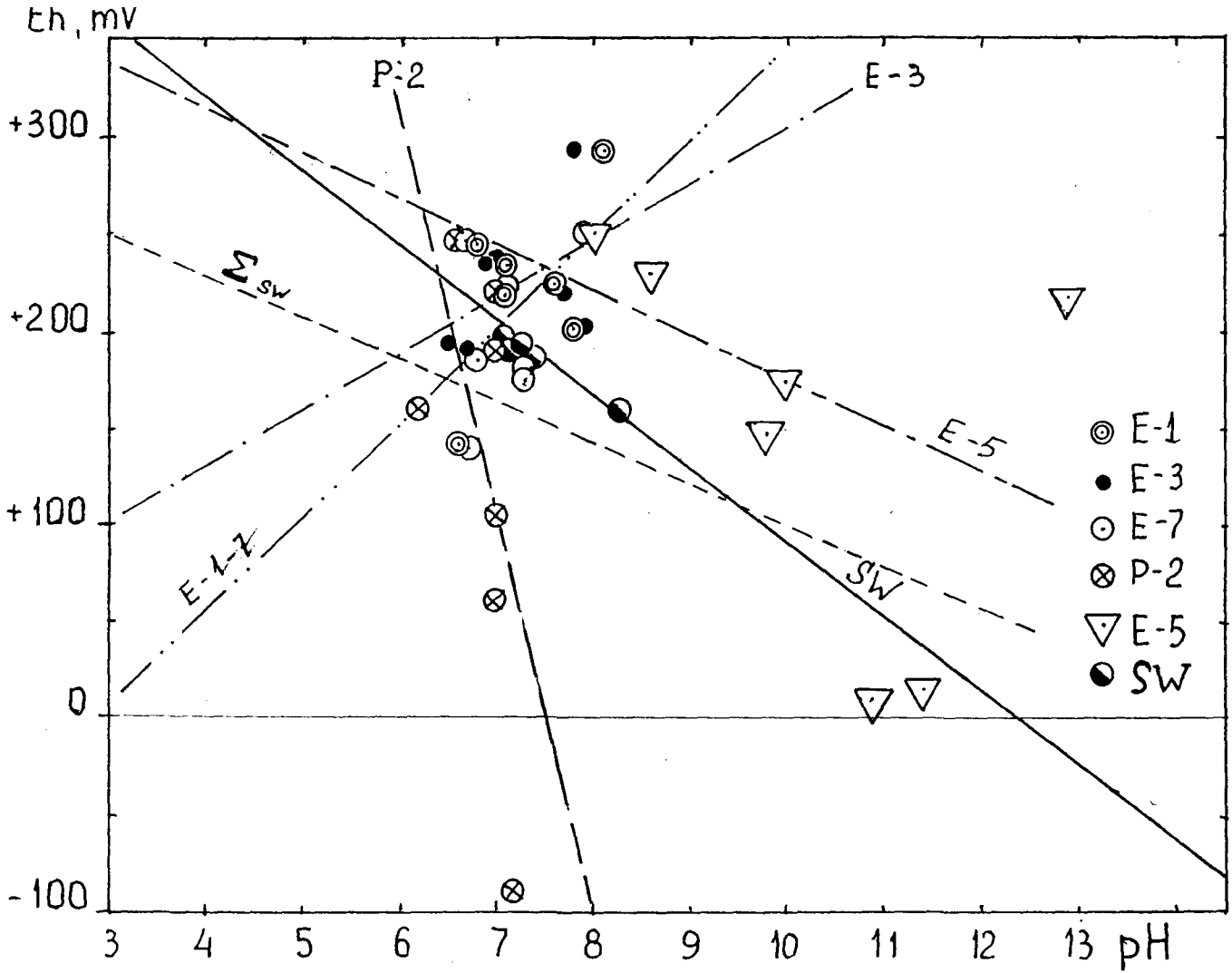
Eh, mV
+300
+200
+100
0
-100
3
4
5
6
7
8
9
10
11
12
13
pH
P-2
E-3
E-5
E-1-7
SW
E-1
E-3
E-7
P-2
E-5
SW

Fig. 21