SKBF TEKNISK
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82-13

Variation in radioactivity, uranium and radium-226 contents in three radioactive springs and along their out-flows northern Sweden

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Nyköping, Sweden, 1982-06-03

SVENSK KÄRNBRÄNSLEFÖRSÖRJNING AB / AVDELNING KBS

POSTADRESS: Box 5864, 102 48 Stockholm, Telefon 08-67 95 40

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STUDSVIK ENERGITEKNIK AB STUDSVIK/NW-82/177

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ABSTRACT

An investigation was performed in three uranium-rich springs in northern Sweden with the aim to observe the temporal and spatial variations of uranium and radium within a natural ecosystem in contact with groundwater. The contents of uranium and radium in spring water, peat and sediment together with measurements of stable elements and environmental data were determined along the furrows during different seasons. There was mostly a disequilibrium between the content of uranium in peat and water. The very high adsorption capacity of peat and its low leaching rate was assumed to be responsible for this discrepancy. The field data were supported by some laboratory experiments. The accumulation by peat was always much higher than the corresponding losses. The effect of freezing seemed not to be of any importance for the leaching rate. However, lowering the pH will highly affect the release of uranium bound to the peat.

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Approved by

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TABLE OF CONTENTS

APPENDICES

1. INTRODUCTION

The solid wastes of high-level repositories comprise a complex set of radionuclides and potential exposure pathways. Reliable risk assessments for the release of such material to the biosphere should include estimations of radiation doses received by the human populations, and involve the solution of an array of exposure pathways for each nuclide. The groundwater flow from the repository to the biosphere will be the major determinant for the dissolution and subsequent emission of contaminants, and the behaviour of the radionuclides in solution will be of ultimate importance for the further dispersion from the repository. When reaching the upper ground layer, the radionuclides will entry the large-scale circulation of elements within the biosphere.

The uranium isotopes U-233, U-234, U-235, U-236 and U-238 and their daughter products, e.g. Ra-226, will all contribute to the dose burden from spent nuclear fuel. Thus, the behaviour of these nuclides in the natural environment is of great importance and will guide our efforts to predict future dispersion routes and transfer rates from radionuclides released from a repository.

The code BIOPATH is used to predict the long-term radiation doses to the human populations from radionuclides which have been released to the biosphere due to contaminated groundwater (1). A dynamic exchange of radionuclides with the biospheric compartments is simulated. The reliability of the calculations is dependent upon factors such as model structure, exposure pathways and uncertainties in the data used. One crucial point is the assessments of the magnitude of the turnover rates of elements, which will determine the steady-state concentrations reached in the different compartments (2).

In order to observe the rate of change of naturally occurring radioactivity within an ecosystem in contact with groundwater, an investigation was performed in three uranium-rich springs in northern Sweden. The springs were localized by the Geological Survey of Sweden (SGU). The uranium contents in spring waters generally reflect the presence of uranium-anomalies in the bed-rock deposits. The dominating vegetation surrounding the springs chosen was bog peat. The peat accumulates uranium and radium and the fixation of cations takes place in humic acids. Very high uranium concentrations in peat have been documented by Armands (3) in the peat bog at Masugnsbyn, northern Sweden. The ratio of uranium content of the peat to that of the water was about 9000. The ability of peat to reflect uranium in water favours this species as a tool in mineral exploration, providing an integrated value of the uranium content of stream waters over a long period.

The objectives of this survey was to study the temporal and spatial variations of radium and uranium in the spring water along the furrows, and to assess the uptake and clearance rates of organogenic and minerogenic material in contact with the water. By simultaneous measurements of dominant constituents of the water, any possible co-variations with radium and uranium could also be detected. The obtained data will form the base for calculating reliable transfer factors for the groundwater-soil compartments, and will illustrate the temporal variations of radionuclide dispersion throughout the seasons.

2. SELECTION OF SPRINGS AND AREA DESCRIPTIONS

2.1 General aspects

The areal distribution of radioactive springs in Sweden is not even. Within certain areas practically all springs are radioactive, while for others only isolated radioactive springs occur. Within the main part of the country however, the springs are generally not radioactive. This uneven distribution of radioactive groundwater is closely related to the bedrock geology. As demonstrated by Ek (4) the amount of uranium (and its daughter products) going into solution in the groundwater is positively correlated to the following parameters:

- Background concentrations of uranium in the bedrock
- Abundance of fractures in the bedrock
- Leachability of uranium from the bedrock
- Presence of uranium mineralizations

The highest frequency of radioactive springs has been found within the distribution areas of certain granites. Only a few cases are known where radioactive springs are related to uranium mineralizations. Armands (3) for example, investigated a radioactive spring and peat-bog at Masugnsbyn, and found that the uranium in solution originated from a granite by the leaching activity of percolating groundwater.

A very large number of radioactive springs have been detected by SGU since 1969 when a large scale, regional uranium exploration program was initiated on the basis of air-radiometric surveys and geochemical surveys. The three radioactive springs in this study: Stugun, Nuortamustjåkkå and Purnuvaare (Figure 1), have been chosen from these in order to give a maximum of information about the influence of various environmental parameters with regard to the migration of uranium and Ra in the secondary environment. The three springs satisfy the following conditions:

- They are different with respect to bedrock geology, quarternary deposits and topographic conditions.
- They are different with respect to climatological factors such as altitude, precipitation and vegetation types.
- The three springs have well developed out-flows, enabling measurements to be made at regular intervals along the stream-channel.
- The three springs are easily accessible from nearby roads, which facilitates repeated sampling during different seasons.

2.2 Stugun area

The radioactive spring at Stugun is located in the county of Jämtland 28 km east of Östersund (Swedish National Network coordinates: 7006750 N, 1471100 W) at an altitude of 284 m above sea level. The region has a broken topography characterized by numerous faults and shear zones, which also are the main channels for the surface and ground water drainage. One of the main tectonic structures of the region is the WNW-ESE trending river valley of Indalsälven 9 km to the north of the spring at Stugun. The dominating forest type is pine (Pinus silvestris) mixed with birch (Betula alba) and spruce (Picea abies).

Bedrock geology is of precambrian age and strongly altered by migmatization and tectonic movements. The dominating rock-units are gneisses and granites, both with remnants of older supracrustal rocks. Pegmatitic intrusions are common. Several uranium mineralizations are indicated by mineralized boulders and outcrops within the region. They occur as U-impregnation in gneissic rocks, in pegmatites and in various rock types strongly altered by shearing and tectonic movements.

Geochemical uranium exploration surveys based upon stream-peat sampling and bog margin sampling (peat) have indicated a large number of very strong uranium anomalies. Many of them are related to radioactive springs and peat bogs, such as the spring at Stugun. The anomalies have been explained as the result of leaching processes of uranium mineralizations by ground water, percolating in the numerous shear zones and fissures. The mineralizations are not thought to be of any economic interest, being too small and scattered within the region.

The precipitation during the sampling period, i.e. from 1st of September 1980 to 31st of July 1981 was 601 mm, (Swedish meterological station at Östersund). The ground is snow-covered during approximately 6 months of the year.

The aquifer drained by the radioactive spring at Stugun is approximately 1.8 km^2, and it is entirely covered by till deposits with an estimated thickness of 2 - 10 m.

2.3 Nuortamustjåkkå area

The radioactive spring at Nuortamustjåkkå is located in the county of Norrbotten, 45 km west of the township of Jokkmokk (Swedish National Network coordinates: 7391500 N, 1635900 W) at an altitude of 450 m above sea level. The region, also called the Lovos area, has mountains with maximum heights of 925 m separated by vast lowland areas covered by peat-bogs. The dominating forest type is pine (Pinus silvestris) mixed with birch (Betula alba), and of spruce (Picea abies) in the more damp areas.

Bedrock geology is of Precambrian age and is dominated by the so-called Jarre granite belonging to the Lina-group of granites (5).

The Jarre granite has among the highest known background content of uranium for all granites in Sweden (19.2 ppm U). Also the background radioactivity is one of the highest known (35 - 70 μR/h) with maximum readings of 500 μR/h in pegmatitic derivates of the granite. Fissures and faults are common enabling the groundwater to percolate through the granite.

Regional geochemical exploration surveys based upon stream-peat sampling and peat sampling from bogs have revealed that the leaching of uranium from the Jarre granite is very intense. Practically all streams have anomalous uranium contents with maximum 4.7 % U in the ash from stream-peat, and some investigated bogs have uranium contents of up to 11.6 % U in the ash from peat. Almost all springs within the area of the Jarre granite are radioactive indicating an intense transport of radon with the ground water.

The total annual precipitation during 1981 was 616 mm (Swedish meteorological station at Jokkmokk). The ground is snow-covered during approximately 7 months of the year. The aquifer drained by the spring at Nuortamustjåkkå is approximately 0.4 km^2 and is entirely covered by till deposits. These are of ablation type and have an estimated thickness of 10 - 20 m.

2.4 Purnuvaare area

The radioactive spring at Purnuvaare is located in the county of Norrbotten 15 km south of Gällivare (Swedish National Network coordinates: 7441400 N, 1710350 W) at an altitude of 460 m above sea level.

The region has a levelled topography, only interrupted by isolated mountains and is therefore mostly poorly drained. Vast peatlands occupy more than 50 % of the area, and the mountains reach heights of 545 m.

The dominating forest type is spruce (Picea abies) in the lowlands and pine (Pinus silvestris) mixed with birch (Betuala alba) on the mountain slopes.

Bedrock geology is of Precambrian age and consists of Lina granite (5). Immediately to the south of the radioactive spring is an outcrop with uranium mineralization (Figure 4). The main part of the outcrop consists of pegmatitic (coarse-grained) granite and of pegmatite. The background radioactivity of the pegmatite is 50 - 100 μR/h, but along a N-S-trending shearzone the radioactivity is 300 - 2 000 μR/h. This mineralized zone is 1 - 5 m wide and can be seen on the outcrop along a distance of 150 m. The uranium content of the mineralization varies between 174 ppm U and 906 ppm U.

Total annual precipitation during 1981 was 592 mm (Swedish meteorological station at Lappträsket). The ground is snow-covered during approximately 7.5 months of the year. The aquifer, drained by the spring is small, approximately 0.25 km^2, and comprises the outcrop with the U-mineralized shearzone. Most certainly the spring, situated in the peatbog immediately to the north of the outcrop, is receiving most of its water from the U-mineralized shearzone.

3. CHARACTERISTICS OF THE SPRINGS AND THEIR OUTFLOWS

3.1 General aspects

The immediate surroundings of the springs and their outflows were first mapped using airphotos and topographical maps (Figures 2 - 4). After that, ten sampling sites were chosen for each spring with outflow, respectively. The sites were marked with sticks in order to enable repeated sampling and measurements at exactly the same spots. Site No 1 was always given to the spring (for Nuortamustjåkkå sites No 1 and No 2), and the Nos 2 to 10 were given in consecutive order downstream.

3.2 Local environmental characteristics

The local environmental characteristics for the three springs have been summarized in Tables 1 - 3. They comprise type of soil, type of vegetation, dominating plant group, width of stream channel and rate of flow.

At Stugun (Figure 2) the ten sampling sites extended from the spring down to lake Stugusjön along a distance of 570 m. The altitude over that distance dropped from 284 m a s l to 278 m a s l. The rate of flow was in general slow for the first five sites and then became fast down to the outflow into the lake. Between sites No 3 and 5 was a bog, where the stream water was more or less seeping through the peat. In addition to the spring (site 1) there was a seepage of radioactive groundwater at three other places: 90 m east of site 1; 70 m south of site 4 and 25 m south of site 9. The ditch that drained into the bog north of site 3 had more or less stagnant water.

At Nuortamustjåkkå (Figure 3) the sampling sites No 1 and 2 were springs. They were located on a mountain slope at an altitude of 450 m a s l. About 60 m downstream from site 1 the two springs had an cofluence forming a rapid stream down to the bog limit between sites No 7 and 8 at 430 m a s l. At sites No 8, 9 and 10 the waterflow was slow, and the stream was gradually seeping into the peat-bog and dissapeared completely at site No 10. The distance between site No 1 and 10 was approximately 530 m.

At Purnuvaare (Figure 4) the spring was located in a peat bog at the edge of a uranium mineralized outcrop (see 2.4). The outflow of water from the spring was very small, and within a distance of 200 m (at site No 5) all spring-water had seeped into the peat bog. Sites No 6 to 10 were in a bigger stream, which at site No 6 was receiving the seepage water from the spring. The rate of flow was slow for sites No 1 to 7 and fast for sites No 8 to 10. The distance between site No 1 and 10 was 1 400 m, and the altitude dropped from 460 m a s l to 428 m a s l.

3.3 Variation in precipitation and groundwater level during the sampling period

Sampling was carried out at three seasons for each spring. The ambition was to make the sampling 1) during or immediately after the snow-melting period, 2) in the middle of the summer, and 3) as late as possible in the autumn. The three springs were sampled during the following periods:

Stugun	October 1 - 5 1980 May 12 - 14 1981 July 23 - 25 1981
Nuortamustjåkkå	May 15 - 17 1981 July 27 - 29 1981 October 6 - 8 1981
Purnuvaare	May 18 - 20 1981 July 30 - August 1 1981 October 7 - 9 1981

The monthly precipitation during the sampling periods at the nearest meteorological stations with respect to the three springs is summarized in Table 4. The stations were located at Hissmofors, Jokkmokk and Lappträsket for the springs at Stugun, Nuortamustjåkkå and Purnuvaare, respectively.

Variation of the groundwater level during the sampling periods is shown in diagrams (Figure 5 - 7). They were from the nearest SGU National Groundwater Network Stations and were the stations Kassjöån No 26002, Jokkmokk No 62003 and Lappträsket No 37001 for the springs at Stugun, Nuortamustjåkkå and Purnuvaare, respectively.

By comparing the precipitation data with the diagrams showing the variation in groundwater level, some conclusions about the character of the sampled springwater could be drawn.

During the sampling in May 1981 the precipitation was moderate at all three stations (Table 4). The groundwater level, however, had distinct maxima, because of intense melting of the snow during the first two weeks of May (Figures 5 - 7).

Thus, the water was strongly diluted with meltwater that most probably had been in contact with the soil and the bedrock for a very short time. The physical and chemical qualities of the spring water during May 1981 were therefore not likely to represent any equilibrium state with the bedrock.

During the sampling in late July 1981 precipitation figures had maxima for the stations at Jokkmokk and Lappträsket, (Nuortamustjåkkå and Purnuvaare springs). For the station of Hissmofors (Stugun spring) July was the second most rainy month of the year. The groundwater diagrams indicate maximum levels for the springs at Nuortamustjåkkå and Purnuvaare and a decreasing trend for the spring at Stugun. This indicates that the groundwater emanating from the springs at Nuortamustjåkkå and Purnuvaare was strongly diluted with fresh rain-water, and that the water emanating from the spring at Stugun was less affected by such rain-water.

The sampling at Stugun in October 1980 was carried out during a period of moderate precipitation, and the groundwater diagram (Figure 5) had a minimum at the sampling occasion. Thus the sampled springwater could be expected to reflect more or less an equilibrium state with the bedrock with respect to physical and chemical parameters.

During the sampling occasions at Nuortamustjåkkå and Purnuvaare in October 1981 the precipitation figures were also moderate, but the groundwater diagrams (Figures 6 - 7) had maxima during the sampling. This indicates that most of the raining during October occurred immediately before or during the sampling.

Therefore, the water sampled during October 1981 at Nuortamustjåkkå and Purnuvaare most probably was a mixture of groundwater and rainwater.

4. FIELD PROCEDURES

As was mentioned in chapter 3.3 sampling and field measurements were carried out during three seasons. They started in October 1980 at Stugun where field sampling and field measurements were carried out during five days (October 1 - 5). The reason for repeating the field procedures during five days was to investigate weather some of the measured variables for the water displayed any short-term fluctuations. After having evaluated these results, the field procedures were modified to comprise only three days per spring and season. Also the analytical program was modified (see 5.1).

4.1 Field measurements

The following field measurements were made: water-flow, water-temperature, pH and radioactivity.

Water-flow was measured using a specially devised equipment and was reported as liter per second. Unfortunately, due to technical problems with the equipment, the measurements could not be carried out as planned.

Water-temperature was measured every day in the middle of the stream as centigrades (C°), with an accuracy of 0.1 degree.

pH was measured every day using a Radiometer, model pHM 20 with a combined glass-calomel electrode, model GK 2211C. The pH-meter was calibrated at sites No 1, 5 and 10.

Radioactivity was measured every day with a scintillation counter, model BGS-2. The values were given as micro-roentgen per hour (μR/h) and was a measure of the radon effluence. The highest reading around each sampling site was noted, and this was in general obtained where living moss vegetation (viz Drepanucladus) was in contact with streaming water.

The results of the daily field measurements are reported in Appendix A. In Tables 10, 11 and 12 the mean values of water temperature, pH and radioactivity for each site and season have been calculated.

4.2 Sampling

Water and (when available) stream peat and minerogenic stream sediments were sampled at every site.

A summary of the water sampling is given in Table 5. Altogether 292 samples were taken, and of these 112 were from Stugun and 90 from Nuortamustjåkkå and Purnuvaare, respectively. Sub-samples were collected in polyethylene bottles for different purposes as follows:

Elements (Volume)	Treatment	Sampling during
Major and minor cations (100 ml)	Filtered through 0.45 µm and acidified	Five days at Stugun in autumn 1980, and one day per sampling occasion during the other seasons
Anions (250 ml)	No treatment	Five days at Stugun in autumn 1980, and one day per sampling occasion during the other seasons
Uranium (250 ml)	No treatment	Five days at Stugun in autumn 1980, and three days per sampling occasion during the other seasons
Radium-226 (5 l)	No treatment	One day per sampling occasion at special sites according to Table 5
H-3 determination (250 ml)	No treatment	One day per sampling occasion; from the springs only

A summary of the stream-peat sampling is given in Table 6. Altogether 272 samples were taken, 92 from Stugun and 90 from Nuortamustjåkkå and Purnuvaare, respectively.

The stream-peat samples were collected immediately below the water table from the banks of the spring and stream, respectively. A handful of material (about 0.5 kg) was taken, and most of the water was squeezed out before being placed in a plastic bag. (For the Ra-226 determinations separate samples of 1 - 2 kg were taken at the same sites as for water.) The stream-peat sample was dominated by decaying vegetation (humus) but also of living roots and mosses. Minerogenic particles from the surrounding soil was also possibly present as well as precipitated hydroxides of iron and manganese (limonite). This sample type has proved very successful in the geochemical exploration for mobile elements such as U, Mo, Zn, Co, Cu, Ni and Be (6). The most active component for the fixation of uranium is the humus material. Generally, the chemical composition of the stream-peat is reflecting the availability of mobile elements in the surrounding groundwater and bedrock.

A summary of the minerogenic stream sediment sampling is given in Table 7. Altogether 89 samples were taken, and of these 27 samples were from Stugun, 54 from Nuortamustjåkkå and 8 from Purnuvaare. As can be seen in Table 7 sediments were found only at sites No 6, 7 and 8 for Stugun. At Nuortamustjåkkå samples were found at sites No 2, 3, 4, 5, 6 and 7. For Purnuvaare only site No 8 could be systematically sampled, although one sample was obtained at site No 7. Minerogenic (alluvial) stream sediment is a well established geochemical sampling type in the mineral exploration throughout the world (7). The mobile elements (e.g. U) occur in stream sediments by precipitation or adsorption on the mineral particles.

About 0.5 kg of material was collected for analysis of U and 24 other metals. For the Ra-226 determination about 2 kg of material was required. These samples were collected only at special sites (Table 7).

5. ANALYTICAL METHODS

A large number of chemical constituents were determined for each sample type in order to obtain the necessary background information for the interpretation of the U and Ra-226 values. The analytical determination of Ra-226, H-3, and of U in minerogenic stream sediments was performed by Studsvik Energiteknik AB. All other determinations were made by SGU. Detection limits for all analysed elements are given in Table 8.

5.1 Water

Conductivity and fifteen constituents were determined for the water samples. Five were anions (HCO_3, F, Cl, NO_3, SO_4), four were major cations (Na, K, Mg, Ca) and six minor cations and trace elements (Fe, Mn, Cu, Zn, U, Ra-226). At the first sampling occasion (Stugun, October 1980) seven more constituents were determined. These were: Be, Cr, Co, Ni, As, Ba and PO_4. As these constituents had concentrations below the detection limit, they were not analyzed during the following sampling occasions. Instead the originally planned program for Ra-226 determinations was expanded.

HCO_3 was determined by titration according to American National Standard ANSI/ASTM D 513.

F, Cl, NO_3 and SO_4 were determined with an ion cromatograph, model DIONEX (8).

Na, K, Mg, Ca, Fe, Mn, Cu, Be, Cr, Co, Ni, As and Ba were determined with IDES/ICP (Image Dissector Echelle Spectrometer) (9,10).

U was fluorimetrically determined after first having separated the uranyl ions from other cations with ion-exchange.

Ra-226 was determined by enclosing the material for three weeks and measuring the radon and daughters in equilibrium with gamma spectroscopy.

H-3 was determined by measuring distilled samples with LSC.

5.2 Stream peat

The stream-peat samples were first dried at 100°C and then ignited at 450°C. The ash was analyzed with XRF for eleven major elements (Na_2O, TiO_2, Fe_2O_3, MnO, Al_2O_3, SiO_2, K_2O, MgO, P_2O_5, CaO and S) and for fifteen trace elements (U, Th, Cu, Pb, Zn, Co, Ni, Cr, Mo, Sr, As, V, Rb, Zr, W).

The samples were weighed before and after ignition, which enabled the dry weight contents to be calculated.

Ra-226 was determined with the delayed neutron activation technique (DNA).

5.3 Minerogenic stream sediments

The minerogenic stream sediments were first sieved through a 1 mm sieve and then grinded. After that they were analyzed on the optical emission spectrograph (11) for six major elements (Ca, Mg, Ba, Fe, Mn, Ti) and for fifteen minor and trace elements (Cu, Pb, Zn, Ag, Bi, Cr, Ni, Co, Mo, Sr, As, Sn, Be, V, W). They were also analyzed with XRF for nine elements (U, Th, Rb, Y, Zr, Mo, Zn, Ni, W).

U and Ra-226 were also determined with the delayed neutron activation technique (DNA) in order to obtain a high precision and a low detection limit for those two elements.

6. ANALYTICAL RESULTS WITH COMMENTS

All analytical data for water, stream-peat and minerogenic stream sediments are assembled in Appendix A.

In this chapter the data are examined with respect to probable sampling error and analytical error in order to extract only the relevant data. Special emphasis is put to U and Ra.

6.1 Hydrochemical data

The uranium determinations of the water samples are shown in Table 9, and a complete set of the hydrochemical data for Stugun, Nuortamustjåkkå and Purnuvaare are shown in Tables 10, 11 and 12, respectively.

For Stugun (Table 10) the uranium values were mean values from sampling during a period of five days (autumn 1980) and three days (spring and summer 1981), respectively. For Nuortamustjåkkå and Purnuvaare (Tables 11 and 12) the uranium values for spring 1981 were mean values from sampling during a period of three days. For the remaining sampling occasions, the uranium values from sampling during only one day per season could be obtained because of incorrect treatment of the other samples at the laboratory. Uranium values of samples collected at the following occasions (Table 9) have been rejected due to probable analytical error:

Stugun	Site No 2, 13th May 1981
Purnuvaare	Site No 4, 20th May 1981
Purnuvaare	Site No 10, 20th May 1981

Regarding other constituents the following five determinations have been rejected, due to probable sample contamination or analytical error:

F: Purnuvaare at site No 9 in spring 1981
Cl: Nuortamustjåkkå at site No 9 in spring 1981
Cl: Purnuvaare at site No 5 in spring 1981
Cl: Purnuvaare at site No 7 in summer 1981
SO_4: Nuortamustjåkkå at site No 10 in autumn 198

6.2 Stream-peat data

As mentioned in chapter 4.2 the stream-peat material had a rather heterogenous composition, being a mixture of organic matter, minerogenic particles and precipitated iron and manganese hydroxides. A study of the correlation coefficient between the ash content and four major constituents will give the following results:

Element	Correlation coefficient
SiO_2	0.812
Al_2O_3	0.644
S	0.076
CaO	0.062

As can be seen the ash content had a high positive correlation with SiO_2 and Al_2O_3, indicating that the ash from organic stream-peat was more or less diluted with minerogenic particles containing SiO_2 and Al_2O_3. This will of course also strongly affect the U content of the stream-peat ash. The reason for this is that U is mainly fixed by the organic matter (humus). Therefore, the ashed stream-peat samples containing a high proportion of minerogenic particles will tend to have lower U contents compared to those containing a low proportion of minerogenic particles. For this reason the U content in stream-peat ash (Table 13) did not give a reliable picture of the fixation of U in stream-peat. If instead the U content was calculated on a dry weight basis (Table 14), values that were more or less independent of the sample inhomogenity were obtained. Accordingly, the dry weight content of U in stream-peat will be used in this study.

As can be seen in Table 14 the following analytical results of U are missing: Nuortamustjåkkå, site No 1 and 2, Purnuvaare, site No 2, 3, 4 and 5). The reason is that these samples produced unsufficient amount of ash for the XRF determination.

In Tables 15, 16 and 17 the mean values of eleven major and fifteen trace elements from all ten sites at Stugun, Nuortamustjåkkå and Purnuvaare, respectively, have been calculated. They showed that U was strongly anomalous at all three springs. All other trace elements, with the exception of Cu at Stugun, had background contents.

6.3 Minerogenic stream sediment data

The U contents of the minerogenic stream sediments are shown in Table 18. The U determination of the sample from site No 6, Stugun 1:st of October 1980 was rejected due to probable sampling error. The results from site 8, Stugun 3rd October 1980 and site 8, Purnuvaare 1:st August 1981 are missing due to unsufficient amount of material after sieving. U was the only trace metal that had anomalous contents in the minerogenic stream sediments.

7. EVALUATION OF ANALYTICAL RESULTS AND FIELD MEASUREMENTS

The purpose of this survey was to study the temporal and spatial migration of radionuclides from bedrock to groundwater, and their subsequent gradual fixation, when the groundwater enters the surface environment.

When evaluating the analytical results and field measurements along the above mentioned guidelines, a number of influencing factors must be considered. The following factors are among the most important ones and will be discussed in the following:

- Bedrock geology:	Type of rock, fracturing, leachability
- Hydrology:	Precipitation and groundwater level, type of aquifer, drainage
- Physical characteristics of the water:	pH, Eh, temperature
- Chemical characteristics of the water:	Alkalinity, major constituents, humic acids
- Local environmental conditions in the spring and along the stream-channel:	Topography, type of soil, type of vegetation outside and within the stream channel

Besides these factors there are other factors of great importance, which have not been considered in this study, for example:

- Bacterial activity: Leaching and fixation of radionuclides

- Redox conditions of the groundwater
- Equilibrium state between U and its daughter products

Many of these factors are interacting and interferring with each other and, therefore, interpretations based upon the measurements made in this survey have to be considered as tentative.

The radioactivity, U and Ra 226 contents in Tables 19 - 20 will be used in the following, because they represent mean values of the daily measurements (when possible) during three different seasons.

7.1 Stugun area

Of the three investigated localities, the spring water at Stugun had the highest U concentration. Mean U content for the ten sites and for the three seasons together was 14.8 ppb (Table 19). This indicated that an intense leaching and transport of U by the groundwater took place. The source of the radionuclides was most certainly the numerous faults and fissures with U-mineralizations occuring in the area (see chapter 2.2). Leaching of U was also enhanced by the alkaline conditions of the groundwater, with high concentrations of carbonate and bicarbonate ions (Table 10).

7.1.1 Temporal variation

The U concentration of the water was strongly affected by variations in precipitation and groundwater level. A comparison of Table 19 with Figure 5 and Table 4 shows that the highest average concentration (24.0 ppb U) was obtained when the groundwater level was at a minimum in October 1980. On the other hand, the lowest average concentration (7.5 ppb U) was obtained in May 1981 when the groundwater level was at a maximum and thus was strongly diluted by water from the melting snow. During the sampling in July 1981 the average U concentration (12.8 ppb U) was low due to heavy dilution by rainwater. However, it is important to point out that these results did not give any information about temporal variations in the amount of U that was leached from the bedrock. The variation in precipitation affected both the U concentration and the volumes of water emanating from the spring. Therefore, a high U concentration and a moderate water flow (Autumn 1980) may very well be comparable with a low U concentration and a strong water flow (Spring 1981) with respect to leached and transported amounts of U. Unfortunately, the water-flow measurements were too incomplete to verify this.

For stream-peat the U concentrations were not changing with season as drastically as for the water. The mean concentration for all ten sites during the three seasons was 461 ppm U. This value gave a geochemical concentration factor of about 32 000, which is more than three times higher than the figure obtained by Szalay (13,14,15). This indicated that the U concentrations in stream-peat and water were not in a state of equilibrium. The highest average concentration for peat (482 ppm U) was obtained in October 1980, which was in agreement with the results obtained for the water (Figure 8). The average concentrations during May 1981 and July 1981 was 416 ppm U and 384 ppm U, respectively, indicating a weak opposite trend compared to that of the water. However, the U concentration of stream-peat changed considerably less between the seasons, compared to the water. These results indicated that stream-peat has a very high accumulation capacity, and that the leaching rate of U at low water concentrations was small (compare with chapter 8.3). It can, therefore, be concluded that stream-peat gives an integrated value of the supply of U with the water throughout the season. This is in fact that main reasons why stream-peat is so suitable for regional geochemical uranium exploration surveys (4).

The U measurements of minerogenic stream sediments could be made only at three sampling sites in the lower parts of the stream channel (sites No 6, 7, 8). Average concentration for all three seasons was 40 ppm U with a maximum of 52 ppm U in October 1980 and a minimum of 32 ppm U in July 1981. These results indicated that the leaching rate of U at low water concentrations was somewhat higher compared to the stream-peat. The geochemical concentration factor was around 2 800, which is more than ten times less than the figure for stream-pet.

The average radioactivity for the ten sites during the three seasons was 37 μR/h. This value should be compared with the background radioactivity of the local rocktypes, which was 20 - 25 μR/h. The spring and its out-flow could be regarded as a radioactive anomaly with the highest readings at the spring itself, where the radioactivity varied between 70 μR/h and 167 μR/h during the three seasons. The highest average radioactivity was obtained in October 1980 and

July 1981, when the value in both cases was 42 µR/h. In May 1981, when the water level was extremely high, the average value was only 27 µR/h.

The radioactivity values are a measure of the radon content of the water, and the results indicate that radon disappears rather rapidly under surface conditions. This is probably due to both radon emanation from the water and a radio adsorption of radon daughters to solid materials. Already at site No 4, which is 150 m downstream from the spring, background readings, ranging between 17 µR/h and 26 µR/h, were observed.

The Ra-226 content of the water varied from less than 3.40 mBq/l to 14.0 mBq/l in ten measurements during the three seasons, indicating a heavy influx of surface water which had not been in contact with the bedrock. There was a clear tendency for the Ra-226 concentrations to be lower in May 1981 compared to the two other seasons, which was in good agreement with the trend found for radioactivity (radon) and uranium in water:

The average Ra-226 concentration in stream-peat was 6.11 Bq/g based upon eight measurements during the three seasons. The lowest average value, 5.44 Bq/g, was obtained in May 1981 compared to a value of 6.30 Bq/g in July 1981 and 6.59 Bq/g in October 1981. This trend was similar to that of the water and indicates that stream-peat has a certain tendency of being leached of Ra-226 at low water concentrations.

7.1.2 Spatial variation

Local environmental characteristics of the Stugun area was described in chapter 3.2. Table 10 clearly shows that the groundwater downstream from the spring gradually changed into surface water. This is manifested by decreasing values of some major constituents (HCO_3, F, NO_3, K, Mg and Ca). As a consequence of this the conductivity values also decreased. Fe and to a certain extent Mn had an increasing trend downstream from site No 5 depending upon leaching of these two elements from the B-horizon of the soil. pH, on the other hand, showed no systematic spatial changes. The pH values were mostly above 7.0 indicating that the water was well buffered due to a high HCO_3 content.

U, which is one of the most mobile trace elements, did not behave in the same manner as the major constituents. First of all, from the daily U determinations (Table 9) it is evident that U in water was subjected to certain short term fluctuations. This fact, in combination with the high solubility of U is the reason why no systematic decrease was obtained along the stream channel. The total sampling distance of 570 m was simply too short. However, between site No 3 and 4, a sudden decrease in the U concentration of the water could be noted for all three seasons. This is explained by the fact that the stream water here entered a bog environment and more or less seeped through the peat material. Thereby, during the seeping through the bog, a certain proportion of the uranyl ions was fixed by the humus material. Downstream the bog, between site No 5 and 10, normal stream channel conditions were again prevailing and the U values of the water became more stable, but at a lower level.

For U in stream-peat the spatial variations were characterized by maximum values at site No 1, ranging from 642 ppm U to 1307 ppm U during the three seasons. Between site No 2 and 10 the values ranged from 269 ppm U to 539 ppm U, but no systematic decrease in downstream direction could be observed. This is certainly due to the fact that the total sampling distance was too short. The irregular spatial variations of the U values along the stream channel may be explained by the heterogenic composition of the stream-peat material (see chapter 6.2), but may also be due to seepage of radioactive groundwater into various parts of the stream channel. This explanation was also supported by the radioactivity measurements.

For the minerogenic stream sediments only limited conclusions can be drawn about the spatial variation of U. It is interesting to note, however, that the increasing trend in downstream direction between site No 6 and 8 was positively correlated to the trend for Fe and Mn. This indicates that the uranyl ions were coprecipitated on the stream sediment material together with Fe and Mn hydroxides (limonite).

The spatial variation of radioactivity indicated that radioactive groundwater also entered the stream channel downstream from the spring. Values above the background of the local rock-types were, for example, noted at sites 6, 8 and 9.

It should also be mentioned that Ra-226 did not have any systematic spatial variation for water and for minerogenic stream sediments, whereas the values for stream-peat indicated an increasing trend in downstream direction.

7.2 Nuortamustjåkkå area

As was mentioned in chapter 2.3, Nuortamustjåkkå is located within the area of the Jarre granite, which has among the highest known background content (19.2 ppm U) of uranium of all granites in Sweden. The high frequency of fractures and a high leachability has favoured an intense leaching and transport of radionuclides with the groundwater to the surface environment of the area. Thus, the anomalous concentrations of radionuclides in the water systems originate from leaching of big volumes of rock (Jarre granite) and not from uranium mineralizations, as was the case at Stugun.

7.2.1 Temporal variation

A general comment about the conditions during the sampling occasions will be made. As can be seen in Figure 6, the three sampling occasions coincided with maxima of the groundwater level. Thus, the hydrochemical measurements were made on water strongly diluted by rainwater or meltwater. Therefore, the concentration of radionuclides most probably were lower than for normal groundwater level conditions during all three sampling occasions. As can be seen in Table 20, the mean U concentration in water from all ten sites and all three seasons was only 3.4 ppb U. The average U content in stream-peat, on the other hand was 447 ppm, which was almost identical with the figure obtained for Stugun (461 ppm U). This indicated that the magnitude of accumulated amounts of U in stream-peat were comparable for the two areas. The geochemical concentration factor for stream-peat was 131470, which illustrates the state of disequilibrium between the U concentrations in stream-peat and water.

The temporal variation of U in water (Figure 9) was characterized by a decreasing trend during the three seasons where 4.7 ppb U in May 1981 dropped to 2.6 ppb U in October 1981. This trend was probably related to an increasing dilution of the spring water with surficial water. The temporal variation of U in stream-peat, on the other hand, showed a maximum of 519 ppm U in July 1981 and almost identical values (406 ppm U and 417 ppm U) for May 1981 and October 1981, respectively. The maximum value for July was correlated with a depression of the groundwater level curve occuring 2 - 3 weeks before the sampling occasion (see Figure 6). During that period the groundwater was less diluted by rainwater and had, therefore, enhanced U concentrations. As a result of this the stream-peat accumulated more U. Since the leaching rate for stream-peat was much smaller than the uptake rate, the U that was accumulated during the preceeding weaks was still retained at the sampling occasion in July.

The temporal variation of U in minerogenic stream sediments was characterized by a decreasing trend during the three seasons with 21 ppm U in May 1981 dropping to 16 ppm U in October 1981. This trend was the same as for water and supports the results from Stugun that the leaching rate of U from minerogenic stream sediments is higher than for stream-peat.

The radioactivity readings were above the background of the local rocks (30 μR/h) only at the two springs, where the readings ranged between 29 μR/h and 40 μR/h. The radioactivity of the spring water was probably depressed due to dilution by rainwater. There were no significant temporal variations between the three seasons.

The Ra-226 determinations gave lower average values for all three sampling media compared to Stugun. This indicated that the state of radioactive equilibrium between U and its daughter products was different from that at Stugun. The temporal variations for water and stream-peat were the same as for U indicating co-variation with U and Ra-226. For minerogenic stream-sediments the average Ra-226 concentration was only 0.0544 Bq/g, which is about 85 times lower compared to Stugun. There were no significant differences between the values from the three seasons.

7.2.2 Spatial variation

The water quality of the two springs at Nuortamustjåkkå was quite different from that at Stugun. Being a water strongly affected by rainwater it also had the characteristics of a groundwater from a granitic environment. The concentrations of major constituents were very low, especially for HCO_3 and Ca, and the pH values ranged between 6.50 and 7.20 with most values below 7.0. The spatial variation of the pH was quite irregular due to the weak buffering capacity of the water. HCO_3, F, Cl, Na and Ca had a decreasing trend in downstream direction, probably due to dilution with surface water. The Fe concentration, on the other hand, had an increasing trend which is explained by leaching of iron hydroxide from the B-horizon of the soil along the stream channel.

The solubility of U was probably low because there was not enough HCO_3 in the water to allow the formation of uranyl carbonate ions (22). This is probably a contributing reason for the low U concentrations of the waters at Nuortamustjåkkå (Table 20). The spatial variation of U did not resemble that of any other major or minor constituent, and the only systematic decrease in downstream direction was obtained for the water samples from May 1981. Between site No 5 and 6 the U concentration dropped abruptly from 7.1 to 2.7 ppb. This can be explained by a heavy influx of meltwater coming from the tributary south of site No 5 (see Figure 3).

For the minerogenic stream sediments the highest values, ranging between 41 ppm U and 50 ppm were obtained at spring No 2, and much lower values, ranging between 8 ppm U and 23 ppm U, from the sites along the stream channel. This is in analogy with the results for stream-peat, except for the fact that the stream-channel samples did not have any systematic decrease in downstream direction.

The radioactivity measurements indicated that most of the radon had evaporated already at site

No 3, i.e. after 50 m. The distinct drop in the background radioactivity level between site No 5 and 6 was due to a transition from glacial till environment to bog environment.

For Ra-226 a decreasing trend in downstream direction was obtained for stream-peat, similarly to that of U. The other two analysed sampling media, water and minerogenic stream sediment, showed no systematic spatial variations with respect to Ra-226.

7.3 Purnuvaare area

The spring at Purnuvaare receives its water from a U-mineralized shearzone located in the immediate vicinity (see chapter 2.4). The radionuclides have, therefore, travelled a very short distance between the bedrock source and the spring. The spring at Purnuvaare is different from those of the other two test areas also in the sense that it is located in a bog environment, and that the spring water has been completely infiltrated in the bog already after 200 m (at site 5). The results from sites No 6 to 10 indicate that only insignificant amounts of radionuclides are seeping through the bog and into the main stream (Table 21). The discussion will, therefore, mainly comprise the results from site No 1 to 5.

7.3.1 Temporal variation

In similarity with Nuortamustjåkkå the sampling at Purnuvaare was carried out during periods when the groundwater level had maxima (Figure 7). The results for water were, therefore, severely affected by dilution from rainwater or meltwater. As can be seen in Table 21, the mean U concentration of the water from sites No 1 to 5 was only 2.0 ppb U during the three seasons. The average U content in stream-peat, on the other hand, was 688 ppm U which gave a geochemical concentration factor for stream-peat of 344 000. This illustrates the great state of disequilibrium between the U concentrations in stream-peat and water. It also supports the findings from the laboratory experiments (8.3) that the accumulation capacity of U in stream-peat is much larger than the leaching capacity.

The temporal variation of U in water (Figure 10) was characterized by a decreasing trend during the three seasons, from 2.6 ppm U in May 1981 to 1.5 ppb U in October 1981. The stream-peat values, on the other hand, had a distinct maximum of 770 ppm U in October compared to values of 646 ppm U and 647 ppm U in May and July, respectively. The explanation for this is the pronounced minimum of the ground water level prevailing during the weeks before the sampling in October. (Compare with the conditions at Nuortamustjåkkå in July 1981.)

The average radioactivity values indicated that the radon effluence was highest in May 1981 (129 μR/h). In July 1981 it was at a minimum (88 μR/h) and showed again increased values in October 1981 (111 μR/h). This temporal variation does not show any resemblance to that of the other two radionuclides and indicates that radon migrates independently of them.

The Ra-226 determinations of the water gave in general higher values compared to those from Stugun. This was probably related to the short distance between the bedrock source and the sampling sites in comparison with the other two test areas. If all three test areas are considered, the results also indicate that the mobility of Ra-226 is small. The temporal variation for the water showed a similar trend compared to U, if only the Ra-226 measurements in the spring (site No 1) are considered. These measurements gave a Ra-226 concentration of 16.00 mBq/l in May, decreasing to 10.00 mBq/l in July and 8.65 mBq/l in October. For stream-peat the Ra-226 concentrations were surprisingly low. The average concentration from eight measurements at sites No 1 and 4 was only 2.108 Bq/g. This value was three times lower compared to that from Stugun and the reason for that is difficult to explain. A possible explanation could be that the physical and chemical properties of the water at Purnuvaare are such that Ra-226 stays in solution.

7.3.2 Spatial variation

The water quality of the spring at Purnuvaare was similar to that of Nuortamustjåkkå, both being located within granitic areas. The low U concentration of the water is therefore correlated to the same factors for both areas: a) Strong dilution by rainwater and b) Low alkalinity. The spatial variation of U in water was characterized by a gradual decrease in the U contents between site No 1 and 5 (except for site No 5, July 1981). Also stream-peat had a decreasing trend for the U concentrations if only sites No 2 to 5 were considered. (The samples from site No 1 were not representative due to inadequate sampling. The reason is that the spring was so large, 25 m by 2 m of stagnant water, that only limited parts of the peat material in the spring was in direct contact with the emerging groundwater. It was also impossible to see exactly where the groundwater emerged in the spring.) The results, however, indicated that most of the U emerging from the spring was absorbed by the peat material before the stream seeped into the bog at site No 5.

The radioactivity measurements showed that the radon content was stronger than for the other two test areas. Readings of 340 μR/h were recorded in May 1981 and of 215 μR/h in October 1981. These high readings were probably related to the short distance to the bedrock source. The spatial distribution pattern of the radioactivity was similar as for the other to test areas. Already 200 m from the spring (at site No 5) background readings were recorded indicating that all radon had evaporated.

For Ra-226 no conclusion about spatial variation could be drawn from the limited sampling that was carried out.

7.4 Conclusions

From these results it is possible to draw some general conclusions about the behaviour of radionuclides in the secondary environment.

The leaching of naturally occuring radionuclides from bed-rock deposits by groundwater is basically of two kinds:

1. Leaching of uranium mineralizations (Stugun and Purnuvaare)
2. Leaching of dispersed uranium, from a radioactive granite (Nuortamustjåkkå)

The results indicate that the relationship between the U and Ra-226 concentrations in groundwater is different with respect to these two types of leaching. It can be assumed that this is due to differences in the radioactive equilibrium state between U and its daughter products.

The results strongly indicate that there is mostly a state of disequilibrium between the content of U in stream-peat and in water. This is manifested by very high values for the geochemical concentration factor at all three test areas. It is assumed that the very high potential adsorption capacity of peat and its low leaching rate is responsible for this.

The results also indicate that the leaching rate of U from minerogenic stream sediments is higher than from stream-peat.

It is also demonstrated, that when radioactive groundwater reaches the surface in a spring, the dissolved radon emanates very rapidly, in general within a distance of 200 m along the stream channel.

For water, the U and Ra-226 concentrations trend to be positively correlated, but no positive correlation have been found for these two elements in stream-peat or minerogenic stream sediments. This is explained by the different chemical properties of the two elements.

8. UPTAKE AND LOSS OF URANIUM BY BOG PEAT - AN EXPERIMENTAL STUDY

Bog peat will develop when dead plant material is gathered during anaerobic conditions. The transformation from plant material to peat occurs through humification processes caused by bacteria and fungi. The major part of the peat (> 90 %) consists of more or less humified organic matter (12). Because of its large capacity to accumulate and retain various elements, bog peat is of main importance for the long-term dispersion of elements supplied by groundwater. This characteristic feature is regularly used in geochemical ore surveys.

Very high uranium concentrations in peat have been documented in northern Sweden (3). The average uranium content in the bog deposit at Masugnsbyn was 15 Bq g^{-1} dry weight (600 ppm) and the ratio of uranium content of the peat to that of the water was about 9 000. This value is in agreement with those experimentally obtained by Szalay (3,14,15), who found an enrichment factor of 10 000 between peat and water. This illustrates the capacity of peat to collect and store uranium supplied by the percolating water.

However, nutrients and trace elements are not permanently stored in peat deposits; many elements are suprisingly mobile. Environmental variables such as the water table, stream flow and pH will affect the exchange of elements between the peat bog and the surrounding percolating water. Damman (16) concluded that the chemical changes in the peat was closely linked to the location and fluctuation of the water table. Many elements seemed to be concentrated in the zone of water level fluctuation, and were removed from the peat before they entered the permanently anaerobic zone (op cit).

Leaching of uranium from weathered rocks is often rapid and its concentration in surface and groundwater is enhanced in neutral to alkaline conditions by complexing with carbonate or silicate ions, and in acid media by complexing with sulphate ions (17). Uranium is removed from aqueous solutions by precipitation in reducing environments, by absorption on clays and by absorption to humic organic matter and iron hydroxides (18).

The major factor influencing uranium geochemistry is its multiple valency: +6 in oxidizing environments and +4 under reducing conditions. In the +6 state, uranium is soluble, particularly if there is enough CO_2 in the system to allow the formation of uranyl carbonate complexes. In the +4 state it forms insoluble precipitates such as UO_2. The extreme insolubility of UO_2 at normal groundwater pH's makes uranium practically immobile in low Eh environments. At intermediate Eh, however, oxidation and leaching of UO_2 is greatly enhanced when phosphate and/or carbonate are present to form their highly stable uranyl complexes (19,21,22).

A high degree of uranium enrichment tends to occur as uranium is precipitated, where streams fed by alkaline groundwater springs flow through peat which is acid or reducing (18).

The fixation of metals to peat can take place through ion exchange and chelate transformation with peat humic acids. The fixation of cations such as Na, K, Ca, Ba, Cr, Fe, Co, Ni, Cu, Zn, Pb and U takes place in humic acids. When describing the fixation of uranium by peat, the expressions "uptake" or "adsorption" are commonly used without making any further explanations about the underlying mechanisms involved. Szalay (13) found the fixation of uranyl ions to be essentially a cation exchange process. Humic acids seemed to be the decisive factor in the fixation of uranium. When extracting the humic acids from the peat with dilute NaOH, the peat lost most of its uranium-fixing capacity (op cit). The concentration factor increased strongly with the valency and with the atomic weight of the cation. Various elements such as ${UO_2}^{2+}$ and the ions of rare earth metals competed with each other in the fixation, and those of higher valency and atomic weight would expel others of lower atomic weight and valency.

In oxidized natural waters with typical amounts of carbonate, fluoride, phosphate and sulfate uranyl (2+) fluoride complexes and UO^{2+} will predominate below pH 5; between pH 4 - 7.5 $UO(HPO_4)_2^{2-}$ is the important species (21). At higher pH's, uranyl di- and tricarbonate complexes predominate. Under anoxic conditions, for waters with typical concentrations of the same ligands, uranous (4+) fluoride complexes predominate below pH 3 - 4, and uranous hydroxy complexes at higher pH's.

The influence of pH on the fixation of uranium was investigated by Szalay (13). Between pH

3 - 7, uranium was well fixed by peat. Below pH 3, the uranyl ions were easily eluted by dilute acids and were exchanged by hydrogen ions. Titayeva (20) showed experimentally that the uptake of uranium by peat was highest around pH 6.

In order to support the evaluation of field data obtained from the three uranium-rich springs, and to determine the general trends of the radioactive equilibrium between peat and water for different environmental conditions, some accumulation and leaching experiments were performed in the laboratory. The main purpose was to obtain information concerning the exchange of uranium between peat and water. The experiments only cover a few of the possible combinations of environmental factors which are of importance in order to clarify the mechanisms responsible for the exchange of uranium between water and peat. The results may be used as a complement to the data obtained from the investigations in the field to interpret the exchange rates and sorption capacities of peat in natural waters.

8.1 Material and methods

Uranium-rich spring water and peat collected at the sampling site of Stugun was used in the laboratory studies. The activity concentration of the water was about 0.35 Bq l^{-1} (~ 14 ppb). "Uraniumfree" peat was also collected nearby Nyköping. The uranium-rich peat from the Stugun area was well humified while the peat from the surroundings of Nyköping was less humified.

The experimental setup for the accumulation and leaching studies is displayed in Figure 11. A pump circulated water from a 24 l reservoir through a column containing a loosely packed lump of peat. Two filters with a mesh size of 90 µm kept the peat in position. The amount of peat used varied between 6.3 and 20.1 g dry wt. The average water flow was 1 l h^{-1}. The influence of temperature upon fixation has been shown not to be important (13), and the experiments were therefore run at a constant temperature of 18°C. Four identical setups were arranged, and the following experiments were performed, one in each column:

	Experimental design	Process
1	Uranium-free peat and uranium-rich spring water	uptake
	+ distilled water	leaching
	+ sulphuric acid	leaching
2	Uranium-rich peat and spring water + UAc	uptake
	+ distilled water	leaching
	+ sulphuric acid	leaching
3	Frozen uranium-rich peat and distilled water	leaching
	+ sulphuric acid	leaching
4	Reference column with spring water	uptake
	+ UAc	uptake
	+ distilled water	leaching
	+ sulphuric acid	leaching

Experiment No 1 will give the uptake rate of uranium by peat which had not earlier been exposed to this element.

In experiment No 2 the effects of an elevated uranium concentration on the uptake by peat in equilibrium with the surrounding water was investigated. Uranylacetate (UAc), $UO_2(Ac)_2$, was added so the initial uranium concentration of the water increased from 14 to 251 ppb.

In order to evaluate the effect of freezing on the leaching rate by peat previously exposed to spring water containing uranium, some of the material from the Stugun area was frozen for two months before the leaching experiment started.

In all three experiments, the effects of a reduced pH on the release rate of uranium from the peat were also investigated. Sulphuric acid was added to the reservoirs containing distilled water until the pH was lowered about 2 units.

The peat in each column was kept intact from the start to the end of the exposure experiment. When changing from the accumulation to the leaching experiments, the reservoirs were replaced by new ones. The uptake of uranium by the peat was measured as the difference in water concentration at successive intervals during the experiments. The leaching of peat with distilled water and subsequent acidification was measured as the increase of the uranium concentration in the water. The successive water samples were mostly taken with daily intervals. When an experiment was finished, the peat was dried and ashed at 540°C. In order to assess the amount of uranium adsorbed to the walls of the experimental apparatus, an identical program was run with a reference column containing no peat.

8.2 Results

The raw data from the different experiments are displayed in Appendix C.

8.2.1 Uptake and leaching by reference column

The capacity of uranium to adsorb to the surfaces of the apparatus without any peat was tested for 12 days, while a leaching experiment was performed during 6 days. The results are viewed in Table 22. After 6 days, 24 % of the total uranium inventory in the water had been adsorbed to the surfaces. After an addition of UAc to the water, 5 % of the total inventory was adsorbed within 5 days.

Leaching with distilled water for 3 days caused a loss of 2.5 % of the amount originally adsorbed. Acidification further accelerated the process and another 6 % was released from the surfaces within the next 3 days interval.

8.2.2 Uptake and leaching by uncontaminated peat exposed to uraniumrich spring water

Uptake

The accumulation curve is viewed in Figure 12. During the first 24 h period the uptake was quite rapid and 53 % of the total uranium content of the water was adsorbed by the peat with a mean uptake rate of 7.1 10^{-1} Bq g^{-1} day^{-1}.

During the subsequent 2 days an additional 9 % was further accumulated with a mean rate of only 5 10^{-2} Bq g^{-1} day^{-1}. A steady state between peat and water was approached, and for the next 3 days the uptake rate had decreased to 3 10^{-2} Bq g^{-1} day^{-1}. Taking into account the loss of uranium to the walls of the experimental apparatus, about 45 % of the available uranium in the water was bound by the peat. This will imply a concentration factor of about 5 500, which is in conformity with concentration factors calculated by other authors (3,12,13).

Leaching

The clearance rates are given in Table 23 and the concentration changes of peat in Figure 13. When exposed to distilled water, the peat released 2 % of its total inventory during the first 24 h with a mean release rate of $2 \cdot 10^{-2}$ Bq g^{-1} day^{-1}. During the following 2 days a small amount of uranium was re-adsorbed with $2 \cdot 10^{-3}$ Bq g^{-1} day^{-1}. When lowering the pH of the water, the release rate increased to $7 \cdot 10^{-2}$ Bq g^{-1} day^{-1} during the first day. For the next 5 days small re-adsorption rates of $(2-6) \cdot 10^{-3}$ Bq g^{-1} day^{-1} were obtained. For the whole 9-day period, a total of about 7 % of the uranium initially bound to the peat was lost to the water.

8.2.3 Uptake and leaching by uraniumrich peat exposed to spring water and UAc

Uptake

The uptake curve is viewed in Figure 14. Peat, with an uranium content of about 36 Bq g^{-1}, was exposed to spring water containing an additional amount of UAc, so the total water concentration reached 6.4 Bq l^{-1}. The calculated uptake by peat for the first 24 h period was 3.1 Bq g^{-1} day^{-1} which constituted 28 % of the initial inventory of the water. During the following 2 days the uptake rate decreased to 1.4 Bq g^{-1} day^{-1}, and for the next 3 days period it further decreased to 0.3 Bq g^{-1} day^{-1}. At the end of the 5 days of exposure, with correction made for the loss of uranium to the walls of the apparatus, about 40 % of the uranium available in the water was bound to the peat, and a concentration factor of about 2 000 was reached.

Leaching

The leaching rates can be seen in Table 24 and the change in uranium concentration of the peat in Figure 15. During the first 3 days only ~ 0.1 % of the total amount of uranium in the peat was released to the water with a rate of $(1-2)\cdot 10^{-2}$ Bq g^{-1} day^{-1}. When lowering the pH, the release increased to $1.5\cdot 10^{-1}$ Bq g^{-1} day^{-1} during the first day. For the following 3 days a re-adsorption occurred with $2\cdot 10^{-2}$ Bq g^{-1} day^{-1}. During the two last days of exposure $1\cdot 10^{-2}$ Bq g^{-1} day^{-1} was leached to the water. Of the total amount of uranium bound to the peat, only $4\cdot 10^{-1}$ % was lost to the water. This is a very small amount compared to the amount of 7 % obtained for the uncontaminated peat. This difference may also be attributed to the different stage of decomposition of the peat, where a highly humified peat may have a lower leaching rate.

8.2.4 Clearance of frozen uranium-rich peat

The leaching rate for peat which had previously been frozen is displayed in Table 25 while the change of uranium content in the peat is given in Figure 16. The figures obtained did not deviate from the corresponding figures given for untreated peat which had been exposed to uranium-rich spring water and UAc. During the first 24 h about 6 10^{-2} % of the total uranium inventory was lost to the water. A lowering of the pH caused a loss of 4 10^{-1} % during the first 24 h where half the amount was released during the initial 2 h. For the following 2 days a slow re-adsorption of about 1 10^{-1} % occurred. During the 4 days totally 4 10^{-1} % of the original uranium content of the peat was lost.

8.3 Conclusions

From these experiments some general conclusions can be made about the exchange rates between bog peat and water.

The relative uptake rates, on one hand by uncontaminated peat exposed to spring water containing uranium, and on the other contaminated peat exposed to elevated uranium concentrations, were almost identical. Thus, the initial uranium inventory of the peat and water is of minor importance for the accumulation in peat. The calculated concentration factors showed that even at low water concentrations we may obtain a significant accumulation in peat. The uranium-rich peat from the Stugun area still accumulated large amounts of UAc, indicating a high potential extraction capacity.

The accumulation by peat was always much larger than the corresponding losses; only a few per cent of the inventory was leached back to the water.

The effect of freezing seemed not to be of any importance for the leaching rate of peat.

A lowering of the pH will highly affect the release of uranium bound to the peat. The leaching rates (% day^{-1} of inventory in peat) increased at once by a factor 20 - 38.

The uptake of uranium by the reference column itself demonstrates that when the uranium concentration is low, the adsorbed fraction of the total inventory would be considerable. With increasing uranium concentration, the fraction which is adsorbed will be smaller and thus will interfere to a less extent with the obtained results. The amount of uranium released to the water is however small.

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Table 1

Stugun: Sampling sites, summary of environmental characters along the stream channel

Site	Type of soil			Type of vegetation			Dominating plant group				Width of stream channel	Rate of flow		
	Peat	Till	Boulder rich till	Bog	Pine bog	Mixed forest	Sphagnum	Diff. mosses	Carex	Brush		Slow	Fast	Torrential
1			X			X		X			1 m	X		
2			X			X		X			0.5m		X	
3	X				X		X	X	X		1 m	X		
4	X				X		X	X	X	X	1 m	X		
5	X				X		X	X	X	X	1 m	X		
6			X			X	(X)*	X	X		0.5m		X	
7			X			X	(X)	X	X		0.5m		X	
8			X			X	(X)	X	X		0.5m		X	
9			X			X	(X)	X	X		0.5m		X	
10	X			X			(X)	X			0.5m		X	
11	X				X		(X)	X			Lake	-	-	-

* Bracklets indicate that Sphagnum is not regularly occurring along the stream channel.

Table 2

Nuortamustjåkkå: Sampling sites; summary of environmental characters along the stream channel

Site	Type of soil			Type of vegetation			Dominating plant group				Width of stream channel	Rate of flow		
	Peat	Till	Boulder rich till	Bog	Pinebog	Mixed forest	Sphagnum	Diff. mosses	Carex	Brush		Slow	Fast	Torrential
1			X			X		X	X		1 m	X		
2			X			X		X	X		1 m	X		
3			X			X		X	X		1 m		X	
4			X			X		X	X		1 m		X	
5			X			X		X	X		0.5m			X
6		X				X		X	X	X	0.5m		X	
7		X				X		X	X	X	0.5m	X		
8	X				X		X				0.5m	X		
9	X			X			X				0.5m	X		
10	X			X			X				0·0m	-	-	-

Table 3

Purnuvaare: Sampling sites, summary of environmental character along the stream channel

Site	Type of soil			Type of vegetation			Dominating plant group				Width of stream channel	Rate of flow		
	Peat	Till	Boulder rich till	Bog	Pinebog	Mixed forest	Sphagnum	Diff. mosses	Carex	Brush		Slow	Fast	Torren-tial
1	X			X			X	X			1.5m	X		
2	X			X			X	X			1.5m	X		
3	X			X			X	X			1.5m	X		
4	X			X			X	X			1.5m	X		
5	X			X			X	X			1.5m	X		
6	X	X				X		X	X	X	1.5m	X		
7	X	X				X		X	X	X	1 m	X		
8	X	X				X		X	X	X	1 m		X	
9	X	X				X		X	X	X	1 m		X	
10	X	X				X		X	X	X	1 m		X	

Table 4

Monthly precipitation (mm) during the sampling period at the nearest meteorological stations: Hissmofors (Stugun), Jokkmokk (Nuortamustjåkkå) and Lappträsket (Purnuvaare).

Year Month	Precipitation (mm)		
	Hissmofors	Jokkmokk	Lappträsket
1980 Sept.	54.5		
Oct.	69.0 1)		
Nov.	21.2		
Dec.	37.1		
1981 Jan.	29.7	27.1	38.5
Febr.	22.5	9.7	21.4
Mars	51.2	40.0	41.6
April	14.3	9.1	15.1
May	10.6 1)	23.0 2)	23.2 3)
June	110.5	90.0	64.2
July	106.8 1)	195.7 2)	114.1 3)
Aug.	71.8	57.7	47.0
Sept.		40.0	41.0
Oct.		64.0 2)	69.0 3)
Nov.		37.0	72.0
Dec.		23.0	45.0

1): Sampling at Stugun
2): Sampling at Nuortamustjåkkå
3): Sampling at Purnuvaare

Table 5

Summary of water sampling (292 samples)

Sampling at Stugun: 7960, 001-050, 061-092, 331-360 (112 samples)
Sampling at Nuortamustjåkkå:7960, 101-190 (90 samples)
Sampling at Purnuvaare: 7960, 201-290 (90 samples)

Stugun	Autumn 1980					Spring 1981			Summer 1981		
Site No	1/10	2/10	3/10	4/10	5/10	12/5	13/5	14/5	23/7	24/7	25/7
1 Spring	1	11	x21xx	31	41	x331xx	341	351	x61xx	71	81
2 Stream	2	12	22	32	42	332	342	352	62	72	82
3 "	3	13	23	33	43	333	343	353	63	73	83
4 "	4	14	24	34	44	334	344	354	64	74	84
5 "	5	15	25	35	45	335	345	355	65	75	85
6 "	6	16	x26	36	46	x336	346	356	x66	76	86
7 "	7	17	27	37	47	337	347	357	67	77	87
8 "	8	18	x28	38	48	338	348	358	68	x78	88
9 "	9	19	29	39	49	339	349	359	69	79	89
10 "	10	20	x30	40	50	x340	350	360	x70	80	90
11 Lake	-	-	-	-	-	-	91	-	-	92	-

Nuortamus-tjåkko	Spring 1981			Summer 1981			Autumn 1981		
Site No	15/5	16/5	17/5	27/7	28/7	29/7	6/10	7/10	8/10
1 Spring	101	111	121	131	141	151	161	171	181
2 "	102	x112xx	122	x132xx	142	152	162	x172xx	182
3 Stream	103	113	123	133	143	153	163	173	183
4 "	104	x114	124	x134	144	154	164	x174	184
5 "	105	115	125	135	145	155	165	175	185
6 "	106	116	126	136	146	156	166	176	186
7 "	107	x117	127	137	147	157	167	x177	187
8 "	108	118	128	x138	148	158	168	178	188
9 "	109	119	129	139	149	159	169	179	189
10 "	110	120	130	140	150	160	170	180	190

Purnu - vaare	Spring 1981			Summer 1981			Autumn 1981		
Site No	18/5	19/5	20/5	30/7	31/7	1/8	7/10	8/10	9/10
1 Spring	201	x211xx	221	x231xx	241	251	261	x271xx	281
2 Stream	202	212	222	232	242	252	262	272	282
3 "	203	213	223	233	243	253	263	273	283
4 "	204	x214	224	x234	244	254	264	x274	284
5 "	205	215	225	235	245	255	265	275	285
6 "	206	x216	226	236	246	256	266	276	286
7 "	207	217	227	237	247	257	267	277	287
8 "	208	218	228	x238	248	258	268	x278	288
9 "	209	219	229	239	249	259	269	279	289
10 "	210	220	230	240	250	260	270	280	290

x Ra-det.
xx H-3 det.

Table 6

Summary of stream-peat sampling (272 samples)

Sampling at Stugun: 8013, 1-92 (92 samples)
Sampling at Nuortamustjåkkå: 8013, 101-190 (90 samples)
Sampling at Purnuvaare: 8013, 201-290 (90 samples)

Stugun	Autumn 1980			Spring 1981			Summer 1981		
Site No	1/10	3/10	5/10	12/5	13/5	14/5	23/7	24/7	25/7
1	1	11^{x}	21	31^{x}	41	51	61^{x}	71	81
2	2	12	22	32	42	52	62	72	82
3	3	13	23	33	43	53	63	73	83
4	4	14	24	34	44	54	64	74	84
5	5	15	25	35	45	55	65	75	85
6	6	16^{x}	26	36^{x}	46	56	66^{x}	76	86
7	7	17	27	37	47	57	67	77	87
8	8	18	28	38	48	58	68	78	88
9	9	19	29	39	49	59	69	79	89
10	10	20^{x}	30	40^{x}	50	60	70^{x}	80	90
11	-	-	-	(91^{x})	-	-	92	-	-

Nuortamustjåkkå	Spring 1981			Summer 1981			Autumn 1981		
Site No	15/5	16/5	17/5	27/7	28/7	29/7	6/10	7/10	8/10
1	(101)	111	121	131	141	151	161	171	181
2	(102)	(112^{x})	(122)	(132^{x})	142	152	162	172^{x}	(182)
3	103	113	123	133	143	153	163	173	183
4	104	114^{x}	124	134^{x}	144	154	164	174^{x}	184
5	105	115	125	135	145	155	165	175	185
6	106	116	126	136	146	156	166	176	186
7	107	117^{x}	127	137	147	157	167	177^{x}	187
8	108	118	128	138^{x}	148	158	168	178	188
9	109	119	129	139	149	159	169	179	189
10	110	120	130	140	150	160	170	180	190

Purnuvaare	Spring 1981			Summer 1981			Autumn 1981		
Site No	18/5	19/5	20/5	30/7	31/7	1/8	7/10	8/10	9/10
1	201	211^{x}	221	231^{x}	241	251	261	271^{x}	281
2	(202)	212	(222)	232	242	252	(262)	272	282
3	203	(213)	223	233	243	253	263	273	283
4	204	(214^{x})	224	234^{x}	244	254	264	274^{x}	284
5	205	(215)	225	235	245	255	(265)	275	285
6	206	216^{x}	226	236	246	256	266	276	286
7	207	217	227	237	247	257	267	277	287
8	208	218	228	238^{x}	248	258	268	278^{x}	288
9	209	219	229	239	249	259	269	279	289
10	210	220	230	240	250	260	270	280	290

^{x} Ra-det. Samples with numbers within bracklets were not analyzed due to insuffient amount of material after ashing.

Table 7

Summary of sampling of minerogenic material (90 samples)

Sampling at: Stugun: 8021:6-8, 16-18, 26-28, 36-38, 46-48, 56-58, 66-68, 76-78, 86-88, 91. (27 samples)

Sampling at: Nuortamustjåkkå: 8021:102-107, 112-117, 122-127, 132-132, 142-147, 152-157, 162-167, 172-177, 182-187. (54 samples)

Sampling at: Purnuvaare: 8021: 227-228, 238, 248, 258, 268, 278, 288

Stugun	Autumn 1980			Spring 1981			Summer 1981		
Site No	1/10	3/10	5/10	12/5	13/5	14/5	23/7	24/7	25/7
1									
2									
3									
4									
5									
6	6	16^{x}	26	36^{x}	46	56	66^{x}	76	86
7	7	17^{x}	27	37^{x}	47	57	67	77$_{x}$	87
8	8	18^{x}	28	38^{x}	48	58	68	78^{x}	88
9									
10									
11				91^{x}					

Nuortamustjåkkå	Spring 1981			Summer 1981			Autumn 1981		
Site No	15/5	16/5	17/5	27/7	28/7	29/7	6/10	7/10	8/10
1									
2	102	112^{x}	122	132^{x}	142	152	162	172^{x}	182
3	103	113$_{x}$	123	133$_{x}$	143	153	163	173$_{x}$	183
4	104	114^{x}	124	134^{x}	144	154	164	174^{x}	184
5	105	115	125	135	145	155	165	175	185
6	106	116$_{x}$	126	136	146	156	166	176$_{x}$	186
7	107	117^{x}	127	137	147	157	167	177^{x}	187
8									
9									
10									

Purnuvaare	Spring 1981			Summer 1981			Autumn 1981		
Site No	18/5	19/5	20/5	30/7	31/7	1/8	7/10	8/10	9/10
1									
2									
3									
4									
5									
6									
7	-	-	227	-	-	-	-	-	-
8	-	-	228	238^{x}	248	258	268	278^{x}	288
9									
10									

^{x} Ra- det.

Table 8

Detection limits for all analyzed elements

Water		Stream-peat ash		Minerogenic stream sediment	
Element	Detection limit	Element	Detection limit	Element	Detection limit
HCO_3	0.6 mg/l	Na_2O	0.01 %	Ca	0.5 %
F	0.03 "	TiO_2	0.01 "	Mg	0.1 "
Cl	0.005 "	Fe_2O_3	0.01 "	Ba	0.1 "
NO_3	0.2 "	MnO	0.01 "	Fe	0.1 "
SO_4	0.4 "	Al_2O_3	0.01 "	Mn	0.1 "
PO_4	0.1 "	SiO_2	0.01 "	Ti	0.1 "
Na	0.01 "	K_2O	0.01 "		
K	0.1 "	MgO	0.01 "	Cu	5 ppm
Mg	0.001 "	P_2O_5	0.005 "	Pb	5 "
Ca	0.001 "	CaO	0.01 "	Zn	10 "
		S	0.005 "	Ag	3 "
Fe	0.01 "			Bi	5 "
Mn	0.01 "	U	10 ppm	Cr	5 "
Cu	0.005 "	Th	10 "	Ni	5 "
Zn	0.010 "	Cu	10 "	Co	5 "
Be	0.003 "	Pb	20 "	Mo	10 "
Cr	0.005 "	Zn	10 "	Sr	10 "
Co	0.005 "	Co	10 "	As	50 "
Ni	0.005 "	Ni	10 "	Sn	5 "
As	0.003 "	Cr	10 "	Be	5 "
Ba	0.005 "	Mo	10 "	V	10 "
		Sr	20 "	W	10 "
U	0.001 "	As	20 "	Th	10 "
		V	10 "	Rb	10 "
Ra-226	0.002 Bq/l	Rb	10 "	Y	10 "
		Zr	10 "	Zr	10 "
H_3 (tritium)	0.05 Bq/ml	W	10 "		
				U	0.01±1 ppm
		Ra-226	0.04 Bq/g ash	Ra-226	0.01 Bq/g ash

Table 9

Uranium (ppb) in water from the three springs and their out-flows, sampled at three different seasons.

Stugun	Autumn 1980					Spring 1981			Summer 1981		
Date / Site No	1/10	2/10	3/10	4/10	5/10	12/5	13/5	14/5	23/7	24/7	25/7
1	26.4	28.5	24.9	22.0	26.3	14.6	9.8	16.6	13.3	17.6	16.7
2	22.3	27.8	27.7	27.1	29.3	9.3	(0.3)	12.7	12.4	14.7	20.6
3	29.3	28.4	31.3	26.3	32.9	10.6	10.4	11.5	18.9	14.3	16.4
4	23.8	19.2	22.1	22.3	17.7	6.1	7.4	5.7	12.5	14.5	12.5
5	21.2	22.7	20.2	22.2	22.2	5.0	7.6	9.0	12.0	10.9	12.5
6	24.1	23.9	23.6	24.0	18.1	5.0	5.3	6.6	10.8	8.3	11.3
7	22.2	25.3	22.0	26.4	24.3	3.9	5.0	6.1	13.1	10.4	14.2
8	20.0	25.7	21.5	26.2	27.1	4.2	6.4	4.3	11.0	9.7	14.2
9	27.2	23.9	20.7	19.8	22.0	4.4	5.8	4.5	10.1	10.8	10.2
10	20.5	22.0	22.7	22.8	19.8	4.1	5.6	5.8	9.4	10.8	9.8
11	-	-	-	-	-	-	1.5	-	-	1.2	-

Nuortamustjåkkå	Spring 1981			Summer 1981			Autumn 1981		
Date / Site No	15/5	16/5	17/5	27/7	28/7	29/7	6/10	7/10	8/10
1	4.6	8.6	4.2		2.4			2.3	
2	3.1	5.3	8.4		6.8			2.5	
3	7.2	8.0	8.1		2.1			3.2	
4	6.3	7.9	9.0		2.4			2.6	
5	7.5	7.1	6.6		2.3			2.8	
6	2.8	2.9	2.4		2.8			2.7	
7	2.6	2.7	2.3		2.8			2.2	
8	2.8	3.0	2.4		2.5			2.9	
9	2.6	3.2	3.3		2.4			2.7	
10	1.7	2.4	1.8		2.7			1.9	

Purnuvaare	Spring 1981			Summer 1981			Autumn 1981		
Date / Site No	18/5	19/5	20/5	30/7	31/7	1/8	7/10	8/10	9/10
1	3.0	2.7	3.0		1.9			2.2	
2	6.6	3.3	1.9		1.7			2.1	
3	4.7	2.4	2.8		1.5			1.5	
4	2.6	2.0	(0.6)		1.5			0.9	
5	1.6	1.0	0.9		2.8			1.0	
6	0.2	0.2	0.3		1.3			0.9	
7	0.2	0.2	0.2		0.6			0.8	
8	0.3	0.3	0.3		1.0			0.9	
9	0.2	0.2	0.2		0.7			0.9	
10	0.2	0.2	(1.0)		0.7			0.8	

Comment: Samples taken on the dates of 27/7, 29/7, 30/7, 1/8, 6/10, 7/10 (Purnuvaare), 8/10 (Nuortamustjåkkå) and 9/10 were spoiled due to incorrect treatment at the laboratory.
Samples in bracklets are probably wrong due to analytical error.

Table 10 STUGUN: Hydrogeochemical data

Season	Site No	Water-flow l/s	Temperature °C	Radioactivity µR/h	pH	Concuctivity κ ms/m	Anions					Major cations				Minor cations					
							HCO_3 mg/l	F mg/l	Cl mg/l	NO_3 mg/l	SO_4 mg/l	Na mg/l	K mg/l	Mg mg/l	Ca mg/l	Mn µg/l	Fe µg/l	Cu µg/l	Zn µg/l	U µg/l	Ra-226 mBq/l±1δ
Autumn 1980	1 Spring		4.7	167	7.25	20.8	133	0.68	1.3	1.4	6.9	2.1	0.70	1.50	42.1	<10	<10	39	3	25.6	14.0±0.02
	2 Stream	4.3	4.7	50	7.49	20.8	133	0.68	1.3	1.4	7.0	2.1	0.70	1.50	41.2	<10	<10	27	6	26.8	
	3 "		4.7	35	7.51	20.7	132	0.68	1.3	1.4	6.9	2.0	0.60	1.50	40.8	<10	<10	21	7	29.6	
	4 "		4.8	17	7.51	19.3	122	0.64	1.3	1.0	6.1	2.0	0.60	1.40	38.2	<10	10	13	4	21.0	
	5 "		4.7	14	7.57	19.1	122	0.63	1.3	1.0	6.0	2.0	0.60	1.40	37.8	10	10	8	7	21.7	
	6 "	7.5	4.6	39	7.57	19.0	120	0.62	1.3	1.0	5.9	2.0	0.60	1.40	37.5	10	20	4	6	22.7	7.26±0.59
	7 "		4.4	22	7.63	19.0	120	0.62	1.3	1.0	5.9	2.0	0.60	1.40	37.8	20	20	5	8	23.7	
	8 "		4.4	24	7.61	19.0	120	0.62	1.3	1.0	5.9	2.0	0.60	1.40	37.9	20	20	6	5	24.1	8.2±0.98
	9 "	7.9	4.2	23	7.59	18.9	119	0.61	1.4	1.0	5.9	2.0	0.70	1.40	37.0	10	20	5	9	22.8	
	10 "		4.1	20	7.54	18.7	118	0.61	1.6	1.0	5.9	2.0	0.50	1.40	36.8	20	20	< 5	10	21.6	6.27±0.88
	11 Lake^x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Mean ($\bar{x}$)	6.6	4.5	41	7.53	19.5	124	0.64	1.3	1.1	6.2	2.0	0.62	1.43	38.7	11	14	13	7	24.0	
Spring 1981	1 Spring		3.9	70	7.20	12.4	69	0.43	1.4	0.9	4.8	1.6	0.86	1.00	49.0	<10	<10	<5	< 5	13.7	6.75±0.77
	2 Stream		4.0	26	7.25	13.1	71	0.46	1.3	1.4	5.1	1.6	0.81	1.00	54.0	<10	<10	< 5	< 5	11.0	
	3 "		4.0	25	7.19	13.1	71	0.45	1.2	1.1	5.1	1.7	0.84	1.10	58.0	<10	<10	< 5	< 5	10.8	
	4 "		7.5	21	7.22	11.0	56	0.53	1.3	1.3	6.1	1.6	0.76	0.93	47.0	10	10	< 5	< 5	6.4	
	5 "		7.4	14	7.08	10.9	56	0.44	1.1	1.1	5.2	1.5	0.74	0.89	41.0	10	30	< 5	< 5	7.2	
	6 "		5.9	41	6.90	9.1	45	0.40	1.3	1.0	4.7	1.5	0.67	0.79	37.0	<10	30	< 5	< 5	5.6	4.19±0.56
	7 "		5.4	19	7.30	9.1	45	0.46	1.4	1.1	4.7	1.5	0.66	0.82	37.0	10	40	< 5	< 5	5.0	
	8 "		5.3	21	7.55	9.1	45	0.47	1.3	1.1	4.7	1.5	0.67	0.80	37.0	10	30	< 5	< 5	5.0	
	9 "		4.8	20	7.30	8.8	44	0.44	1.3	1.0	4.6	1.5	0.69	0.75	35.0	<10	40	< 5	< 5	5.0	
	10 "		4.9	9	7.53	8.9	44	0.48	1.3	1.0	4.5	1.8	0.91	0.85	35.0	10	20	< 5	10	5.2	<10.0
	11 Lake^x		5.0	4	7.80	7.0	35	0.20	1.1	0.7	2.6	1.4	0.61	0.58	12.0	<10	60	< 5	< 5	1.5	
	Mean ($\bar{x}$)		5.8	27	7.25	10.5	55	0.46	1.3	1.1	5.0	1.6	0.76	0.89	43.6	8	22	< 5	<5	7.5	
Summer 1981	1 Spring		4.0	135	7.50	21.0	123	0.68	1.6	0.8	6.3	2.0	0.90	1.50	41.0	<10	10	< 5	<10	15.9	
	2 Stream	6.8	4.8	54	7.70	20.0	121	0.67	1.5	0.8	6.1	2.0	0.90	1.60	41.0	<10	60	< 5	<10	15.9	8.30±0.80
	3 "		5.0	39	7.75	19.7	121	0.67	1.5	0.8	4.8	2.0	0.90	1.60	41.0	<10	<10	< 5	<10	16.5	
	4 "		10.0	26	7.75	16.6	100	0.62	1.4	0.4	4.8	1.9	0.80	1.30	34.0	<10	40	< 5	<10	13.7	
	5 "		10.0	25	7.80	16.8	101	0.62	1.4	0.3	4.8	1.9	0.80	1.30	33.0	<10	30	< 5	<10	11.8	
	6 "	11.2	9.8	36	7.65	16.5	99	0.61	1.4	0.3	4.7	1.9	0.80	1.40	33.0	<10	40	< 5	<10	10.1	
	7 "		9.5	29	7.85	15.9	98	0.63	1.4	0.5	4.7	1.9	0.80	1.40	33.0	10	50	< 5	<10	12.6	13.9±1.2
	8 "		8.5	30	7.75	16.9	98	0.60	1.3	0.2	4.8	1.9	0.80	1.40	33.0	10	50	< 5	<10	11.6	
	9 "		8.0	30	7.80	16.2	103	0.59	1.4	<0.2	4.8	1.9	0.80	1.40	33.0	<10	70	<5	<10	10.4	
	10 "		8.0	18	7.80	16.6	97	0.58	1.3	<0.2	4.7	1.9	0.80	1.40	33.0	10	50	<5	<10	9.6	<3.4
	11 Lake^x		13.0	5	8.10	7.4	39	0.16	1.6	<0.2	4.1	1.2	0.70	1.40	14.0	<10	40	<5	<10	1.2	
	Mean (x)	9.0	9.1	42	7.94	17.6	106	0.62	1.4	0.4	5.1	1.9	0.83	1.43	35.9	7	41	<5	<10	12.8	

x) Not included in mean

Table 11 NUORTAMUSTJAKKA. Hydrogeochemical data

Season	Site No	Water flow l/s	Temperature C°	Radioactivity κ µR/h	pH	Conductivity ms/m	Anions					Major cations				Minor cations					
							HCO_3 mg/l	F mg/l	Cl mg/l	NO_3 mg/l	SO_4 mg/l	Na mg/l	K mg/l	Mg mg/l	Ca mg/l	Mn µg/l	Fe µg/l	Cu µg/l	Zn µg/l	U µg/l	Ra-226 mBq/l±1δ
Spring 1981	1 Spring		3.2	40	6.90	3.3	17	0.94	0.80	<0.2	1.3	1.6	0.66	0.58	3.4	< 10	< 10	< 5	< 5	5.8	
	2 "		2.1	40	6.82	3.2	13	0.75	0.87	< 0.2	1.2	1.9	0.67	0.73	4.0	< 10	< 10	< 5	< 5	5.6	3.1±1
	3 Stream		5.3	22	6.85	3.0	13	0.77	0.84	<0.2	1.2	1.2	1.00	0.77	3.2	< 10	70	< 5	< 5	7.8	
	4 "		7.3	15	7.08	2.9	11	0.82	0.84	<0.2	1.1	1.2	0.97	0.71	3.0	< 10	110	< 5	< 5	7.7	3.2±1 E-3
	5 "		7.1	19	6.80	2.6	11	0.73	0.81	<0.2	1.1	1.1	0.89	0.74	2.6	< 10	100	< 5	< 5	7.1	
	6 "		3.2	8	7.15	2.2	8	0.57	0.73	<0.2	1.1	0.9	0.85	0.66	2.2	< 10	160	< 5	< 5	2.7	
	7 "		3.2	9	6.70	2.0	8	0.52	0.60	<0.2	1.1	0:9	0.85	0.55	2.0	< 10	160	< 5	< 5	2.5	9.4±1 E-3
	8 "		3.2	6	6.85	2.1	7	0.55	0.69	<0.2	1.1	0.9	0.88	0.61	2.0	< 10	190	< 5	10	2.7	
	9 "		3.5	6	6.50	2.5	8	0.55	1.30	<0.2	1.1	0.9	0.90	0.60	2.0	< 10	170	< 5	< 5	3.0	
	10 "		4.5	5	6.82	2.4	9	0.58	0.71	<0.2	1.0	0.9	0.94	0.60	2.2	30	520	< 5	< 5	1.6	
	Mean$^{(x)}$		4.3	17	6.85	2.6	11	0.68	0.77	<0.2	1.1	1.2	0.86	0.66	2.7	< 10	149	<5	<5	4.7	
Summer 1981	1 Spring		6:2	30	6.50	2.9	12	0.87	0.58	< 0.2	1.3	1.5	0.60	1.10	2.9	< 10	40	< 5	< 10	2.4	
	2 "		5.5	32	6.80	2.5	22	0.70	0.58	< 0.2	1.2	1.7	0.40	0.90	3.7	< 10	< 10	< 5	< 10	6.8	2.1±0.7
	3 Stream	23.2	7.0	23	6.72	2.4	20	0.67	0.54	< 0.2	1.2	1.2	0.30	0.80	2.6	< 10	40	< 5	< 10	2.1	
	4 "		8.2	10	6.95	2.4	19	0.69	0.42	<0.2	1.3	1.2	0.30	0.80	2.6	< 10	50	< 5	< 10	2.4	2.2±0.6
	5 "		9.0	14	6.92	2.4	12	0.67	0.49	<0.2	1.5	1.2	0.30	0.80	2.5	< 10	90	< 5	< 10	2.3	
	6 "	35.0	10.0	8	6.62	2.3	16	0.87	0.49	<0.2	1.8	1.1	0.20	0.80	2.6	< 10	130	< 5	< 10	2.8	
	7 "		10.5	9	6.62	2.3	14	0.56	0.58	<0.2	1.5	1.1	0.30	0.80	2.5	< 10	140	<5	<10	2.8	
	8 "		11.0	5	6.65	2.3	16	0.54	0.49	<0.2	1.5	1.0	0.30	0.70	2.4	<10	170	<5	<10	2.5	2.5±0.7
	9 "		11.0	6	6.72	2.3	9	0.55	0.45	<0.2	1.5	1.1	0.30	0.80	2.5	< 10	140	<5	<10	2.4	
	10 "		13.00	5	7.20	2.3	8	0.55	0.41	<0.2	1.6	1.1	0.30	0.70	2.1	< 10	140	<5	<10	2.7	
	Mean ($\bar{x}$)	29.1	9.1	14	6.77	2.4	15	0.67	0.50	<0.2	1.4	1.2	0.33	0.82	2.6	<10	97	< 5	< 10	2.9	
Autumn 1981	1 Spring		2.7	39	6.82	3.1	18	0.78	0.80	<0.2	1.4	1.5	0.48	0.75	3.0	< 10	40	< 5	< 10	2.3	
	2 "		2.5	29	7.02	3.4	16	0.91	1.20	<0.2	1.5	1.7	0.51	0.87	3.9	< 10	10	< 5	< 10	2.5	<4.22
	3 Stream		2.9	23	6.88	3.1	15	0.77	1.00	<0.2	1.6	1.6	0.52	0.89	3.3	< 10	70	< 5	< 10	3.2	
	4 "	10.5	3.1	13	7.10	3.0	14	0.95	1.20	<0.2	1.5	1.6	0.50	0.80	3.1	< 10	60	< 5	20	2.6	3.4±0.54
	5 "		3.4	15	7.12	2.9	15	0.76	1.00	<0.2	1.5	1.6	0.49	0.72	3.1	< 10	110	< 5	20	2.8	
	6 "		3.8	8	6.99	2.7	10	0.67	0.90	<0.2	1.4	1.5	0.45	0.78	2.3	< 10	160	<5	10	2.7	
	7 "	13.5	3.8	9	6.98	2.6	12	0.67	1.00	<0.2	1.3	1.5	0.44	0.78	2.8	< 10	150	<5	<10	2.2	1.39±0.35
	8 "		3.5	5	6.95	2.7	10	0.67	1.10	<0.2	1.5	1.5	0.46	0.77	2.8	<10	160	<5	<10	2.9	
	9 "		3.8	6	6.98	2.6	11	0.65	1.00	<0.2	1.4	1.5	0.43	0.62	2.2	<10	140	<5	<10	2.7	
	10 "		4.2	5	6.88	3.1	11	0.63	1.60	<0.2	0.2^{x}	1.5	0.44	0.83	2.7	<10	140	<5	<10	1.9	
	Mean (x)	12.0	3.4	15	6.97	2.9	13	0.75	1.10	<0.2	1.5	1.6	0.47	0.78	2.9	<10	104	<5	10	2.6	

x) Not included in mean due to probable analytical error

Table 12 PURNUVAARE. Hydrogeochemical data.

Season	Site No	Water flow	Temperature	Radioactivity	pH	Conductivity	Anions					Major cations				Minor cations					
		l/s	C°	κ μR/h		mS/m	HCO_3 mg/l	F mg/l	Cl mg/l	NO_3 mg/l	SO_4 mg/l	Na mg/l	K mg/l	Mg mg/l	Ca mg/l	Mn μg/l	Fe μg/l	Cu μg/l	Zn μg/l	U μg/l	Ra-226 mBq/l ± 1σ
Spring 1981	1 Spring		3.0	100	7.38	5.4	25	0.11	0.91	<0.2	5.0	2.2	2.2	1.1	6.9	<10	<10	<5	<5	2.9	16.0±0.30
	2 Stream		5.2	340	7.18	5.5	25	0.11	0.83	<0.2	4.9	2.1	2.3	1.0	6.3	<10	<10	<5	<5	3.9	
	3 "		8.0	130	7.32	5.4	25	0.11	0.82	<0.2	4.9	2.0	2.1	0.9	6.1	<10	<10	<5	<5	3.3	
	4 "		10.5	57	7.05	5.2	24	0.11	0.94	<0.2	4.7	2.0	2.1	1.0	5.9	<10	<10	<5	<5	1.7	8.83±0.44
	5 "		11.6	18	6.78	4.8	21	0.11	x) 1.00	<0.2	4.6	2.0	2.7	0.8	5.0	<10	<10	<5	<5	1.2	x = 2.6
	6 "		4.0	2	5.92	1.9	7	0.08	0.74	<0.2	1.2	0.8	1.2	0.6	1.4	<10	340	<5	<5	0.2	4.0±0.2
	7 "		4.7	3	5.95	1.8	6	0.07	0.63	<0.2	1.2	0.8	1.2	0.5	1.4	<10	310	<5	<5	0.2	
	8 "		1.4	9	6.02	2.0	7	0.08	0.54	<0.2	1.5	0.7	1.1	0.8	2.0	<10	620	<5	<5	0.3	
	9 "		1.3	2	6.20	1.8	7	0.33 x)	0.53	<0.2	1.1	0.7	1.0	0.6	1.7	<10	640	<5	<5	0.2	
	10 "		2.1	3	6.50	2.1	9	0.06	0.55	<0.2	0.9	0.7	1.1	0.8	2.2	<10	790	<5	<5	0.2	
	Mean		5.2	66	6.63	3.6	16	0.09	0.75	<0.2	3.0	1.4	1.7	0.8	3.9	<10	273	<5	<5	1.4	
Summer 1981	1 Spring		3.9	170	6.74	6.1	27	0.11	0.56	<0.2	5.6	1.9	1.6	1.4	4.9	<10	<10	<5	<10	1.9	10.0±0.1
	2 Stream		6.0	145	6.92	5.9	32	0.10	0.50	<0.2	5.4	2.0	1.9	1.3	5.9	<10	<10	<5	<10	1.7	
	3 "		5.2	90	6.94	5.9	31	0.10	0.49	<0.2	5.3	2.0	1.9	1.4	6.2	<10	<10	<5	<10	1.5	
	4 "		7.4	30	6.72	5.7	29	0.09	0.46	<0.2	5.2	1.9	1.7	1.2	5.6	<10	20	<5	<10	1.5	16.0±0.2
	5 "		12.1	4	6.35	5.5	31	0.09	0.42	<0.2	3.8	1.8	1.4	1.2	5.8	<10	30	<5	<10	2.8	$\bar{x}$ = 1.9
	6 "		12.8	2	6.20	2.6	19	0.15	0.60	<0.2	1.3	1.1	0.4	1.2	2.8	<10	330	<5	<10	1.3	3.6±0.4
	7 "		12.5	2	6.28	3.3	17	0.07	x) 2.00	<0.2	1.2	1.1	0.6	1.0	3.0	<10	390	<5	<10	0.6	
	8 "		12.5	2	6.15	2.4	15	0.07	0.39	<0.2	1.6	1.1	0.4	1.0	2.3	<10	500	<5	<10	1.0	
	9 "		12.8	3	6.40	2.6	10	0.07	0.46	<0.2	1.7	1.1	0.4	1.1	2.8	<10	1200	<5	<10	0.7	
	10 "		13.0	3	6.50	2.7	10	0.06	0.40	<0.2	1.4	1.2	0.4	1.2	3.1	<10	1000	<5	<10	0.7	
	Mean		9.8	45	6.52	4.3	22	0.09	0.48	<0.2	3.3	1.5	1.1	1.2	4.2	<10	349	<5	<10	1.4	
Autumn 1981	1 Spring		2.4	190	7.10	6.0	28	0.17	1.20	<0.2	5.0	2.2	2.4	1.2	6.3	<10	<10	<5	10	2.2	8.65±1.21
	2 Stream		2.3	215	7.10	6.1	28	0.12	0.90	<0.2	4.9	2.1	2.4	1.2	6.4	<10	20	<5	10	2.1	
	3 "		2.1	110	7.10	5.9	27	0.11	0.70	<0.2	4.6	2.1	2.4	1.2	6.5	<10	40	<5	10	1.5	
	4 "		0.9	34	7.08	5.6	25	0.12	0.80	<0.2	5.0	2.1	2.3	1.3	5.7	<10	<10	<5	20	0.9	8.15±1.06
	5 "		1.0	4	7.05	5.7	27	0.12	1.00	<0.2	5.1	2.0	2.0	1.2	5.8	<10	50	<5	<10	1.0	x = 1.5
	6 "		2.5	3	6.96	3.0	10	0.09	1.00	<0.2	2.9	1.3	0.8	1.2	3.1	<10	360	<5	20	0.9	<5.78
	7 "		2.5	4	6.92	2.9	10	0.10	1.00	<0.2	3.0	1.3	0.8	1.2	3.3	<10	420	<5	10	0.8	
	8 "	29.3	2.7	4	6.92	3.1	11	0.09	0.90	<0.2	3.2	1.3	0.9	1.2	3.6	<10	490	<5	20	0.9	
	9 "		1.6	3	6.86	2.8	11	0.11	1.70	<0.2	3.4	1.1	0.7	1.2	2.9	<10	790	<5	10	0.9	
	10 "		1.6	4	6.85	3.0	14	0.10	1.20	<0.2	3.0	1.2	0.8	1.2	3.2	<10	860	<5	<10	0.8	
	Mean		2.0	57	6.99	4.4	19	0.11	1.04	<0.2	4.0	1.7	1.6	1.2	4.7	<10	304	<5	12	1.2	

x) Not included in mean due to probable analytical error

Table 13

Uranium (ppm) in stream-peat from the three springs and their out-flows, sampled at three different seasons. Ash-contents.

Stugun	Autumn 1980			Spring 1981			Summer 1981		
Date / Site No	1/10	3/10	5/10	12/5	13/5	14/5	23/7	24/7	25/7
1	4040	5680	8600	3010	4690	4220	3310	2080	1750
2	2480	1330	2210	1230	1200	1310	2130	1660	1220
3	1470	1370	1400	1200	990	1110	1380	970	550
4	1080	1870	1210	2930	680	790	1320	2000	1200
5	1740	2380	3090	1360	1270	1610	3820	1920	3950
6	1220	1480	1250	1110	1210	1370	1010	1090	1280
7	240	1240	1110	530	940	1300	950	840	2280
8	1600	630	520	850	520	480	1120	820	1220
9	1470	2030	2190	1160	1210	840	2020	1500	1750
10	1050	930	1100	1210	1090	1820	1080	1070	3230
11								1280	

Nuortamus-tjåkkå	Spring 1980			Summer 1981			Autumn 1981		
Date / Site No	15/5	16/5	17/5	27/7	28/7	29/7	6/10	7/10	8/10
1		8130	8870	6150	5660	6940	8870	7700	9000
2					5970	4610	10810	2610	
3	1430	2890	1960	1610	3120	3130	550	700	1260
4	950	1760	900	1060	1810	850	880	1340	810
5	470	870	380	690	770	1210	1020	710	1190
6	1110	900	1110	470	940	660	690	510	740
7	300	670	220	290	310	280	360	320	550
8	420	250	580	550	510	520	620	570	540
9	560	770	880	660	500	670	810	810	650
10	840	710	800	680	770	700	660	640	560

Purnuvaare	Spring 1981			Summer 1981			Autumn 1981		
Date / Site No	18/5	19/5	20/5	30/7	31/7	1/8	7/10	8/10	9/10
1	830	1610	1790	460	560	620	3630	5180	930
2	2420	4120	11810	11440	10630	9460		12510	11750
3				6960	5840	6150	3970	4760	3440
4	3180		3400	3270	4100	2380	4490	7600	8030
5	1330	1200	2170	840	2050	3060	1120	1430	3330
6	94	52	76	190	28	31	64	140	180
7	39	150	81	140	33	< 10	75	150	210
8	95	78	48	22	42	69	16	48	74
9	46	< 10	< 10	< 10	< 10	< 10	< 10	< 10	<10
10	10	< 10	10	< 10	< 10	< 10	< 10	< 10	<10

Table 14

Uranium (ppm) in stream-peat from the three springs and their out-flows sampled at three different seasons. Dry weight.

Stugun	Autumn 1980			Spring 1981			Summer 1981		
Date / Site No	1/10	3/10	5/10	12/5	13/5	14/5	23/7	24/7	25/7
1	905	1227	1789	858	1233	1127	847	571	509
2	355	364	400	406	392	330	351	372	216
3	462	474	463	402	341	386	395	317	175
4	264	445	299	360	243	274	337	390	323
5	421	545	652	351	351	438	520	336	533
6	407	398	408	337	420	408	314	289	369
7	167	446	434	262	390	424	364	248	622
8	397	260	245	319	248	239	357	257	293
9	306	441	372	333	396	273	360	350	471
10	278	261	285	303	294	337	269	220	585
11	-	-	-	-	-	-	-	238	-

Nuortamus-tjåkkå	Spring 1981			Summer 1981			Autumn 1981		
Date / Site No	15/5	16/5	17/5	27/7	28/7	29/7	6/10	7/10	8/10
1	-	650	1268	966	685	1083	878	909	1332
2	-	-	-		1695	1996	1405	788	-
3	440	870	380	533	521	520	293	350	459
4	512	920	331	405	729	320	377	364	360
5	82	392	188	347	391	555	275	337	244
6	369	355	333	195	320	212	255	201	291
7	157	298	157	146	140	141	165	103	189
8	195	157	260	239	221	255	262	232	254
9	287	146	356	220	251	294	274	224	269
10	239	302	156	115	115	109	104	108	109

Purnuvaare	Spring 1981			Summer 1981			Autumn 1981		
Date / Site No	18/5	19/5	20/5	30/7	31/7	1/8	7/10	8/10	9/10
1	137	158	154	35	48	80	530	575	82
2	327	408	1689	1350	1637	1277	-	1676	2186
3	-	-	-	717	508	1477	345	438	299
4	496	-	418	265	902	414	445	600	731
5	197	-	375	87	281	389	-	217	586
6	25	17	32	32	6	9	21	53	54
7	15	66	29	32	8	2	32	59	62
8	11	15	18	11	10	13	7	28	20
9	4	2	1	2	1	2	2	2	2
10	2	3	3	2	3	1	3	3	4

Table 15

Mean values of eleven major and fifteen trace elements in stream peat from the ten sites at Stugun. Dry weight

Element		Spring 1981	Summer 1981	Autumn 1981	All three seasons
Na_2O	%	0.0866	0.0377	0.1174	0.0801
TiO_2	"	0.1298	0.1005	0.1090	0.1130
Fe_2O_3	"	4.2267	2.8862	3.7563	3.6150
MnO	"	0.7674	0.3863	0.4566	0.5351
Al_2O_3	"	4.2774	3.3301	4.6073	4.0634
SiO_2	"	13.3982	9.4986	12.6638	11.8277
K_2O	"	0.8339	0.5710	0.7159	0.7055
MgO	"	0.5638	0.4184	0.4908	0.4902
P_2O_5	"	0.2228	0.1852	0.0649	0.1580
CaO	"	4.9353	4.3116	4.3674	4.5356
S	"	0.5757	0.5682	0.8416	0.6608
Cu	ppm	134	107	130	124
Pb	"	18	13	12	14
Zn	"	111	75	95	93
Co	"	12	7	11	10
Ni	"	27	20	29	25
Cr	"	27	21	30	26
Mo	"	31	22	34	29
Sr	"	56	46	50	51
As	"	20	15	28	21
V	"	44	31	43	39
Rb	"	56	40	46	47
Zr	"	65	52	71	62
Th	"	15	10	16	14
U	"	405	384	482	424
W	"	8	6	8	7

Table 16

Mean values of eleven major and fifteen trace elements in stream peat from the ten sites at Nuortamustjåkkå. Dry weight

Element		Spring 1981	Summer 1981	Autumn 1981	All three seasons
Na_2O	%	0.3392	0.2741	0.3347	0.3152
TiO_2	"	0.1468	0.1439	0.1396	0.1433
Fe_2O_3	"	7.4252	6.0580	5.2185	6.1913
MnO	"	0.4089	0.3687	0.2400	0.3367
Al_2O_3	"	3.2829	2.7625	2.7202	2.9090
SiO_2	"	20.2306	18.9694	18.7541	19.2855
K_2O	"	0.8639	0.8246	0.8484	0.8450
MgO	"	0.4830	0.4571	0.4529	0.4637
P_2O_5	"	0.3069	0.3036	0.2707	0.2933
CaO	"	1.8532	1.7529	1.7205	1.7728
S	"	0.2297	0.2277	0.1729	0.2094
Cu	ppm	12	14	14	13
Pb	"	12	11	11	11
Zn	"	91	87	69	82
Co	"	25	22	18	22
Ni	"	12	12	10	11
Cr	"	23	23	21	22
Mo	"	30	27	24	27
Sr	"	65	63	64	64
As	"	18	15	15	16
V	"	26	24	29	26
Rb	"	33	33	30	32
Zr	"	61	61	55	59
Th	"	8	7	7	7
U	"	406	519	417	447
W	"	5	6	5	5

Table 17

Mean values of eleven major and fifteen trace elements in stream peat from the ten sites at Purnuvaare. Dry weight

Element		Spring 1981	Summer 1981	Autumn 1981	All three seasons
Na_2O	%	0.2309	0.2531	0.3880	0.2919
TiO_2	"	0.0573	0.0577	0.0857	0.0670
Fe_2O_3	"	7.9449	6.2447	8.7690	7.6084
MnO	"	0.1280	0.0804	0.0995	0.1012
Al_2O_3	"	0.8279	0.8992	1.2475	0.9952
SiO_2	"	8.5094	9.7490	10.2391	9.5409
K_2O	"	0.6264	0.5256	0.5889	0.5774
MgO	"	0.5043	0.3686	0.4883	0.4499
P_2O_5	"	0.4450	0.3332	0.3414	0.3798
CaO	"	2.0521	1.6236	2.0551	1.8982
S	"	0.3025	0.2944	0.3754	0.3242
Cu	ppm	10	7	10	9
Pb	"	14	12	14	13
Zn	"	34	22	27	27
Co	"	3	2	4	3
Ni	"	4	6	6	6
Cr	"	16	22	22	20
Mo	"	5	4	5	5
Sr	"	44	38	49	44
As	"	33	28	40	33
V	"	62	53	80	65
Rb	"	12	13	15	13
Zr	"	16	16	24	19
Th	"	2	1	2	2
U	"	296 (646)^x	328 (647)^x	338 (770)^x	321 (688)^x
W	"	2	2	2	2

x) Site No 1 to 5.

Table 18

Uranium (ppm) in minerogenic stream sediments from the three springs and their out-flows, sampled at three different seasons.

Stugun	Autumn 1980			Spring 1981			Summer 1981		
Site No \ Date	1/10	3/10	5/10	12/5	13/5	14/5	23/7	24/7	25/7
1									
2									
3									
4									
5									
6	(2.99)*	72.51	23.24	29.23	29.55	23.69	19.32	23.25	24.69
7	22.52	66.62	26.01	30.16	36.50	32.95	25.95	29.82	37.53
8	72.45	-	63.20	36.07	52.23	47.33	38.48	49.14	39.45
9									
10									

Nuortamus-tjåkkå	Spring 1981			Summer 1981			Autumn 1981		
Site No \ Date	15/5	16/5	17/5	27/7	28/7	29/7	6/10	7/10	8/10
1									
2	71.70	39.36	37.25	48.36	40.82	38.96	13.18	45.13	36.96
3	9.05	9.07	8.55	7.04	7.31	9.86	12.60	13.81	11.11
4	14.39	9.57	8.98	8.19	5.89	11.40	8.86	8.57	9.16
5	25.48	22.04	23.90	26.99	18.72	19.25	13.38	17.81	12.97
6	16.07	11.46	11.97	15.40	7.17	15.07	7.41	8.66	10.53
7	28.72	17.32	10.43	11.61	7.79	36.01	12.31	10.19	11.69
8									
9									
10									

Purnuvaare	Spring 1981			Summer 1981			Autumn 1981		
Site No \ Date	18/5	19/5	20/5	30/7	31/7	1/8	7/10	8/10	9/10
1									
2									
3									
4									
5									
6									
7			5.37						
8	-	-	3.80	2.83	3.29	-	3.28	2.99	3.25
9									
10									

* This value should be rejected due to probable sampling error.

Table 19

Radioactivity, U and Ra 226 contents of the ten sites at Stugun.

Season	Site No	Radio-activity	Uranium			Radium - 226		
		µR/h	water ppb	stream peat ppm	stream sed. ppm	water mBq/l	stream peat Bq/g	stream sed. Bq/g
Spring 1981	1	70	13.7	1073		6.75	4.54	
	2	26	11.0	376				
	3	25	10.8	376				
	4	21	6.4	292				
	5	14	7.2	380				
	6	41	5.6	388	28	4.19	5.71	(0.316)
	7	19	5.0	359	33			4.12
	8	21	5.0	269	45			5.10
	9	20	5.0	334				
	10	9	5.2	311		(<10.00)	6.08	
	Lake	(4)	(1.5)					
	Mean	27	7.5	416	35	5.47	5.44	4.61
Summer 1981	1	135	15.9	642			4.08	
	2	54	15.9	303		8.30		
	3	39	16.9	296				
	4	26	13.2	350				
	5	25	11.8	463				
	6	36	10.1	322	22		(0.477)	6.37
	7	29	12.6	411	31	13.90		-
	8	30	11.6	302	43			2.77
	9	30	10.4	394				
	10	18	9.6	358		(<3.40)	7.51	
	Lake	(5)	(1.2)	(238)				
	Mean	42	12.8	384	32	11.10	6.30	4.57
Autumn 1980	1	167	25.6	1307		14.00	4.22	
	2	50	26.8	374				
	3	35	29.6	466				
	4	17	21.0	336				
	5	14	21.7	539				
	6	39	22.7	404	48	7.26	7.04	(0.318)
	7	22	23.7	440	39			4.94
	8	24	24.1	301	68	8.20		4.45
	9	23	22.8	373				
	10	20	21.6	275		6.27	8.52	
	Mean	42	24.0	482	52	8.93	6.59	4.70
Mean for all three seasons		37	14.8	461	40	8.50	6.11	4.62

Values in bracklets are not included in mean.

Table 20

Radioactivity, U and Ra-226 contents of the ten sites at Nuortamustjåkkå.

Season	Site No	Radio-activity µR/h	Uranium			Radium-226		
			water ppb	stream peat ppm	stream sed. ppm	water mBq/l	stream peat Bq/g	stream sed. Bq/g
Spring 1981	1	40	5.8	959				
	2	40	5.6	-	50	3.1	0.940	0.0481
	3	22	7.8	563	9			
	4	15	7.7	588	11	3.2	0.601	0.0542
	5	19	7.1	290	23			
	6	8	2.7	352	13			
	7	9	2.5	204	18	9.4	0.334	0.0752
	8	6	2.7	204				
	9	6	3.0	263				
	10	5	1.6	232				
	Mean	17	4.7	406	21	5.2	0.625	0.0592
Summer 1981	1	30	2.4	911				
	2	32	6.8	1846	42	2.1	1.300	0.0508
	3	23	2.1	525	8			
	4	10	2.4	485	8	2.2	0.618	0.0536
	5	14	2.3	431	22			
	6	8	2.8	242	12			
	7	9	2.8	142	19		1.300	-
	8	5	2.5	238		2.5		
	9	6	2.4	255				
	10	5	2.7	113				
	Mean	14	2.9	519	19	2.3	1.073	0.0522
Autumn 1981	1	39	2.3	1040				
	2	29	2.5	1097	41	(<4.22)	1.180	0.0432
	3	23	3.2	367	13			
	4	13	2.6	367	9	3.4	0.863	0.0512
	5	15	2.8	285	15			
	6	8	2.7	249	9			
	7	9	2.2	152	11	1.39	0.512	0.0655
	8	5	2.9	249				
	9	6	2.7	256				
	10	5	1.9	107				
	Mean	15	2.6	417	16	2.2	0.852	0.0530
Mean for all three seasons		15	3.4	447	19	3.2	0.850	0.0544

Values in bracklets are not included in mean

Table 21

Radioactivity, U and Ra-226 contents of the ten sites at Purnuvaare.

Season	Site No	Radio-activity	Uranium			Radium-226		
		µ R/h	water ppb	stream peat ppm	stream sed. ppm	water mBq/l	stream peat Bq/g	stream sed. Bq/g
Spring 1981	1	100	2.9	150		16.00	2.790	
	2	340	3.9	1689				
	3	130	3.3	-				
	4	57	1.7	457		8.83	1.790	
	5	18	1.2	286				
	x̄(1-5)	129	2.6	646	-	12.42	2.290	
	6	2	0.2	25		4.00	0.317	
	7	3	0.2	36	5			
	8	9	0.3	15	4			-
	9	2	0.2	2				
	10	3	0.2	3				
	x̄(6-10)	4	0.2	16	5	4.00	0.317	-
	x̄(1-10)	66	1.4	296	5	9.61	1.632	-
Summer 1981	1	170	1.9	54		10.00	2.540	
	2	145	1.7	1421				
	3	90	1.5	901				
	4	30	1.5	527		16.00	1.230	
	5	4	2.8	335				
	x̄(1-5)	88	1.9	647	-	13.00	1.885	
	6	2	1.3	16		3.6		
	7	2	0.6	14				
	8	2	1.0	11	3		0.297	0.0304
	9	3	0.7	2				
	10	3	0.7	2				
	x̄(6-10)	2	0.9	9	3	3.60	0.297	-
	x̄(1-10)	45	1.4	328	3	9.53	1.356	-
Autumn 1981	1	190	2.2	553		8.65	2.200	
	2	215	2.1	1931				
	3	110	1.5	371				
	4	34	0.9	592		8.15	2.100	
	5	4	1.0	402				
	x̄(1-5)	111	1.5	770	-	8.40	2.150	
	6	3	0.9	45		< 5.78		
	7	4	0.8	51				
	8	4	0.9	18	3		0.271	0.0362
	9	3	0.9	2				
	10	4	0.8	3				
	x̄(6-10)	4	0.9	24	3	< 5.78	0.271	-
	x̄(1-10)	57	1.2	338	3	-	1.524	-
Mean for all three seasons	x̄(1-5)	109	2.0	688	-	11.27	2.108	
	x̄(6-10)	3	0.7	16	4		0.295	
	x̄)1-10)	56	1.3	352	4		1.504	

Table 22 Uptake and loss of uranium by the reference column

t(h)	t_{cum}	% day^{-1}
Uptake from spring water		
48	48	9
24	72	- 13 (leaching)
72	144	7
Uptake from spring water + UAc		
120	120	1
Leaching with distilled water		
72	72	0.8
Leaching with acidified water		
72	72	2

Table 23 Leaching by uncontaminated peat, previously exposed to spring water. (+) indicates an uptake by the peat.

t(h)	t_{cum}	Bq g^{-1} day^{-1}	% day^{-1}	
24	24	$1.9 \cdot 10^{-2}$	2.1	dist. H_2O
48	72	(+)$1.9 \cdot 10^{-3}$	$2 \cdot 10^{-1}$	-"-
24	96	$6.7 \cdot 10^{-2}$	7.5	acidified H_2O
72	168	(+)$2.2 \cdot 10^{-3}$	$3 \cdot 10^{-1}$	-"-
48	216	(+)$6.5 \cdot 10^{-3}$	$8 \cdot 10^{-1}$	-"-

Table 24 Leaching by uranium peat, previously exposed to spring water and UAc. (+) indicates an uptake by the peat.

t(h)	t_{cum}	Bq g^{-1} day^{-1}	% day^{-1}	
24	24	$2 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	dist. H_2O
48	72	$9 \cdot 10^{-3}$	$2 \cdot 10^{-2}$	-"-
24	96	$1.5 \cdot 10^{-1}$	$4 \cdot 10^{-1}$	acidified H_2O
72	168	(+)$1.6 \cdot 10^{-2}$	$4 \cdot 10^{-2}$	-"-
48	216	$1.1 \cdot 10^{-2}$	$3 \cdot 10^{-2}$	-"-

Table 25 Leaching by uranium-rich peat previously frozen for two months. (+) indicates an uptake by the peat.

t(h)	t_{cum}	Bq g^{-1} day^{-1}	% day^{-1}	Bq g^{-1} h^{-1}	% h^{-1}	
4	4			$2 \cdot 10^{-3}$	$6 \cdot 10^{-3}$	dist. H_2O
20	24	$1.4 \cdot 10^{-2}$	$4 \cdot 10^{-2}$			-"-
2	26			$4.4 \cdot 10^{-2}$	$1.23 \cdot 10^{-2}$	acidified H_2O
22	48	$6.5 \cdot 10^{-2}$	$1.80 \cdot 10^{-1}$			-"-
48	96	(+)$1.4 \cdot 10^{-2}$	$3.8 \cdot 10^{-2}$			-"-

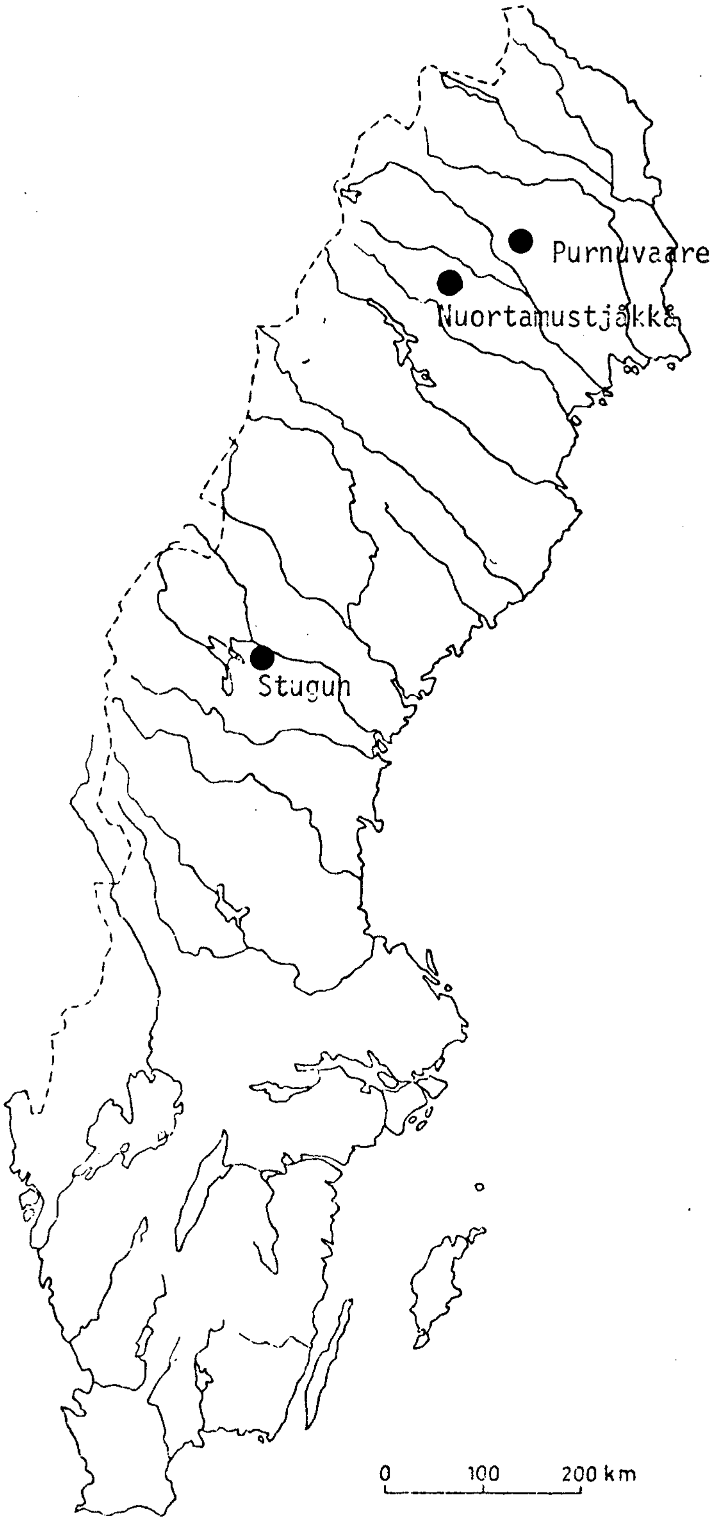


Figure 1

Location of the three research areas,
Stugun, Nuortamustjåkkå and Purnuvaare

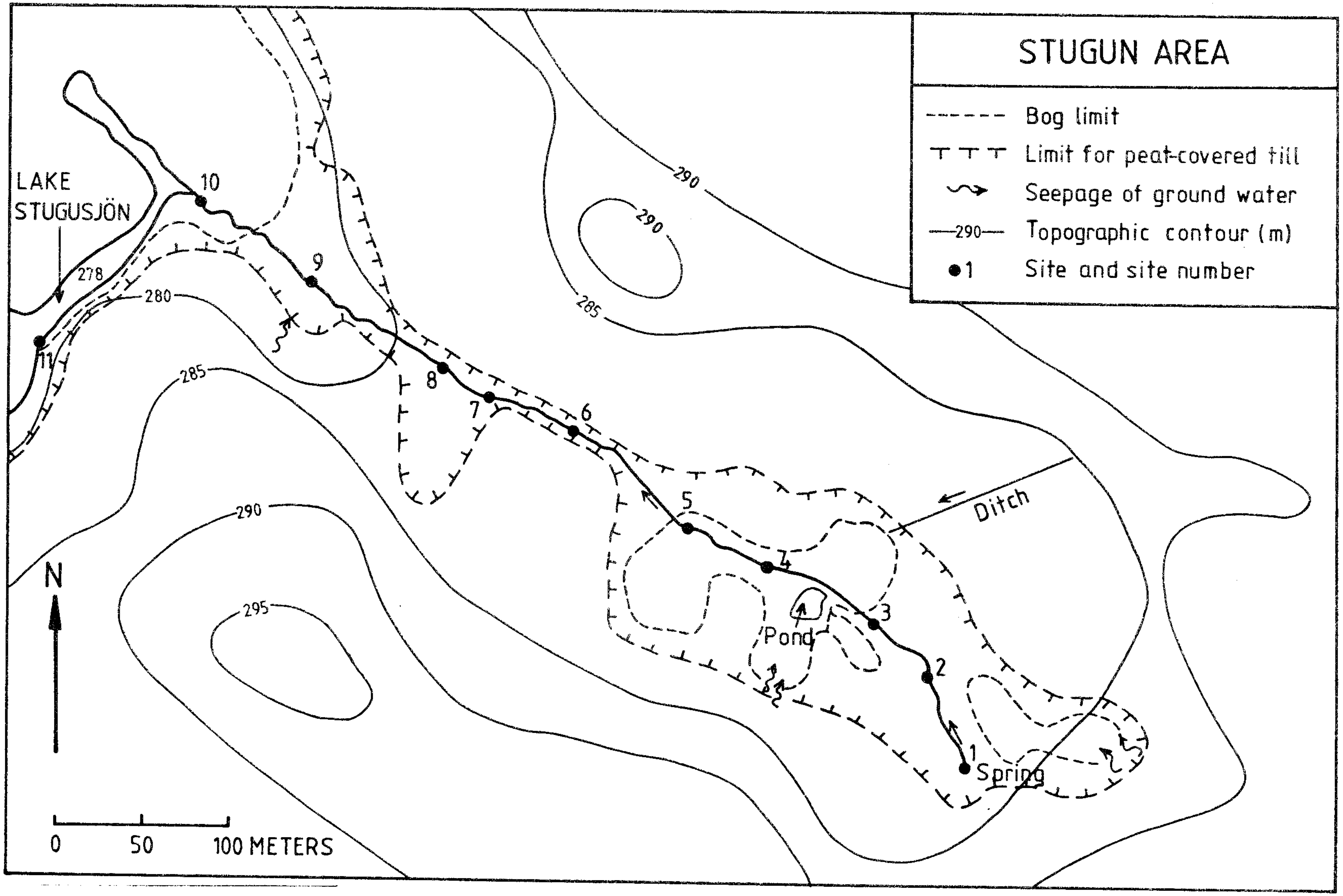


Figure 2 The Stugun area.

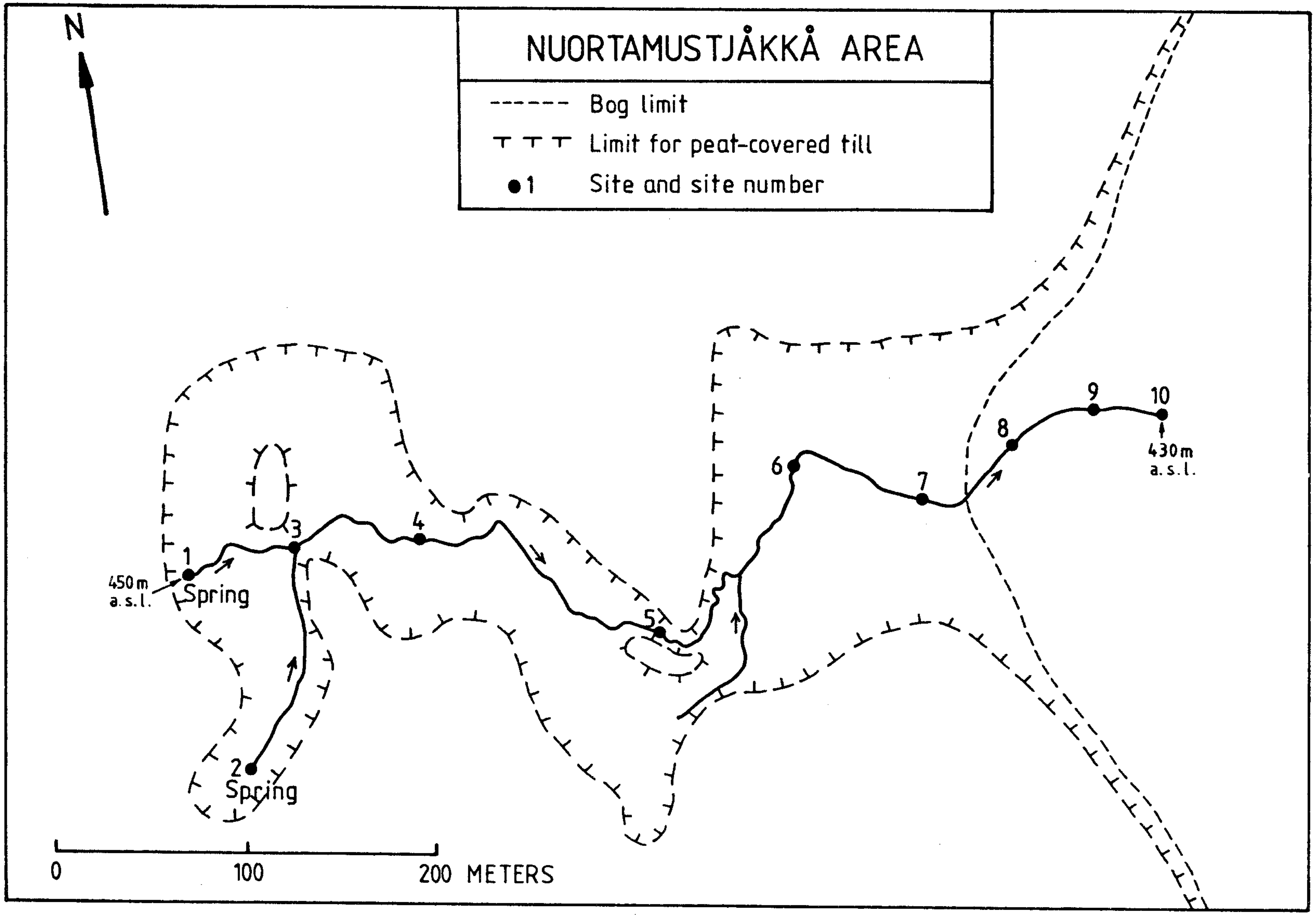


Figure 3 The Nuortamustjåkkå area.

Figure 4

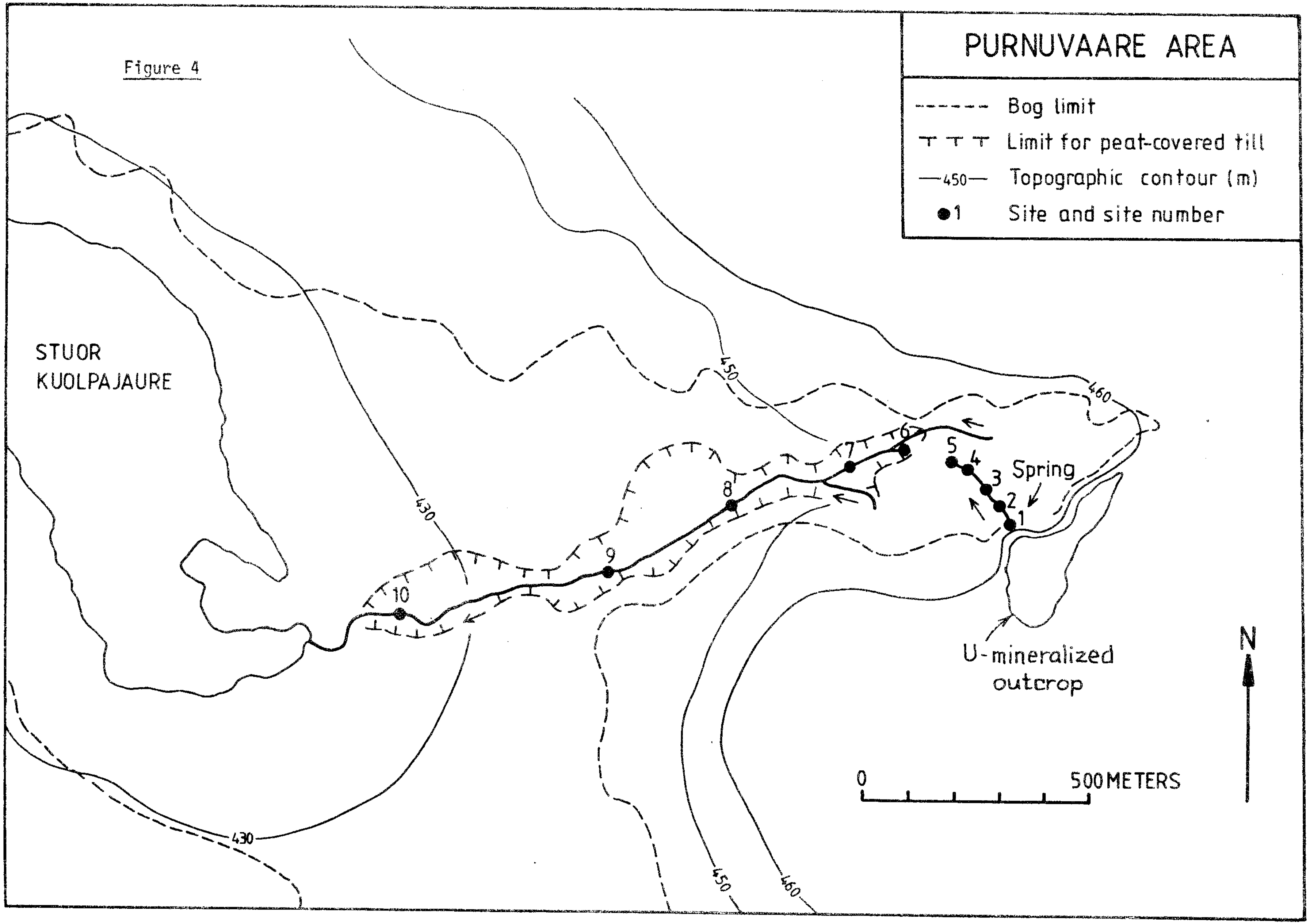
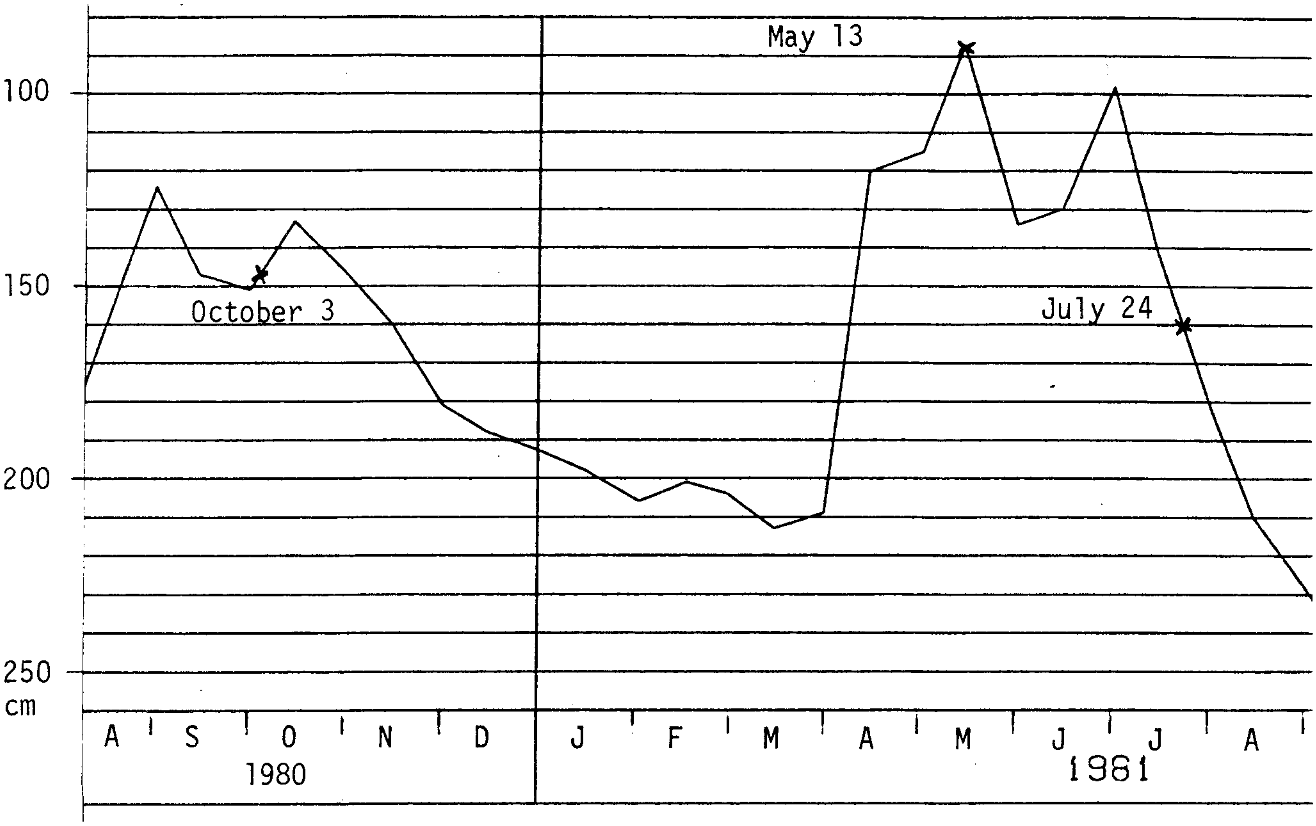
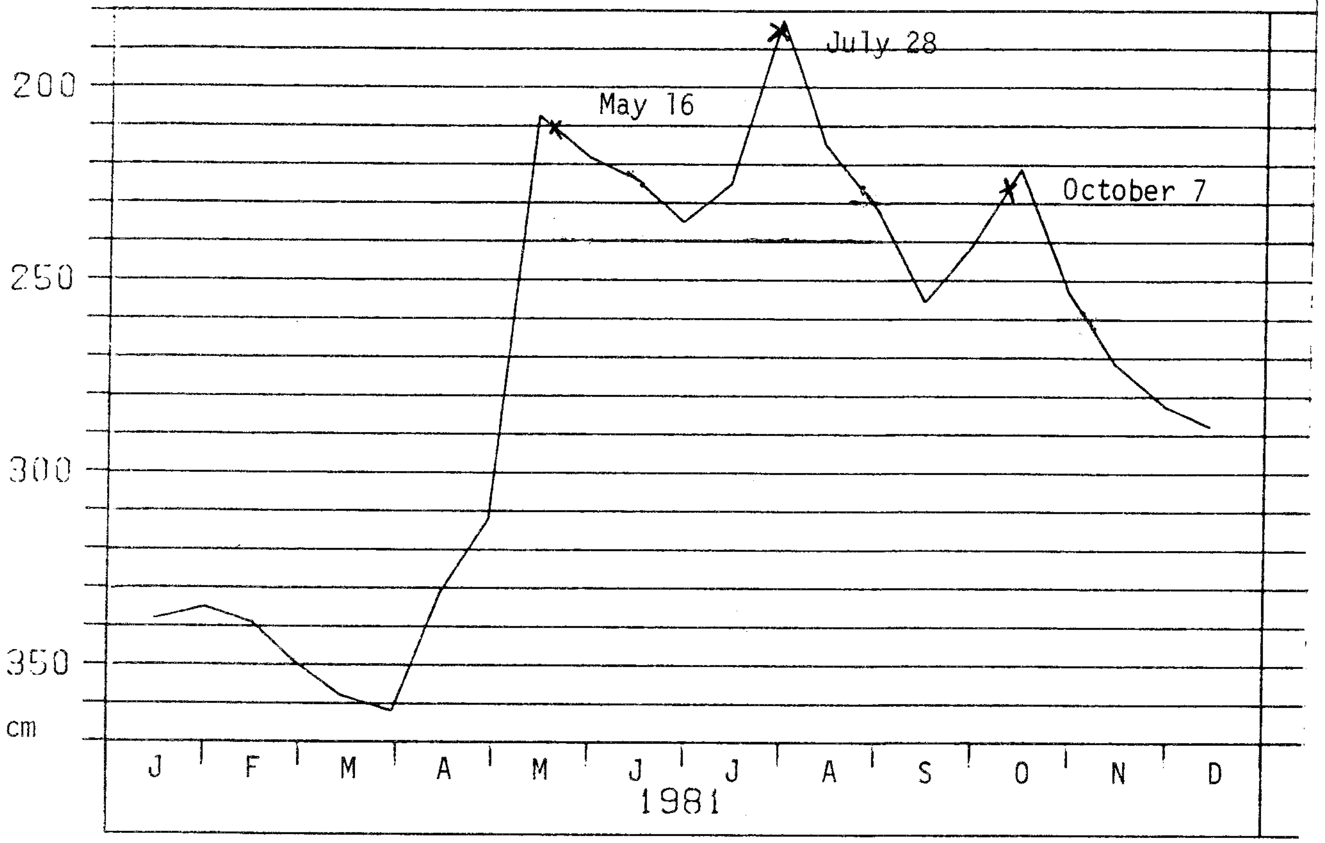

PURNUVAARE AREA
Bog limit
Limit for peat-covered till
450 Topographic contour (m)
●1 Site and site number
STUOR
KUOLPAJAURE
430
430
450
450
460
460
1
2
3
4
5
6
7
8
9
10
Spring
U-mineralized
outcrop
N
0
500 METERS

Figure 5



Variation of the groundwater level in till at Kassjöån (SGU National Groundwater Network Station No 26002), located 70 km SE from the spring at Stugun. The three sampling occasions at Stugun are indicated in the diagram.

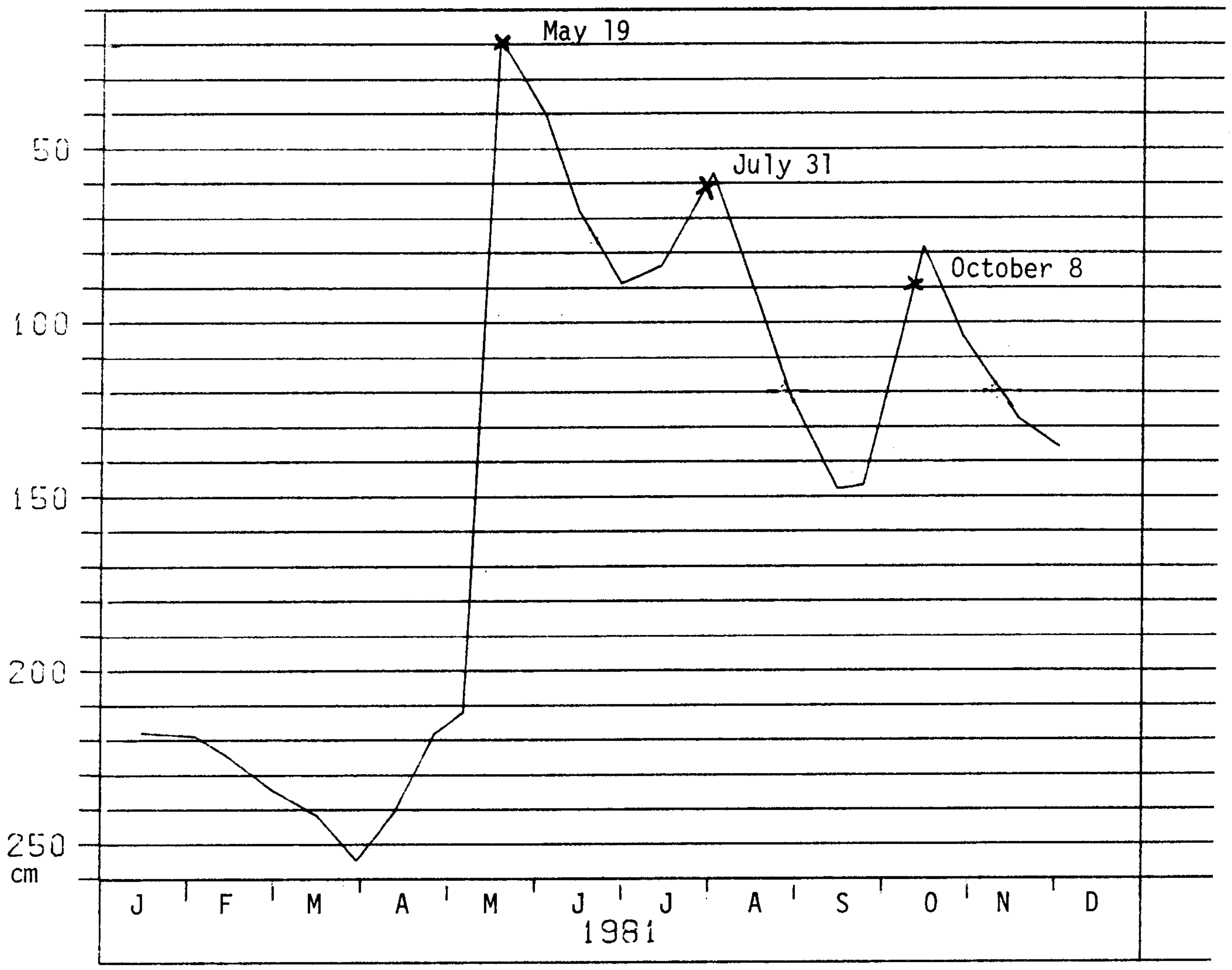
Figure 6



Variation of the groundwater level in till at Jokkmokk (SGU National Groundwater Network Station No 62003) located 45 km ENE from the spring at Nuortamustjåkkå.

The three sampling occasions at Nuortamustjåkkå are indicated in the diagram.

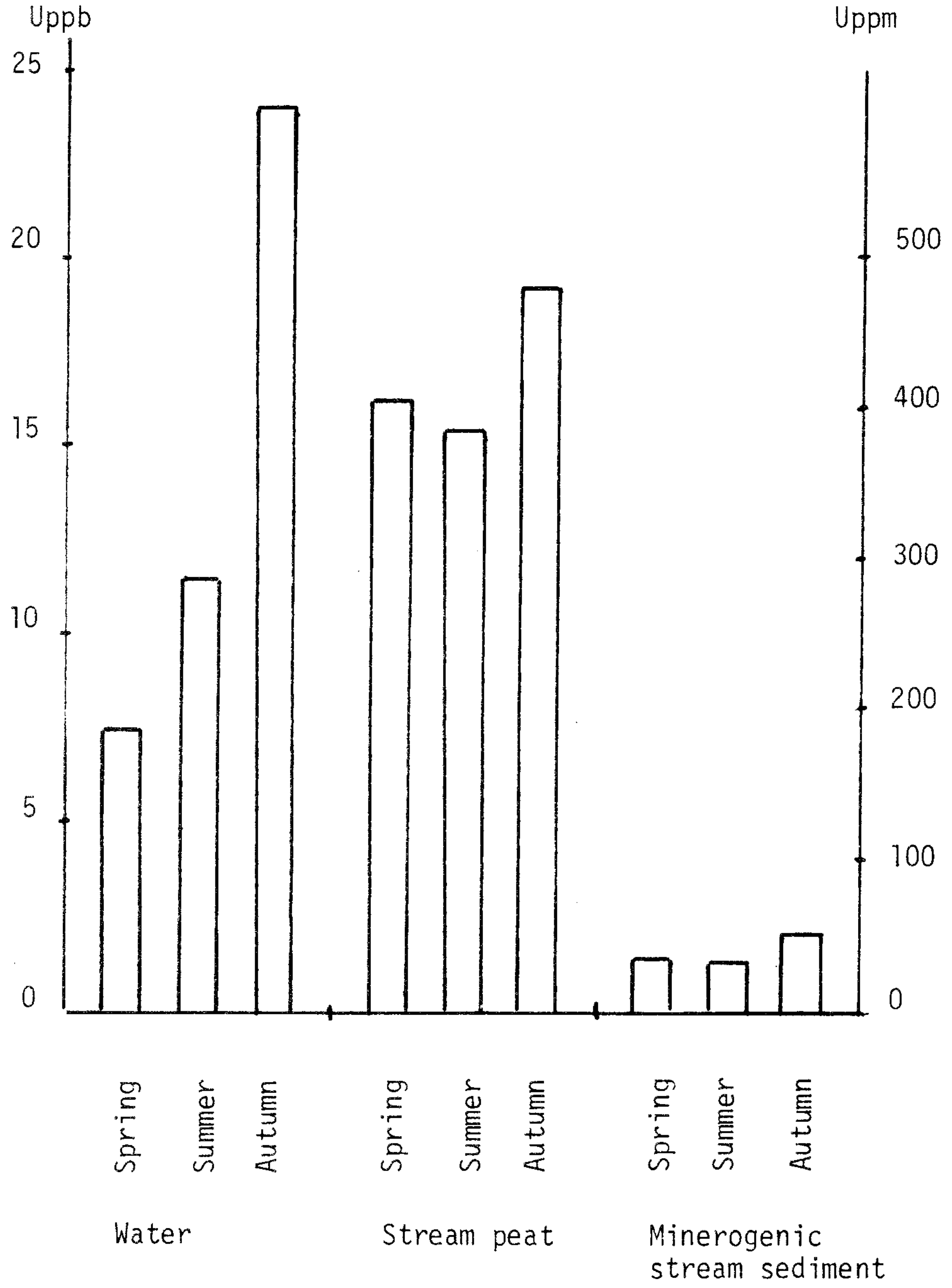
Figure 7



Variation of the groundwater level in till at Lappträsket (SGU National Groundwater Network Station No 37001) located 82 km SE from the spring at Purnuvaare.

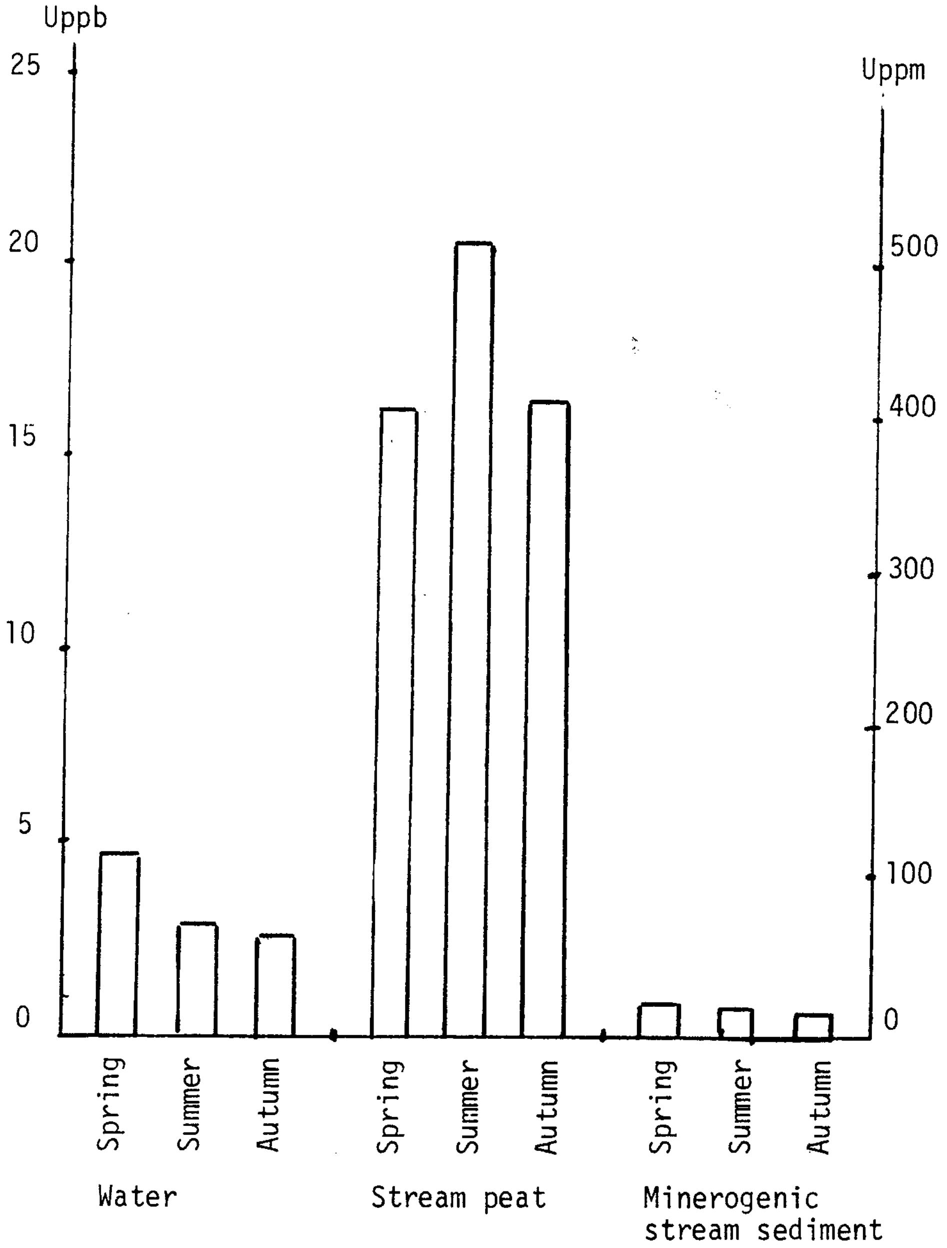
The three sampling occasions at Purnuvaare are indicated in the diagram.

Figure 8



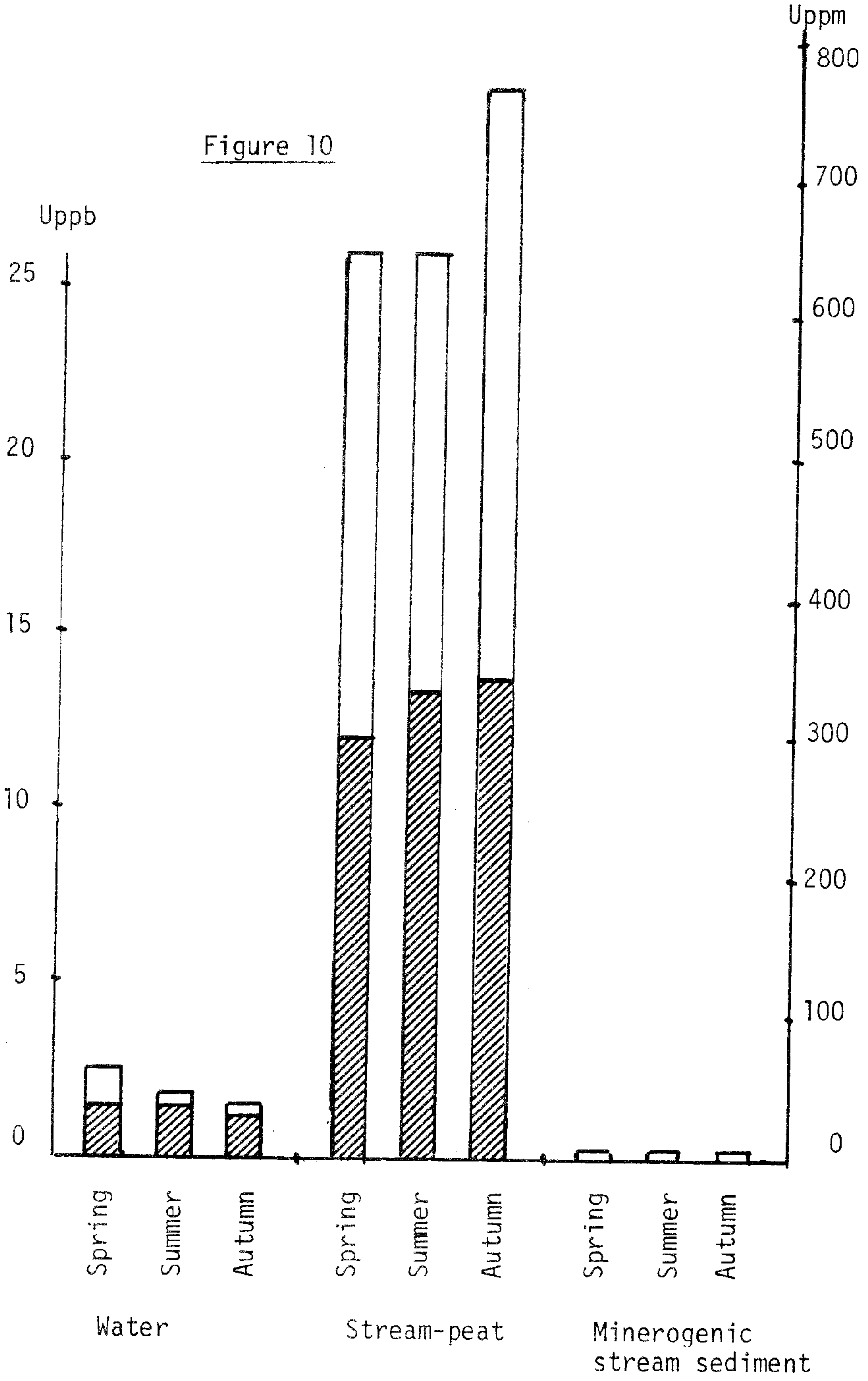
Variation in U-content in water (ppb), stream-peat (ppm) and minerogenic stream sediments (ppm) during three seasons from the ten sites at the spring at Stugun. (Mean values of site No 1 to 10).

Figure 9



Variation in U-content in water (ppb), stream-peat (ppm) and minerogenic stream sediments (ppm) during three seasons from the ten sites at the spring at Nuortamustjåkkå. (Mean values of site No 1 to 10).

Figure 10



Variation in U-content in water (ppb), stream-peat (ppm) and minerogenic stream sediments (ppm) during three seasons from the ten sites at the spring at Purnuvaare. (Mean values of site No 1 to 5 are unscreened and of site No 1 to 10 screened).

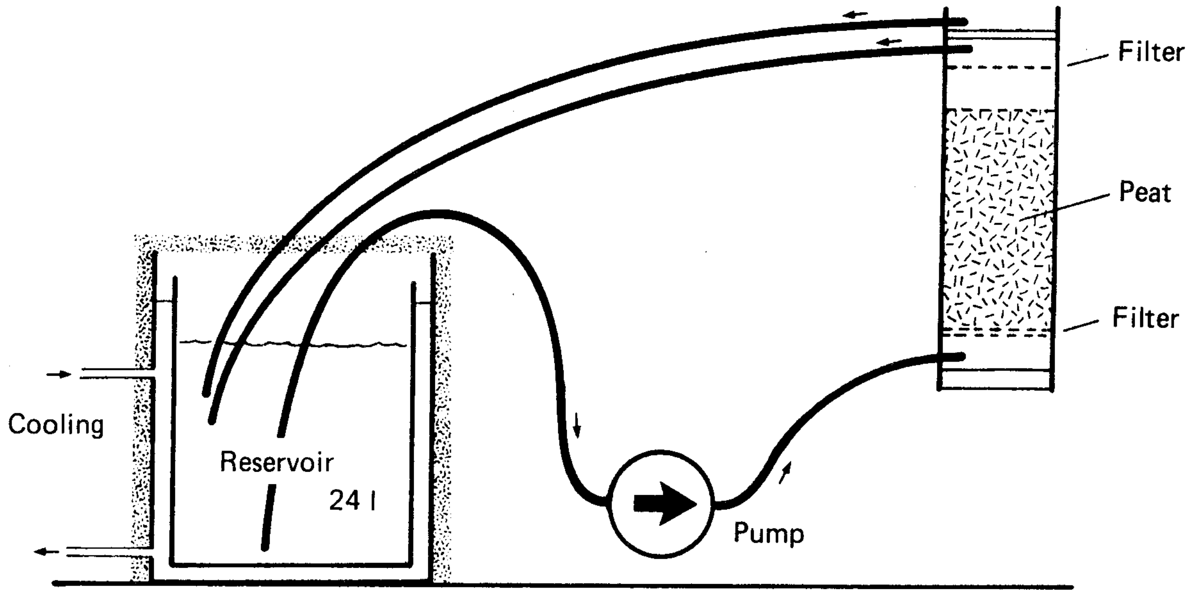


Figure 11

The experimental set-up for the uptake and leaching experiments.

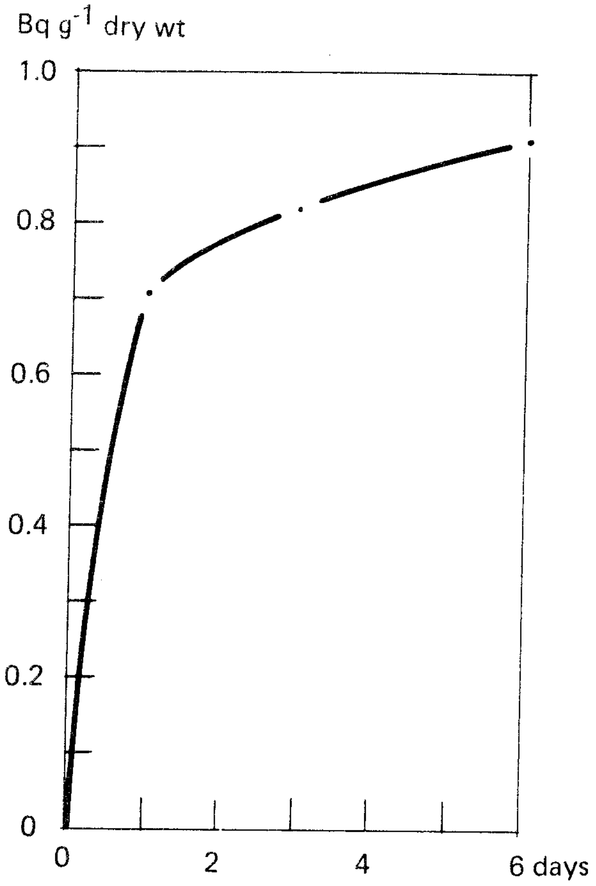


Figure 12

Accumulation of uranium by uncontaminated peat exposed to uranium-rich spring water.

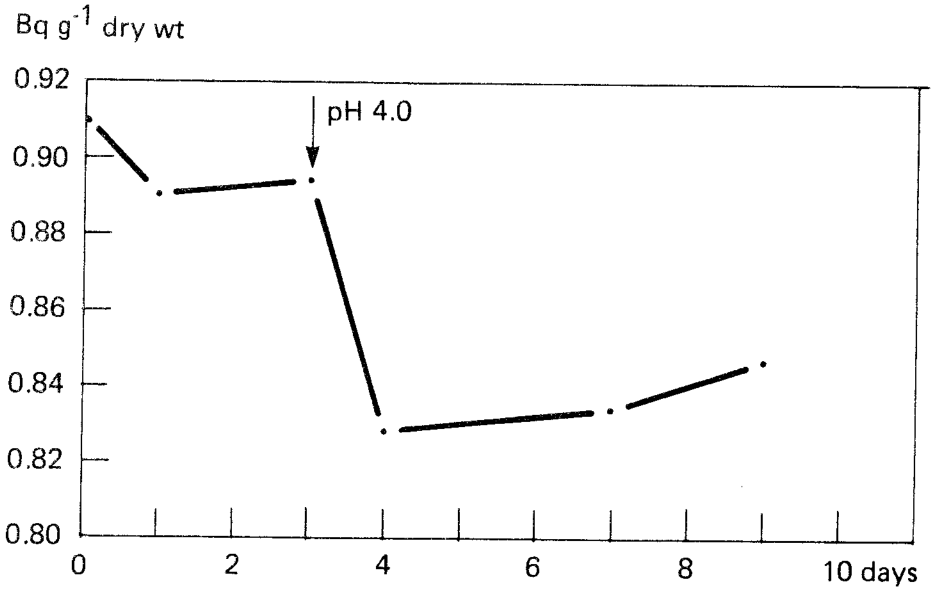


Figure 13

Clearance of uranium by peat previously exposed to uranium-rich spring water.

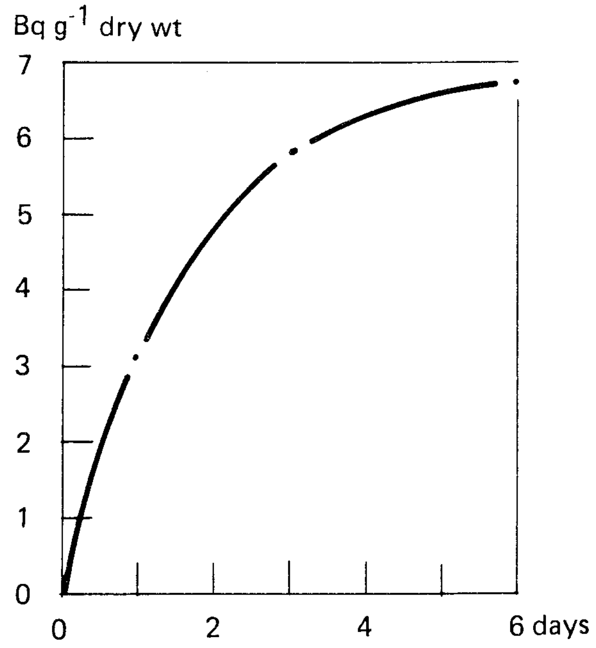


Figure 14

Accumulation of uranium by uranium-rich peat exposed to uranium-rich spring water and UAc.

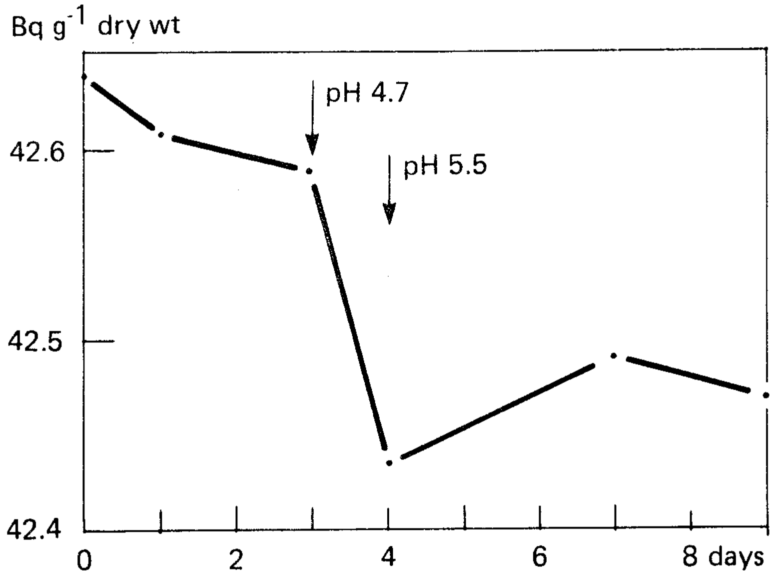


Figure 15

Clearance of uranium by peat previously exposed to uranium-rich spring water and UAc.

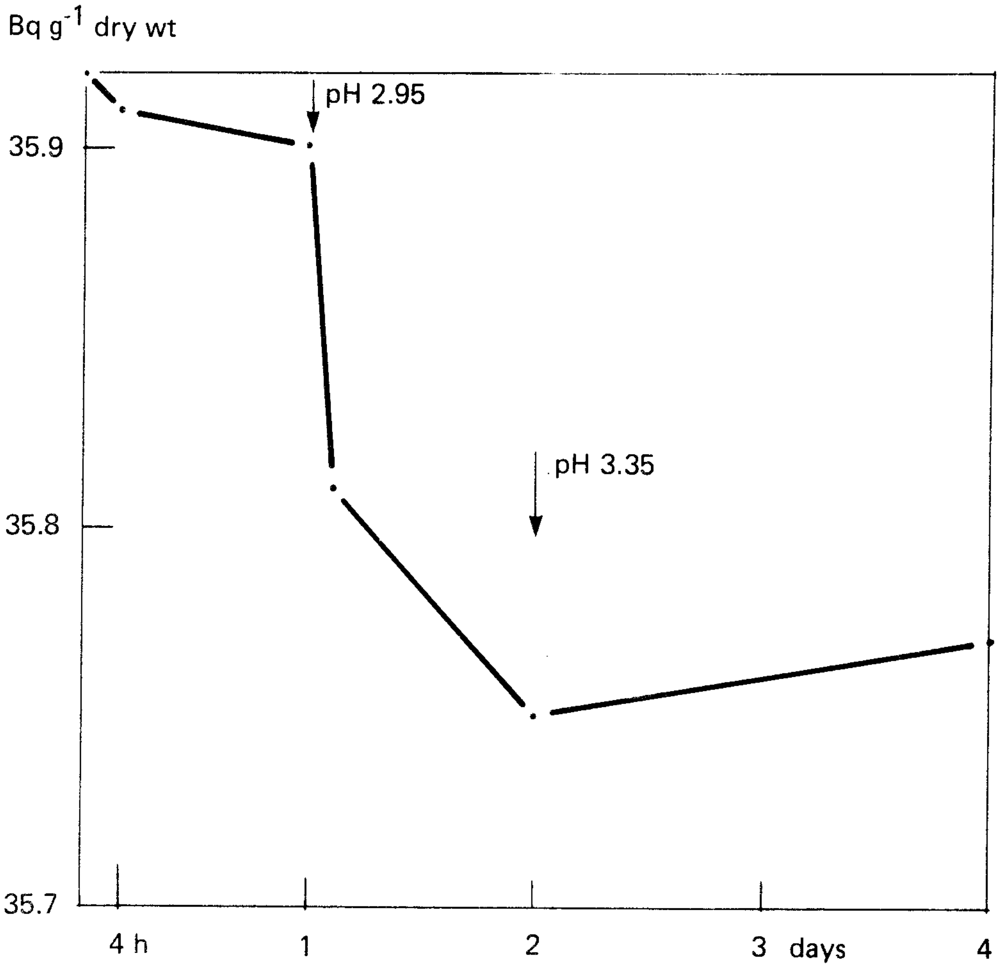


Figure 16

Clearance of uranium by frozen uranium-rich peat.

1. Primary data for the different uptake and leaching experiments

U-concentration in water Bq/l	Time	Process under study	Changes in experimental condition
0.351 (∿ 14 ppb)	Start		Start with 10.5 l
0.286	2 days	Adsorption to the walls	
0.322	3 days	"-	
0.259	6 days	"-	Addition of UAc
	Start		
5.89 (∿ 232 ppb)	1 h	"-	
7.69	1 day	"-	
7.32	6 days	"-	Column emptied. Ne can (24 l) filled with dist. water
-	Start	Loss of U from the walls	
0.004	3 days	"-	Acidification pH=4
0.004	Start		
0.014	6 days	"-	

2. Uptake and leaching by uncontaminated peat exposed to uranium-rich spring water

U-concentration in water Bq/l	Time	Process under study	Changes in experimental condition
0.351 (~ 14 ppb)	Start		24 l water
0.165	1 day	Uptake	
0.136	3 days	"-	
0.110	6 days	"-	Column emptied of water. New can with dist. water
-	Start		
0.005	1 day	Leaching	
0.004	3 days	"-	Acidification pH=4
0.004	Start	"-	
0.023	1 day	"-	
0.021	4 days	"-	
0.018	6 days	"-	6.3 g peat (dry wt)

3. Uptake and leaching by uranium-rich peat exposed to uranium-rich spring water and UAc

U-concentration in water Bq/l	Time	Process under study	Changes in experimental condition
6.39 (~ 251 ppb)	Start		24 l water
4.60	1 day	Uptake	
2.99	3 days	"-	
2.41	6 days		Column emptied of water. New can witl dist. water
-	Start		
0.11	1 day	Leaching	
0.021	3 days	"-	Acidification pH=4
0.021	Start		
0.115	1 day	"-	
0.085	4 days	"-	
0.100	6 days	"-	13.5 g peat (dry wt

4. Leaching by peat previously frozen

U-concentration in water Bq/l	Time	Process under study	Changes in experimental condition
-	Start		Start with 24 l
0.007	4 h	Leaching	
0.020	1 day	"-	Acidification pH = 2.95
0.020	Start		
0.104	2 h	"-	
0.169	1 day	"-	pH = 3.35
0.140	2 days	"-	20.2 g peat (dry wt)

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Akke Bengtsson **
Bertil Grundfelt **
Ivars Neretnieks *
April, 1982

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** KEMAKTA Consultant Company
Stockholm, Sweden

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TR 82-09:2 Radioactive waste management plan
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Ove Persson
Geological Survey of Sweden, Uppsala
Ove Landström, Studsvik Energiteknik, Nyköping
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ASEA-ATOM, Västerås, Sweden, 1982-08-11

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Royal Institute of Technology
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Sverker Evans
Lennart Ljungqvist
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