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Radionuclide deposition and migration within the Gideå and Finnsjön study sites, Sweden: A study of the fallout after the Chernobyl accident. Phase I, initial survey.

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RADIONUCLIDE DEPOSITION AND MIGRATION WITHIN THE GIDEÅ AND FINNSJÖN STUDY SITES, SWEDEN: A STUDY OF THE FALLOUT AFTER THE CHERNOBYL ACCIDENT

Phase I, initial survey

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ABSTRACT

Radionuclides originating from the Chernobyl accident in April 1986 were deposited over large areas of Sweden. The distribution and migration of the radionuclides during the first months after deposition were measured in a comprehensive survey within two study sites, Gideå in Ångermanland county and Finnsjön in Uppland county. The sites are previously investigated in the SKB site characterization programme and well defined regarding geology and hydrology.

The survey was concentrated to a small sub-area in each study site, 0.9 km^2 in Gideå and 0.7 km^2 in Finnsjön. The measurements performed will, together with environmental conditions, primarily constitute the basis for budget calculations of radionuclide redistribution within the studied areas. The aim is to utilize the results in radioecological and geohydrological migration modelling in the time perspective of several years.

Sampling and measurements in situ were carried out on five occations from June 1986 to February 1987. A total of 374 samples of soil, rock, vegetation, water and sediment were taken at 85 sampling sites and analysed by gamma spectrometry and autoradiography. Soil profile samples were characterized regarding; texture, geological classification, organic matter, pH and trace element composition. Measurements in situ of the ground surface deposition were performed at 46 sites by gamma spectrometry and along 65 lines at 32 sites by exposure rate measurements.

Radionuclides analysed are; Mn-54, Co-60, Sr-90, Zr-95, Nb-95, Mo-99, Ru-103, Ru-106, Ag-110m, Sb-125, I-131, Cs-134, Cs-136, Cs-137, Ba-140, La-140, Ce-141 and Ce-144. The Cs-137 surface activity gave a range of 30-100 kBq/m^2 in Gideå and 20-40 kBq/m^2 in Finnsjön.

Radionuclide migration is observed in soil profiles, groundwater and rock fissures. An active transport by surface water is also evident from sediment samples. Radionuclides have been absorbed in different types of vegetation. In October 1986 five months after the deposition on the ground surface, radionuclides were found at 20 cm depth in soil profiles. A faster and different manner of migration for Sb-125, Ru-106 and Co-60 compared to cesium is also observed. Nine month after the deposition Ru-106 is found in fairly deep groundwaters sampled in artesian drill holes. In a shallow well was, beside Ru-106, also Ag-110m, Cs-134 and Cs-137 found five months after the deposition.

Keywords: Chernobyl fallout, radionuclides, redistribution, migration, sampling, measurements in situ, rock, soil, water, sediment, vegetation.

TABLE OF CONTENTS

1. INTRODUCTION

After the Chernobyl accident in April 1986 large areas of Sweden were exposed to precipitation and dry deposition containing considerably amounts of radioactive nuclides. In spite of the many questiones that appeared, especially in agriculture, this gave an opportunity to study the migration and sorption behaviour of the many radionuclides in biological and geological systems.

In this study radionuclide deposition, redistribution and migration within geologically and hydrologically well defined areas with sufficient activity are measured. The aim is to utilize the results of these measurements, together with important environmental conditions, in radioecological and geohydrological migration and turnover modelling in the time perspective of several years. The results are also intended to constitute the basis for budget calculations on radionuclide redistribution. Comparison with radionuclide migration from deposits and in laboratory experiments will be feasible.

Two sites previously investigated in the SKB programme for site characterisation have been selected for the study of deposition and migration of the fallout from the Chernobyl accident. The sites are Gideå in Ångermanland county c. 30 km north-east of Örnsköldsvik and Finnsjön in Uppland county c. 140 km north of Stockholm (Fig. 1.1).

Relevant data for recent conditions are presented and since environmental conditions and the composition/deposition of the radionuclides are essential in redistribution and migration processes, these are subject to a comprehensive description in this study.

Together with other associated projects concerning the scientific basis for the storage of high-level radioactive waste in deep underground repositories the results of the present study will hopefully give relieable data of radionuclide redistribution and migration in relation to

important environmental conditions and thus enhance knowledge on radionuclide migration and sorption in naturally complex environments.

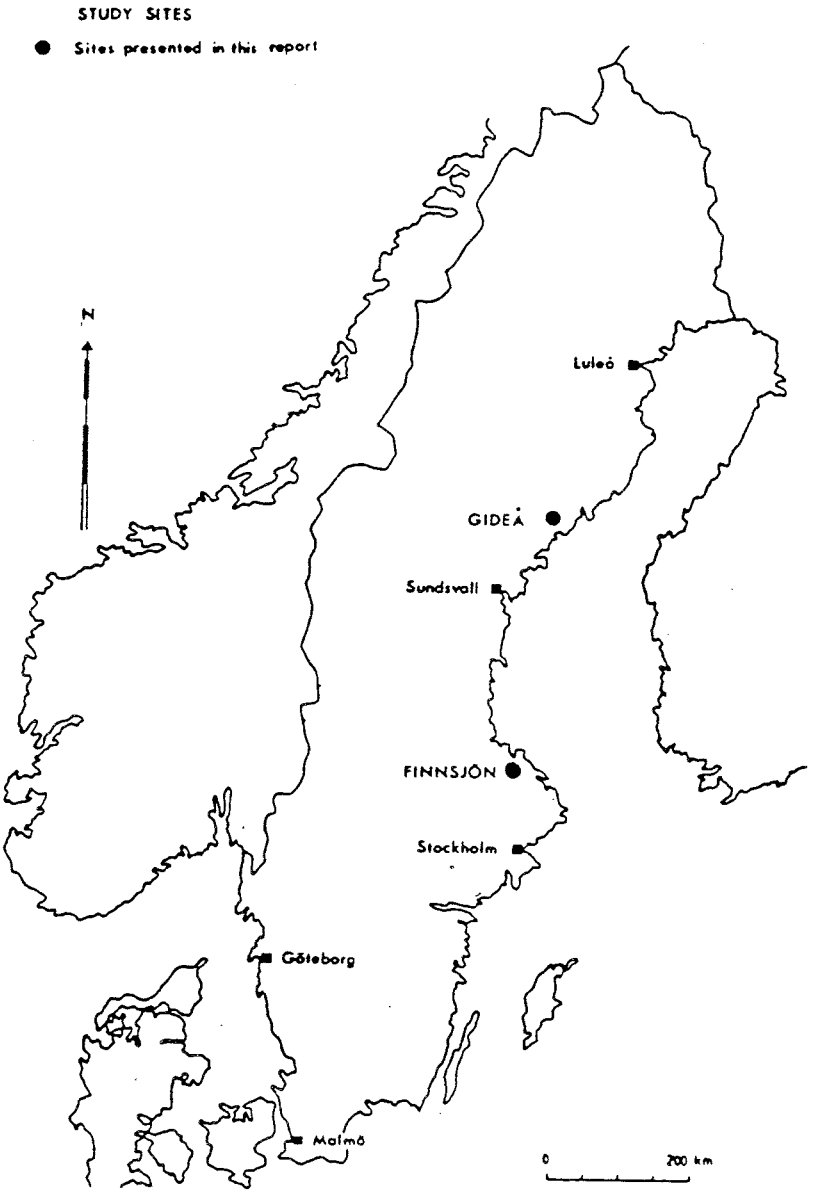

Figure 1.1 Location of the Gideå and Finnsjön study sites.

2. CHARACTERIZATION OF THE FALLOUT

This chapter will summarize the present knowledge about the fallout in Sweden, especially with concideration to the Finnsjön- and Gideå areas. A more detailed report about the transport process from Chernobyl, fallout mechanisms and the fallout pattern over Sweden is given by Liljenzin et. al. (1987).

2.1 Introduction

On Monday April 28, 1986 at 7 a.m. a worker passing a contamination monitor at Forsmark 1 nuclear power plant got an alarm for radiation from his shoes. This started a search for the activity source both inside and outside the plant. This search soon showed that release from the plant could be excluded. Shortly afterwards reports from other Swedish facilities indicated similar situations as Forsmark. Early gamma spectra showed a Cs-134 to Cs-137 ratio which proved that the origin of the fallout over Sweden was a nuclear reactor with a fuel burnup of 7-10 MWd/kg. The ratio between I-133 and I-131 gave the result that the release came from a shut down late night April 25 or early morning April 26 Swedish daylight saving time, assuming a thermal power reactor.

2.2 Meteorological Conditions

The presentation of meteorological conditions during the transportation time for the radioactivity from Chernobyl to Sweden are based on data presented by Persson, Rodhe and De Geer (1986).

Warm air from the southeast reached southern Sweden on April 27 behind a warm front, and then continued up over central Sweden during April 28. A rain area was generated over middle Scandinavia during April 28 due to interaction between the warm front from the southeast and a cold front approaching from the west.

The rain moved to the north and reached northern Sweden on April 29. During this time there was just a weak wind. On April 30 a weak cold front passed over Sweden carrying in air from the west.

On May 1 a new high-pressure area formed over southern Scandinavia and the weak winds from the west moved over southern and central Sweden. The high-pressure area moved slowly in a northeast direction and on May 3 winds from the southeast began to blow over Sweden again. At the same time the winds from the Chernobyl area were still of northerly direction. A low-pressure above the British Islands and a high-pressure above the Baltic areas permitted air from the Chernobyl area to reach Scandinavia again during May 5-6, which is clearly indicated when the activity increases in the air-filters again (c.f. Fig. 2.4).

On May 8 most of Sweden was covered with warm air from the southeast. A cold front through Denmark and Norway moved in over Sweden from the west and caused rainfall in the southwestern part of the country. This caused the essential deposition on the west coast.

In the evening of May 9 the air from the west had covered southern and central Sweden and from May 10 it covered the whole country. After this, no further activity of importance reached Sweden from the Chernobyl area.

2.3 Radionuclide Transport and Deposition Processes

The main part of the cloud formed at the explosion on April 25, 2123 GMT, rose to an altitude of about 1000 m. During April 26, when the active cloud passed White Russia, a strong vertical mixing from the surface up to 2000 m occurred. Early on April 27 when the cloud left the eastern coast of the Baltic Sea, it seems likely that the cloud was split in at least two parts. Most of the upper part, at an altitude of 1000-2000 m, moved towards Finland and the lower part towards Sweden.

The deposition of activity can occur principally by three processes, namely wet deposition, dry deposition by sedimentation and finally sorption where small particles and gasses are adsorbed on surfaces.

A qualitative description of the transportation and fallout processes of the initial relese from Chernobyl is presented in Figure 2.1.

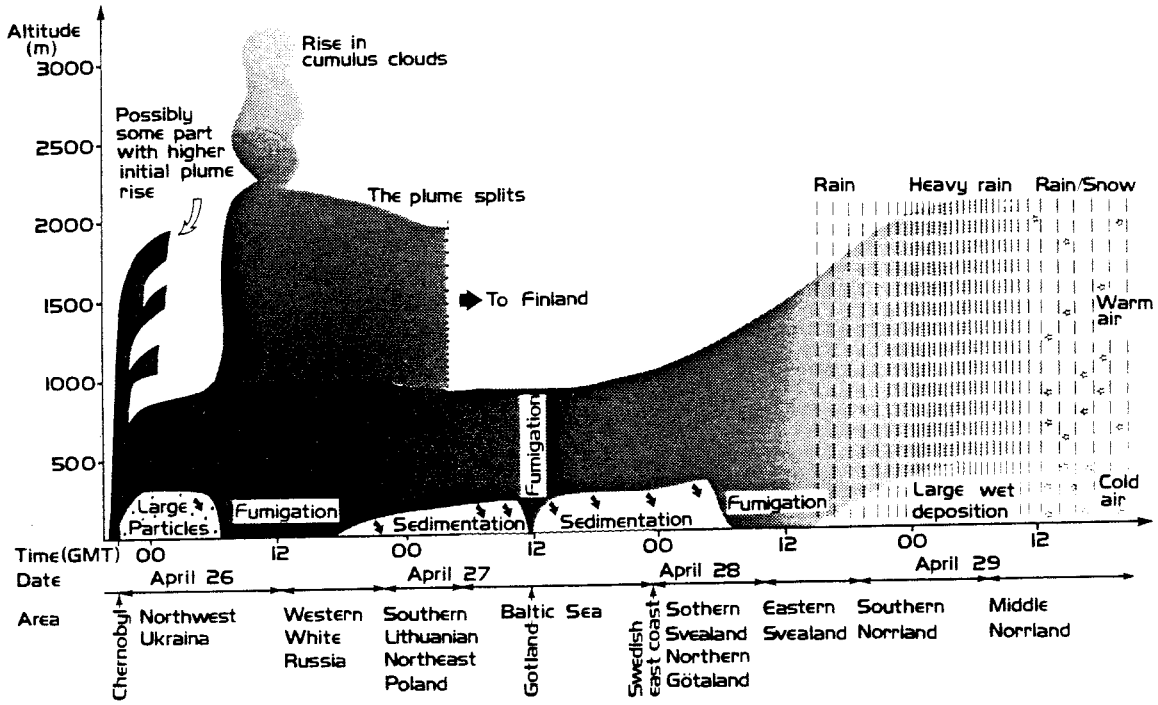

Figure 2.1 A qualitative description of transport, dispersion and fallout for the initial release from Chernobyl (Persson, Rodhe and De Geer, 1986).

Except for some showers that occurred in northern Ukraina during April 26-27, no precipitation occurred which could remove airborne activity until parts of the very stable air mass reached the eastern part of Sweden. The first activity in Sweden was recorded in Uppland at 1200 GMT on April 27.

During the afternoon and evening of April 27 there was a considerable increase in air activity in the southeastern part of Sweden (eastern Götaland and Svealand). The fallout from this time was characterized by a high concentration of refractory elements such as Mo, Ba, La, Ce and Np carried by particles with high deposition speed. This can be seen in the nuclide composition in the Finnsjön area, where a high concentration of Ce-144 can be found, cf. Table 2.3.

On April 28 the active cloud was spread over central Sweden. Airplane sampling at 300 m altitude during the evening showed that the concentration in the air was high, especially of volatile elements such as I, Te and Cs. The highest concentration could be measured at the east coast of central Sweden (the coast of Uppland). During the night a heavy rainfall was generated primarily over the eastern part of central Sweden, as mentioned in section 2.2. In the night between April 28-29 the rain moved to the north. The total precipitation in (mm) for the period April 28 0600 to April 30 0600, Swedish daylight saving time is presented in Figure 2.2. A comparison between the surface contamination map for Cs-137 (Fig 2.2) and the precipitation map (Fig 2.3) shows a striking resemblance between the isocurves. Measurements of the Cs-137 activity in the precipitation recalculated to activity per area unit do, however, show some variations compared to the ground surface activity. The ratio between water activity per area unit and the real ground-surface activity in different places in Sweden varies between 30-170%. The lower ratio which is observed for the area close to Finnsjön, can be interpreted in such a way that a large fraction of the fallout was dry deposited. Higher ratios, however, are more significant in the central east to northeast of Sweden. This might be explained either by high local variations in the fallout, or by the fact that the surface in this area, which also includes the Gideå area, was covered by approximately 0.5 m snow during the time of activity deposition. Later on, when the snow was melting, there might have been a substantial transport of the activity by water from these areas. Deposition on snow is further discussed in section 2.6.

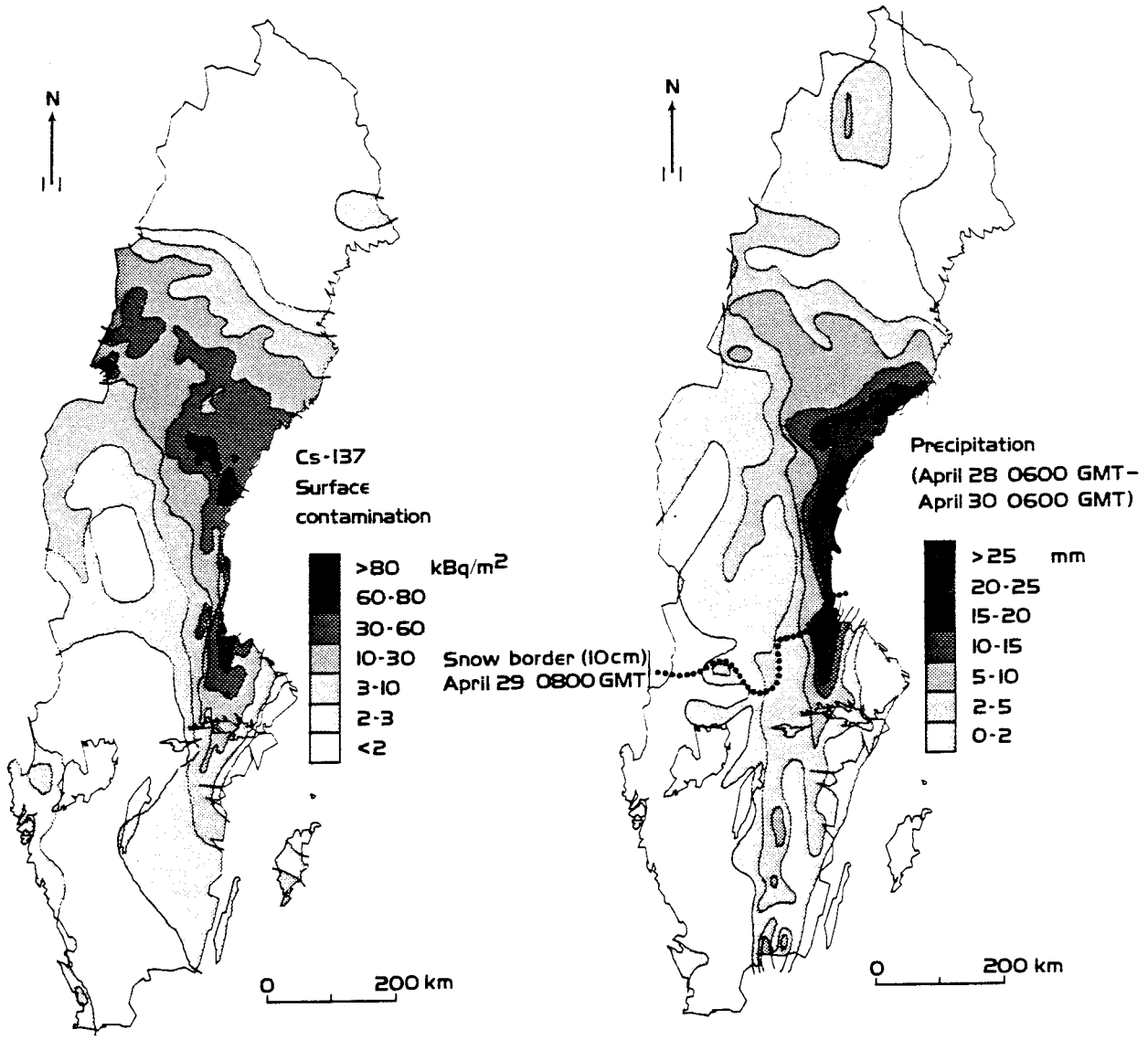

Figure 2.2 Deposition of Cs-137 computed from air surveys, using 2-4 NaI detectors with a volume of 4.2 liters. The map is based on data from measurements performed between May and October 1986 by Swedish Geological Company on commission by the National Institute of Radiation Protection.

Figure 2.3 Measured precipitation (mm) over Sweden during April 28 0600 to April 30 0600, Swedish daylight saving time. (Data from Persson,Rodhe and De Geer, 1986). North of the snow border, Sweden was covered by more than 10 cm snow on April 29 0800 GMT.

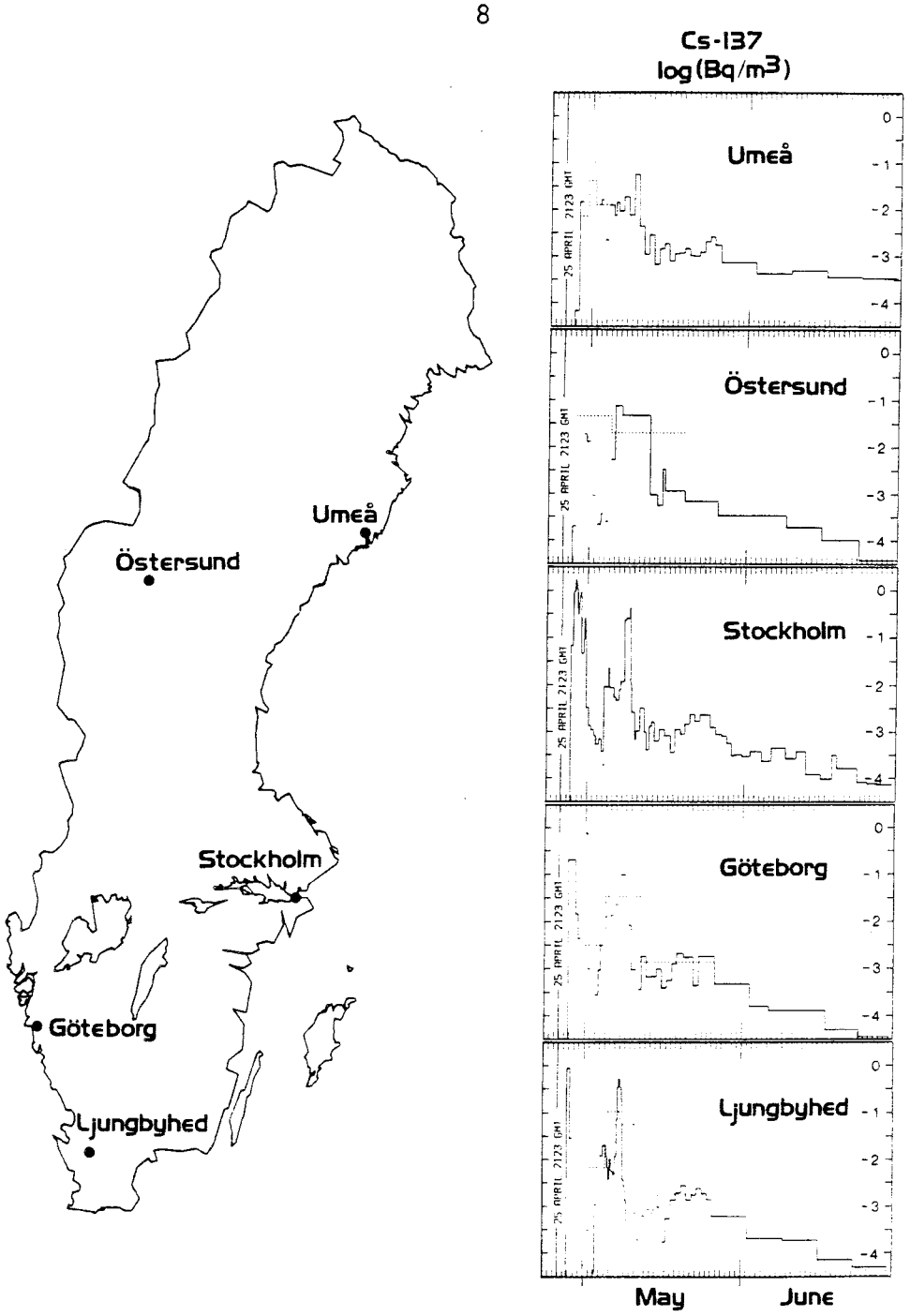

Figure 2.4.a The Swedish air monitoring network for particulate radioactivity (National Defence Research Institute). The stations in this study are located at Ljungbyhed (56 04 N 13 10 E), Göteborg (57 48 N 11 54 E), Stockholm (59 21 N 18 04 E), Östersund (63 12 N 14 31 E), and Umeå (63 46 N 20 08 E). All activities are corrected for decay back to April 25 2123 GMT. The curves show how the particulate Cs-137 activity in air varied with time at each station. (Data from De Geer et al, 1986).

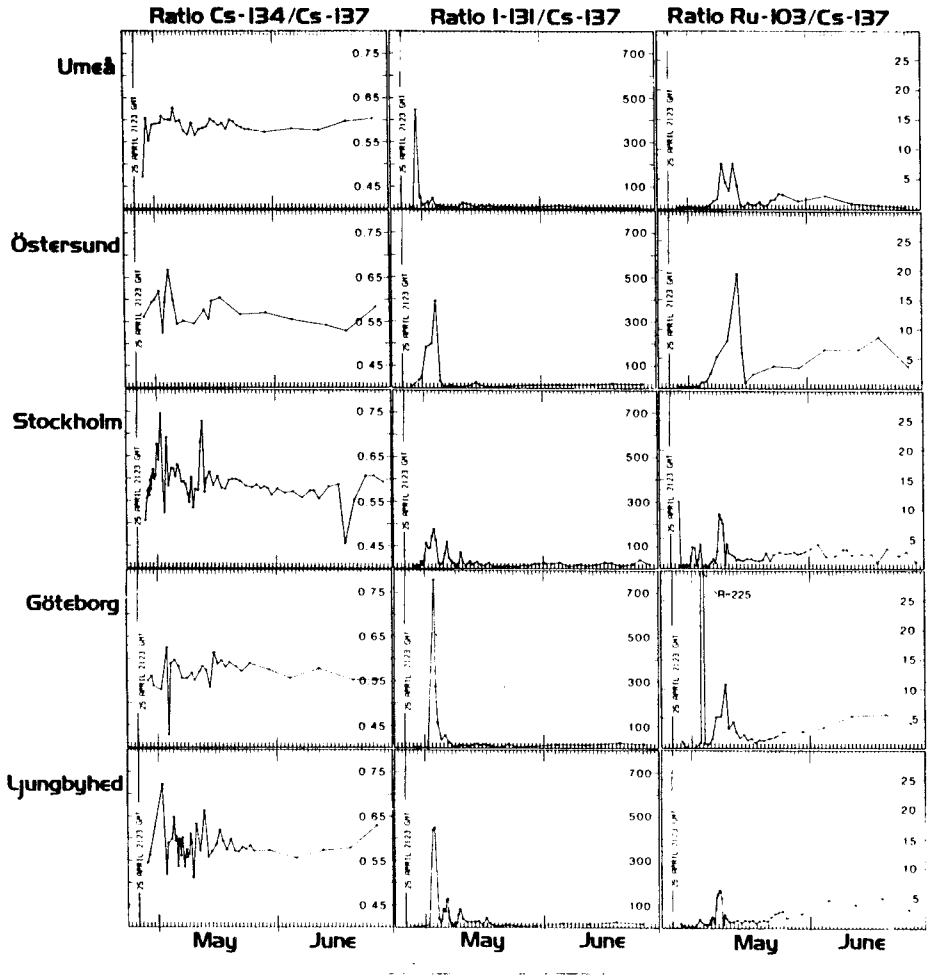

Figure 2.4.b. Ratios of particulate Cs-134, I-131 and Ru-103 activities to that of Cs-137 as a function of time (Data from De Geer et al, 1986). All activities are corrected for decay back to April 25 2123 GMT.

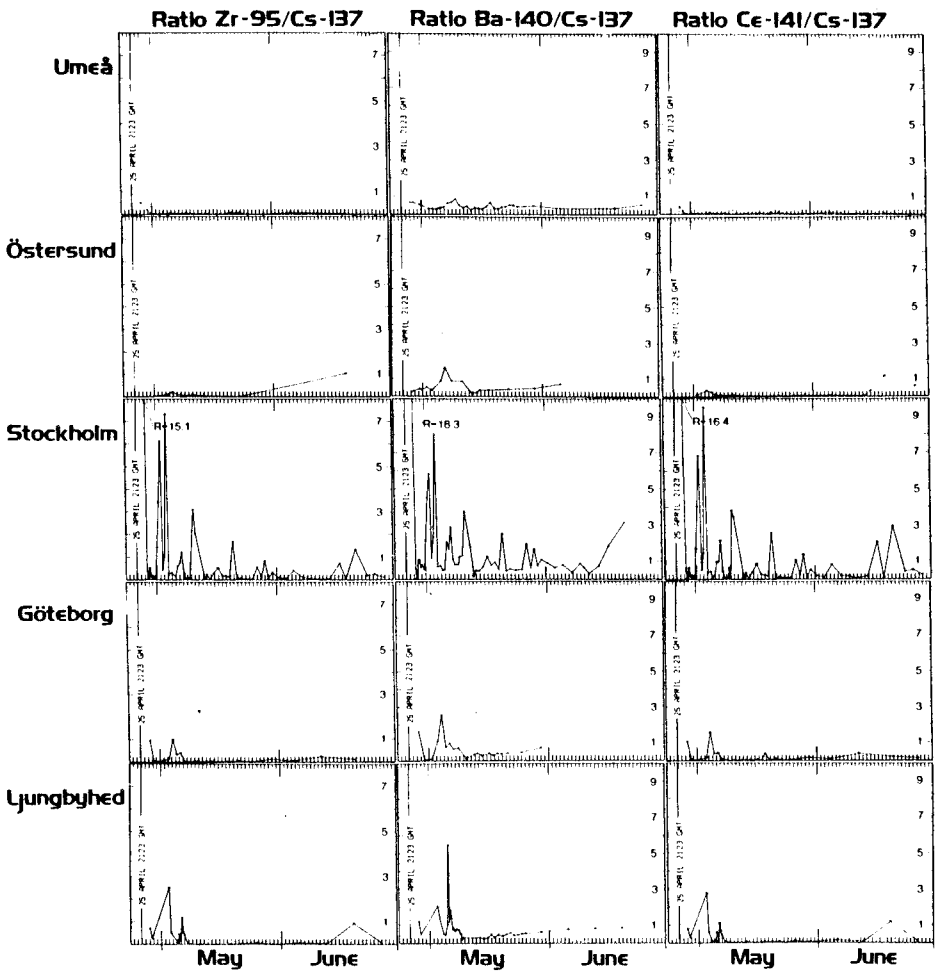

Figure 2.4.c. Ratios of particulate Zr-95, Ba-140 and Ce-141 activities to that of Cs-137 as a function of time (Data from De Geer et al, 1986). All activities are corrected for decay back to April 25 2123 GMT.

As mentioned in section 2.2 a weak cold front passed over Sweden on April 30 carrying fresh air from the west. At this time the air activity decreased considerably which could be seen at sampling stations for airborne activity (cf. Fig 2.4). The Soviet report to IAEA presents the daily release of radioactive substances to the atmosphere (IAEA,1986). There we can see that the initial release on April 26 was followed by a decreased emission of activity for five days until May 2. Then a new release occurred which is about 70% of the initial release. After May 5 a sudden drop in the emission is observed.

From air filter data, cf. Fig 2.4, we can see that a new, small increase in air activity is obtained around May 3 containing a large amount of iodine. Not until May 8 another activity increase in air filters is observed. This time the element ruthenium was present in high concentrations.

The transport of activity during the period May 8-10 was made possible by warm air like the active cloud on April 27-28. No rain interfered with the second cloud until it arrived in Sweden. This time trajectory maps show that the active cloud entered Sweden from the southeast and moved up through the country during May 8.

On May 8-10 a cold air mass with rain moved in to Sweden from the west and a new washout of activity occurred. This could be observed especially on the west coast of Sweden on May 8. After May 10 no further activity of importance reached Sweden.

2.4 Composition of the Fallout

A short summary of the known composition of the fallout is given below. The nuclides that have been observed in the fallout are summarized together with the half lifes in Table 2.1.

Table 2.1 Nuclides identified in the Chernobyl fallout.

Nuclide	Half life	Nuclide	Half life
Mn-54	312.2d	Cs-134	2.06y
Co-60	5.3y	Cs-136	13.16d
Zn-65	244d	Cs-137	30.17y
Zr-95	66d - Nb-95 35d	Ba-140	12.75d - La-140 40.3h
Mo-99	66h - Tc-99 6.0h	Ce-141	32.5d
Ru-103	39.4d	Ce-144	284.4d
Ru-106	368d - Rh-106 30s	Eu-152	13.3y
Rh-105	35.5h	Eu-155	4.96y
Ag-110m	249.9d	Pu-238	87.8y
Sb-124	60.3d	Np-239	2.36d
Sb-125	2.77y	Pu-239	$2.4\ 10^4$y
Te-129m	33.6d	Pu-240	6550y
I-131	8.02d	Pu-241	14.4y
Te-132	76.3h - I-132 2.3h	Am-241	433y
I-133	20.8h	Cm-242	163d
		Cm-244	18.11y

2.4.1 Airborne activity

Since 1957 Sweden has a continuous surveillance program for monitoring particulate radioactivity in air. Today there are seven places with sampling stations in Sweden, see Figure 2.4. These stations collects airborne activity on a 0.6 x 0.6 m glass fibre filter. The air is pumped through the filter by a high capacity centrifugal pump with a rate of about 24000 m^3/day (Vintersved and De Geer, 1982). A survey of the air filter data published by the National Defence Research Institute has been made (De Geer et al, 1986). Data from five of the stations are presented in Figure 2.4.

The most complete set of data is from the Stockholm station. All activities have been decay corrected to April 25, 2123 GMT. Usually the filters are changed more seldom than during this time.

As mentioned before, the meteorological conditions have a marked influence on the air activity. The first pulse of activity during April 28-30 is best followed by the Stockholm station. The second activity pulse, which was quite small, reached Stockholm on May 3. It was followed by a much larger pulse around May 7-9.

When comparing activity ratios of other nuclides to the activity of Cs-137, cf Fig 2.4.b.c., we can get a rough idea of how different elements behave. By comparing the ratio between the chemically identical Cesium isotopes Cs-134/Cs-137 we can observe that the ratio has varied a great deal. To some extent this variation depend on uncertainties in the gamma spectrometric measurements and variation in particle size etc. But it can, however, also be interpreted as showing the burn up of the fuel.

During the initial phase a relatively low burn-up fuel (low Cs-134/Cs-137 ratio, ~0.5) arrived in Sweden. It increased to a maximum on April 30 (~0.65), before it dropped again around May 2. These variations in the cesium ratio are observed until May 15. After this a more or less stable Cs-134/Cs-137 ratio of 0.57 is obtained. If these observations are correct there could be small local variations in the Cs-134/Cs-137 ratio in different places in Sweden.

The ratio of I-131/Cs-137 showed compared to other volatile elements, which include cesium, that the first activity that reached Umeå contained a large amount of iodine. It could possibly have been transported by parts of the higher altitude cloud moving in the direction towards the west coast of Finland. All air filter stations show an increase in the I-131/Cs-137 ratio on May 2-3.

The ratio between I-133/I-131 (decay corrected to April 25, 21.23 GMT) shows a new small increase during May 2 to May 3 at the Stockholm air filter station. Other similar observations were made at the Forsmark nuclear power plant showing a I-133/I-131 ratio higher than observed any time before. This indicates that a second criticallity did occur in Chernobyl between May 1 and May 4. That might explain the heating-up of the reactor which led to a new release during May 2-5. It must be observed that the air filter values just show the amount of particulate iodine. Studies e.g. at Studsvik AB (Norrman and Devell,1986) and the Finnish Center for Radiation and Nuclear Safety (Sjöblom, 1986), show that 60-85% of the iodine activity passes a glass fibre filter but can be trapped on a charcoal cartridge.

On May 7-8, when the last activity reached Sweden, the air filter measurements show that a large amount of ruthenium was present. This element belongs as a pure metal to the refractory elements. It is, however, possible that the metal has been oxidized to a volatile oxide, which left the reactor when it became warm again.

The other elements Zr, Ba, and Ce which belong to the nonvolatile elements, show a remarkable similarity in behaviour at the different air filter stations, see Fig. 2.4.c. The largest difference between these elements and Cs is observed in the central and south of Sweden. The same tendency is also observed when comparing surface contaminations, cf Table 2.2, between the southern, central and northern part of Sweden.

2.4.2 Surface activity

The data base created by the National Institute of Radiation Protection (SSI), concerning grass samples collected during the first weeks after the accident, was first concidered to be used in this study for determining the nuclide composition in the surface deposited activity. However, these data could not be used, primarily explained by uncertainties during sampling procedures, and by the fact that a lot of important information is missing in the data base. The data base contains almost only I-131 and Cs-137 values. Therefore it has been necessary to do a small survey within this project, in which surface samples were taken and the activity ratio of different nuclides was compared to that of Cs-137. Except for the Finnsjön and Gideå areas, five other locations have been selected in the most contaminated parts of Sweden. The surface contamination at the locations selected are presented in Figure 2.5. The dominating tendency is that the refractory elements, especially cerium, are found in high concentrations in the southern part around Finnsjön and to some extent in the mountain areas at Gäddede. This might be explained by the fact that during the night between April 28-29 a part of the active cloud moved towards Norway while some of it moved back to the east coast of the central and northern part of Sweden and caused a high fallout during the rain- and snowfall. Finnsjön is also covered by a large amount of ruthenium. Analysis of the ruthenium activity shows that it is found to a high extent as particles. High amounts of ruthenium can also be found at N. Tannflo.

Some deductions about the chemical behaviour of the radionuclides can be made by studying the behaviour in the soil samples. The high mobility of ruthenium observed in soil profiles (see section 3.3 and 4.3.) together with the relatively high activity concentration found in surface waters (see section 3.5. and 4.5.) contridicts the fact that ruthenium "hotspot" samples were impossible to dissolve even in strong acids (see Appendix C.3). There seems to be two chemically different forms of ruthenium, one insoluble form which stays where it was deposited and one soluble form which is transported with water.

High mobility in soil profiles is also observed for cobalt and antimony compared to cesium (see section 3.3. and 4.3.). Cerium on the other hand seems to be detained in the very upper layer of the soil (see section 4.3.), which could be expected if cerium exists as a cation.

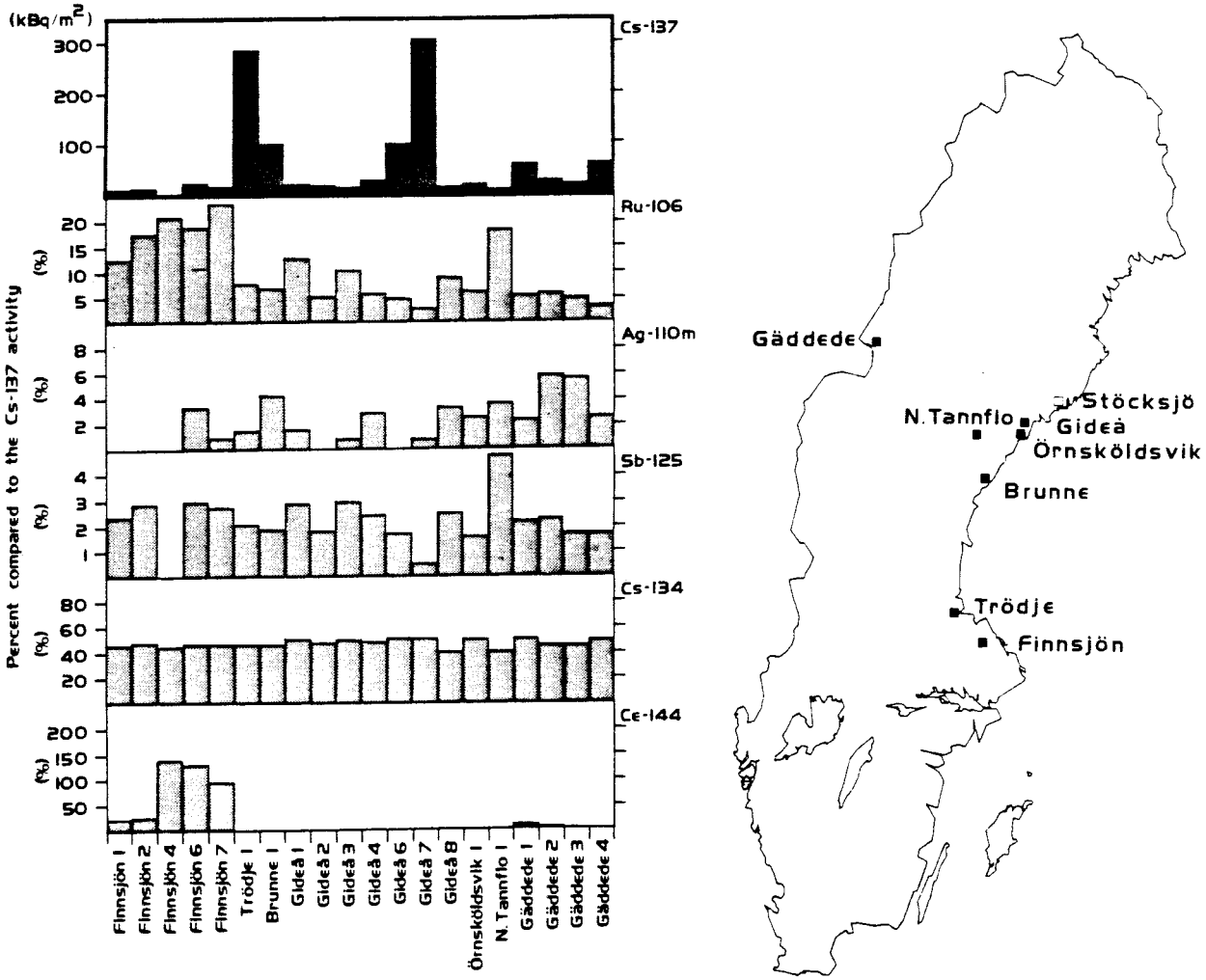

Figure 2.5 Surface contamination at some locations in Sweden, marked with filled squares (Finnsjön 6022N 1754E, Trödje 6049N 1711E, Brunne 6242N 1731E, Örnsköldsvik 6315N 1840E, Gideå 6328N 1903E, N.Tannflo 6323N 1657E, Gäddede 6430N 1408E). The diagram shows the Cs-137 surface activity and the relative percentage occurence of Ru-106, Ag-110m, Sb-125, Cs-134 and Ce-144 compared to Cs-137. All activities have been decay corrected to April 26, 1986. The open square marks the location for snow sampling at Stöcksjö (6346N 2009E), see Figure 2.8.

2.5 The Finnsjön area

The fallout in the Finnsjön area consists, as mentioned before, of a high amount of refractory elements. The similar behaviour for these elements can be seen in the air filter measurements, cf Fig. 2.4, which, possibly, indicate that they were transported together. During the time in May, when Sweden was reached by activity for the last time, a group at Studsvik AB performed measurements on particles in air taken with a particle size fractionating sampler (Chyssler and Devell, 1986 and Chyssler 1986). The analysis shows a somewhat nuclide dependent size distribution. The nuclides studied were Ru-103, I-131, Cs-134 and Cs-137. The particles studied have a size distribution between 0-10 um with the dominating activity below 3.3 um. An investigation from Oslo, where they have studied the particulate activity in rain water (Norges Offentlige Utredninger, 1987:1), showed that a high amount was washed out by the rain. These particles had a molecular weight $>10^4$ u, see Table 2.2.

Table 2.2 Fraction of particulate activity in rain water from Oslo May 6, 1986.

Nuclide	% fraction with molecule weight $>10^4$ u
Zr-95	80
Ru-103	75
I-131	50
Cs-134	75
Cs-137	75
Ba-140	65
Ce-141	90

To get an idea of the activity distribution in the very small scale, rock samples were taken on outcrops exposed to the fallout and analysed by autoradiography, see Fig 2.6. Gamma spectrometric measurements of the rock samples show the same nuclide composition as can be seen in soil samples and gamma spectrometric measurements in situ from the same location.

During this rock sampling we found some very active particles on a vegetation free outcrop, from which the soil cover had been removed and the bare outcrop washed a few weeks prior to the fallout. By searching an area of 9 m^2 (Appendix A) with small contamination instruments we found seven active small areas (cm^2). By using a portable diamond drill we could remove two of the active spots. The drill cores were put on the X-ray film for 1-55 hours and could thereby be identified as point sources, see Appendix A. By gammaspectrometric measurement we could identify these hot-spots containing Ru-103 and Ru-106 with an activity of 10-20 kBq Ru-103 (ref date April 26, 0000 GMT) and an activity ratio Ru-103/Ru-106 = 6.5. By optical microscopy it was also possible to show that the particle size is <5 um.

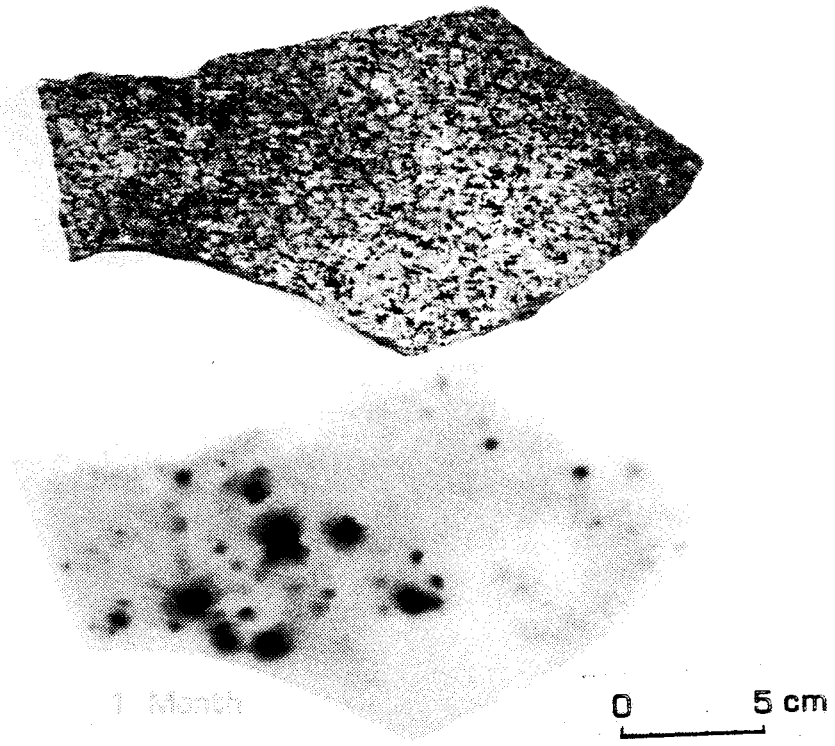

Figure 2.6 Picture showing rock sample (left) and autoradiogram (right) from Finnsjön, sampling site F8 (October 1986). Exposure time about one month.

Analysis of a soil sample collected June 24 1986, on a bowl-shaped, vegetation free, outcrop at Finnsjön (sampling site F8) shows the radionuclide composition presented in table 2.3. (Skålberg et al, 1986).

Table 2.3. Analysis of the radionuclide content in a soil sample collected at Finnsjön (sampling site F8), June 24 1986, (Skålberg et al, 1986).

Nuclide	Activity* (kBq/kg)	Nuclide	Activity* (kBq/kg)
Sr-90	0.17	Sb-125	2
Zr-95	22	I-131	6.2
Nb-95	41	Cs-134	10.5
Ru-103	18	Cs-137	22.2
Ru-106	16	Ce-141	8
Ag-110m	0.6	Ce-144	33

* recalculated to the sampling time

A soil sample from sampling site F8 was analysed even with respect to Sr-90 activity. As can be seen the Sr-90 activity is present to about 0.8 % to that of Cs-137. To investigate the activity distribution in the very small scale, approximately 0.4 g of the sample was distributed over an adhesive tape, which then was placed close to a X-ray film and exposed for 33 days. The result is shown in Figure 2.7. It is obvious that an essential part of the activity is present as particles.

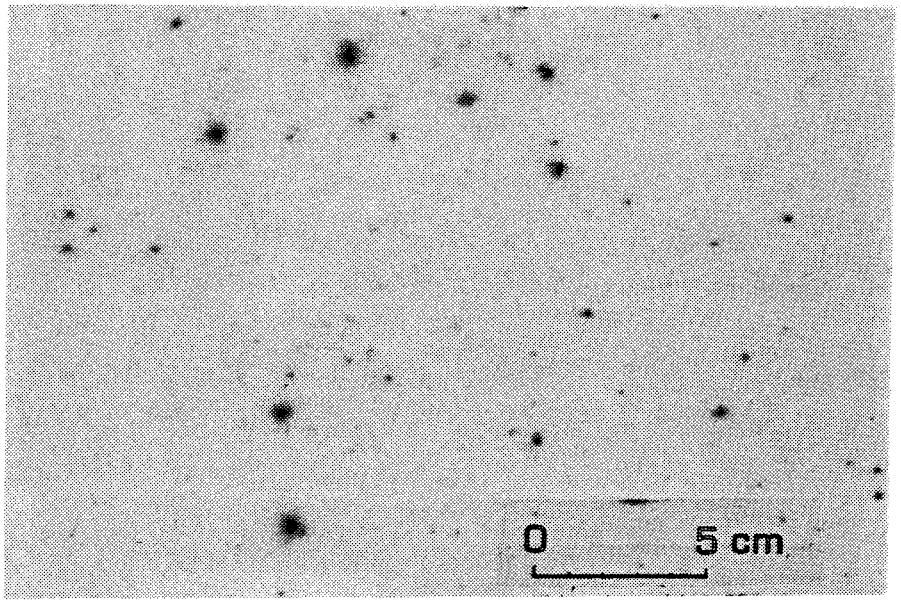

Figure 2.7. Autoradiogram of 0.4 g soil sample from Finnsjön (sampling site F8) taken at a bowl-shaped vegetation free outcrop. The sample was distributed over 155-235 mm adhesive tape. The exposure time was 33 days.

2.6 The Gideå area

During the fallout in the Gideå area there was a snow cover of approximately 0.5 m thickness. The fallout activity will reach the ground either by migration through the snow or at the time when the snow is melting. A snow profile has been taken and analyzed, from an area about 80 km north of the Gideå area, see Figure 2.10. The sample was taken after a heavy rainfall and the snow was very wet. It gave approximately 0.7 l water per litre snow.

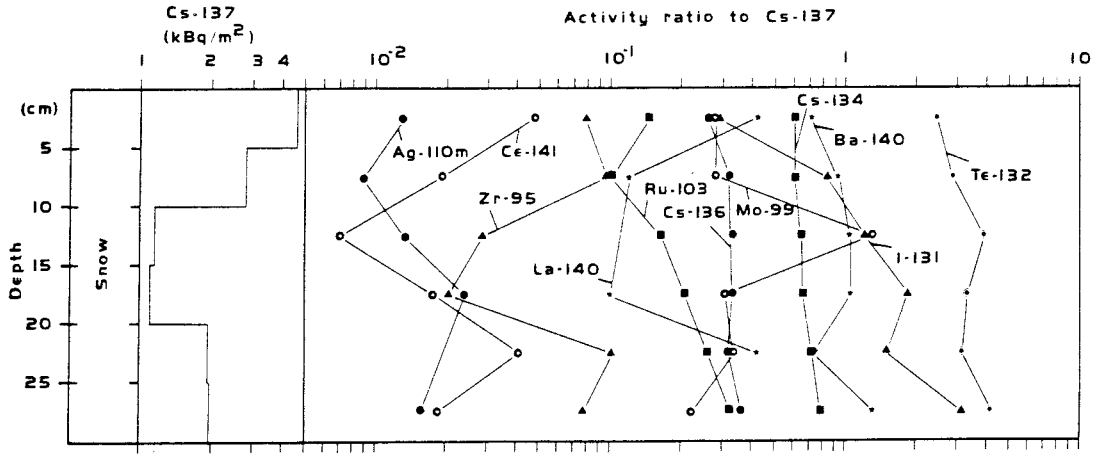

Figure 2.8. Snow profile taken at Stöcksjö (63 46 N 20 09 E) on May 2 at 1700 Swedish daylight saving time (see Fig. 2.5). All data are given as log(Bq/kg) and recalculated to the sampling time.

The snow depth was 30 cm and separated from the ground by an ice layer. This and other investigations (Sundblad, 1986) show the same tendency. The iodine activity has moved through the snow and was found in the bottom layer. On the other hand cations seems to be cought in the top layer, except for ruthenium, which could be found in the same amount in the bottom layer. These observations can be interpreted in the way that ruthenium is to some extent deposited as hydrofilic species or as an anion which was transported by water. The high activity of the other cations in the top layer can be explained by particles or colloids caught by the snow. Another explanation might be that the cations are hydrated and thereby integrated in the ice structure in the snow and thus stopped in the top layer.

When the snow was melting the activity reached the ground by water transportation. This might explain the different appearence of autoradiograms from Gideå compared to Finnsjön, see Figures 2.6. and 2.11. It was difficult to find rock samples without lichen at Gideå. Therefore it is difficult to compare these autoradiograms. However, we can see that a lot of the activity was caught by the lichen (c.f. Figs. 3.2.6, 3.2.7). Small areas free from lichen on the same stone show, however, very little activity.

This observation indicates that the activity has been dissolved, at least to some extent, before it reached the ground.

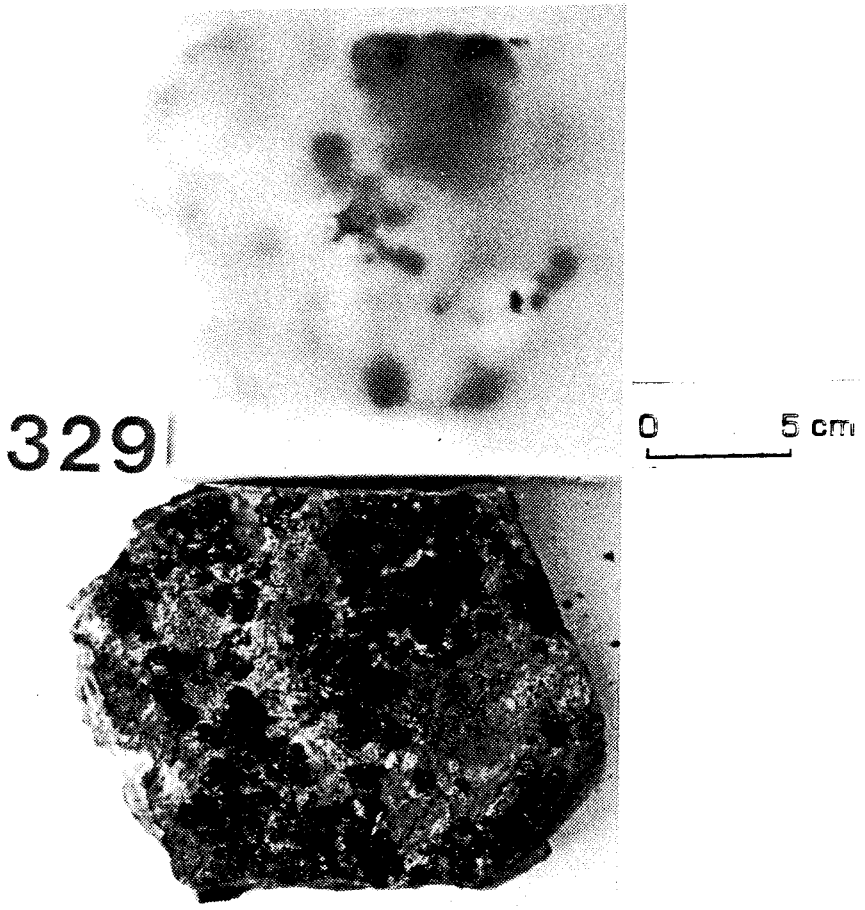

Figure 2.9. Picture showing rock sample (bottom) and autoradiogram (top) from Gideå, sampling site G26 (October 1986). The exposure time was 48 days.

2.7 Summary

The fallout is different in the Finnsjön and Gideå areas with respect to radionuclide composition and the amount of activity, depending on the content in the plumes, deposition and surface conditions.

Substantial local variations in the ground surface deposition are observed both within Finnsjön and Gideå areas.

The total surface deposition of Cs-134 and Cs-137 is about twice as high in Gideå compared to Finnsjön, which also was valid for I-131 the first month.

The fallout within the Finnsjön area contains a lot of refractory elements like cerium, which is not found in Gideå. The activity per area unit of Ce-144 in Finnsjön is comparable to that of Cs-137.

Investigations of early samples from Finnsjön indicate that an essential part of the activity was deposited as particles.

The Gideå area was covered by snow during the fallout, which could dissolve some of the deposited particulate activity before reaching the ground surface, which is indicated in this investigation.

When looking into the chemical behaviour of the fallout it seems as two chemically different forms of ruthenium occur, one insoluble which stays where it was deposited and one form which is transported by water.

The mobility of cobalt and antimony in soil profiles is higher compared to cesium. Cerium, however, seems to be detained in the very upper layer of the soil, indicating that cerium exists as a trivalent cation.

3. DEPOSITION AND MIGRATION WITHIN THE GIDEÅ STUDY SITE

To be able to perform accurate budget calculations and mathematical model calculations of radionuclide migration and redistribution, based on a limited number of field measurements, the Chernobyl fallout study has been concentrated on two smaller sub-areas within the Gideå study site:

- o Orrmyrberget catchment area (0.74 km^2)
- o Gi 2 area (0.14 km^2)

The deposition and migration of the radionuclide fallout in biota, soils, surface waters, shallow groundwaters and on outcrops within the sub-areas have been traced by measurements in situ and sampling (followed by laboratory measurements) on 49 sites at several occasions since June 1986. The sites (Fig. 3.1.1) represent different geological, hydrological and biological domains within the area studied. The measurements in situ and sampling performed are summarized in Table 3.1.1.

The surface deposition was measured at 24 sites by gamma spectrometeric measurements in situ, with 50 % of the count rate arising from activity within a radius of 3 m at a typical site. At nine of these sites soil profiles have been sampled for gammaspectrometric analysis at the laboratory to provide direct measurements of the activity distribution in the soil profile, and secondly to be used in comparison with the spectrometric measurements in situ for determination of the absolute surface deposition. On the outcrops drillcore samples and rock surfaces picked by hammer were collected for autoradiographic studies.

To get a rough estimate of the rate which the radionuclides might migrate in the soils, eight sites were selected for repeated gammaspectrometeric measurements in situ and soil profile sampling and analysis. Measurements and sampling were performed in June and November 1986.

Surface- and groundwater were sampled for analysis of nuclide composition, environmental isotopes and physico-chemical parameters. Surface water was sampled at five sites in the system of creeks which drains the Gideå study site. Groundwater were sampled in a shallow dug well and from two discharging artesian drill holes. One of the drill holes was sectioned with two rubber packers to study nuclide migration in shallow, intermediate and deep groundwater.

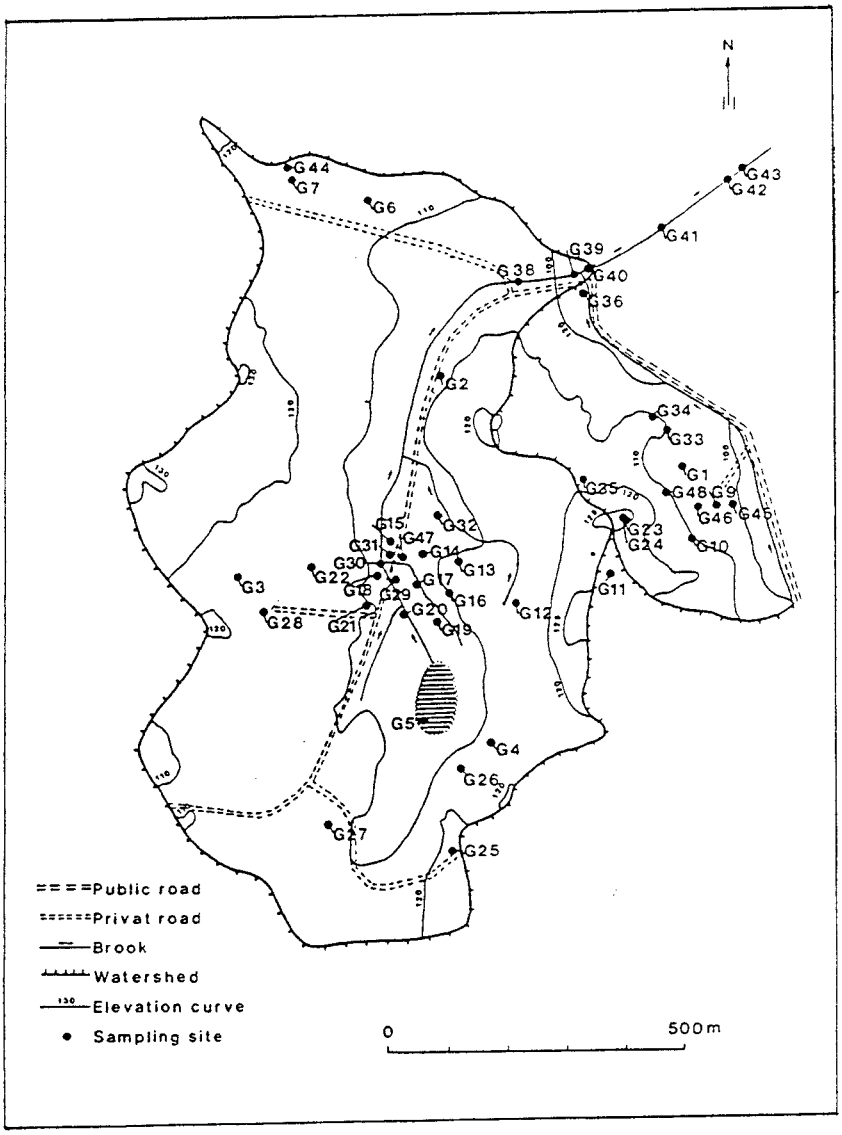

Figure 3.1.1 Sampling sites within the Gideå study site.

To be able to estimate the removal of radionuclides from the Gideå area, not only water but also sediment samples were taken in the creek which drains the area.

The sediment samples were taken at four sites down stream (outside the area) where the water velocity was slow enough to allow suspended particles to settle out.

Vegetation samples were taken at several sites and some of them coincided with sites for gamma spectrometric measurements in situ. The aim was to get a rough estimate on the distribution of radioactivity between surface cover and uptake by the vegetation at this early stage. Lichens, mosses, dwarf shrubs and trees (especially leaves and needles) were collected and analysed.

Table 3.1.1 Sampling and measurements in situ within the Gideå study site.

Site	Soil	γ-spectr. In situ	Water	Sediment	Vegetation	Rock
G1	C	D			C	
G2	C E	A D				
G3	C	D	C			
G4	C	D				
G5	C					
G6	C	D				
G7	C	D				
G8	C	D				
G9		A D	BC E			
G10		A D				
G11		A D				
G12		A D				
G13	D	A D				
G14		A			A	
G15	A D	A D	A			
G16		A				
G17		A			A	
G18		A				
G19		A				
G20		A				
G21		A				
G22		A D			A	
G23		D				
G24		D				
G25		D				C
G26					C	C
G27					B	
G28						C
G29			AB D	B	B	
G30			D			
G31			A CDE			
G32			E			
G33						C
G34					C	C
G35					AB	
G36	A E					
G37			B			
G38				C		
G39				C		
G40			CDE			
G41				C		
G42				C		
G43				C		
G44	C				C	C
G45	A				A	
G46	A				A	
G47	A					
G48	B		B			
G49			A			

A 25-26 Jun 86
B 7-11 Jul 86
C 18-19 Oct 86
D 4- 5 Nov 86
E 17-19 Feb 87

3.1 Site Description

3.1.1 Geology and topography

The Gideå study site is situated in the northern part of Ångermanland county c. 30 km north-east of Örnsköldsvik, see Figures 1.1 and 3.1.2 (mapsheet 19 J Husum NW). A geological, geophysical and hydrogeological description of the Gideå area is given by Ahlbom et. al. (1983).

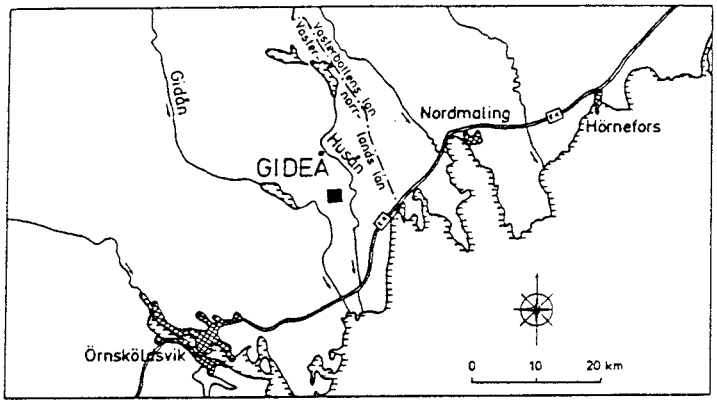

Figure 3.1.2 Location of the Gideå study site.

The study site is located on a flat plateau surrounded by major fracture zones which can be observed as dominating lineaments in the terrain. A topographical map of the study site, including locations of fracture zones at the surface, is presented in Figure 3.1.3.

The study site is forested interchanging with minor mires. The soil cover consists primarily of till and sand, overlain in depressions by peat.

Geologically the area belongs to the Sveco-Karelian mega unit. The dominating rock type is a more or less migmatized gneiss of sedimentary origin. In a smaller scale the gneiss consists of a fine-grained biotite rich paleosom and a quartz-feldspar rich neosom. Pegmatite bodies as well as veins of pegmatite have been found within the test site. The youngest rocks in the area are the cross cutting mostly E-W striking dolerites. A geological map for the Gideå study site is presented in Appendix A.

Among the fracture zones indicated at the surface within the test site, the following three zones are the most prominent: Zone 1 and 2 striking NNE dipping 40° SE and 70° NW respectively, situated in the eastern part of the area and Zone 5 (E-W/subvertical) in the northern part of the area (Fig 3.1.3). It can be noted that subhorisontal fractures dominate within the site.

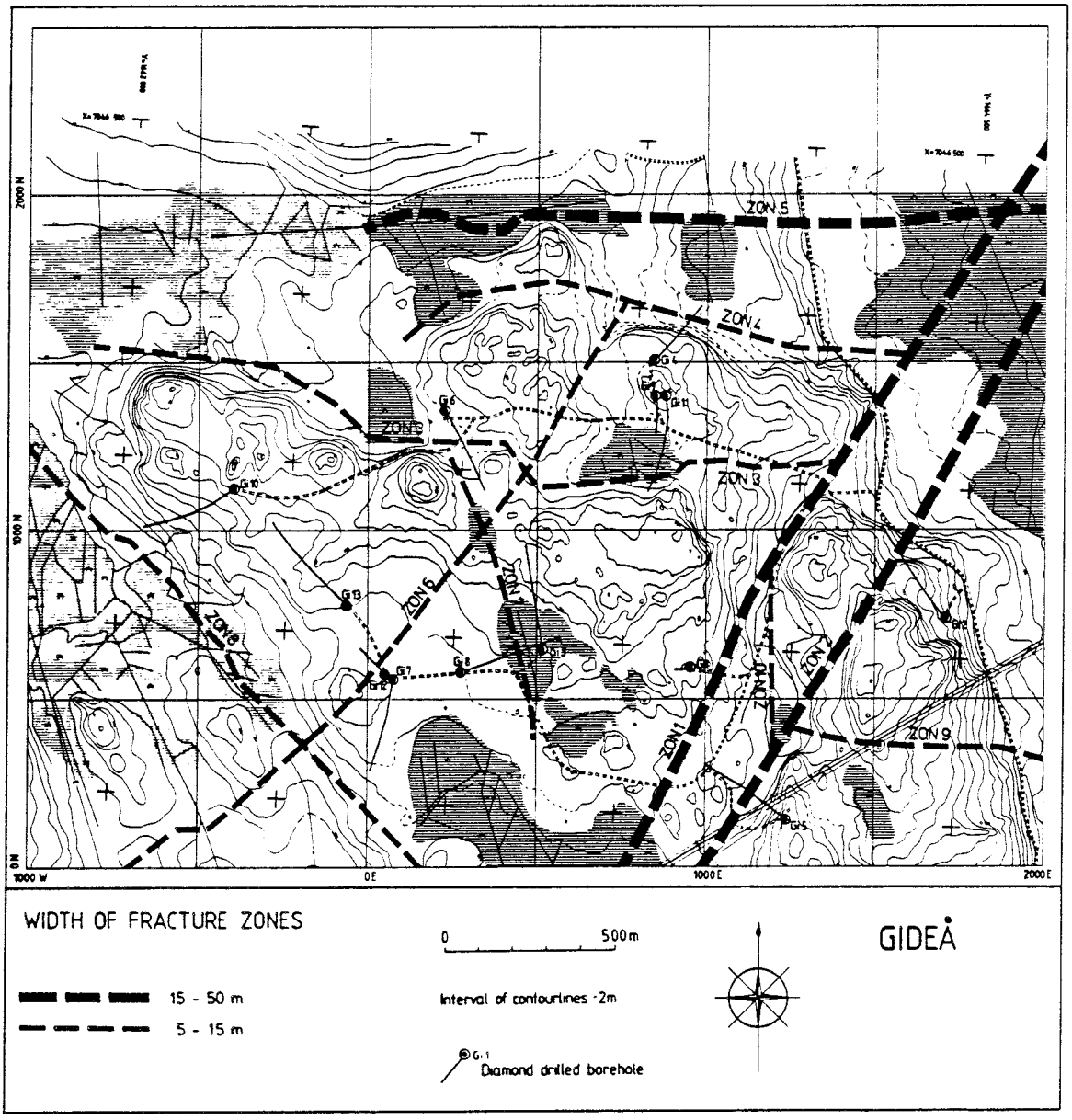

Figure 3.1.3 Topographical map of the Gideå study site. Major fracture zones are marked with broken lines.

Within the study site two smaller sub-areas have been selected for the Chernobyl fallout study:

1) The Gi 2 area; This consists of the area within the radius of influence from the groundwater discharge of the artesian drillhole Gi 2 (Fig. 3.1.4). The area is characterized by moss and lichen covered outcrops, till and outwashed sediments.

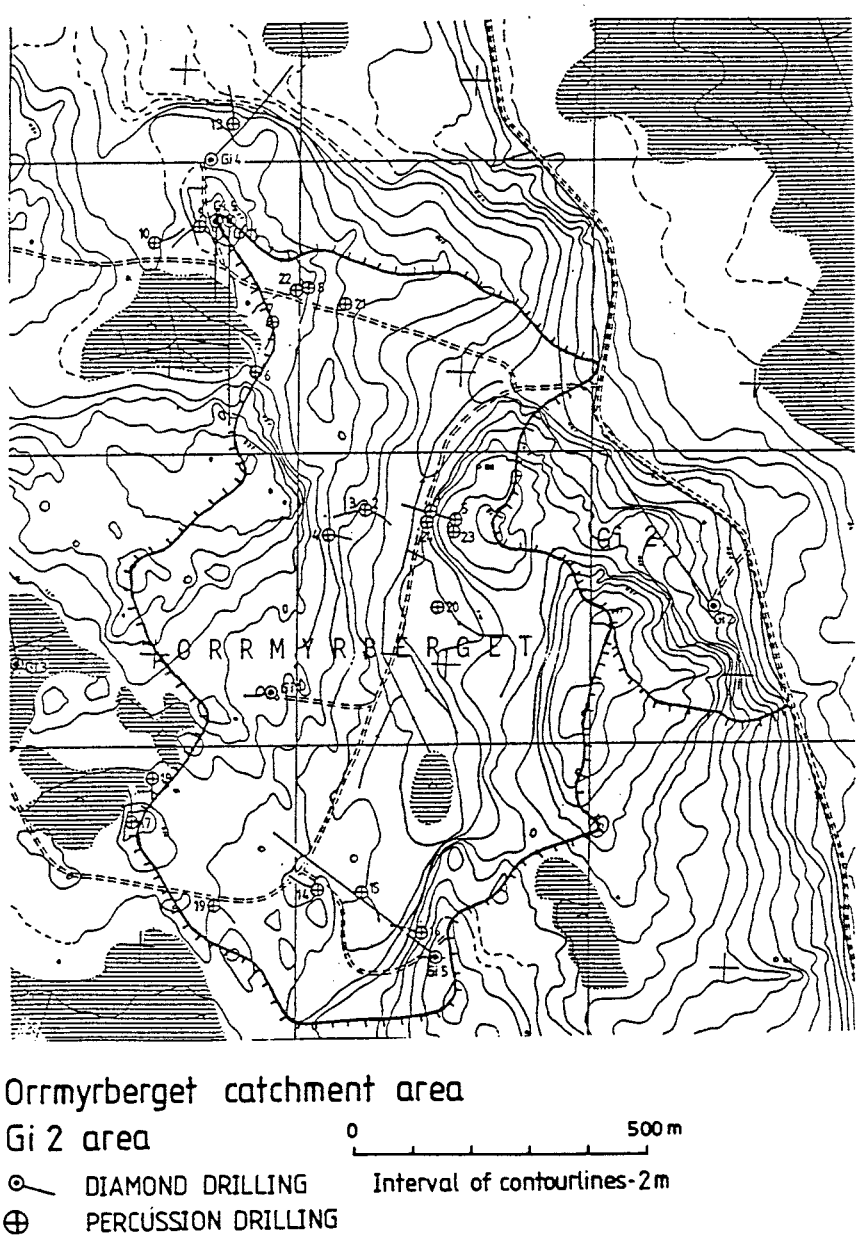

Figure 3.1.4 Sub-areas selected for the Chernobyl fallout study, Gideå study site.

Figure 3.1.5 Areal view of Orrmyrberget catchment area, Gideå study site (photo towards north-west from site G26).

2) The catchment area Orrmyrberget (Figs. 3.1.4 and 3.1.5); The catchment area is dominated by a seventeen-year-old clearcut. A large part is covered with grass and widely scattered pine trees. The recharge parts of the area are dominated by till and outcrops mostly covered with moss and lichen. The recharge character of the area is shown e.g. by the presence of Fe-coatings (probably FeOOH) on the fissure walls found down to c. 25 m core length in drill hole 5.

Since the whole area is situated below the highest coast line the soils are all reworked by the regressing sea. This has resulted in old shore lines of shingle. On the slopes till with washed surfaces is found. In the lower, central part of the catchment area there is sand and outwashed sediment. In the south there is a small fen dominated by sphagnum peat. Fracture zones within the sub-area are, except for the above described Zone 1 and 2, Zone 10 (N-S/90^{o}) which connects Zone 1 and Zone 2. Additionaly one zone striking E-W, dipping 70^{o} N (Zone 9) is identified in the area.

The areal distribution of quaternary deposits and outcrops within the Orrmyrberget catchment area and the Gi-2 area is given in Table 3.1.2 and Figure 3.1.6. The distribution is preliminary determined from air-photo interpretation and field checks. The distribution of clearcut, fen and forested areas is given in Table 3.1.3 and Figure 3.1.7.

Table 3.1.2 The areal distribution of quartenary deposits and outcrops within the Orrmyrberget and Gi 2 areas (preliminary determined from air-photo interpretation).

Orrmyrberget area	73.6 ha	100 %	Note
Outcrop	18.2	25 %	
Peat	0.8	1 %	Fen in central part
Till	29.6	44 %	
Sand	25.0	30 %	Partly with a thin peat cover, especially in the lower central parts.
Gi 2 area	**14.0 ha**	**100 %**	**Note**
Outcrop	6.8	49 %	
Till	1.6	11 %	
Sand	5.6	40 %	Partly with a thin peat cover

Table 3.1.3 The areal distribution of forest, clearcut and fen within the Orrmyrberget and Gi 2 areas.

Orrmyrberget area	73.6 ha	100 %	Note
Forest	20.6	28 %	Old conifer, with lichens, some mosses and dwarf shrubs, dry.
Clearcut	52.2	71 %	Including outcrops, see Figs. 3.1.6, 3.1.7. Grass and scattered pine trees. Clearcut 1970.
Fen	0.8	1 %	With sphagnum peat.
Gi-2 area	**14.0 ha**	**100 %**	**Note**
Forest	2.7	19 %	Old conifer, with lichens, some mosses and dwarf shrubs, dry.
Clearcut	11.3	81 %	Including outcrops, see Figs. 3.1.6, 3.1.7. Grass and scattered pine trees. Clearcut 1970.

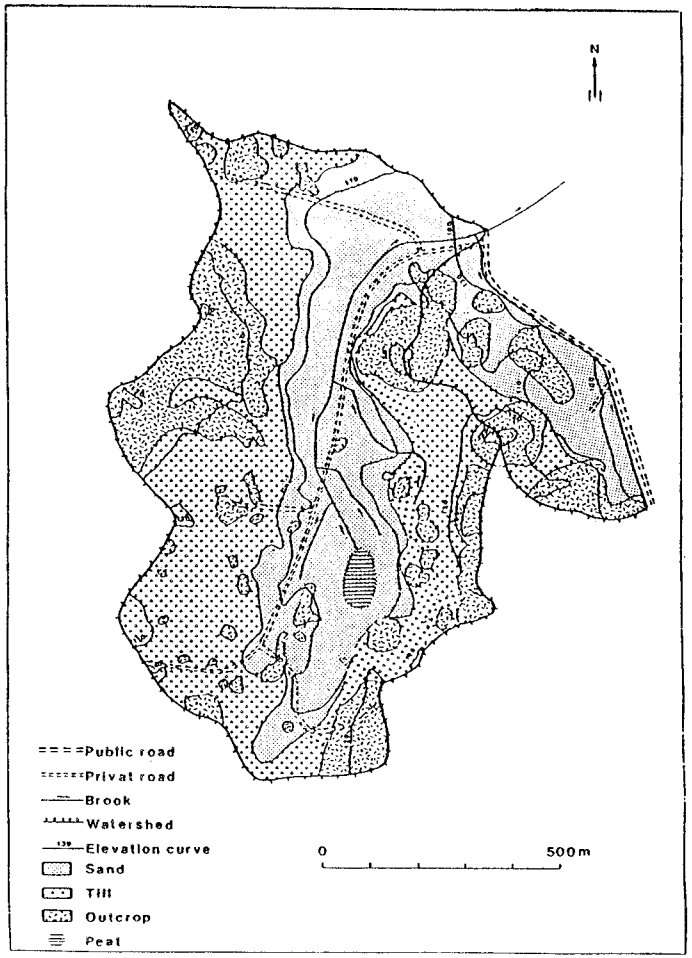

Figure 3.1.6 Quaternary deposits and outcrops within the Gi-2 area and the Orrmyrberget catchment area, Gideå study site.

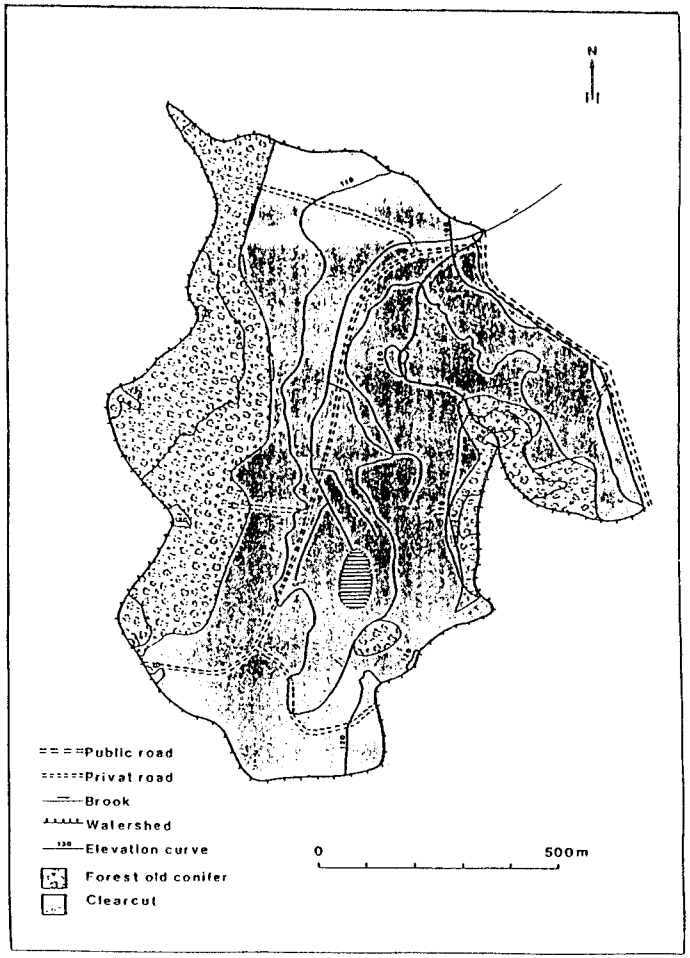

Figure 3.1.7 The areal distribution of Forest, Clearcut and Fen within the Gi-2 area and the Orrmyrberget catchment area, Gideå study site.

3.1.2 Hydrological and meteorological conditions

The Gideå study site is located on the water divide between two drainage basins. The small local catchment area Orrmyrberget, selected for the Chernobyl fallout study, in the south-east part of the Gideå study site, is drained towards the north-east by small streams to the stream Husån (Fig. 3.1.2) which ultimately drain into the Baltic sea, after 19 km.

The comparatively elevated position of the study site in the terrain, in relation to its surroundings, implies that it can be regarded as a recharge area. Minor local discharge areas are found in low-lying parts, in most cases consisting of peat bogs.

Hydrological and meteorological data and conditions in the Gideå study site are based on statistical information obtained from SMHI (the Swedish Meteorological and Hydrological Institute). The meteorological station at Örnsköldsvik airport approx 10 km south-west of the Gideå study site has been regarded as representative for the study site. Precipitation, temperature and snow depth have been registrated there since 1971. The station is situated at 103 m.a.s.l. which coincides well with the mean altitude of the Gideå site, 107 m.a.s.l.

The mean monthly precipitation at Örnsköldsvik airport is specified in Table 3.1.4. Monthly precipitation during the period April 1986 throughout February 1987 is specified in Table 3.1.5. Compared to the mean precipitation the actual period had an excess precipitation of 14 mm (+ 2 %) i.e. very close to the mean value. This is also valid for the period May-October 1986, i.e. from the event of fallout and surface deposition to the last gamma spectrometric measurements and soil profile sampling before the winter, 364 mm c.f. 371 mm (-2 %). However, in April and May there was 60 % more precipitation than the monthly mean values (122 mm c.f. 76 mm) and in June there was 68 % less (17 c.f. 53).

Of the annual mean precipitation, 33 % is in the form of snow. Snow cover duration data have been obtained from measurement stations Mellansel and Nordmaling. At Mellansel, the ground is snow-covered for 160 days and at Nordmaling for 167 days. During the winter 1985/1986 the ground was snow covered until 6 May at Örnsköldsvik airport and from 4 December 1986 there was again a durable snow cover. The duration of the ground frost period per annum is c. 143 days according to data from the Kasa meteorological station.

Table 3.1.4 Estimated monthly mean precipitation (mm) at Örnsköldsvik airport.

Precipitation	J	F	M	A	M	J	J	A	S	O	N	D	Year
unadj	46	37	34	38	38	53	73	81	65	61	73	61	660
adj	55	45	41	46	46	62	73	92	74	73	87	71	765
% snow	92	92	87	37	2					12	54	70	

Table 3.1.5 Monthly precipitation (mm) at Örnsköldsvik airport April 1986 - February 1987.

Precipitation	J	F	M	A	M	J	J	A	S	O	N	D
unadj 1986				64	58	17	69	73	100	47	91	73
unadj 1987	12	36										

When estimating the temperature conditions at the study site, data from Örnsköldsvik airport, and the neighbouring stations Hemling and Kasa have been utilized. Table 3.1.6 shows monthly mean values. The annual mean temperature at Örnsköldsvik airport is c. +2.7^{o}C. Monthly mean temperatures during the period April 1986 through-out February 1987 are shown in Table 3.1.7. During this period April was colder than the normal mean value (-0.6^{o}C c.f. +0.5^{o}C) and there was a warm November (+0.4 c.f. -2.6).

Table 3.1.6 Monthly mean temperature (^{o}C) at Örnsköldsvik airport, Hemling and Kasa.

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
Hemling	-10.7	-9.5	-5.1	0.3	6.3	12.3	13.9	12.4	7.5	1.9	-4.0	-7.8	+1.5
Kasa	-7.5	-7.8	-3.8	0.9	6.8	12.7	14.8	13.6	9.0	3.8	-1.8	-5.0	+3.0
Ö-viks airport	-8.5	-8.7	-4.4	0.5	7.0	13.2	15.1	13.7	8.8	3.3	-2.6	-5.8	+2.7

Table 3.1.7 Monthly mean temperature (^{o}C) at Örnsköldsvik airport April 1986 - February 1987.

	J	F	M	A	M	J	J	A	S	O	N	D
1986				-0.6	8.0	15.2	14.9	10.8	6.0	4.2	0.4	-8.5
1987	-15.8	-9.0										

Values of potential evaporation have been obtained from the Bredbyn and Vännäs meteorological stations. Values of the actual evaporation in the Gideå site have been interpolated from the isoline evaporation chart of Sweden (Eriksson, 1980). The potential evaporation amounts to 420 mm/year, the actual evaporation has been estimated at 410 mm/year in the Gideå area. Table 3.1.8 specifies the estimated actual evaporation as monthly mean values.

Table 3.1.8 Estimated actual evaporation in the Gideå area.

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
Adjusted Gideå	0	0	5	20	75	110	100	65	28	7	0	0	410

There are no runoff observations for the Gideå study site prior to the Chernobyl fallout study, but setting out from observation data from other water courses with similar hydrological conditions the runoff pattern during a c. 50-year period has been simulated (Timje, 1983). These estimated run-off values which should be regarded as approximate are used for comparison with the runoff from the small catchment area Orrmyrberget measured once a month. In Table 3.1.9 estimated runoff per month is specified. The annual mean runoff amounts to 11 l/s km^2 (345 mm/year). The runoff is low during the winter, in March and in August. Except for a peak, 50 l/s km^2, in May, the runoff is comparatively evenly distributed, between 8 and 12 l/s km^2, during the remaining part of the year.

Table 3.1.9 Monthly mean runoff (l/s km^2) for the Gideå study site.

	Monthly mean												
runoff	J	F	M	A	M	J	J	A	S	O	N	D	Year mean
l/s km^2	3	2	2	11	50	11	10	6	8	12	10	7	11

Discharge measured once a month in the small stream which drains Orrmyrberget catchment area are shown together with run off in Table 3.1.10. The measurement started in October 1986. During February and March 1987 measurements were impossible due to ice. The discharge for these months was estimated to one litre per second.

Table 3.1.10 Discharge and runoff measured once a month for the Orrmyrberget catchment area within the Gideå study site. October 1986 - March 1987.

Discharge/ Runoff	J	F	M	A	M	J	J	A	S	O	N	D
l/s										6.2	9.2	11.8
l/s km^2										8.4	12.4	15.9
l/s		1.1	ice	ice								
l/s km^2		1.5	1.4*	1.4*								

*estimated values

The water balance at the study site is determined by the following factors: precipitation, evaporation, runoff, change in storages and groundwater flow through the boundaries of the area. The precipitation amounts to the total of the other factors. The water balance of the Gideå site for the period 1951-1980 has been calculated to (Ahlbom et al, 1983):

Adjusted precipitation	765 ± 25 mm/year
Actual evaporation	410 ± 25 mm/year
Runoff	345 ± 10 mm/year

The annual precipitation exceeds the sum of the actual evaporation and runoff by about 10 mm which is about 3 % of the runoff. This may be a function of the uncertainty caused by the estimated basic values and should thus be regarded as acceptable. Groundwater drainage through the boundaries of the study site is considered to be negligible.

3.1.3 Groundwater conditions

Within the Gideå site, the existing groundwater conditions have been determined 1) by measuring the hydraulic properties of the bedrock by means of water injection tests in 13 drill holes and by test pumping in 5 drill holes and 2) by monitoring the groundwater table and the groundwater pressure at different depths in 37 drill holes (Timje, 1983).

The data obtained have together with the hydro-meteorological conditions constituted the basis for numerical modelling of the groundwater flow (Carlsson et al 1983). According to the numerical modelling the groundwater percolation rate to the bedrock has been calculated to approx. 75 mm/year. Consequently the major portion (270 mm/year) of the runoff is circulated in the soil horizon and the uppermost part of the fractured bedrock.

In the Chernobyl fallout study the groundwater table has been measured once a month since October 1986 in 13 selected drill holes within the local catchment area Orrmyrberget.

These groundwater level data coinside well with the previous observations and the following general description of the groundwater conditions in the Gideå site is regarded as representative for the Orrmyrbrget catchment area.

The position of the groundwater table is at its lowest in January through March. During snow melting the groundwater table rises towards the end of March, reaching its maximum in April. From May through early August, the groundwater table continues to subside, even though there may be a couple of minor recovery periods. In the middle and end of August there is a marked recovery and a new maximum is reached, due to low evaporation in combination with precipitation on the ground which has not yet become impermeable due to freezing. After that, the groundwater table is highly situated and comparatively stable until the beginning of December, when it again starts to subside.

The measurement results are well in accordance with the normal annual variation of the groundwater table in southern Norrland, where there is, apart from the groundwater recharge in late spring, a secondary period of recharge during the autumn (Knutsson and Fagerlind, 1977).

In general, the profile of the groundwater table reflects on a much smoother scale the topographical relief. In the Gideå area the groundwater table is located 1-3 m below the ground surface although in the more hilly parts and adjacent slopes the depth to the groundwater table can exceed 10 m. As a consequence the groundwater level varies between 100-120 m above sea-level in the Orrmyrberget catchment area. Groundwater discharge areas are found at topographical low points in the central part of the catchment area, in conjunction with fracture zones 1 and 2. The discharge areas are shown in Figure 3.1.8. The areal distribution of recharge and discharge areas are shown in Table 3.1.11. In the recharge areas there is a downward oriented gradient for the groundwater, whereas an upward oriented gradient characterizes the discharge areas.

Table 3.1.11 Groundwater recharge and discharge areas within the Orrmyrberget catchment area and the Gi-2 area, Gideå study site.

Area	Distribution of recharge and discharge areas		
Orrmyrberget	Total area	73.6 ha	100 %
	Recharge area	ca 65.6 ha	89 %
	Discharge area*	ca 8.0 ha	11 %
Gi-2 area	Total area	14.0 ha	100 %
	Recharge area	14.0 ha	100 %
	Discharge area	-	-

* The discharge areas in the near vicinity of the narrow creeks are not included.

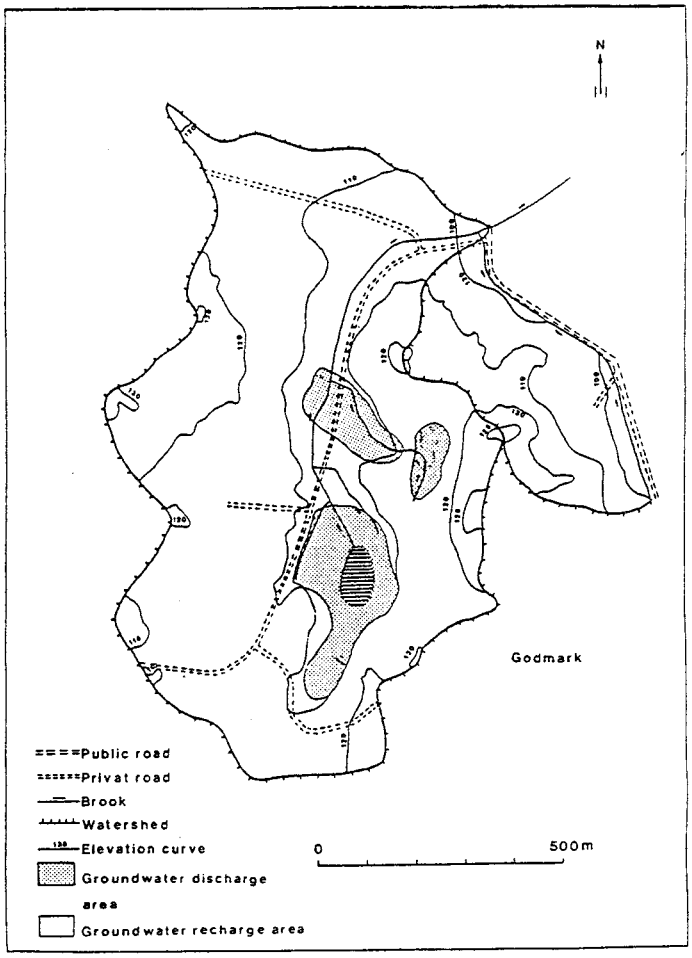

Figure 3.1.8 Groundwater discharge and recharge areas within the Gi 2 and Orrmyrberget catchment area, Gideå study site.

The sum of the discharge areas within the Orrmyrberget catchment area is c. 8 hectars which is about 11 per cent of the area.

Drill hole 20, located in a discharge area, is artesian (Fig. 3.1.4). In drill hole 15, located on the boundary of another discharge area, the pressure gradient changes which indicates the near vicinity of the drill hole being a discharge area during the summer and a reacharge area in the autumn. Otherwise the areal extent of the discharge areas seems to be fairly constant through-out the year.

Drill hole Gi 2, located just outside the catchment area in a slope of a high rock section, is also artesian and the groundwater pressure has been measured to 4.8 m above ground surface. However, the artesic water flow is probably caused by the drill hole itself intersecting and short-circuiting hydraulically conductive horizontal fractures. It can be noticed that results from the local hydraulic flow model show water flow directed downward (Carlsson et al, 1983).

In drill hole Gi 2 the section 97-106 m was sealed off with rubber packers during June 1986 exclusively for water sampling in the Chernobyl fallout study. The drill hole is cased down to 28 m and both the 28-96 m and the 97-106 m section is artesian and have been sampled for groundwater on three occassions.

Geoghysical logging has been carried out in all the diamond drilled holes and is reported by Stenberg (1983). The temperature as well as the resistivity logging show an inflow of fresh water at c. 100 m level in drill hole Gi 2. Results from the SP (self-potential)-logging and the core mapping show the presence of pyrit in the upper part of the drill hole. This combined with the presence of calcite coating within the fractures all along the drill hole indicate that no extensive inflow of oxygenated water of low pH has occured in the undisturbed system.

3.2 Gamma Spectrometric Measurements

Gamma spectrometric measurements have been performed in Gideå on two occasions, in June and November 1986. The method is described in Appendix C.1, the sites are presented in Figure 3.2.1.

Site	Description
G1	Till covered by moss and grass
G2	Gravel plane at road cut
G3	Moor
G4	Till covered by moss and grass
G6	Shallow till and outcrop
G7	Outcrop at borehole H22
G8	Peatland outside the catchment area, 700 m to the east
G9	Gravel plane at borehole Gi2
G10	Boulder rich soil
G11	Outcrop
G12	Bog
G13	Bog
G14	Moor
G15	Shallow peat on till
G16	Outcrop
G17	Moor covered by grass
G18	Till, grass
G19	Moor
G20	Moor
G21	Till overgrown by grass
G22	Till
G23	Outcrop
G24	Outcrop
G25	Outcrop at borehole Gi5

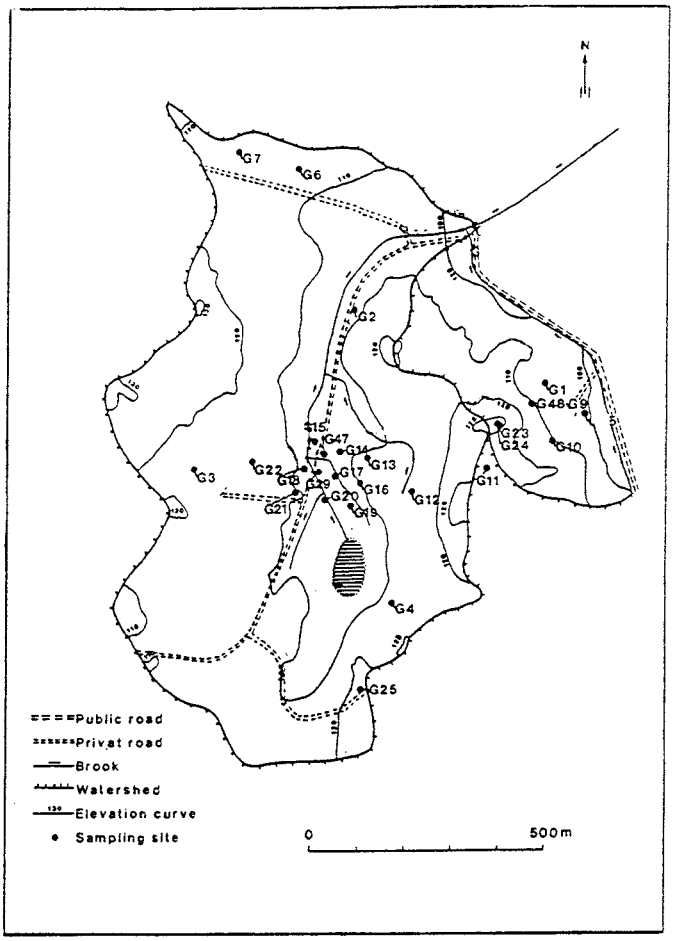

Figure 3.2.1 Gamma spectrometric sites, Gideå study site.

The measurements represent an average deposition of a circular area. The contribution is decreasing with increasing distance from the detector. The distance, where the fraction of the total photon fluence is 50 %, is approximately 3 m for a typical site. The corresponding value for a perfect infinite disc source is approximately 8 m.

Table 3.2.1 Estimation of surface deposition with spectro-metric measurements in situ, given as kBq/m^2 (± 1 s). Compensated for shielding effects due to surface roughness and migration of activity. Measuring time: 2000 seconds. Reference date 1986-04-28.

SITE	DATE	K 40	ZR 95	NB 95	RU103	I131
G 1	861105.	56.3 - 2.50	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 2	861105.	95.1 - 5.60	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 3	861105.	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 4	861105.	98.3 - 5.92	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 6	861105.	64.7 - 4.72	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 7	861105.	84.4 - 5.39	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 8	861106.	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 9	860625.	99.9 - 4.41	2.1 - .27	3.5 - .26	14.7 - .57	166.7 - 26.78
9	861104.	93.5 - 4.45	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 10	860625.	103.2 - 3.97	2.1 - .78	4.0 - .40	15.6 - .78	281.3 - 36.27
10	861104.	102.5 - 8.27	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 11	860625.	99.4 - 3.91	0.0 - 0.00	1.9 - .42	15.1 - .80	295.1 - 35.93
11	861104.	87.4 - 5.31	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 12	860625.	0.0 - 0.00	2.2 - .58	4.8 - .58	16.3 - 1.50	554.5 - 74.38
12	861104.	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 13	860625.	15.7 - 2.51	0.0 - 0.00	3.1 - .47	18.8 - 1.25	496.0 - 62.10
13	861104.	16.7 - 2.83	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 15	860625.	9.8 - 2.34	0.0 - 0.00	1.8 - .53	12.0 - .99	366.6 - 79.78
15	861104.	9.8 - 1.19	0.0 - 0.00	6.1 - 1.42	0.0 - 0.00	0.0 - 0.00
G 22	860625.	24.0 - 2.86	2.7 - .23	4.7 - .26	28.1 - 1.18	2429.2 - 77.85
22	861105.	12.8 - 1.40	0.0 - 0.00	5.2 - 1.30	0.0 - 0.00	0.0 - 0.00
G 24	861106.	86.4 - 7.11	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 25	861105.	58.3 - 4.42	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00

error due to counting statistics only (± 1 Sigma) given in the right column

0.0 = not detectable

Table 3.2.1 cont Estimation of surface deposition with spectro-metric measurements in situ, given as kBq/m^2 (± 1 s). Compensated for shielding effects due to surface roughness and migration of activity. Measuring time: 2000 seconds. Reference date 1986-04-28.

SITE	DATE	CS134	CS137	SB125	LA140	AG110M
G 1	861105.	27.8 - .70	47.4 - 1.31	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 2	861105.	26.2 - .64	44.9 - 1.14	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 3	861105.	25.0 - .53	42.2 - .92	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 4	861105.	59.9 - .90	99.8 - 1.82	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 6	861105.	29.4 - .73	51.3 - 1.22	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 7	861105.	20.6 - .65	38.2 - .89	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 8	861106.	19.1 - .46	33.5 - 1.26	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 9	860625.	29.8 - .60	50.9 - 1.32	0.0 - 0.00	38.8 - 3.77	.8 - .14
9	861104.	26.5 - .61	45.0 - .93	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 10	860625.	32.4 - .69	56.8 - 2.80	0.0 - 0.00	41.8 - 4.53	.9 - .33
10	861104.	27.9 - .82	50.2 - 1.30	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 11	860625.	32.9 - .48	57.7 - 2.03	0.0 - 0.00	44.9 - 5.64	.8 - .22
11	861104.	33.1 - .82	59.8 - 1.11	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 12	860625.	32.8 - .91	63.8 - 2.95	0.0 - 0.00	51.9 - 8.08	1.1 - .38
12	861104.	28.8 - .57	50.8 - 1.10	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 13	860625.	34.4 - .95	60.3 - 2.10	0.0 - 0.00	52.8 - 7.22	.9 - .26
13	861104.	27.8 - .63	46.9 - 1.58	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 15	860625.	25.7 - .58	61.0 - 2.16	0.0 - 0.00	37.8 - 10.65	0.0 - 0.00
15	861104.	20.7 - .34	36.8 - .58	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 22	860625.	31.7 - .75	68.3 - 2.39	1.7 - .23	127.0 - 8.60	1.4 - .08
22	861105.	30.8 - .40	52.3 - .84	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 24	861106.	57.7 - 1.32	104.7 - 2.37	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
G 25	861105.	37.9 - .69	65.5 - 1.14	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00

error due to counting statistics only (± 1 Sigma) given in the right column

0.0 = not detectable

A problem with this technique is the obvious influence of the surface roughness, thus causing an underestimation of the measured surface deposition due to shielding effects. A method to compensate for this effect and comparison with soil samples is given in Appendix C.1.

The number of spectrometric sites is limited. However, to be able to study the variations in a microscale (decimeter to meter) exposure rate measurements have also been performed around the different sites and along lines (Fig. 3.2.1).

Results of the spectrometric measurements are presented in Table 3.2.1 covering the two periods in June and November 1986. Due to the half-life of the radionuclides and the measuring times used, it was possible to detect I-131, Cs-134, Cs-137, Ru-103, La-140, Sb-125, Zr-95, Nb-95 and Ag-110 m in June, and C-134, Cs-137 and Nb-95 in November. K-40 is also presented in the table and represents a measure of the mineral content of the site.

The gamma spectrometric measurements are summarized in Table 3.2.2. The variation between different sites and nuclides is shown for the two cesium isotopes. The coefficient of variation (CV) is around 10 % for Cs-134 and Cs-137, around 30 % for the other nuclides except I-131, which has a CV of 120 %.

Table 3.2.2 Gideå, gamma spectrometric measurements, summary. Measuring time: 2000 seconds.

Date	Nuclide	Mean (kBq/m^2)	Coefficient of variation (%)
1986-06-25--26	I-131	655	121
(7 sites)	Cs-134	31.3	9
	Cs-137	59.9	9
	La-140	61.8	50
	Ru-103	17.2	30
	Nb-95	3.5	35
1986-11-04--05	Cs-134	31.4	38
(16 sites)	Cs-137	54.3	38

Gamma spectrometric measurements were also performed on a relatively homogeneous surface to study the variations in a larger scale. A gridnet with the gridpoints 50 m apart was chosen. The number of points was nine. The result is shown in Table 3.2.3. The coefficient of variation is around 30 %.

Table 3.2.3 Surface deposition (kBq/m^2) in grid net (3x3 sites, 50 m separation), Gideå. Reference data 1986-04-28. Measuring time: 2000 seconds.

Nuclide	Min	Max	Uncertainty (1 sigma %)	Mean	Coefficient of variation (%)
I-131	230	750	10	470	31
Ru-103	10	22	8	15	23
Cs-137	39	95	3	58	27
Cs-134	22	53	3	32	28
Nb-95	1.3	4.2	10	2.8	32
La-140	13	73	15	52	33

In Figure 3.2.2 the variation in activity between the two periods for site G11, outcrop, is shown. The activity of cesium is almost the same, while there is a decrease of 60-80 % for site G15, shallow peat on till, see Figure 3.2.3.

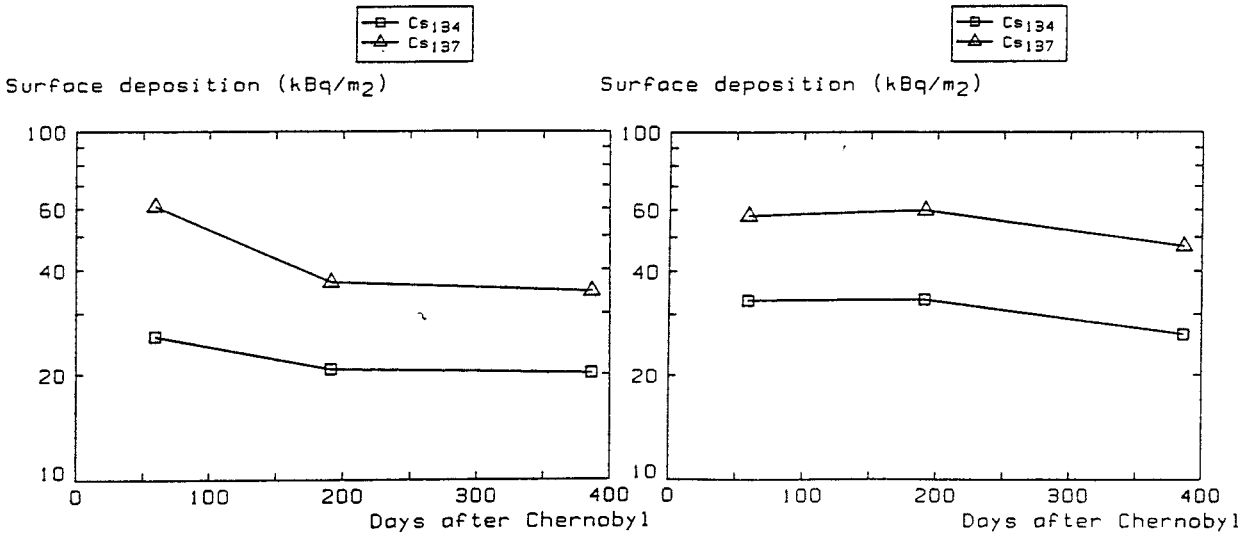

Fig 3.2.2 Surface deposition site G11, outcrop, 1986.

Fig 3.2.3 Surface deposition site G15, shallow peat on till, 1986.

In Appendix C.1 it is shown how a decrease of photon fluence between two measurement occasions could be interpreted as an increase of the relaxation length or the half value depth of the soil profile. A decrease of 10 % of the photon fluence will correspond to an increase of the half value depth by 30 %. A source of uncertainty is the change of density of the upper soil layer due to change of water content, which will cause a equivalent reduction of the photon fluence.

The gamma spectrometric measurements in situ will only give the radiation pattern in a mesoscale. However, it is important to know the variations in a micro scale also. These variations in a microscale will give information of the initial deposition pattern and the redistribution after the deposition. One way to study this, in a simple way, is to measure the exposure rate (uR/h). The measurements were carried out by following two perpendicular lines, meeting at the spectrometer site. Complementary measurements, randomly distributed in the quadrants were also done.

The exposure rate at the different sites was measured in November, by large volume scintillation detector, and the results are presented in Table 3.2.4. The variation within the sites is smaller than that between the sites, CV is equal to 10 and 20 % respectively.

Table 3.2.4 Exposure rate (uR/h), Gideå study site, November 1986.

Site	G1	G2	G4	G6	G7	G8	G9	G10	G11	G12	G13	G15	G22	G23	G24	G25	Mean	CV
uR/h	24.2	27.4	23.5	24.3	23.6	13.4	21.9	24.0	25.4	19.4	19.3	18.0	22.4	22.4	35.5	23.8	23.0	20%

The exposure rate was also measured along a 800 m line from site G9 to G22, see Figure 3.2.4. The measurements were done every two metres, at a height of 0.7 m above the ground. These measurements represent the exposure rate including the natural background radiation.

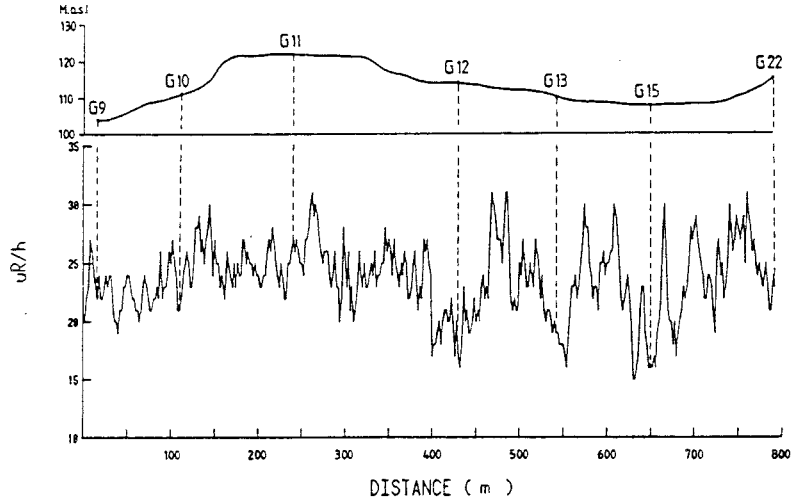

Figure 3.2.4 Exposure rate along a 800 m line from site G9 to G22. Measured every two metre, at a height of 0.7 m above the ground.

The background values for the Gideå area are about 8-10 uR/h, obtained from the content of uranium, thorium and potassium-40 in soil and bedrock. In Figure 3.2.4 the values are shown and the seven different sites are marked. The increased average 23.6 uR/h (CV = 13 %) is due to the surface deposition.

In Figure 3.2.5 an example from a "hot spot" is shown. The two curves are perpendicular to each other. The exposure rate above the "hot spot" is about two times as high as in the surroundings.

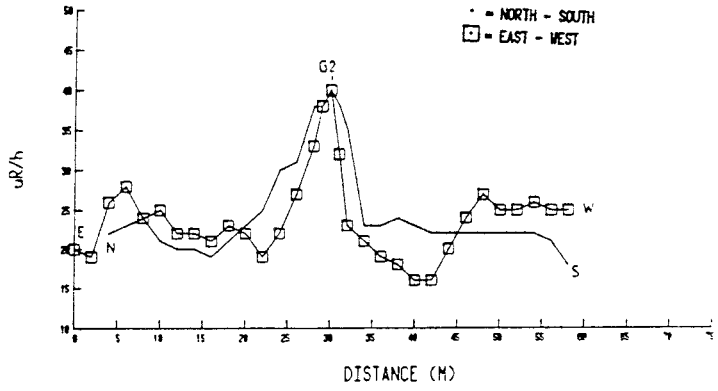

Figure 3.2.5 Exposure rate along to perpendicular lines (north-south and east-west) intersecting at site G2. Measured every two metres, at a height of 0.7 m above the ground.

In Figures 3.2.6 and 3.2.7 the exposure rate from a outcrop area partly covered with lichen is shown. The two lines are perpendicular to each other and meet at the cross. It is evident that the lichen holds higher content than the outcrop, especially in the lower part of the outcrop area, the right side of the figures.

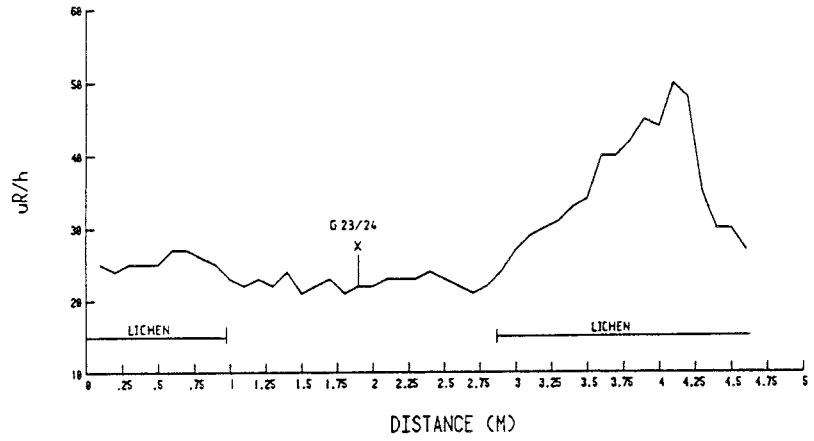

Figure 3.2.6 Exposure rate from a outcrop area partly covered with lichen at site G23/24.

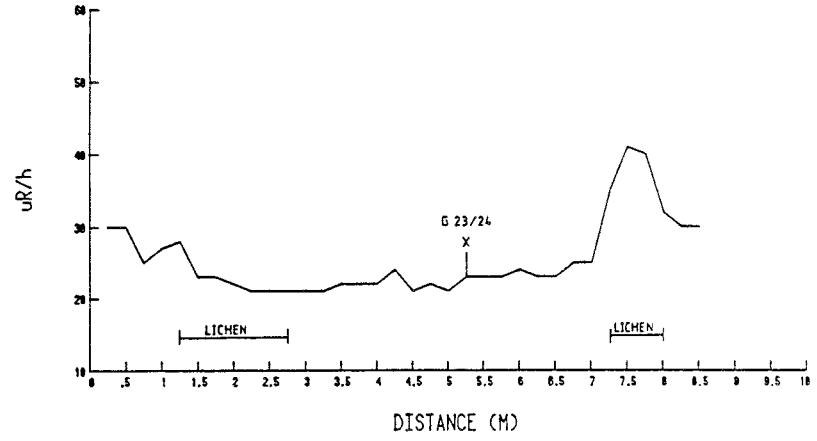

Figure 3.2.7 Exposure rate from a outcrop area partly covered with lichen at site G23/24.

To get a statistical value of the variation of the radiation pattern is to study the covariation between adjacent points in a series of values. This is done by calculation of the autocorrelation of the series. The result from these calculations is presented in Figures 3.2.8 and 3.2.9.

The autocorrelograms in Figure 3.2.8 correspond to the line G9 - G22, with the measuring point distance of 2 metres, see Figure 3.2.4, and two perpendicular lines at site G2, point distance 1 metre, see Figure 3.2.5, respectively. The interpretation of the correlogram is that points within 25 to 30 meters, in line G9 to G22, are correlated at the 95% confidence level. The corresponding distance is 3 to 4 meter for site G2.

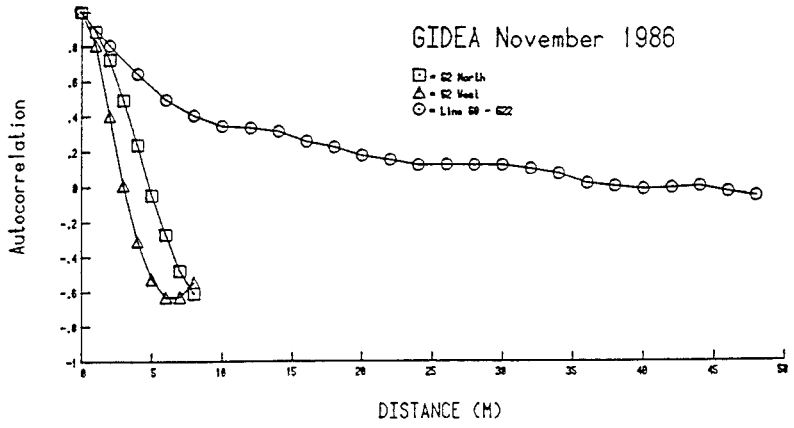

Figure 3.2.8 Auto-correlograms corresponding to the exposure rate along the line G9 - G22 (Fig. 3.2.4) and the perpendicular lines at site G2 (Fig. 3.2.5).

These two examples of correlograms presented in Fig. 3.2.8 represent two different radiation patterns. One pattern with big differences within a short distance and the other with a more slowly fluctuating pattern.

Another way to measure gammaradiation, in macroscale, is by an airborne divice. This has earlier been done in different parts of Sweden for prospecting purposes. Unfortunately no measurements have been performed directly over the Gideå site. However, an area only 5 km north-east of the site and with the same type of bedrock has been measured prior to the Chernobyl accident in 1984 by Swedish Geological Company.

Results from these flight-lines are presented for thorium and uranium (potasium was negligible) together with line G9 - G22.

The correlation for the measurements from the airborne device is higher, as can be expected because of the difference in resolution. However the line G9 - G22 can be divided into two parts. The first part, representing the point difference of 0 to 15 meters, has a fast decline. The second part, point separation greater than 15 metres, has a slower decline comparable to the flight-line correlogram. The interpretation of this can be that the first part reflects the deposition pattern superpositioned on the background correlation from the bedrock, corresponding to the second part of the correlogram.

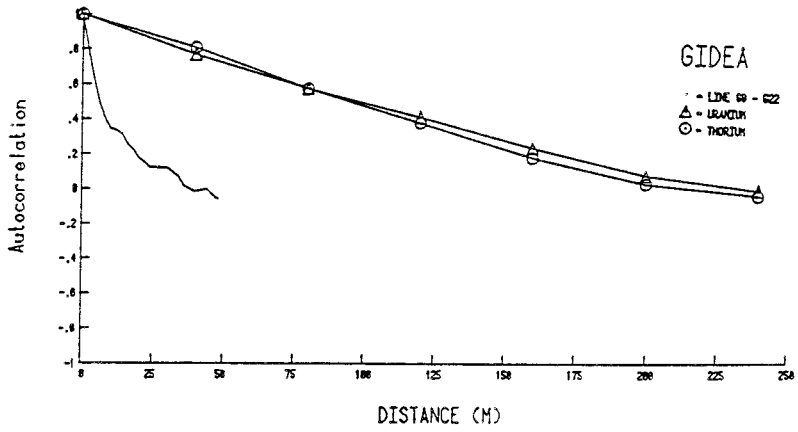

Figure 3.2.9 Auto-correlograms corresponding to the exposure rate along the line G9 - G22 and flight-lines for uranium and thorium.

The correlogram can be locked upon as a "finger-print" of the radiation pattern. Repeated measurements and calculation of the autocorrelation can describe the redistribution of the gamma emitting nuclides.

3.3 Soil Profiles

The use of soil profiles is twofold. Firstly, they provide a direct measure of the activity distribution in the soil, from which the relaxation lengths and half value depths can be estimated. These data can be compared with each other and with literature data, and they provide a foundation for a discussion of transport mechanisms.

Secondly, soil profiles have been used in comparison with the gammaspectrometric measurements in situ for estimation of the absolute surface deposition. The technique of soil sampling and the comparison with the spectrometric measurements are described in detail in Appendix C.2.

Soil profile samples have been taken in June, October and November 1986. The sites are presented in Figure 3.3.1.

Site	Description
G1	Till covered by moss and grass
G2	Gravel plane at road cut
G3	Moor
G4	Till covered by moss and grass
G5	Fen, with sphagnum peat
G6	Shallow till and outcrop
G7	Outcrop at borehole H22, with thin soil cover (5 cm)
G8	Peatland, outside the catchment area, 700 m to the east
G15	Peat,on clay
G36	Till
G45	Till
G46	Till
G47	Gravel

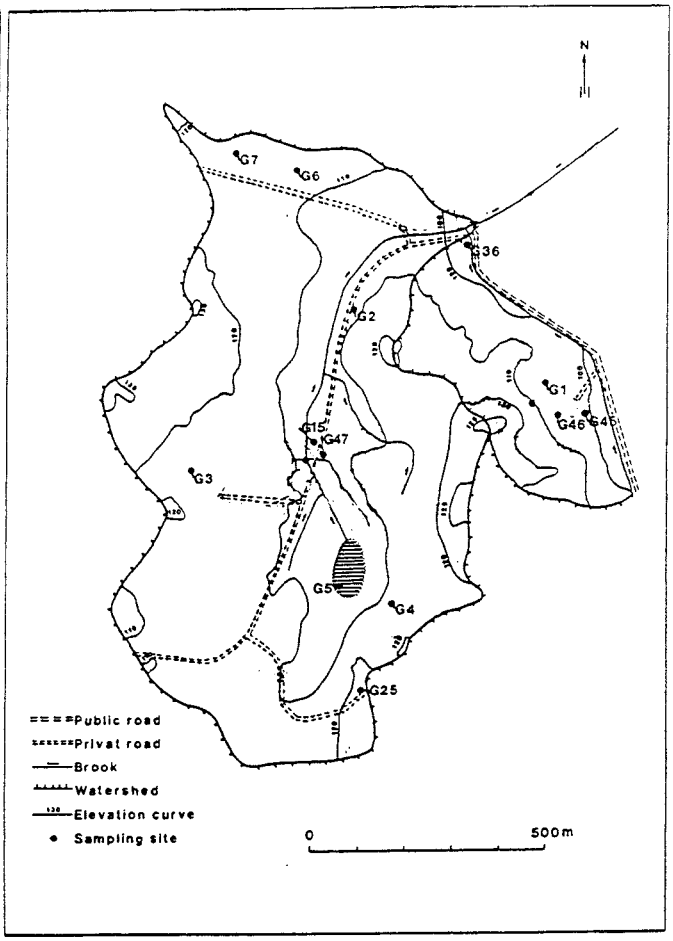

Figure 3.3.1 Soil profile sampling sites, Gideå study site.

Site G15 sampled in June and November and sites G1, G2, G3, G4, G6, G7 and G8 sampled in October coincide with sites for gamma spectrometric measurements in situ. The activity of the samples are presented in Tables 3.3.1-3.3.3. Some of the radionuclides measured within the soil profiles are: Cs-137, Cs-134, Sb-125, Ru-106, Co-60, Ag-110m and in some cases also Zr-95. The results are exemplified in Figures 3.3.2-3.3.12 showing soil activity profiles.

The results show that the nuclides migrate faster in peat than in till and sand. In till and sand profiles most of the nuclides are caught in the vegetation and the raw humus layer. However, a migration into the mineral soil can be detected.

The activity ratios are very useful to compare the distribution and migration of the nuclides. A small decrease in the Cs-134/Cs-137 ratio can be observed versus depth, from 0.53 to 0.43, indicating old bomb-test derived Cs-137 still present in the soil. In the profiles Sb-125, Ru-106 as well as Co-60 mostly exhibit increased values related to Cs-137 versus depth. This increase does not apply to the Cs-134/Cs-137 ratios indicating a faster and different manner of migration for the other nuclides compared to cesium. This difference is more pronounced in the till and sand profiles compared to the peat.

The soil profile measurements from site G15 and G36 have been used for curve fitting with least square approximations to different analytical functions, exponental and power curve together with direct integration of the total activity in the different layers. The results are presented in Table 3.3.4.

Direct integration provides the best estimate of the total activity, used for comparison with the spectrometric measurements, and the power and exponential curve have been used for estimation of the half value depth. The power function provides the best fit to the experimental data, for sites G15 and G36 indicating other transport mechanisms than pure diffusion. The uncertainty in curve fitting is however high, due to the limited number of data.

Table 3.3.1 Activity in soil profile samples (Bq/kg d w) from Gideå study site. Sampling 1986-10-18--19. Reference date same as sampling date.

Number	Sample description	Date of sampling	Date of analysis	Depth (cm)	Area (m2)	pH	% H2O	Dry wght	Geom	Wght (g-a)
1	G1, Litter fall incl. surface vegetation (moss, grass, twigs).	861018	870207	0-7	,0625		82,30	53,90	M 500	48,60
2	Root carpet, rawhumus	861018	870207	7-10	,0625	4,45	80,90	87,60	M 500	73,90
3	Rawhumus	861018	870207	10-12	,0625		77,60	134,30	M 500	126
4	Rawhumus	861018	870208	12-14	,0625		78	283,40	M 500	138
5	Rawhumus incl. gravelly till.	861018	870313	14-16	,0625		72	334	M 500	198
6	Gravelly till	861018	870313	16-22	,0225	4,45	34,90	1190,60	M 500	657,80
7	G2, Litter fall incl. surface vegetation (grass).	861018	870216	0-4	,0625		77,30	109	M 500	96,50
8	Root carpet, rawhumus	861018	870217	4-7	,0625		68,50	242,50	M 500	189,70
9	Rawhumus	861018	870214	7-10	,0625	4,50	52	356,80	M 500	329,60
10	Sand - bleached horizon	861018	870214	10-12	,0625		20,20	980	M 500	781
11	Litter fall incl. surface vegetation (grass)	861018	870215	0-10		4,50	47,30	295,70	M 500	295,70
12	Sand - bleached horizon	861018	870227	10-17		4,60	11,70	908,90	B 250	479
13	Sand - bleached horizon	861018	870228	17-25		4,90	27	753,40	B 250	457,20
14	Sand - enrichment layer	861018	870228	25-37		4,90	24,30	753,60	B 250	482
15	Sand - enrichment layer	861018	870301	40-48		5,10	56,90	430,30	B 250	380
16	Sand - bleached horizon	861018	870302	50-51		5,10				
17	G3, Sphagnum sp. incl. vegetation (heather, twigs).	861018	870213	0-8	,0625		94,30	44	M 500	37
18	Sphagnum peat	861018	870213	8-15	,0625		92,50	110,50	M 500	45
19	Sphagnum peat - degree of decomposition H3'	861018	870214	15-18	,0625		92,10	153,80	M 500	62,30
20	Sphagnum peat - degree of decomposition H3'	861018	870216	18-22	,0625		94	116,50	M 500	86
21	Sphagnum peat - degree of decomposition H3'	861018	870215	22-27	,0625		95,70	91,70	M 500	88
22	Water sample from groundwater surface.	861018	870326	27-		4	100		M 500	363
23	Residue* from water sample above (22) presented in (Bq/l water).	861018	870328	27-					B60	363
24	G4, Litter fall incl. surface vegetation (grass, moss and lingonberry twigs).	861019	870218	0-4	,0625		73,40	86,20	M 500	77,40
25	Root carpet incl. some stones, rawhumus	861019	870219	4-8	,0625	4,60	51,20	470	M 500	248,50
26	Rawhumus	861019	870219	8-12	,0625	4,70	49,50	699,30	M 500	328
27	Stony sandy till - enrichment layer	861019	870219	12-16	,0625		19,40	1074	M 500	806
28	Stony sandy till - enrichment layer	861019	870219	16-24		4,90	12,80	1063,20	M 500	982
29	G5, Sphagnum sp.	861019	870223	0-10	,0225	3,60	95,10	44,40	M500	30
30	Sphagnum peat - degree of decomposition H2-H3'	861019	870222	10-20	,0225		93,60	44	M500	44
31	Sphagnum peat - degree of decomposition H2-H3'	861019	870222	20-30	,0225		94,90	39,30	M500	39,30
32	Sphagnum peat - degree of decomposition H2-H3'	861019	870221	30-50	,0225		95,70	37	M500	35
33	Sphagnum peat - degree of decomposition H2-H3'	861019	870220	50-70	,0225		95,70	39,60	M500	39,60
34	Sphagnum peat - degree of decomposition H2-H3'	861019	870219	70-90	,0225		96,70	32	M500	32
35	G6, Litter fall incl. surface vegetation (lichen, moss, heather twigs).	861019	870211	0-2	,0625		35,50	234	M 500	114
36	Rootcarpet, rawhumus	861019	870211	2-4	,0625		58,70	170,30	M 500	161
37	Rawhumus	861019	870216	4-5	,0625		45,10	205,90	B 250	187,60
38	Sandy till - bleached horizon	861019	870212	5-6	,0625	4	20,10	717,80	M 500	676,80
39	Sandy till - bleached horizon	861019	870212	6-8	,0625		21,40	898,90	M 500	780
40	Sandy till - (bleached horizon) + enrichment layer.	861019	870325	8-10	,0625	3,90	21,10	1399	M 500	684
41	Gravelly till - enrichment layer.	861019	870324	10-13	,0625	4,80	17,40	1379	M 500	831
42	Gravelly till - enrichment layer.	861019	870213	11-21			10,20	1180	M 500	1072,80
43	G7, Litter fall incl. vegetation (lichen).	861019	870220	0-2	,0625		74	182,70	B 250	115,50
44	Rawhumus	861019	870220	2-3.5	,0625		56,30	389	B 250	223
45	Rawhumus	861019	870220	3.5-4.5	,0625	4,20	48,60	420,70	B 250	243,50
46	G8, Sphagnum peat - cultivated, drained.	861019	870301	0-10	,06		79,70	478,40	M 500	90,40
47	Sphagnum peat - cultivated, drained.	861019	870225	10-20	,0625		78,40	642,60	M 500	76,60
48	Sphagnum peat - cultivated, drained.	861019	870301	20-30	,0625		86,50	413	M 500	76,40
49	Sphagnum peat - cultivated, drained.	861019	870302	30-40	,04		88,50	343,20	M 500	100,30
50	Sphagnum peat - cultivated, drained.	861019	870227	40-50	,04		87,60	398	M 500	172
51	Sphagnum peat - cultivated, drained.	861019	870226	50-60	,04	3,70	85,40	447,30	M 500	241,30

' According to von Post (1921).
* Filter paper, retention 25 um.

Table 3.3.1 cont. Activity in soil profile samples (Bq/kg d w) from Gideå study site. Sampling 1986-10-18--19. Reference date same as sampling date.

Number	K-40	Unc	Mn-54	Unc	Co-60	Unc	Zr-95	Unc	Ru-103	Unc	Ru-106	Unc	Ag-110m	Unc	Sb-125	Unc	Cs-134	Unc	Cs-137	Unc	Ce-144	Unc
1	12,50	12,60	,60	37	1,09	31,40	5,21	19,50	8,55	41,20	27,56	18,10	5,44	17,90	10,56	14,50	173,10	,60	375,10	,40		
2	15,21	6,60	,38	49,10	1,03	20,50	5,33	13	15,70	10,90	50,69	5,10	2,11	28,80	9,39	7,90	146,60	,40	325,50	,30		
3	19,86	3,50	,31	37	,95	13,80			6,96	14,40	16,85	9			7,54	7	122	,30	275,30	,20		
4	17,50	7,60			,38	42,30					5,73	21,10			1,47	40,40	34,56	1,30	79,35	,80		
5	9,11	32									2,75	60,90	1,52	40,90			6,27	5,30	20,18	2		
6	143,60	5,60	,54	45									1,11	49,50					13,81	2,60		
7	30,06	6,10			1,92	20,50			12,33	28,20	20,20	24,30			8,10	20,30	245	,50	560,70	,30		
8	85,54	4,50			,82	52,30					6,87	37,70			5,93	30,30	141,20	,90	344,60	,60		
9	187,50	3									10,23	30,60			2,46	36,70	38,77	1,80	111,10	,90		
10	641	,50	,16	72,90	,20	62,70					3,99	24,50			1,06	,27	18,12	1	64,78	,40		
11	176,20	1,90	,87	34,40	2,06	17,10					23,75	18,20	3,39	15,80	6,07	22,80	275,20	,40	649,50	,20		
12	377,70	1,80															4,29	7,90	11,83	3,30		
13	301,20	2,40																	1,08	20,90		
14	343	,90																	,34	26,70		
15	259,70	2,90																				
16																						
17	15,61	11,90			1,17	33,80					12,52	23,30	4,31	20,20	7,86	18,50	161	,70	365,30	,50		
18	10,79	4,90			,21	33,90					4,12	20,40			1,65	15,20	25,13	,70	57,23	,50		
19	9,63	12,20									5,52	22,90			1,55	44,80	23,36	1,90	56,94	1,10		
20	10,09	11			,34	44,70			4,59	35,60	13,42	16			3,30	19,50	35,65	1,30	81,73	,80		
21	10,52	13,60			,26	72,90					9,99	23,50			2,17	31,70	24,89	2	59,91	1,20		
22																			,36	29,80		
23					,11	75,80					3,19	28,40			,56	41	6,94	2,20	15,60	1,20		
24	17,89	10,30			2,96	21,20			27,83	22,20	54,71	14,20	20,06	7,10	22,55	10,50	385,50	,50	845	,30		
25	135,50	3,50			,87	50,10	5,95	27,70					3,90	67,30	5,55	24,30	118,60	1	288,40	,60		
26	162,10	3,30			,32	89					4,11	39,40					24,76	2,80	64,76	1,30		
27	674,20	1,40																	30,16	1,80		
28	871,80	,90	,44	66,70											,79	69	2,48	15,40	7,69	3,60		
29	17,98	9,60			,60	40,40							1,87	83,60			51,97	1,30	125,50	,80		
30	12,44	5											,42	65,90	,43	41,20	5,78	2,10	18,09	1		
31	7,38	8,20											,15	89,20			,83	8,60	2,83	3,20		
32	5,02	19,80															,42	19,10	1,90	6,70		
33	6,65	7,80															,39	13,20	1,25	4,20		
34	7,33	7,30									,92	31,90	,09	87,60			,33	16,90	,93	5,90		
35	20,85	10,20	1,96	37,80	6,58	13,50	6,91	47,10	24,40	36,60	78,31	8,30			34,84	10,80	1054	,30	2327	,20		
36	54,94	2,10	,68	23,50	2,01	11			6,27	34,80	27,46	5,50			11,41	7,80	299,50	,20	688,40	,20		
37	95,08	2,20	,25	77,20	,55	34,60					10,91	12,90			3,26	19,50	107,30	,50	239,70	,30		
38	640,10	1,50			,55	66,80											52,42	1,40	139,30	,80		
39	808,10	1,20															24,24	2,40	82,46	,90		
40	338,20	1,90	,78	36,90	,35	72,50							1,71	40,90	,53	83,50	10,87	3,20	45,21	,90		
41	529,10	,90									2,87	60,50	,85	51,10	,71	52,30			27,58	1		
42	918,40	1,10									6,94	48,10			2,16	30,90			30,86	1,70		
43	33,04	10,50			10,18	14			39,21	47,50	142,40	13,60	32,27	10	34,99	17,60	2209	,20	4967	,10		
44	87,60	5,90			7,98	19					52,74	24,20	16,37	23,40			1834	,30	4175	,20		
45	102,30	5			4,28	26,40					54,77	32,80	12,03	37,80	17,41	26,80	956,60	,40	2184	,20		
46	12,40	13,30			,60	49,30					10,60	39,20	4,16	23,90	4,44	24,90	63,88	1,40	160	,80		
47	6,44	10,30									1,04	45,70					2,32	3,70	12,33	1,20		
48	8,91	7,30															,53	11,70	9,50	1,40		
49	7,01	16																	6,72	2,80		
50	10,05	5,40									,74	49,60							4,97	1,70		
51	9,02	7,30									,82	38							2,98	3		

Table 3.3.2 Activity (Bq/kg d·w) in soil profile samples, taken 1986-06-25--26.
Reference date 1986-04-28.

No.	Site	Type	Depth (cm)	Area (m^2)	Water content (%, ww)	Organic content (%, dw)	Zr-95	Ru-103	Ru-106	Ag-110m	I-131	Cs-134	Cs-136	Cs-137	Ba-140	Ce-141	Ce-144
9	G15 B	Grass			76		1.17E3	1.13E3	3.00E2			1.32E3		2.52E2	2.40E3	1.03E3	1.10E2
6	"	Peat	0-3		65			4.20E2			1.30E3	7.87E2		1.57E3			1.00E2
7	"	"	3-10		56			3.20E2				7.85E1		1.54E2			
8	"	"	10-20		72			1.42E1				1.98E1		2.83E1			
1	G36 A	Litter	0-2	0.075	13		7.4E1	1.66E3	7.47E2	8.0E1	5.56E4	4.65E3	2.25E2	8.99E3	6.0E3	1.9E1	1.71E2
2	"	Raw humus	2-4	0.025	8			9.70E1			1.90E3	1.61E2		3.15E2			
3	"	Humus	4-6	0.025	14			6.54E1				1.77E2		3.46E2			
4	"	Soil,eluvial	10-13	0.025	5			3.27E1				2.52E2		4.55E2			
5	"	" ,illuvial	20-23	0.025	6			6.55E1				1.79E2		3.67E2			
12	G45 K	Grass		0.5	76	13	2.41E2	2.74E3	8.66E2	1.70E2		3.02E3	5.57E3	6.72E3	8.30E2		
21	G45 L	Litter/grass			53			1.66E3	5.12E2	3.90E1	4.30E4	2.32E3		4.44E3			
27	"	Soil	3-6	0.045	17			3.41E2	1.15E2		8.50E3	2.77E2		5.40E2			
25	G46 K	Soil/moss	0-3	0.045	58		1.33E2	1.13E3	2.66E2			1.31E3		2.60E3			
26	"	Soil	3-6	0.090	33			1.08E2	4.75E1			1.27E2		3.36E2			
28	G47 N	Gravel			57			4.16E1	2.58E1			6.66E1		1.22E2			

Table 3.3.3 Activity (Bq/kg d·w) in soil samples, taken 1986-11-04--05. Reference date 1986-04-28.

No.	Site	Type	Depth (cm)	Water content (%, ww)	Cs-134	Cs-137	Cs-134/ Cs-137
201	G15	Peat	0-3	69	2.4E3	4.2E3	
202	"	"	3-4.5	74	3.2E2	2.1E2	
203	"	"	4.5-6	69	4.4E2	3.3E2	
204	"	"	6-11	68	<6.0E1	6.4E2	
205	"	"	11-16	72	3.5 E1	1.5 E2	
206	"	Clay	16-21	35	<2.0 E1	2.0 E1	
207	"	"	21-25	20	1.1 E2	1.0 E2	
208	G15:2	Peat	0-1	69	1.4E3	3.0E3	
209	"	"	1-2	68	1.8E3	2.5E3	
210	"	"	2-3	77	4.5E2	1.1E3	
211	"	"	3-5	73	3.0E2	1.1E2	
212	"	"	5-7	71	3.0E2	9.4E2	
213	"	"	7-10	74	<2.0E1	1.1E2	
214	"	"	10-13	63	<2.0E1	1.3E2	
215	"	"	13-16	67	<2.0E1	7.0E1	
216	"	Clay	16-19	60	<2.0E1	<2.0E1	
217	"	"	19-22	54	<2.0E1	<2.0E1	
218	G36	Litter	0-2	59	4.0E3	6.7E3	
219	"	"	2-3	57	3.2E3	6.0E3	
220	"	Till	3-4.5	60	1.7E3	2.0E3	
221	"	"	4.5-5.5	59	2.5E2	1.1E3	
221A	"	"	5.5-6.5	61	1.5E2	4.7E2	
222	"	"	6.5-7.5	55	<2.0E1	2.2E1	
223	"	"	7.5-11	23	<2.0E1	3.5E1	
224	"	"	11-13.5	31	<2.0E1	<2.0E1	
225	"	"	13.5-18.5	56	<2.0E1	<2.0E1	
226	"	"	18.5-23	20	<2.0 E1	<2.0 E1	

Table 3.3.4 Soil profile evaluation. Spectrometer estimation of activity based on an efficiency with 1/alpha = 2.0. Least square approximation with large weights on upper layer points. A zero value for quotient SPEC/SAMP means that no spectrometer measurements was available.

SITE	TIME	NLAY	NUCL	EXPONENTIAL PROFILE SURF ACT. (BQ/KG)	D 1/2 (CM)	INT. ACT. (BQ/M2)	R2	POWER PROFILE SURF ACT. (BQ/KG)	D 1/2 (CM)	INT. ACT. (BQ/M2)	R2	DIRECT INTEGRATION INT ACT. (BQ/M2)	QUOT. SPEC/ SAMP
G 36	860625	5	CS134	2.17E+03	4.4	2.22E+05	.49	2.95E+03	1.8	3.05E+05	.78	2.40E+05	0.
			CS137	4.31E+03	4.8	4.74E+05	.46	5.70E+03	1.8	6.68E+05	.76	4.73E+05	0.
			RU103	1.41E+03	4.0	1.30E+05	.68	1.59E+03	1.9	2.20E+05	.80	1.04E+05	0.
G 15	860625	3	CS134	2.28E+02	3.6	1.91E+04	.91	4.43E+02	1.7	2.44E+04	1.00	2.07E+04	1.2
			CS137	7.33E+02	2.5	4.15E+04	.92	1.00E+03	1.6	3.57E+04	1.00	3.91E+04	1.6
			RU103	1.97E+02	2.9	1.32E+04	.85	2.53E+02	1.7	1.18E+04	.98	1.10E+04	1.1
G 36	861106	6	CS134	2.86E+03	1.7	1.14E+05	.86	1.95E+03	2.2	2.39E+05	.64	1.26E+05	0.
			CS137	4.96E+03	1.7	1.92E+05	.86	3.44E+03	2.1	1.12E+06	.66	2.41E+05	0.
G 15	861106	3	CS134	1.57E+03	1.3	4.64E+04	.85	1.37E+03	1.5	3.58E+04	.91	5.30E+04	.39
			CS137	2.92E+03	1.3	8.91E+04	.90	2.27E+03	1.7	1.07E+05	.83	8.64E+04	.43
G 15	861106	5	CS134	3.99E+02	-12.	1.13E+05	.03	4.47E+02	3.76E-06	6.78E+03	.01	1.26E+05	.16
			CS137	1.02E+03	2.5	6.00E+04	.76	6.95E+02	3.7	2.39E+04	.78	8.35E+04	.44

Table 3.3.5 Half value and quarter value depth in soil profiles, October 1986. Determined by curve fitting, with a logarithmic function, to experimental data from large area (25x25 cm) soil profile samples.

Site	Soil profile	# of points	Cs-134, 1/2-depth	1/4-depth	# of points	Ru-106, 1/2-depth	1/4-depth
G1	Till, medium, sandy (podsol)	4	7.2	9.0	4	7.2	9.3
G2	Sand	5	3.8	4.5	4	3.7	5.5
G3	Peat	3	5.5	11.1	2	10.3	27.2
G4	Till, coarse, gravel (podsol)	3	2.8	4.4	2	3.4	4.8
G5	Peat	4	7.6	10.7	0	---	---
G6	Till, medium, sandy (podsol)	6	1.7	2.5	4	0.8	2.9
G7	Organic-leachen	3	2.4	3.7	3	1.9	3.0
G8	Peat	3	6.8	9.8	2	5.4	16.1

The half value depths, presented in Table 3.3.4, are generally between 1 and 2 cm.

Half value and quarter value depths have also been determined in the soil profiles G1 - G8, from large area (25x25 cm) soil profile samples. Cs-134 and Ru-106 depths were calculated. The cesium isotope Cs-134 was chosen because it is not present in the soil before April 1986.

The depths have been determined by curve fitting to a logarithmic function which provided the best fit to the experimental data. The results are presented in Table 3.3.5. The 1/2-value depth is approximately similar for Cs-134 and Ru-106, except for the peat profile G3 where the 1/2-value depth was 5.5 and 10.3 cm respectively. The 1/2-value depth is approx. 7 cm in the peat profiles G5 and G8 and 4 cm in the till and sand profiles. Interestingly the 1/4-value is generally deeper for Ru-106, which is more pronounced in the peat profiles, indicating the existence of a fast migrating chemical form of Ru-106.

From the results presented in Table 3.3.4 and Figures 3.3.10-3.3.12 one can conclude that it is difficult to compare profiles, because of the variation in the initial surface deposition. Profile G36 shows that the activity has decreased by 50 % from June to November. The conditions are the opposite for profile G15, where an increase has been observed. The G15 and G15:2 profiles taken in November show a difference of a factor of two in spite of the fact that the profiles are taken only 0.5 m apart.

Thus, it is obvious that single profile samples are not enough for studying the migration of activity in soil, especially when the time development is in focus. Cumulative samples from 10-20 profiles, taken within a radius of a few meters will be another sampling technique, to be used in the future. This technique is being developed.

Surface activity at sites G1 - G8 determined from large area (25x25 cm) soil samples is presented in Table 3.3.6. The relative distribution (per cent) between the activity in the uppermost layer and the complete profile is also given.

The activity of soil and some vegetation samples from June 1986 is summarized in Table 3.3.7.The Cs-137 activity of the different soil layers (0-3 cm, 3-6 cm and 6-10 cm), lichen and grass is shown in the summary table as well as the activity ratio in relation to Cs-134.

The mean surface activity of Cs-137 is 5500 Bq/kg d w. This is equivalent to grass samples, while the lichen holds about 10 times higher activity.

In 1982 Studsvik AB (Sundblad and Bergström,1983) measured the activity levels at the Gideå study site. The Cs-137 content of the upper soil (0-25 cm) varied between 10 to 30 Bq/kg d w. The content in grass was 5 Bq/kg d w.

Table 3.3.6 Surface activity (kBq/m^2) in soil profile samples taken 1986-10-18--19.

Surface activity within Gideå area

				Activity kBq/m^2 (sampling date)										Ratio
Site	Date	Area	Depth	Zr-95	Ru-103	Ru-106	Ag-110m	Sb-125	Cs-134	Cs-137	Ce-144	Co-60	Mn-54	Cs-134/Cs-137
G1	861018	25x25 cm	0-22 cm	0.2	0.6	2.0	0.2	0.5	9.23	21.79		0.07	0.06	0.42
+			0-7 cm	48	27	24	47	34	33	30		29	0	
G2	861018	25x25 cm	0.12 cm		0.2	0.8		0.3	8.01	19.58		0.05		0.41
+			0-4 cm		100	49		46	55	52		65		
G3	861018	25x25 cm	0-27 cm		0.1	1.1	0.08	0.4	6.17	14.22		0.04		0.43
+			0-8 cm		0	22	100	39	50	49		53		
G4	861019	25x25 cm	0.16 cm	0.2	0.5	1.1	0.5	0.6	10.95	26.64		0.09		0.41
+			0-4 cm	0	100	87	75	71	60	56		59		
G6	861019	25x25 cm	0-13 cm	0.2	0.9	3.4	0.05	1.5	43.26	98.48		0.3	0.1	0.44
+			0-2 cm	100	88	75	0	78	80	78		77	61	
G7	861019	25x25 cm	0-4.5 cm		1.0	6.6	1.6	1.4	133.5	302.6		0.6		0.44
+			0-2 cm		100	55	51	65	42	42		43		
G8	861019	25x25 cm	0-60 cm			1.2	0.4	0.4	5.99	17.55		0.05		0.34
+			0-10 cm			81	100	100	94	80		100		

+ Percent activity within the first layer

Table 3.3.7 Summary of soil, lichen and grass samples taken 1986-06-25--26. Reference date 1986-04-28.

		Cs-137		Ratios to Cs-134							
Type	No. of samples	Mean	CV (%)	Cs-137	Zr-95	Ru-103	Ru-106	I-131	Ba-140	Ce-141	Ce-144
Soil (0-3 cm)	9	5 500	74	1.89	0.05	0.62	0.20	15	1.3	0.08	0.13
Soil (3-6 cm)	5	260	80	2.32	-	0.85	0.42	21	-	-	-
Soil (6-10 cm)	3	63	65	2.28	-	1.30	0.59	53			
Lichen	1	60 000	-	1.93	0.03	0.33	0.11	21	1.0	0.09	0.04
Grass	5	5 120	85	1.96	0.28	0.67	0.22		2.5	0.32	0.08

G 1

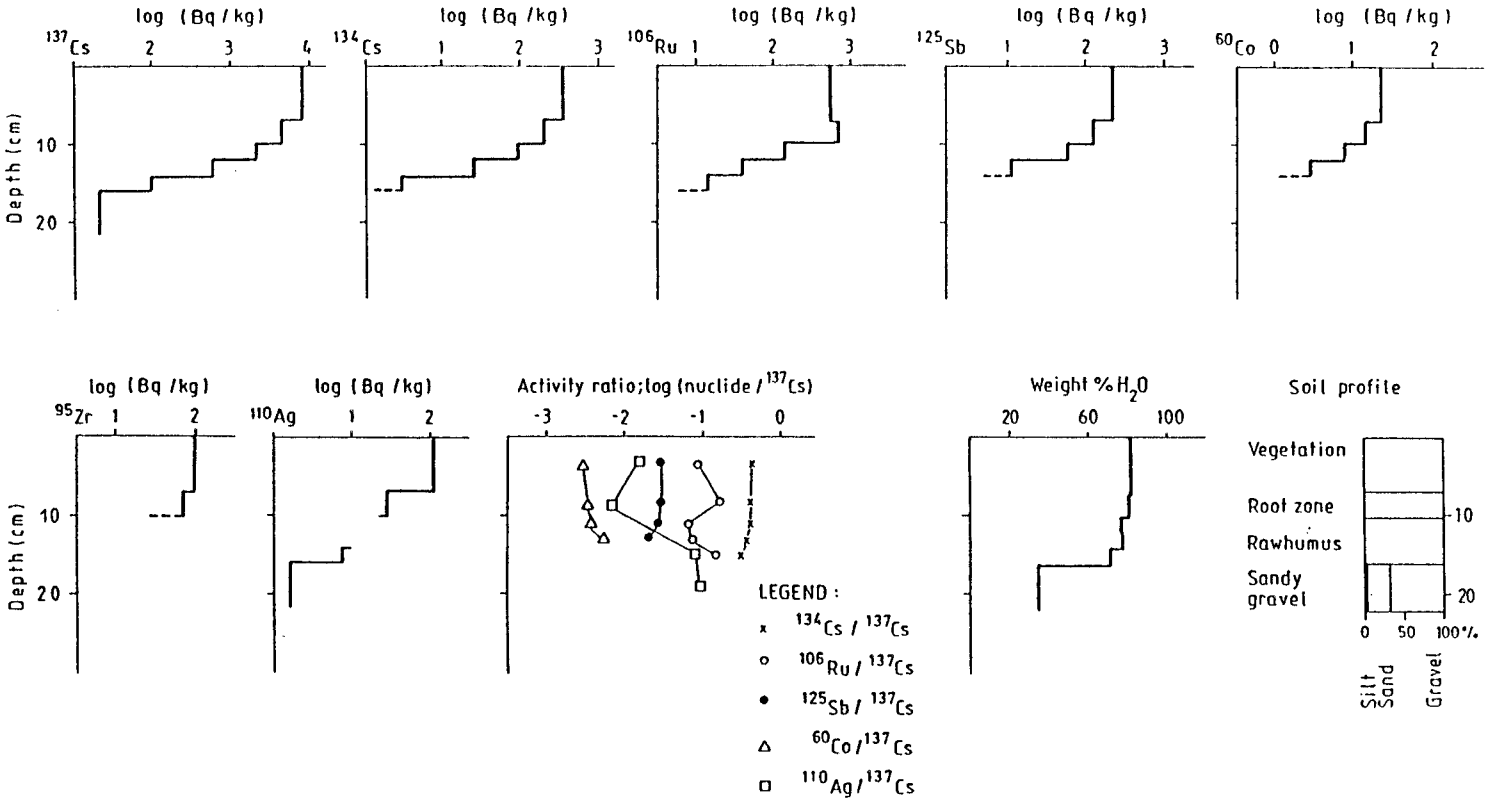

Figure 3.3.2 Soil profile at site G1. Sampling 1986-10-18.

G 2

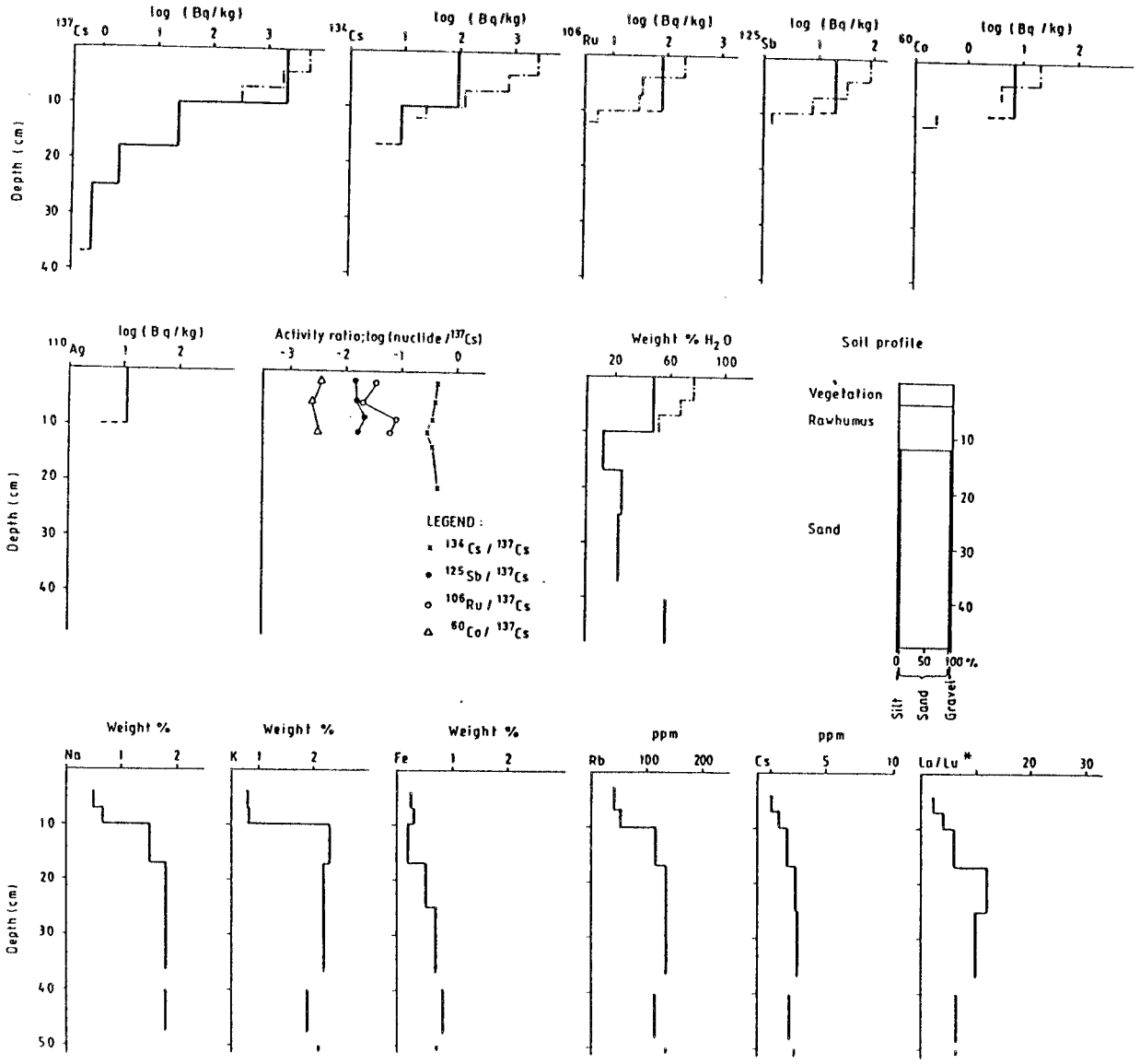

Figure 3.3.3 Soil profile at site G2. Sampling 1986-10-18.

G 3

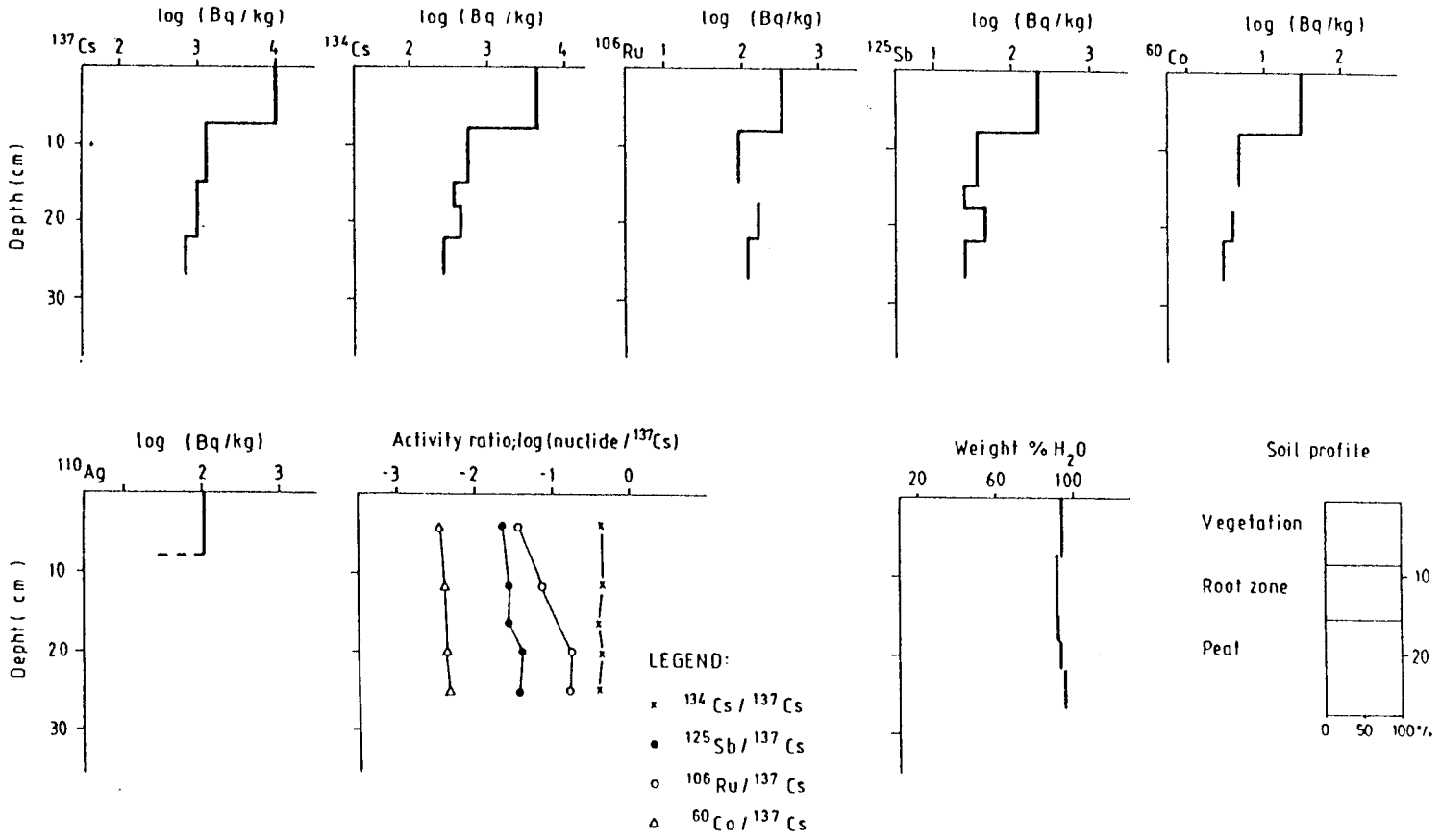

Figure 3.3.4 Soil profile at site G3. Sampling 1986-10-18.

G 4

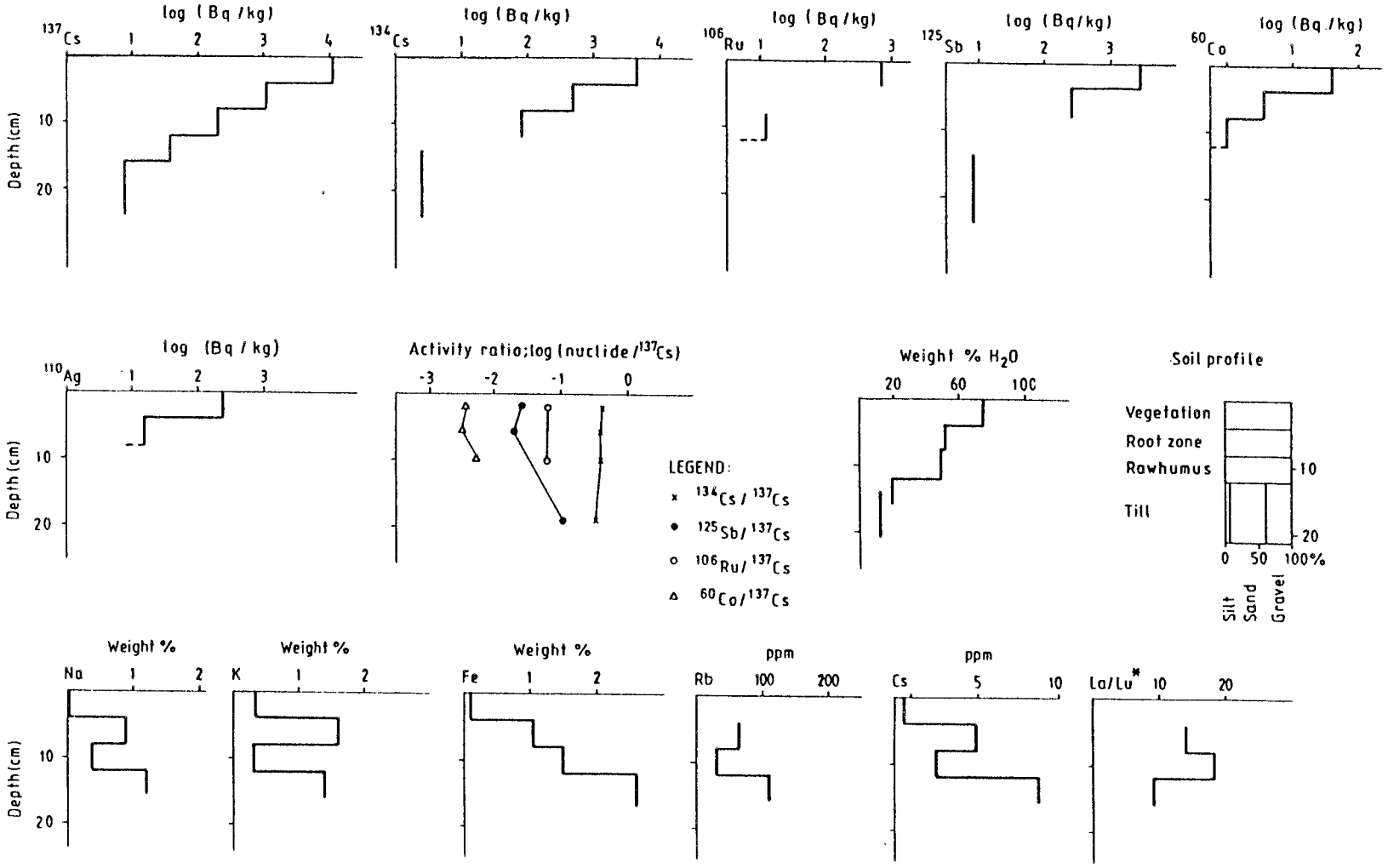

Figure 3.3.5 Soil profile at site G4. Sampling 1986-10-19.

G 5

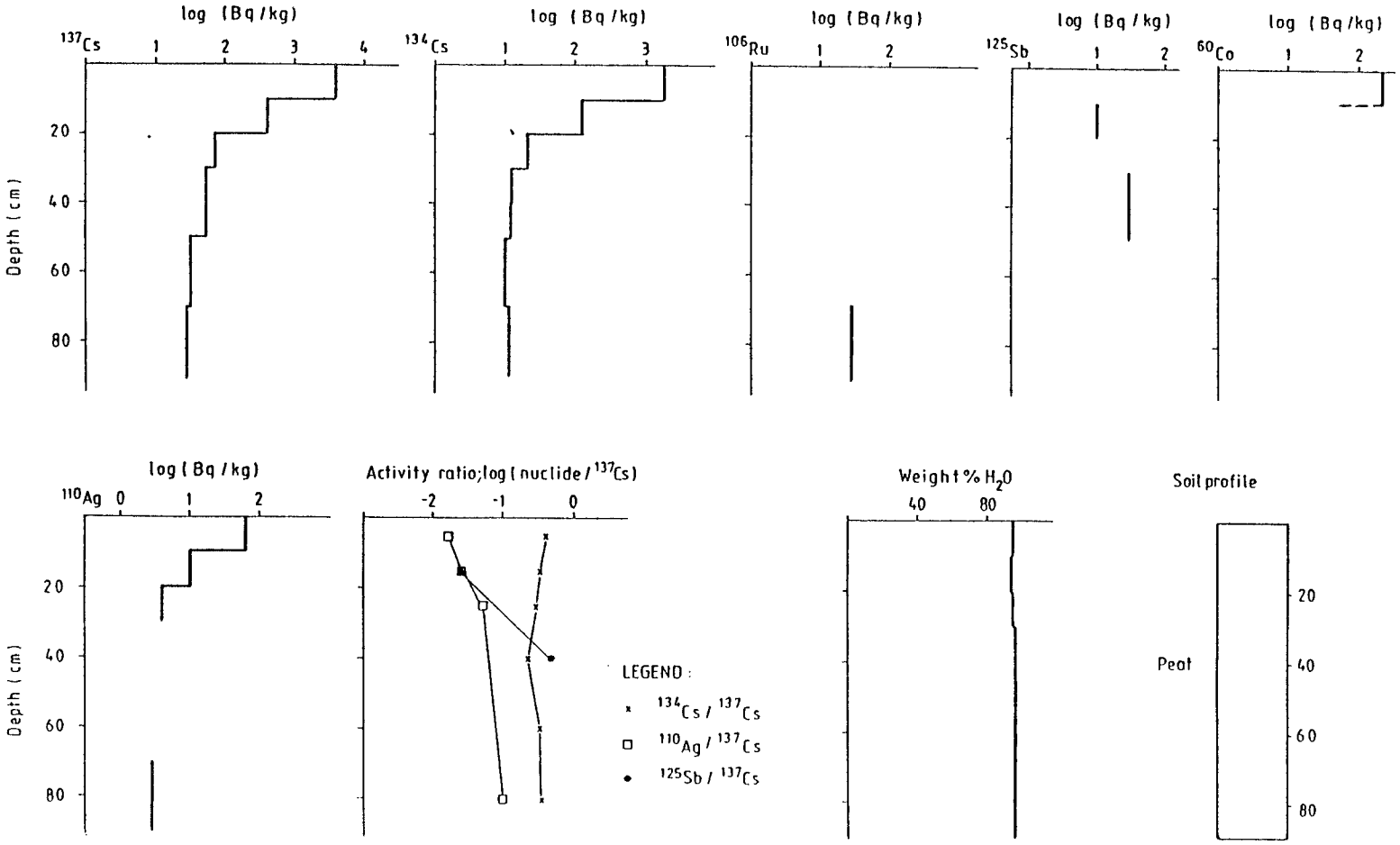

Figure 3.3.6 Soil profile at site G5. Sampling 1986-10-19.

G 6

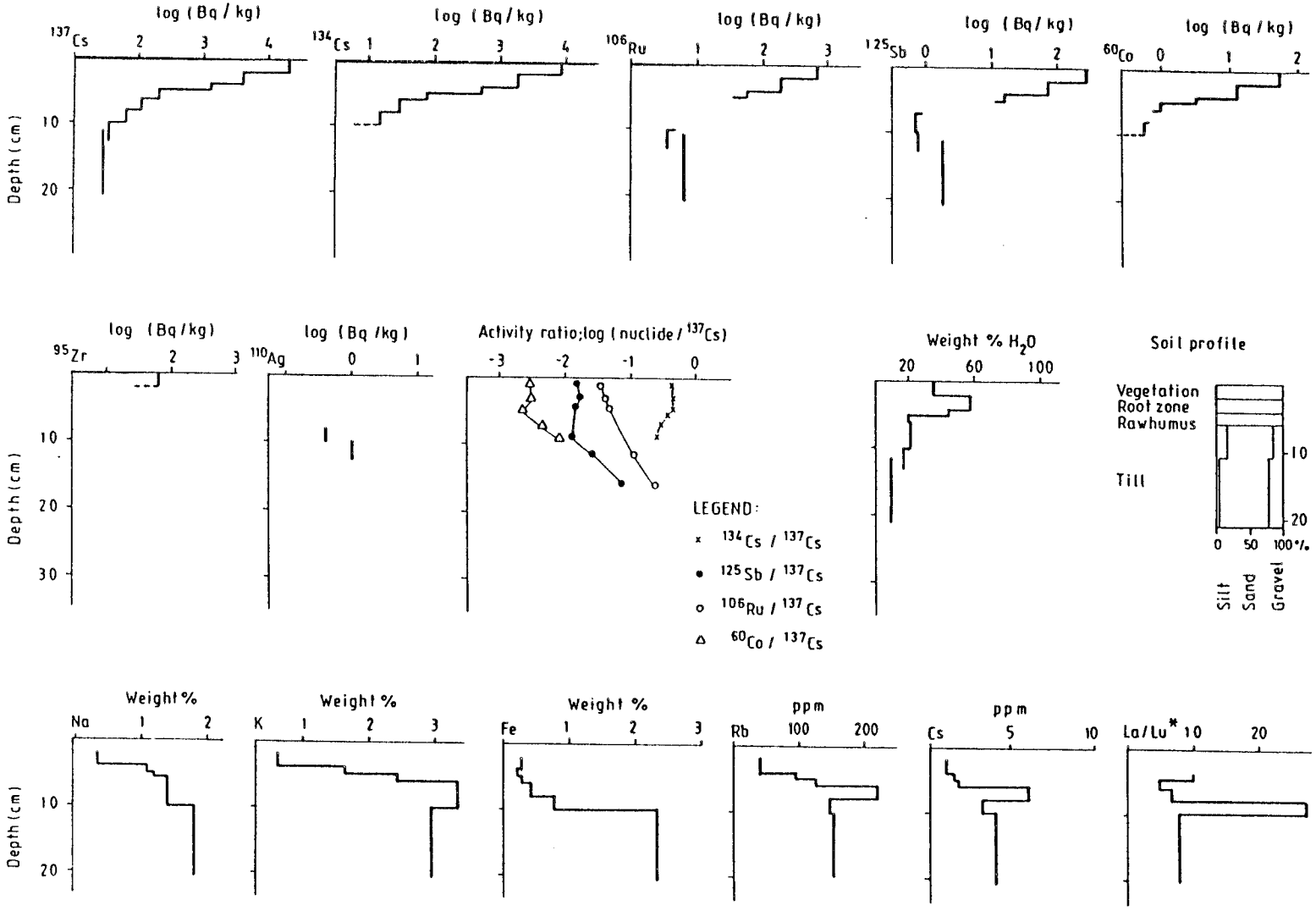

Figure 3.3.7 Soil profile at site G6. Sampling 1986-10-19.

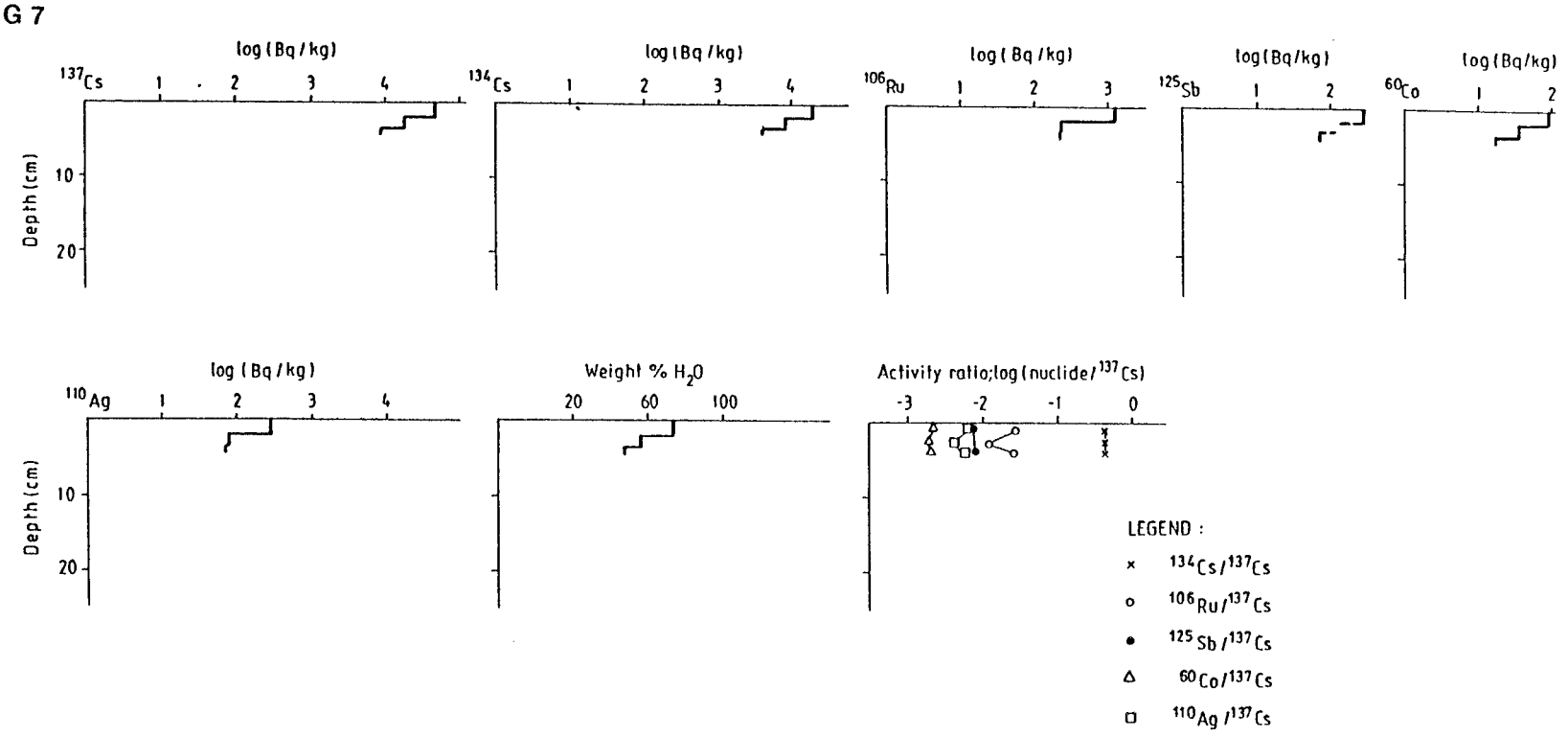

Figure 3.3.8 Soil profile at site G7. Sampling 1986-10-19.

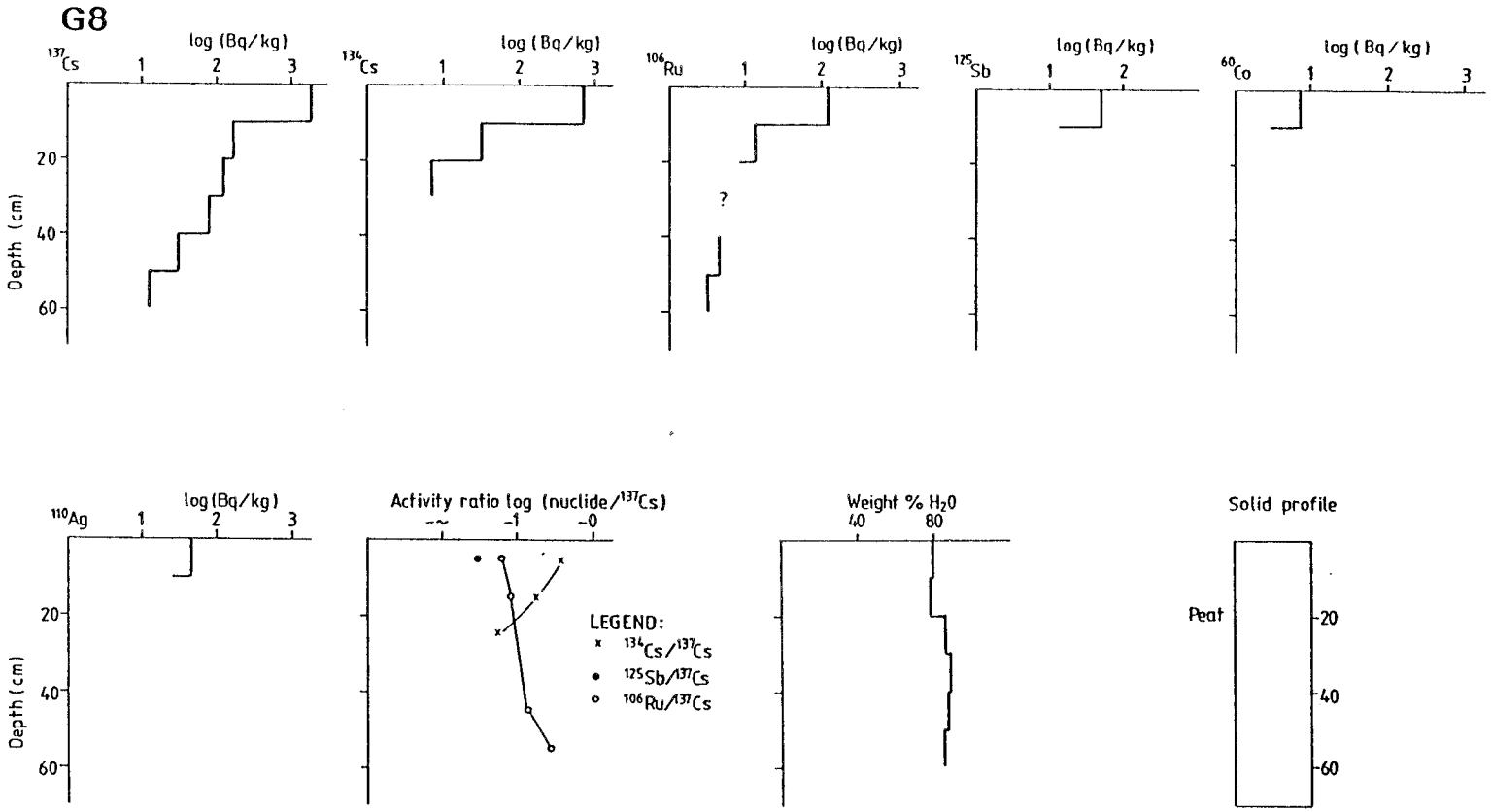

Figure 3.3.9 Soil profile at site G8. Sampling 1986-10-19.

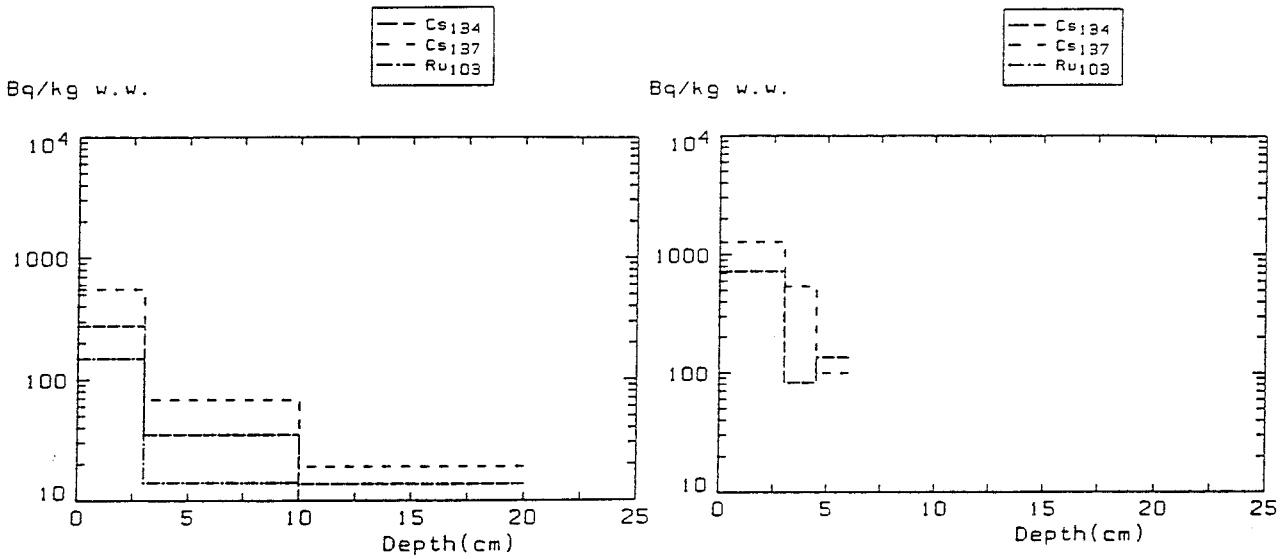

Figure 3.3.10 Soil activity profile (Bq/kg w w) in peat, at site G15. 1986-06-25, left and 1986-11-06, right.

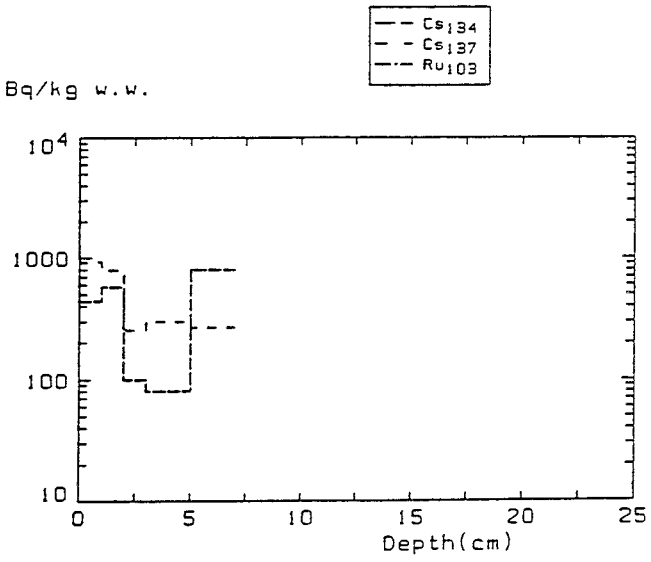

Figure 3.3.11 Soil activity profile (Bq/kg w w) in peat, at site G15:2, 1986-11-06.

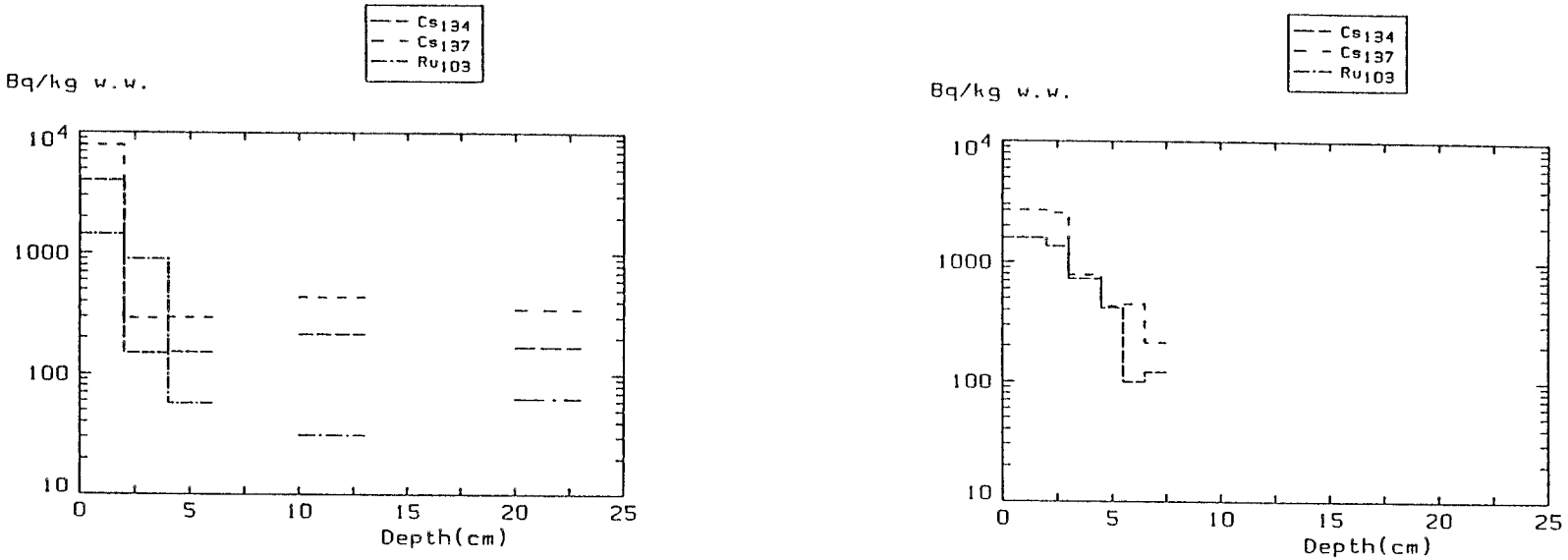

Figure 3.3.12 Soil activity profile (Bq/kg w w) in till, at site G36. 1986-06-25, left and 1986-11-06, right.

3.4 Outcrops and Fractures

Drillcore samples were collected from the outcrop at sampling site G25. One of the drillcores consists of finegrained biotit rich paleosom and the other core was drilled in medium grained granitic neosom. Additionally seven samples of more or less exfoliated rock surfaces were picked by hammer at sampling sites G26,G28,G33 and G34. At sample site G44 another 4 drillcore samples were collected. All samples consist of the sedimentary gneiss which dominates the area. The sample collection and analysis is described in more detail in Appendix C.3. The sampling sites are presented in Figure 3.4.1 and the results of the analyses are presented in Table 3.4.1.

Site	Description
G25	drill core
G26	rock surface
G28	"
G33	"
G34	"
G44	drill core

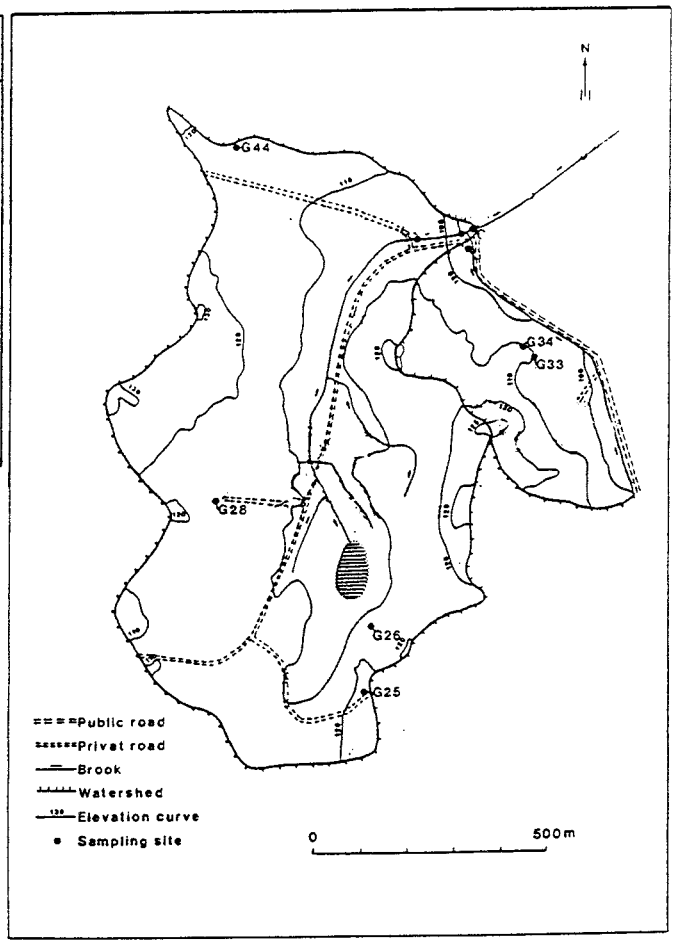

Figure 3.4.1 Drillcore and rock surface sampling sites on outcrops, Gideå study site.

Table 3.4.1 Results from analyses of drillcore and rocksurface samples, taken 1986-10-18--19.

Number	Sample description	Date of sampling	Date of analysis	Lichen cover	Autoradiogram	Exposure time	Remarks:
1	625, Drill core	861018	861103,871013	No	Yes	360 h, 298 d	(1) Very weak blackening.(2) Weak blackening with a spot.
2	Drill core	861018	861103,870205	No	Yes	360 h, 48 d	(1,2) One strong black spot.
3	626, Hammer rock sample	861018	861103,870205	Yes	Yes	360 h, 48 d	(1,2) Weak uneven blackening.
4	628, Hammer rock sample	861018	861103,870205,871013	No	Yes	360 h, 48 d, 209 d	(1,2,3) Weak blackening with one black strong spot.
5	Hammer rock sample	861018	870205,871013	No	Yes	48 d, 209 d	(1,2) Weak blackening with 3 small discrete spots.
6	Hammer rock sample	861018	870605	Partly	Yes	79 d	Weak blackening with one spot.
7	633, Hammer rock sample	861019	861103, 870205	Yes	Yes	360 h, 48 d	(1) Weak blackening. (2) Weak blackening, many small spots.
8	634, Hammer rock sample	861019	870205	No	Yes	48 d	Weak blackening.
9	Hammer rock sample	861019	870205	No	Yes	48 d	No blackening.
10	644, Drill core	861019	860705	No	Yes	79 d	Weak blackening.
11	Drill core	861019		No	No		
12	Drill core	861019		No	No		
13	Drill core	861019	860705	No	Yes	79 d	Weak blackening with one small spot.

The autoradiographic study of the rock surfaces indicates an even coating, but with high radioactivity on lichen covered surfaces and very low activity on rock surfaces without moss and lichen, see Figure 2.11. However, most of the rock surfaces are covered with mosses and thin layer of lichen.

From exposure rate measurements it is also evident that lichen holds higher activity than the uncovered outcrop area (cf. Figures 3.2.6 and 3.2.7)

This sorption by lichen indicates that the activity has been dissolved in the snow cover, at least to some extent, before it reached the rock surfaces, c.f. section 2.6.

No differences in activity can at present be correlated to different mineralogical composition or grain size of the rock samples.

Gamma spectrometric measurements in situ have also been performed on outcrops (cf Fig. 3.2.1) and the results from the sites G7, G11, G24 and G25 are presented in Table 3.2.1.

Exposure rate measurements at the spectrometer sites (Table 3.2.4) show somewhat higher values on the outcrops (sites G7,G11,G23,G24 and G25), e.g. the more elevated parts, than the surroundings. Since the study site was snow covered during the time of deposition and snow cover is usually thinner on the elevated parts in a hilly area, the migration/transportation of the radionuclides by melting snow, may have been smaller from these parts.

3.5 Water and Sediment

Within the study site surface water, groundwater and sediment were sampled for analysis of nuclide activity. In some samples also environmental isotopes and physico-chemical parameters were analysed. The sampling sites are presented in Figure 3.5.1

Site	Description
G9	water, drill hole Gi 2
G15 B	water, brook
G29	water, brook
G31	water, dug well
G32	water, drill hole 20
G37	water, dug pit outside the area 700 m to the east
G40	water, brook
G48	water, rock crevice
G49	water, brook outside the area 500 m to the north
G38	sediment, from brook
G39	"
G41	"
G42	"
G43	"

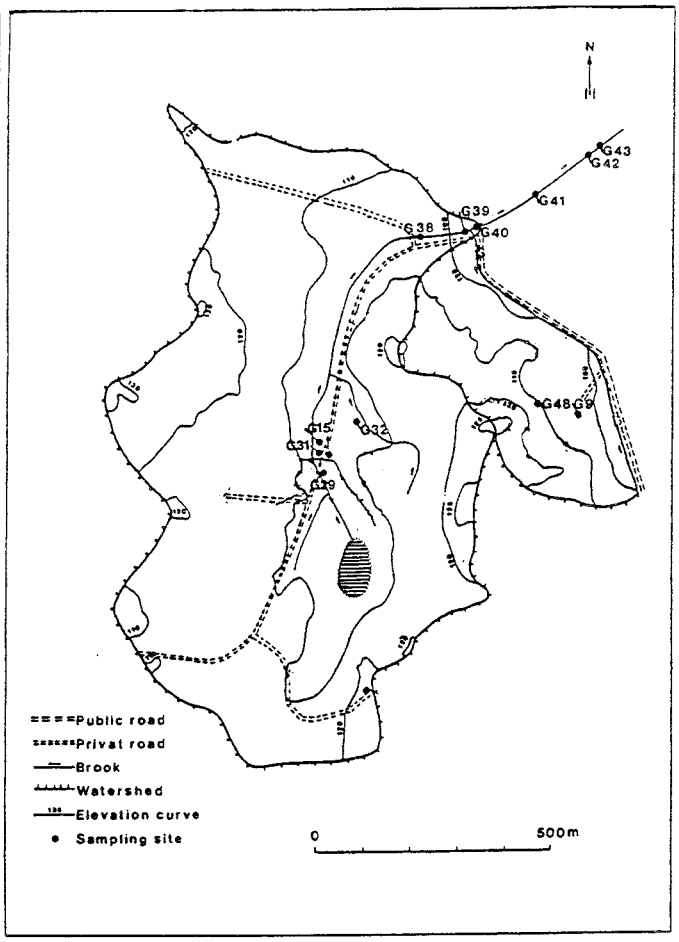

Figure 3.5.1 Water and sediment sampling sites, Gideå study site.

Groundwater was sampled in a shallow well (site G 31) in the central part of the Orrmyrberget catchment area, with a depth to the groundwater table of c. 0.40 m at the end of October. Discharging groundwater was also sampled from the artesian drill holes 20 and Gi 2 (sites G 32 and G 9). Nuclide activity in groundwater samples and samples from the creek which drains the Orrmyrberget catchment area (site G 15B, G 29, G 40 and G 49) is presented in Tables 3.5.1. and 3.5.2.

In Table 3.5.2 also activity in water and sediment from river Gideälven is presented. In Table 3.5.3 radionuclide activities in sediments, sampled within the Gideå study site, are presented.

It is observed that: 1) many of the fallout nuclides are found in the brooks, draining the catchment area, and 2) the activities decrease from June to July.

Ruthenium, though in very low activities, are found in water sampled from drill hole Gi 2 level 97-106 m (site G9) and from drill hole 20 (site G32). Ruthenium is also present in water from the shallow well (site G31) in the area. In the well also Ag-110m is found.

Analysis of the ruthenium activity (cf. section 2.4) shows that it seems as if two chemically different forms of ruthenium occur, one insoluble form which is detained on outcrops and in the uppermost layer of the soils and one form which is transported by water, e.g. high mobility in soil profiles. Ruthenium found in the well and the drill holes gives further indications on the existence of the latter form.

In the sediment samples (Table 3.5.3) activities of naturally occuring K-40,reflecting the weathering processes of the bedrock and soils, are found. The activities of Ru-106, Ag-110m, Cs-134 and Cs-137 indicate transportation by water from the study site of these radionuclides.

According to the physico-chemical analysis the water sampled at the 28 to 96 m section within Gi 2 can be described as a HCO_3-Na-Ca water of pH 7.7. The water is not saturated in respect of $CaCO_3$. Compared with analyses of the artesic groundwater sampled at 178 m core length, reported by Laurent (1983), the water shows a lower content of Fe^{2+} as well as higher content of SO_4^{2-} indicating less reducing conditions than in the deeper groundwater.

Table 3.5.1 Activity in water samples (mBq/l, sampling date) from Gideå study site.

Number	Sample description:	Date of sampling	Date of analysis	Volume (l)	pH	Geom	Co-60	Unc Is	Zr-95	Unc Is	Ru-103	Unc Is	Ru-106	Unc Is	Ag-110m	Unc Is	Sb-125	Unc Is
1	69, ground water from level 28-96 m.	860711	870321	95		M500												
2	ground water from level 97-106 m.	860711	870322	47		M500												
3	ground water from level 107- m.	860711	870323	23		M500												
4	ground water from level 28-96 m.	861019	870317	145 - 8		M500												
5	ground water from level 28-96 m.	870218	870319	115		M500												
6	ground water from level 97-106 m.	870218	870320	125		M500							4,70	37,60				
7	629, brook water	860625	871028	10		B60J												
8	brook water	860708	870906	10		B60J	6,16	28,60					105	28,30				
9	brook water	860710	870317	24		B250			169	72,80	540 #		108	46,90	53,80	62,70	45,70	42,50
10	631, stagnant water from a well.	861019	870315	100	7,5	M500	1,14	54,50										
11	stagnant water from a well.	870224	870327	125		M500							3,99	96,50	14,90	21,10		
12	632, drillhole water	870218	870419	125		M500							4,51	73,50	5,20	29,70		
13	637, dug pite in sandy till, collecting inflow water.	860710	870915	10		B60J	5,28	23,80					112	21,70			14,90	32,90
14	dug pite in sandy till, collecting inflow water.	860710	870315	24		B250					120 #				35	56,50		
15	640, brook water, medium fast flow.	860707	870904	10		B60J	6,14	24,90										
16	brook water, medium fast flow.	860710	870316	48		B250	4,43	66,60			140 #				37	52		
17	brook water, medium fast flow.	861001	870314	50		M500							52,10	32,20	18,40	41,70		
18	brook water, medium fast flow.	861019	870312	100	5,4	M500							28,70	32,80	15,20	24,90	4,93	53,60
19	brook water, slow flow under ice.	870218	870330	100		M500							19	22,30	7,33	23,20	3,84	35,70
20	648, stagnant water from a crevice.	860708	870908	10		B60J	7,04	14,90					109	18,50			18,90	21,30

Number	Cs-134	Unc Is	Cs-137	Unc Is	Ce-144	Unc Is	Cs-134/Cs-137	Remarks:
1			1,81	23,80				
2								
3								
4			,36	63,90				
5								
6								
7	677	1,50	1370	,80			,49	
8	448	1,10	918	,60			,49	
9	312	4,20	772	2,10			,40	
10	109	1,30	297	,70			,37	
11	75	1,10	222	,60			,34	Water sampled by S-E Westerin later in february.
12								
13	239	1,20	515	,60			,46	
14	166	4,90	419	2,30			,40	
15	293	1,40	619	,70			,47	
16	217	3,50	520	1,80			,42	
17	79	4,50	221	2,10			,36	
18	69,30	2,60	204	1,20			,34	
19	63,40	1,50	193	,70			,33	
20	369	,80	777	,40			,48	

Date of analyze: Aug 1986.
Measured and analyzed by a 15% HPGe-detector (FWHM 1.9 keV), connected to a 8192-channel Seiko EG&G MCA, calibrated by a Amersham mixed standard solution.

Table 3.5.2 Activity in water (Bq/kg) and sediment samples (Bq/kg d w) from Gideå study site and from the river Gideälven.Sampling 1986-06-25--26. Reference date 1986-04-28.

No.	Site	Type	Depth (cm)	Area (m**2)	Water content (%, ww)	Organic content (%, dw)	Zr-95	Ru-103	Ru-106	Ag-110m	I-131	Cs-134	Cs-136	Cs-137	Ba-140	Ce-141	Ce-144
34	G9	Water 0- 96 m										-		-			
35	"	Water 97-106 m										-		<1.0E0			
36	G15 B	Water, creek										5.2E1		1.20E0			
39	G31 E	Water, dug well										8.60E-1		2.30E0			
37	G49	Water, creek										4.70E-1		2.30E0			
38	Gideälven	Water										6.80E-1		<1.0E0			
40	"	Sediment	0-2		74	5		2.32E2				7.84E2		1.81E3			
41	"	"	2-4		60							-		4.10E1			
42	"	"	0-4	2.8E-3								3.21E1		6.80E1			

Table 3.5.3 Activity in sediment and residue from water, Gideå study site. Reference date same as sampling date.

Number	Sample description:	Date of sampling	Date of analysis	Area	% H2O	Dry wght	Geom	Wght (g-a)	K-40	Junc 1s	Co-60	Junc 1s
1(1)	638, Residue from water 1(3) (filter paper, retention 25 um) (Bq/l water).	861019	870414	,08			B60		56,50	11,60		
1(2)	Residue from water 1(3) (glass fiber filter, retention 1,2 um) (Bq/l water).	861019	870428	,08			B60		63,60	2,50	,42	23,20
1(3)	Water collected together with sediment, filtrated.	861019	870811	,08			B250	88,20	122,60	6,90		
1(4)	Sediment (sand and dead vegetation).	861019	870410	,08	14,70	746	B250	594	508,20	2,90	1,60	58,30
2(1)	639, Residue from water 2(3) (filter paper, retention 25 um) (Bq/l water).	861019	870413	,08			B60		87,94	7,20		
2(2)	Residue from water 2(3) (glass fiber filter, retention 1,2 um) (Bq/l water).	861019	870416	,08			B60		91,70	3,90	,97	23,70
2(3)	Water collected together with sediment, filtrated.	861019	870812	,08			B250	54	136,30	14,60		
2(4)	Sediment (sand and dead vegetation).	861019	870409	,08	18,80	746,20	B250	554,20	642,20	1,10	2,20	21,10
3(1)	641, Residue from water 3(3) (filter paper, retention 25 um) (Bq/l water).	861019	870514	,16			B60		51,90	7,50		
3(2)	Residue from water 3(3) (glass fiber filter, retention 1,2 um) (Bq/l water).	861019	870508	,16			B60		49,50	12,50		
3(3)	Water collected together with sediment, filtrated.	861019	870810	,16			B250	106	100,40	7,70		
3(4)	Sediment (sand and dead vegetation).	861019	870410	,16	18	698	B250	543,80	546,20	,70	1,30	16
4(1)	642, Residue from water 4(3), incl. precipitation (filter paper, retention 25 um) (Bq/l water).	861019	870414	,09			B60		8,76	6,70		
4(2)	Residue from water 4(3), incl. precipitation (glass fiber filter, retention 1,2 um) (Bq/l water).	861019	870513	,09			B60		35,24	6,90		
4(3)	Water collected together with sediment, filtrated.	861019	870812	,09			B250	156	40,40	11,90		
4(4)	Sediment (sand and dead vegetation).	861019	870413	,09	29,70	453,50	B250	416	924	,80	1,80	28,80
5(1)	643, Residue from water 5(3), incl. precipitation (filter paper, retention 25 um) (Bq/l water).	861019	870415	,06			B60		10,45	12,90		
5(2)	Residue from water 5(3), incl. precipitation (glass fiber filter, retention 1,2 um) (Bq/l water).	861019	870504	,06			B60		14,15	6,20		
5(3)	Water collected together with sediment, filtrated.	861019	871109	,06			B250	452,80	9,90	12,70		
5(4)	Sediment (sand and dead vegetation).	861019	871108	,06	28,10	103	B60	81,80	976,30	1,23	3,30	26,80

Number	Zr-95	Junc 1s	Ru-106	Junc 1s	Ag-110m	Junc 1s	Sb-125	Junc 1s	Cs-134	Junc 1s	Cs-137	Junc 1s	Ce-144	Junc 1s	134/Cs-137	Remarks:
1(1)									10,82	5,70	25,56	3,40			,42	
1(2)			7,11	17,40			,89	29,20	,50	32,30	1,34	9,90			,37	
1(3)											3,20	21,90				
1(4)					20	30,80			283	,90	700,20	,50			,40	
2(1)									5,63	11,60	12,12	6,40			,47	
2(2)			14,21	17,20			1,91	28,20			,61	43,70				
2(3)											5,10	35,60				
2(4)			10,60	52,80	26,70	12,50			398,10	,40	980	,20			,41	
3(1)									3,80	10,70	8,65	4,40			,44	
3(2)																
3(3)											2,90	20,50				
3(4)			5,40	52,20	18,50	7,40			236,10	,20	587,50	,10			,40	
4(1)									4,27	5,80	8,76	3,40			,49	
4(2)											,49	37				
4(3)											4,10	10,90				
4(4)							3,50	67,40	497,80	,40	1146,60	,20			,43	
5(1)									,71	15,40	1,69	8			,42	
5(2)																
5(3)									,40	38,80	1,20	8,50			,33	
5(4)									457,70	,50	1053,20	,30			,44	

This is also demonstrated in the lack of measurable S^{2-}. However, there is no evidence from the drillhole of extensive oxidation of pyrite in the undisturbed system. It should also be pointed out that the SO_4^{2-} content can be of anthropogene origin. The upper section (28-96 m) also shows a higher content of Ca^{2+} and Mg^{2+} than the deeper sections sampled. This is typical for a near-surface water as ion exchange processes will progressively decrease especially the Mg-content in deeper groundwaters. The salinity, in terms of Cl and Na content, is higher in the water sampled in sections below 100 m core length.

The tritium content (Table 3.5.4) indicates a more recent water discharging from drill hole Gi 2, sections 97-106 m and 28-96 m than the water discharging from drill hole 20. A noticeable low tritium content in the well (site G31), especially when considering that activities of Ag-110m and Ru-106 from the Chernobyl fallout are found in this water. Groundwater mixing seems as a reasoneable explanation.

Table 3.5.4 Tritium content (T.U.) in water samples from Gideå study site, November 1986.

Site	Depth/Note	Date	Tritium (T.U.)
G 9	28 - 96 m	861105	28
G 9	28 - 96 m	870218	28
G 9	97 - 106 m	861105	25
G 9	97 - 106 m	870218	30
G 31	Shallow well	861105	18
G 32	0 - 100 m	870218	8
G 40	Creek	861105	26

3.6 Vegetation

Vegetation samples were taken at several sites and some of them coincided with sites for gamma spectrometric measurements in situ. The aim was to get a rough estimate on the distribution of radioactivity between surface cover and uptake by the vegetation at this early stage. Lichens, mosses, dwarf shrubs and trees (especially leaves and needles) were collected and analysed. Some of the collected samples are specified in Table 3.6.1 and the activity is presented in Tables 3.6.2, 3.6.3 and 3.6.4.

Table 3.6.1 Example of vegetation samples collected within the Gideå area.

Mosses:	Polytrichum strictum
	Racomitrim microcarbon
	Pleurozium scheberi
	Sphagnum russowii
Lichen:	Cladina rangiferina
	Cladina sp.
	Cetraria islandica
Schrubs:	Empetrum nigrum
	Juniperuc Communis
	Calluna vulgaris
Trees:	Pinus silvestris
	Picea abies

The activity of Cs-137 in grass and pine samples is c. 4 000 Bq/kg d w, while the lichens holds about 10 times higher activity. The birch leaves have 1 500 Bq/kg d w. This can be explained by the fact that the leaves were not exposed to the initial deposition.

Table 3.6.2 Gideå summary from June 1986. Cs-137 (Bq/kg d w) and ratios (Cs-134). Reference date 1986-04-28.

		Cs-137		Ratios to Cs-134							
Type	No. of samples	Mean	CV (%)	Cs-137	Zr-95	Ru-103	Ru-106	I-131	Ba-140	Ce-141	Ce-144
Lichen	1	60 000	-	1.93	0.03	0.33	0.11	21	1.0	0.09	0.04
Birch leaves	1	1 500		2.02							
Grass	5	5 120	85	1.96	0.28	0.67	0.22		2.5	0.32	0.08
Pine needles	1	4 370		-	0.04	0.51	0.20	-	1.8	0.14	-

Table 3.6.3 Activity in vegetation samples (Bq/kg d w) from Gideå study site. Sampling 1986-06-25-26. Reference date 1986-04-28.

No.	Site	Type	Depth (cm)	Area (m**2)	Water content (%, ww)	Organic content (%, dw)	Zr-95	Ru-103	Ru-106	Ag-110m	I-131	Cs-134	Cs-136	Cs-137	Ba-140	Ce-141	Ce-144
29	G13 D	Moss			18		5.75E1	1.99E3	3.43E2	1.01E2	7.20E3	1.85E3	1.38E3	3.42E3			
17	G14 C	Birch leaf			57							7.44E2		1.50E3			
22	"	Peat/grass			27			1.07E3	5.67E2		4.50E4	2.20E3		3.97E3			
10	G17 F	Grass		0.5	85			2.92E2				2.50E3		4.43E3		1.60E2	
20	"	Litter/grass			20		2.10E2	1.58E3	8.11E2	1.53E2	6.20E2	2.58E3		4.79E3			
18	G22 M	Pine needle			63		1.02E2	1.18E3	4.53E2	1.56E2		2.31E3			4.10E3	3.20E2	
19	"	Lichen			64		1.03E3	1.02E4	3.32E3	1.06E3	6.60E4	3.12E4	2.09E4	3.00E4	3.90E3	1.30E3	
11	Gideå Bruk	Grass		0.5	72	91		1.82E2				4.21E2		8.26E2			

Table 3.6.4 Activity in vegetation samples (Bq/kg d w, sampling date) from Gideå study site.

Number	Sample description	Date of sampling	Date of analysis	% H2O	Dry wght	Geom	Wght (g-a)
	Vegetation						
1	61, Juniper twigs	861018	870321	52,90	51,80	B250	51,80
2	Pine needle, shoots of this year	861018	870321	96,80	27	B250	27
3	Pine needle, older twigs	861018	870322	70,80	42	B250	30
4	Heather	861018	870322	52,90	48	B250	48
5	Crowberry, -twigs	861018	870323	62,20	42	B250	42
6	Lingonberry, -twigs	861018	870504	84,10	8,20	B60	6
7	Spruce twigs	861018	870323	69	75,30	B250	59,50
	Moss and lichen						
8	Polytrichua strictua	861018	870313	93,30	29,80	M500	29,80
9	Cladina sp	861018	870322	64,80	106	B250	93
10	Cladina rangiferina	861018	870322	58,10	88,50	B250	69
	Vegetation						
11	626, Heather	861018	870408	31,20	49,80	B250	49,80
12	Crowberry, -twigs	861019	870325	60,20	48	B250	48
13	Spruce twigs	861019	870326	53,90	50,30	B250	50,30
14	Pine twigs	861019	870326	68,20	35,90	B250	68,20
	Moss and lichen						
15	Racomitrium microcarpon	861018	870407	77,30	53,90	B250	41,70
16	Centraria islandica	861018	870505	67,90	42	B60	9
17	Cladina sp	861018	870407	52,40	69	B250	69
18	Pleurozium schreberi	861018	870408	84,20	14,20	B250	14,20
19	Cladina sp	861019	870408	55,60	59,50	B250	59,50
	Moss and lichen						
20	627, Polytrichua sp	860625	860527	5	3,80	B60	3,80
21	Cladina sp	860625	860529	11,30	11,80	B60	11,80
	Moss and lichen						
22	629, Polytrichua strictua	860625	860529	72,60	17,70	B60	11,20
	Vegetation						
23	635, Heather, perched	860710	870527	26	55,50	B250	40,20
	Moss and lichen						
24	Sphagnua neaoreua	860625	870527	80,40	15,50	B250	4
25	Cladina rangiferina, stellaris	860709	870529	60,20	61,50	B60	16,80
26	Polytrichua sp	860710	870527	46,20	24,20	B250	22,80
27	Cladina rangiferina, stellaris	860710	870527	19,10	229	B250	57,80

Table 3.6.4 cont. Activity in vegetation samples (Bq/kg d w, sampling date) from Gideå study site.

Number	K-40	Iunc 1s	Mn-54	Iunc 1s	Co-60	Iunc 1s	Zr-95	Iunc 1s	Ru-103	Iunc 1s	Ru-106	Iunc 1s	Ag-110m	Iunc 1s	Sb-125	Iunc 1s	Cs-134	Iunc 1s	Cs-137	Iunc 1s	Ce-144	Iunc 1s	Cs-134/Cs-137	Remarks:
1	26,30	22,40											62	54,90	44	47,70	405	3,90	990	2,10			,41	
2	592	22,60			25	64,30							195	51,10			1374	3,40	3410	1,90			,40	
3	372	19,40			20	47					282	59,20	304	25,80	125	36,50	2391	1,40	5923	,80			,40	
4	283	26,30			29	51,20					474	45	388	22,80	164	42,20	4365	1,30	10517	,70			,42	
5	235	23,50			21	42,70					203	60,10	275	26,70	139	29,50	2962	1,10	7260	,60			,41	
6	760	21,50															1727	2,30	3862	1,40			,45	
7	197	26,10			20	45,90					154	78,20	263	29,50	114	38,30	2341	1,40	5787	,80			,41	
8	111	54,20			73	19,60					563	36,90	924	12,10	191	31,70	5732	,90	15339	,50			,37	
9	114	24,90			71	13,90					733	19,40	764	11,80	181	25,90	11398	,30	27129	,20			,42	
10	184	19			81	17,90					352	37,80	327	16,30	253	20,40	9593	,50	31232	,30			,31	
11	94	51,20			29	35,30					221	69,30	552	16,30	133	36,10	3488	1,10	9094	,60			,38	
12	129	15,60			11	20,50					224	18,20	239	9,40	66	18,60	1309	,80	2708	,40			,48	
13	246	12,80			18	30,70					272	33,80	239	19,60	128	21,10	2451	,80	5968	,50			,41	
14	232	16,50									95	58,10	62	17,50	42	38,20	425	2,50	1082	1,40			,39	
15	131	46,50			57	25,40					412	57,10	1045	12,40	208	32,20	6719	,80	17873	,40			,38	
16	902	12,70			87	12,70					940	22,70	281	29,80	248	41	11656	,70	26978	,40			,43	
17	66	56,40			39	22,50					446	30,80	682	11,40	151	26,60	4239	,80	11343	,40	1739	33,50	,37	
18	320	44			147	25,90					1797	31,70	2720	12,30	220	22,50	16331	,90	41486	,50			,39	
19	110	31,90			21	31,70					304	35,90	412	13,90	86	34	2499	1	6724	,50			,37	
20					1897	22,20					21695	19,70	6655	23,10	7360	25,50	236737	,60	476316	,40			,50	
21	607	24,10			236	21,40					2772	16,70			588	34,40	31856	,60	64136	,40			,50	
22	796	13,10			35	47,40											4354	1,20	8854	,70			,49	
23	493	17			97	25,70					1894	27,30	1706	18,90	672	18,30	11585	,90	25746	,50			,45	
24					585	45,50					6275	66,40	10050	35,50			81475	1,30	181050	,70			,45	
25	484	18,90			42						799	18,80			328	18,90	4533	1,10	9854	,70			,46	
26	477	26,50			74						1987	26,60	1029	24,40	395	32	7171	1,50	16079	,80			,45	
27	163	37,30			44						775	48,30	635	21,20	208	39,80	5272	1,20	11886	,70			,44	

3.7 Nuclide Deposition, Distribution and Migration; Summary

The radionuclide deposition within the Gideå study site is summarized in the following items:

Within the study site there was a deposition of different gamma emitting radionuclides which are possible to trace in the time perspective of several years (e.g Co-60, Ru-106, Ag-110m, Sb-125, Cs-134, Cs-137).

The Gideå area was covered by approximately 0.5 m snow at the time of radionuclide deposition, which seems to have influenced the chemical behaviour of different elements in the fallout, however, in a more easily conceiveably way. The radionuclide migration in a snow profile (c.f. section 2.6) indicates a dissolution of particulate activity, e.g. ruthenium, before it reached the ground surface.

Substantial local variations in the ground surface activity are observed, e.g soil profiles taken close to each other can differ by a factor of two in radionuclide content. This shows that an essential variation of radionuclide deposition has occured even in the very local scale.

The ground surface deposition, determined from gamma spectrometric and exposure rate measurements in situ and from laboratory measurements on large area (25x25 cm) soil profile samples are summarized in Tables 3.2.2 - 3.2.4 and 3.3.6, 3.3.7 where the following data is given.

- o The total surface deposition mean values were in June 1986 31 kBq/m^2 of Cs-134 and 60 kBq/m^2 of Cs-137, measured by gamma spectrometry in situ at 7 sites. The coefficient of variation (CV) was 9 % for both nuclides.

- o In November 1986 measurements in situ at 16 sites gave mean values of 31 and 54 kBq/m^2 of Cs-134 and Cs-137 respectively, with a CV of 38 %.

- The surface activity of Cs-137 is c. 5500 Bq/kg d w. This is equivalent to grass samples, while lichen holds about 10 times higher activity.

- In 1982 Studsvik AB (Sundblad and Bergström, 1983) measured the activity levels at the Gideå site. The Cs-137 content of the upper soil (0-25 cm) varied between 10 to 30 Bq/kg d w. The content in grass was 5 Bq/kg d w.

- In June 1986 also 9 sites, in a grid net with 3x3 sites and 50 m separation, were measured with gamma spectrometry in situ. The coefficient of variation was around 30 % for all nuclides measured, e.g I-131, Ru-103, Cs-134, Cs-137, Nb-95, La-140.

- The mean activity of the refractory elements La-140 and Ru-103 was 62 and 17 kBq/m^2 respectively, according to measurements in June 1986.

- The mean surface deposition of I-131, measured in June 1986 was 650 Bq/m^2.

- In November 1986 the exposure rate was measured on 16 sites, at a height of 0.7 m from the ground. The mean value was 23 uR/h and CV was 20 %. The background values for the Gideå area are about 8-10 uR/h, obtained from the content of uranium, thorium and potassium-40 in soil and bedrock. The increased average is due to the surface deposition.

- Auto correlation analysis of exposure rate (measured every 2nd metre at 0.7 m from the ground along a 800 m long line) shows that measuring points situated closer than 25 metres are significantly correlated (on 95% significance level).

- In the smaller scale auto correlation analysis of exposure rate measurements on an outcrop area (every 0.1 m and 0.1 m from the ground) shows that points closer than 1.0 metre are significantly correlated.

In summary the distribution and migration of the radionuclides are described in the following items:

- Some of the radionuclides measured within the soil profiles are: Cs-134, Cs-137, Sb-125, Ru-106, Co-60, Ag-110m, and in some cases also Zr-95.

- The radionuclides migrate faster in the peat than in the till and sand profiles. Within the till and sand profiles most of the nuclides are caught in the vegetation and raw humus layer. However, a migration into the mineral soil can be detected.

- A faster and different manner of migration is indicated in the soil profiles for Sb-125, Ru-106 and Co-60 compared to cesium.

- In some soil profiles fallout from Chernobyl is found below 20 cm depth after 5 months, indicating other transport mechanisms than only diffusion.

- In October 1986 the 1/2-value depth for Cs-134 and Ru-106 was approx. 7 cm in the peat profiles and 4 cm in the till and sand profiles. The 1/4-value depth is generally deeper for Ru-106, which is more obvious in the peat profiles indicating the existence of a fast migrating chemical form of Ru-106.

- The autoradiographic study of rock surface samples indicates an even coating, but with high radioactivity on lichen covered surfaces and very low activity on rock surfaces without moss and lichen. It is also evident from exposure rate measurements that lichen holds higher activity than the uncovered outcrop.

- The sorption by lichen indicates that the activity has been dissolved in the snow cover, at least to some extent, before it reached the rock surfaces.

- Exposure rate measurements at the spectrometer sites show somewhat higher values on the outcrops i.e. the more elevated parts, than the surroundings.

- Relatively high concentrations of radionuclides are found in samples from the brook which drains the studied area. Also in stagnant water from rock crevices and shallow groundwater, sampled at the bottom of the dug pits remaining from the soil profile sampling, relatively high concentrations are obtained.

- Already in February 1987 Ru-106 could be detected in fairly deep groundwaters sampled in the artesian drill-holes Gi 2 (97-106 m) and 20 (1-100 m).

- In a shallow well also Co-60, Ag-110m, Cs-134 and Cs-137 was found, besides Ru-106 in October 1986.

- Ruthenium found in the well and the drill holes gives further indications on the existence of a water soluble fast migrating chemical form of ruthenium.

- The sediment samples show that an active transport of radionuclides (Ru-106, Ag-110m, Cs-134 and Cs-137) has occurred by water. The nuclides have later been coprecipitated with other types of sediment.

- The vegetation samples show that radionuclides have been absorbed in different types of vegetations.

- The activity of Cs-137 in grass and pine samples is c. 4 000 Bq/kg d w, while lichen holds about 60 000 Bq/kg d w. The birch leaves have 1 500 Bq/kg d w. This can be explained by the fact that the leaves were not exposed to the initial deposition.

4. DEPOSITION AND MIGRATION WITHIN THE FINNSJÖN STUDY SITE

Within the Finnsjön study site the deposition and migration of the Chernobyl radionuclide fallout have been intensively studied in two smaller sub-areas:

- o Brändan catchment area (0.59 km^2)
- o Gåvastbo area (0.14 km^2)

The deposition and migration of the radionuclide fallout in biota, soils, surface waters and on outcrops have been traced by measurements in situ and sampling (followed by laboratory measurements) at 36 sites on several occations since April 1986. The sites (Fig. 4.1.1) represent different geological, hydrological and biological domains within the studied area. The measurements in situ and sampling performed are summarized in Table 4.1.1.

The surface deposition was measured at 22 sites by gamma spectrometric measurements in situ, with 50% of the count rate arising from activity within a radius of 3 m at a typical site. At 10 of these sites soil profiles have been sampled for gamma spectrometric analysis at the laboratory to provide direct measurements of the activity distribution in the soil profile, and secondly to be used in comparison with the spectrometric measurements in situ for determination of the absolute surface deposition. On the outcrops drillcore samples and rock surfaces by hammer were collected for a autoradiographic study of the exposed surfaces.

To get a rough estimate of the rate to which the radionuclides might migrate in the soils, gamma spectrometric measurements in situ and soil profile sampling and analysis were repeated at 3 sites. Measurements and sampling were performed in June, October and November 1986.

To be able to perform budget calculations of radionuclide redistribution, surface water was sampled at 6 sites in the system of creeks and bogs which drains the Brändan catchment area. To determine the removal of the radionuclides by water transportation also sediment samples were taken at 4 sites.

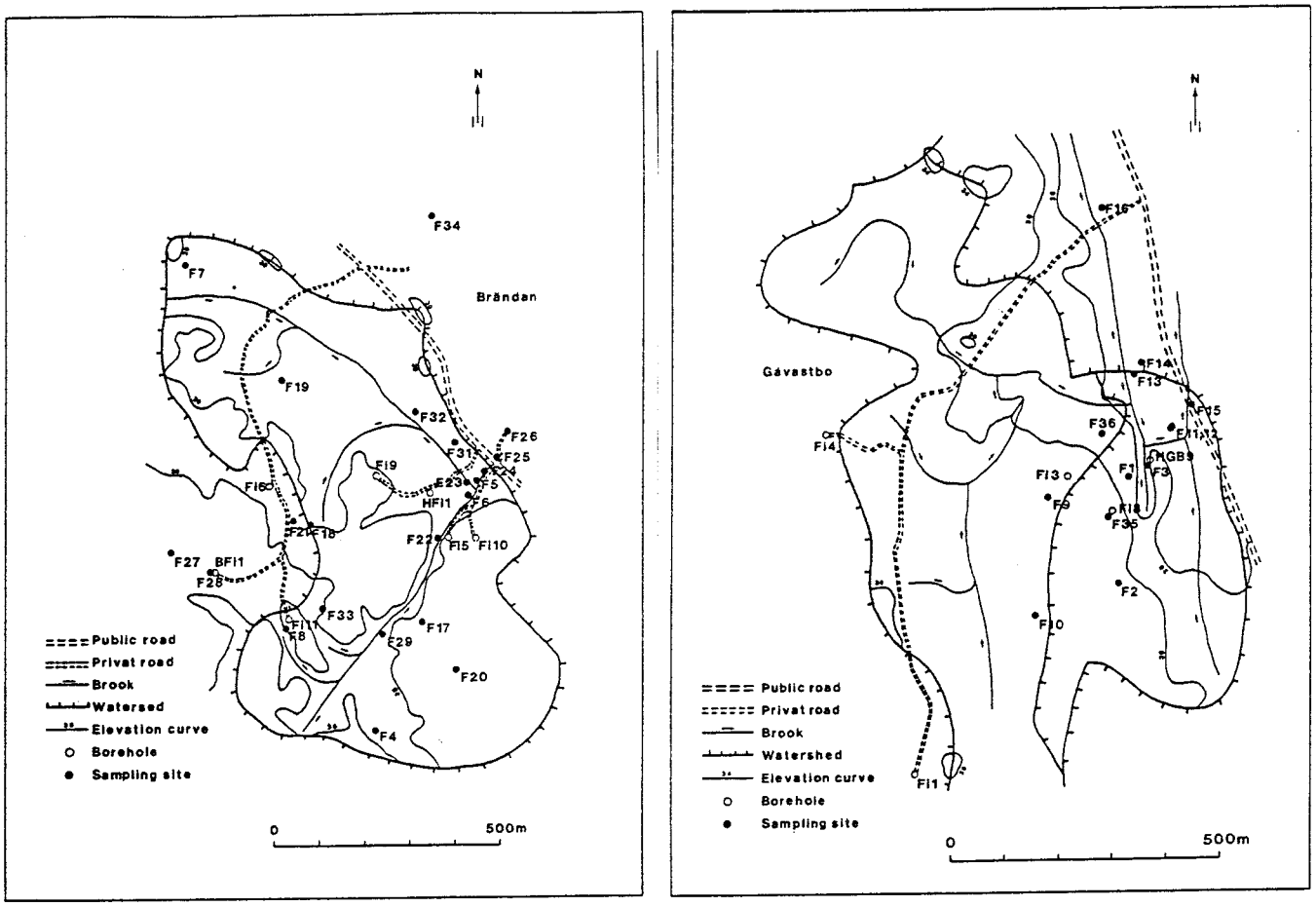

Figure 4.1.1 Sampling sites in the Brändan and Gåvastbo areas, within the Finnsjön study site.

Vegetation samples were taken at eight sites of which six coincided with sites for gamma spectrometric measurements in situ. The aim was to get a rough estimate on the distribution of radioactivity between surface cover and uptake by the vegetation at this early stage. Lichens, mosses, dwarf shrubs and trees (especially leaves and needles) were collected and analysed.

Table 4.1.1 Sampling and measurements in situ within the Finnsjön study site.

Site	Soil	In situ -spectr.	Water	Sediment	Vegetation	Rock
F1**	BCDE	BC				
F2**	D	C				
F3**	B DE	B E	E			
F4*	D	E				
F5*	D	E				
F6*	D	E				
F7*	DE	E				
F8*	B D	C	AB D	B D		D
F9**		BC			D	D
F10**		C			C	
F11**	C	C			C	
F12**	C	C			C	
F13**		BC				
F14**		C				
F15**			E	E		
F16	BC	BC			BC	
F17*		B E				
F18*		C				
F19*		E				
F20*		E			E	
F21*		E				
F22*			A E			
F23*			D	D		
F24*			B D	DE		
F25*			D	D		
F26*				E		
F27			AB		B	
F28			A			
F29*			A			
F30	B					
F31*	B					
F32*	B	B			B	
F33*	B				B	
F34						D
F35**						D
F36**		B				

A 29 Apr 86
B 24-28 Jun 86
C 1-2 Oct 86
D 14-15 Oct 86
E 6-7 Nov 86

** Gåvastbo area
* Brändan area

4.1 Site description

4.1.1 Geology and topography

The Finnsjön study site is situated in the northern part of Uppland county,see Figures 1.1 and 4.1.2. The area has been described e.g. by Almen et.al. (1979) and Olkiewicz & Arnefors (1981).

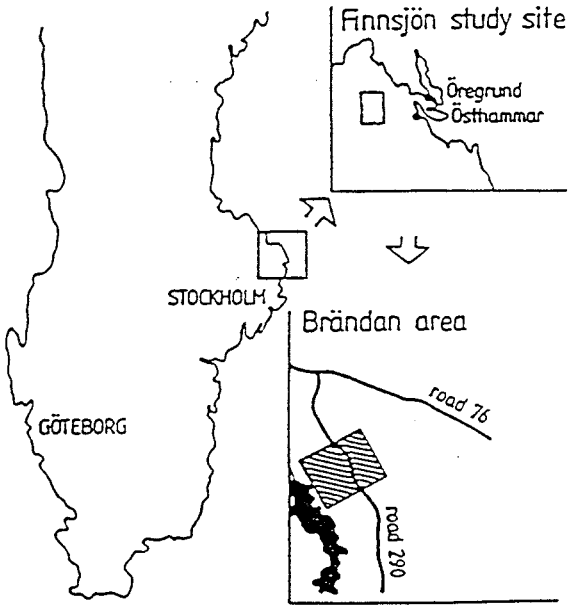

Figure 4.1.2 Location of the Finnsjön study site.

The area is characterized by a relatively flat topography. Peat deposits are widespread, particulary in the central parts. A sandy silty clay with 10-20% $CaCO_3$ is the most common sediment. As the area is situated below the highest coastline the till is washed out and sand deposits are found in the depressions e.g. at Gåvastbo. The area is mostly forested with exceptions for more swampy parts. There are also parts that are old clear-cuts and culturally influenced areas.

The bedrock at Finnsjön is of Svecokarelian age, about 1800-2100 Ma and consists mainly of four rock types; leptite, metabasite, granodioritic gneiss and a late orogenic granite. The granodioric gneiss dominates in the sub-areas chosen for the Chernobyl fallout study. Hydrothermal alteration has produced hematized zones that often coinside with the hydraulically defined fracture zones.

Most of the lineaments found within the investigated area trend N-S and N50-60W. The Gåvastbo fault, striking NNW, situated in the eastern part of the area is one of the most prominent lineaments. Within the Fracture Zone Project the Brändan zone area has been investigated in detail (Ahlbom et. al., 1986). Fractures within the area mostly show vertical to subvertical dips. However, a major sub-horizontal fracture zone has been encountered at depths ranging from 100m to 300m.

Two sub-areas within the Finnsjön test site have been sampled for the Chernobyl fallout study; 1) The area close to the Gåvastbo fault and 2) The Brändan catchment area, see Figure 4.1.3.

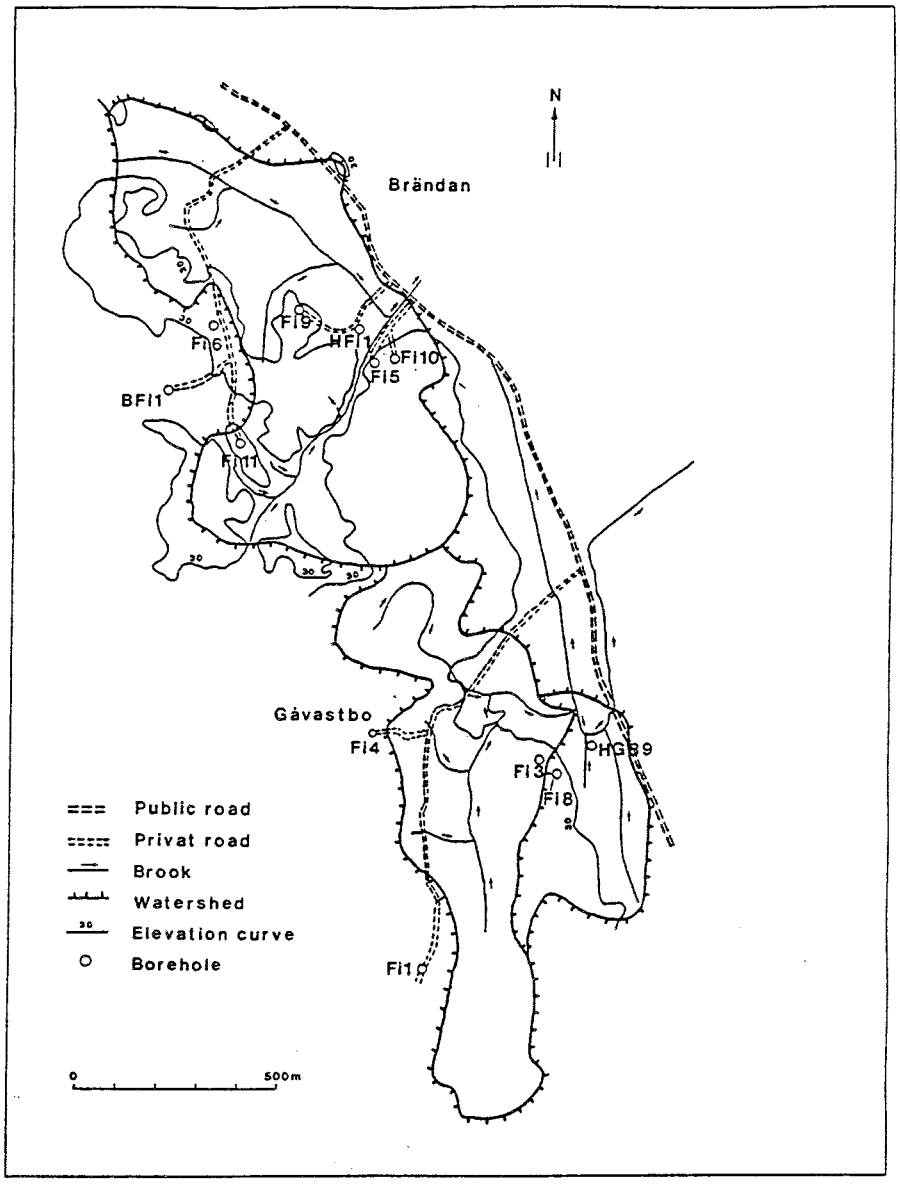

Figure 4.1.3 Gåvastbo and Brändan areas, Finnsjön study site.

The recharge area within the Gåvastbo area is dominated by outcrops while in the discharge area, around drill hole HGb 9, the quartenary deposits have a maximum depth of about 5 m. The rock is overlain by till, clay and on the top a thin layer of peat. The areal distribution of quarternary deposits and outcrops within the Gåvastbo area is presented in Table 4.1.2.

The Brändan area is dominated by exposed rock in the middle and south-western parts. Between the outcrops, the thin soil cover primarily consists of till and peat. Under the peat there is generally a thin layer of sand, sometimes resting on clay. The clay is always underlain by till. In the eastern part of the Brändan area the percentage of outcrops is much smaller than in the western part. Instead till, bogs, clay and outwashed material are more dominant. The areal distribution of quartenary deposits and outcrops within the Brändan area is presented in Table 4.1.3.

Table 4.1.2 The areal distribution of quartenary deposits and outcrops within the Gåvastbo area.

Total area	14.2 ha	100%
Outcrop	5.7	40.1
Till	6.7	47.2
Clay	0.3	2.1
Glacial clay	1.1	7.8
Sand	0.4	2.8

Table 4.1.3 The areal distribution of quartenary deposits and outcrops within the Brändan catchment area.

Total area	59.3 ha	100%
Outcrop	35.7	60.2
Peat-covered outcrop*	0.8	1.3
Till	4.6	7.8
Peat-covered till	10.8	18.2
Peat-covered sand	0.7	1.2
Glacial clay	0.1	0.2
Fen peat	0.3	0.5
Bog peat	6.3	10.6

* Peat layer less than 0.5 m thick

4.1.2 Hydrological and meteorological conditions

The Finnsjön study site is located within the drainage basin of river Forsmarksån in northern Uppland county. The topography is relatively flat, with levels between 20 and 44 metres above the sea level. The site which is of marked north-westerly extension is located on a slope dipping slightly towards the north-east. Calculations and field mapping showed that about 30 % of the study site consists of areas for groundwater discharge (Carlsson and Gidlund, 1983). Flat lands, even at "high" altitudes, are water-logged due the humid climate and insufficient drainage. Consequently swamps and peat bogs are found there.

Hydrological and meteorological data and conditions in the Finnsjön study site are based on statistical information obtained from SMHI (the Swedish Meteorological and Hydrological Institute). Two meteorological stations have been regarded as representative for the study site, Lövstabruk approx. 1 km north of the site and Films Kyrkby 11 km south of the Finnsjön study site. At Lövstabruk only precipitation is measured.

The mean monthly precipitation at Lövstabruk, based on 1931-60 values, is specified in Table 4.1.4. Monthly precipitation during the period April 1986 throughout February 1987 is specified in Table 4.1.5. During the 1931-60 period relatively large fluctuations in monthly precipitation were noted, but still a comparison of monthly precipitation April 86 - February 87 with the mean monthly values may be considerable.

Compared to the mean precipitation, the actual period had an excess precipitation of 216 mm (+ 39 %). During the period May-October 1986, i.e. from the event of fallout and surface contamination to the last gamma spectrometric measurements and soil profile sampling before the winter there was 43 % more precipitation than the monthly mean values (482 mm c.f. 336 mm).

Table 4.1.4 Monthly mean precipitation (mm) at Lövstabruk.

Precipitation	J	F	M	A	M	J	J	A	S	O	N	D	Year
unadj*	46	30	28	35	32	49	63	77	60	55	59	48	582
adj+	60	40	40	40	40	50	80	80	70	60	70	60	960

* 1931-60

\+ interpolated values from isoline precipitation charts (Eriksson, 1980)

Table 4.1.5 Monthly precipitation (mm) at Lövstabruk and Films Kyrkby April 1986 - February 1987.

Precipitation unadjusted	J	F	M	A	M	J	J	A	S	O	N	D
Lövsta 1986				70	39	31	109	186	86	31	47	87
Film 1986				50	43	27	106	173	55	29	44	99
Lövsta 1987	56	28										
Film 1987	48	28										

The precipitation is generally in the form of snow from the middle of November to the middle of April. The proportion of snow is about 35 per cent of the annual mean precipitation. The durability of the snow cover varies considerably between different years. In general, the durability of the snow cover is about 110 days. During the winter 1985/86 the ground was snow covered until 24 April at Films Kyrkby and from 13 December 1986 there was again a durable snow cover.

The annual mean temperature in northern Uppland is about +5.5^{o}C. The temperature is below 0^{o}C for almost five months of the year. Monthly mean temperatures during the period April 1986 throughout February 1987 are shown in Table 4.1.6.

Table 4.1.6 Monthly mean temperature (^{o}C) at Films Kyrkby April 1986 - February 1987.

	J	F	M	A	M	J	J	A	S	O	N	D
1986				1.5	12.4	16.1	16.0	12.3	7.2	6.0	3.7	-2.9
1987	-13.7	-6.0										

Both the potential and the actual evaporation vary substatially during the year. The potential evaporation (valid in discharge areas) is 540 mm/year and the actual evaporation (recharge areas) has been estimated to 380 mm/year in the Finnsjö area (Eriksson, 1980).

There are no long-term runoff observations for the Finnsjön study site, but water discharge measurements have been carried out during 1973-1979 in the river Forsmarksån and since 1925 in the river Tämnarån north of the Finnsjön study site. In Table 4.1.7 runoff data from these drainage basins are specified.

Table 4.1.7 Monthly mean runoff (l/s km^2) from the river Forsmarksån and river Tämnarån drainage basins.

Drainage basin	J	F	M	A	M	J	J	A	S	O	N	D	Year
Forsmarksån * 1973-79	5.3	4.6	6.0	9.3	8.3	4.0	3.3	3.3	4.3	3.6	6.3	9.3	5.6
Tämnarån + 1931-60	8.3	8.0	8.1	16.0	12.2	5.2	3.1	3.3	3.9	4.5	7.7	9.3	7.5

* Drainage basin 302 km^2, Lake area 6.9 %
\+ Drainage basin 1176 km^2, Lake area 4.2 %

Discharge in the small stream that drains the Brändan catchment area has been measured on three occations during 1986: June, October and November. At the end of June there was no measureable flow. In the middle of October there was about 1.8 l/s which corresponds to c. 3.1 l/s km^2 and in the beginning of November there was about 3.2 l/s, i.e. runoff was c. 5.6 l/s km^2.

The water balance of the Finnsjön study site has according to Carlsson and Gidlund (1983) been calculated to:

Adjusted precipitation	670 mm/year
Actual evaporation	430 mm/year
Runoff	240 mm/year

The evaporation is slightly higher than in the Gideå study site and the precipitation is about 100 mm/year less. Consequently runoff is lower, 2/3 of that measured in Gideå, which is evident in a comparison between the duration curves for the sites.

4.1.3 Groundwater conditions

Within the Finnsjön site the hydraulic properties and groundwater conditions have been determined by 1) numerous water injection tests, test pumpings and tracer tests in and between drill holes in the bedrock and 2) by measuring the groundwater pressure at different depths in drill holes and groundwater table monitoring in bedrock and soil.

The hydraulic properties and groundwater conditions in the Finnsjön study site have been described by, among others Ahlbom et al (1986, 1987), Carlsson and Gidlund (1983), Gustafsson and Klockars (1981, 1984) and Larsson and Jacobsson (1982).

The Finnsjön study area is like the surrounding region very flat. This, in combination with a humid climate which entails ample access to groundwater recharging precipitation, implies that the depth down to the groundwater table in the area is small. This also means that the hydraulic gradient in the area is generally small.

The general rule applies that the groundwater table is largely conformal with the ground surface. In the low-lying parts of the study area, the groundwater head is in general at, or slightly above, the ground surface. These parts constitute discharge areas for groundwater and as a rule coincide with tectonic lineaments in the underlying bedrock. The more elevated parts of the area usually constitute recharge areas for groundwater and the general depth down to the groundwater table is greater here than in the case of the discharge areas.

In the recharge areas there is a downward oriented gradient for the groundwater, whereas an upward oriented gradient characterizes the discharge areas.

The relation between altitude and depths to the groundwater table in 36 observation points within the Finnsjön study site are shown in Figure 4.1.4. This is assumed to apply to an ideal profile through the study site. In reality, local depressions in the terrain may constitute local discharge areas. The small catchment area Brändan, selected for the Chernobyl fallout study, in the north-west part of the study site has a plateau character (26-32 m.a.s.l) with a mosaic-type surface of exposed bedrock, bogs and till-filled depressions. As a consequence, the water drainage system is very diffuse. The discharge areas are estimated to approx. 6 hectars which is about 10 per cent of the catchment area.

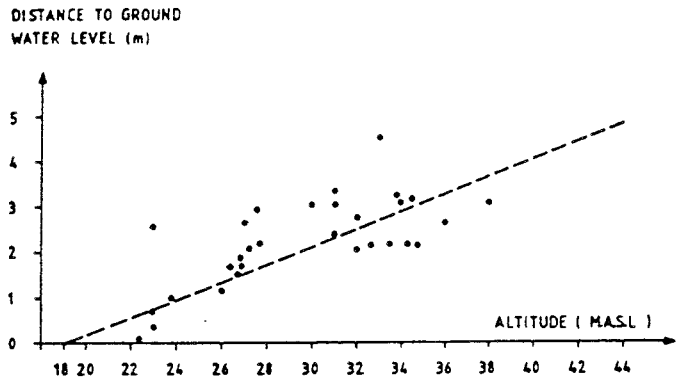

Figure 4.1.4 Relation between altitude and observed depth to the groundwater table in the bedrock within the Finnsjön study site (Carlsson and Gidlund, 1983).

In the Finnsjön study site the groundwater table normally is on its minimum level in late summer August-September. A maximum is reached during November-December due to heavy precipitation and low evaporation. After that, the groundwater table slowly starts to subside but during snow melting it rises and a secondary maximum is reached in April-May. Then it declines to the minimum level in late summer.

4.2 Gamma Spectrometric Measurements

Gamma spectrometric measurements have been carried out within the Finnsjön study site on three occasions; in June, October, and November 1986. The sites are shown in Figure 4.2.1 and described in Table 4.2.1.

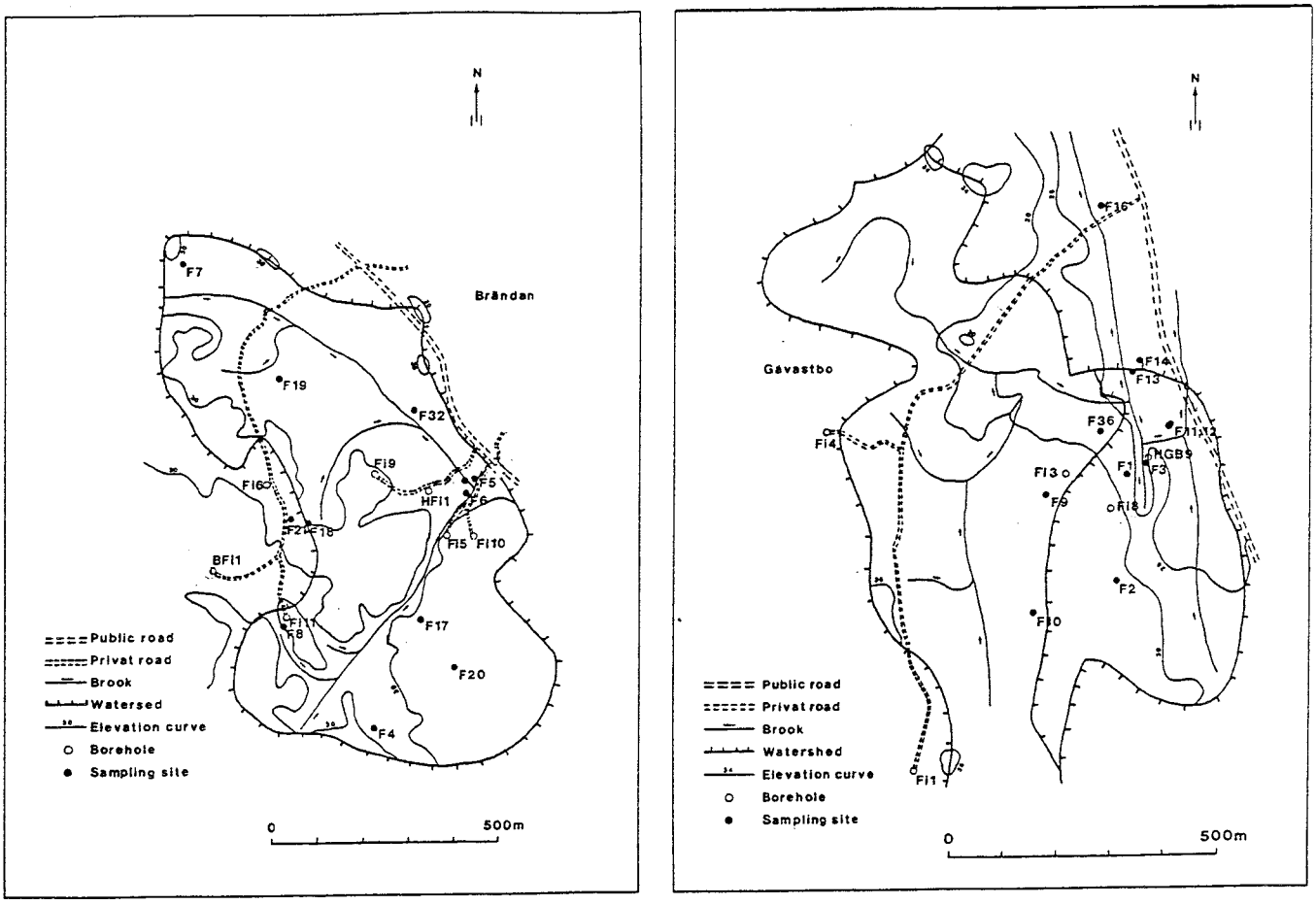

Figure 4.2.1 Finnsjön gamma spectrometric sites.

The results of the gamma spectrometric measurements are presented in Table 4.2.2 and summarized in Table 4.2.3.

The decrease of photon flux from cesium is about 20 % from June to November, which corresponds to an average increase of the half value depth by about 60 %. The coefficient of variation between the different sites is 15 to 30%. See also Figures 4.2.2 and 4.2.3 as examples of these variations.

As a complement to the gamma spectrometric measurements the exposure rate was measured around the spectrometer sites to give the radiation pattern in a microscale which will give information of the deposition pattern and the redistribution after the deposition.

The measurements were carried out by following two perpendicular lines, meeting at the spectrometer site . Complementary measurements, randomly distributed in the quadrants were also done. The results are presented in Table 4.2.4. The average for all sites is 16.6 uR/h (CV = 20 %). Measurements of the background radiation were unfortunately not performed in the Finnsjön area prior to the Chernobyl accident.

Table 4.2.1 Finnsjön gamma spectrometric sites.

Site	Description
F1	Till, forest old conifer
F2	Till, forest pine
F3	Muck soil, discharge area in forest opening
F4	Bog, recharge area with scattered pine trees
F5	Fen, moss-rich conifer forest with shrubs
F6	Fen, vegetation see F5
F7	Till, forest pine
F8	Outcrop
F9	Outcrop
F10	Outcrop and moor
F11	Clay, narrow forest opening
F12	Clay, forest conifer stand
F13	Till, forest opening
F14	Forest mixed stand
F16	Sand clay, pasture
F17	Till, forest conifer
F18	Outcrop
F19	Till, bog forest mixed stand
F20	Outcrop
F21	Till shallow, lichen and heater
F32	Bog
F36	Till, forest conifer

Table 4.2.2 Estimation of surface deposition with spectrometric measurements in situ, given as kBq/m^2 (± 1 S). Compensated for shielding effects due to surface roughness and migration of activity. Measuring time: 2000 seconds. Reference date 1986-04-28.

SITE	DATE	K 40	ZR 95	NB 95	RU103	J131
F 1	860627.	79.2 - 4.20	19.6 - .94	28.0 - 1.02	29.9 - 1.54	384.0 - 57.39
1	861001.	58.9 - 5.90	18.5 - 1.88	36.0 - 2.16	28.6 - 5.99	0.0 - 0.00
1	861107.	58.7 - 4.80	23.1 - 1.44	39.8 - 1.45	29.7 - 4.94	0.0 - 0.00
F 2	861001.	48.6 - 4.20	13.1 - 1.68	26.2 - 1.94	18.9 - 3.71	0.0 - 0.00
F 3	860627.	87.2 - 5.30	13.8 - 0.80	21.6 - 1.06	21.8 - 1.18	367.5 - 59.20
3	861001.	53.5 - 4.50	16.2 - 2.80	33.8 - 2.75	0.0 - 0.00	0.0 - 0.00
F 4	861106.	0.0 - 0.00	14.7 - 2.10	29.1 - 2.62	29.0 - 6.47	0.0 - 0.00
F 5	861106.	41.0 - 4.02	12.6 - 2.02	27.0 - 2.57	0.0 - 0.00	0.0 - 0.00
F 6	861107.	39.6 - 4.36	16.5 - 2.36	30.8 - 2.59	0.0 - 0.00	0.0 - 0.00
F 7	861106.	63.6 - 2.00	14.3 - 1.09	27.4 - 1.18	20.8 - 3.46	0.0 - 0.00
F 8	861002.	115.2 - 6.13	11.3 - 2.03	23.9 - 2.05	9.4 - 5.27	0.0 - 0.00
F 9	860627.	122.7 - 7.33	17.5 - 1.12	26.3 - 1.26	27.3 - 1.62	393.5 - 72.71
9	861001.	118.5 - 6.01	15.8 - 1.79	34.9 - 2.20	21.3 - 4.23	0.0 - 0.00
F 10	861001.	74.5 - 4.99	16.5 - 1.78	33.9 - 2.13	32.8 - 4.23	0.0 - 0.00
F 11	861001.	72.6 - 5.26	19.1 - 1.80	28.9 - 2.02	31.4 - 4.42	0.0 - 0.00
F 12	861001.	64.9 - 4.55	11.8 - 1.77	25.8 - 2.32	22.6 - 4.87	0.0 - 0.00
F 13	860627.	118.0 - 7.32	19.0 - .89	29.5 - 1.28	32.0 - .84	425.2 - 29.15
13	861001.	86.1 - 5.38	18.7 - 2.05	32.3 - 2.28	25.4 - 5.13	0.0 - 0.00
F 14	861001.	70.5 - 5.32	11.1 - 1.68	24.1 - 2.05	15.8 - 3.99	0.0 - 0.00
F 16	860627.	90.6 - 7.32	20.9 - 1.03	30.2 - 1.06	33.5 - 1.42	434.0 - 97.14
16	861001.	71.9 - 4.83	13.4 - 1.71	29.6 - 2.08	17.6 - 4.28	0.0 - 0.00
F 17	860627.	57.3 - 4.55	16.2 - .80	25.2 - .97	29.5 - 1.31	363.1 - 65.45
17	861106.	62.6 - 4.48	0.0 - 0.00	24.9 - 3.66	0.0 - 0.00	0.0 - 0.00
F 18	861002.	103.7 - 5.82	19.5 - 1.91	36.2 - 2.29	31.6 - 4.30	0.0 - 0.00
F 19	861106.	32.1 - 3.98	19.6 - 2.78	25.3 - 2.36	0.0 - 0.00	0.0 - 0.00
F 20	861106.	108.9 - 5.89	16.5 - 3.00	34.6 - 2.95	0.0 - 0.00	0.0 - 0.00
F 21	861106.	63.2 - 4.74	19.4 - 2.79	31.0 - 3.05	43.3 - 8.78	0.0 - 0.00
F 22	860627.	0.0 - 0.00	15.3 - .78	22.8 - .90	25.7 - 1.63	247.4 - 80.23

error due to counting statistics only (± 1 Sigma) given in the right column
0.0 = not detectable

Table 4.2.2 cont. Estimation of surface deposition with spectrometric measurements in situ, given as kBq/m^2 (± 1 S). Compensated for shielding effects due to surface roughness and migration of activity. Measuring time: 2000 seconds. Reference date 1986-04-28.

SITE	DATE	CS134	CS137	SB125	LA140	AG110M
F 1	860627.	17.0 - .76	31.0 - 1.09	0.0 - 0.00	62.7 - 7.90	0.0 - 0.00
1	861001.	15.4 - .48	28.6 - .82	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
1	861107.	15.1 - .29	26.6 - .41	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 2	861001.	12.7 - .45	21.7 - 1.24	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 3	860627.	13.8 - .50	24.2 - 1.25	0.0 - 0.00	37.7 - 7.62	0.0 - 0.00
3	861001.	11.2 - .47	22.2 - .70	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 4	861106.	12.6 - .42	21.0 - .67	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 5	861106.	13.4 - .63	24.8 - .74	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 6	861107.	12.4 - .49	21.7 - .69	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 7	861106.	13.2 - .25	23.1 - .36	1.1 - .38	0.0 - 0.00	0.0 - 0.00
F 8	861002.	13.0 - .48	22.3 - 1.21	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 9	860627.	17.5 - .61	31.9 - .88	0.0 - 0.00	40.7 - 12.11	1.1 - .46
9	861001.	16.7 - .47	29.6 - 1.09	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 10	861001.	16.1 - .53	27.7 - 1.08	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 11	861001.	15.0 - .53	25.8 - .82	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 12	861001.	12.3 - .50	23.0 - .71	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 13	860627.	19.5 - .39	35.5 - 1.50	0.0 - 0.00	72.1 - 7.48	0.0 - 0.00
13	861001.	15.4 - .43	26.1 - .77	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 14	861001.	10.5 - .42	19.6 - .99	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 16	860627.	21.2 - .63	37.9 - .89	0.0 - 0.00	67.3 - 7.26	0.0 - 0.00
16	861001.	15.2 - .50	28.0 - 1.00	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 17	860627.	16.2 - .73	30.9 - 1.41	0.0 - 0.00	60.1 - 7.14	0.0 - 0.00
17	861106.	13.1 - .58	25.3 - .75	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 18	861002.	19.9 - .47	35.1 - .92	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 19	861106.	13.3 - .45	25.9 - 1.06	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 20	861106.	16.2 - .53	29.5 - 1.19	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 21	861106.	17.9 - .54	31.4 - .89	0.0 - 0.00	0.0 - 0.00	0.0 - 0.00
F 22	860627.	14.2 - .61	23.6 - 1.57	0.0 - 0.00	42.7 - 12.22	.9 - .53

error due to counting statistics only (± 1 Sigma) given in the right column
0.0 = not detectable

Table 4.2.3 Finnsjön, gamma spectrometric measurements, summary. Measuring time 2000 seconds.

Date	Nuclide	Mean (kBq/m^2)	Coefficient of variation (%)
1986-06-27--28	I-131	127	17
(7 sites)	Cs-134	17	15
	Cs-137	31	18
	La-140	58	22
	Ru-103	29	14
	Nb-95	27	12
1986-10-01--02	Cs-134	15	16
(11 sites)	Cs-137	26	17
	Ru-103	23	32
	Nb-95	31	16
1986-11-06--07	Cs-134	14	14
(10 sites)	Cs-137	25	13
	Ru-103	31*	-
	Nb-95	31	15

* 4 sites.

Table 4.2.4 Exposure rate (uR/h), Finnsjön study site. November 1986.

Site	F1	F2	F3	F4	F5	F6	F7	F8	F11	F12	F14	F17	F18	F19	F20	F21
Mean	16.3	19.0	14.8	11.1	15.5	15.0	16.0	24.1	16.2	15.5	15.3	16.3	15.9	13.0	21.7	18.7
CV (%)	-	8.8	8.3	5.4	9.5	10.6	6.4	6.9	9.3	5.7	8.0	13.1	6.6	12.2	5.4	13.8

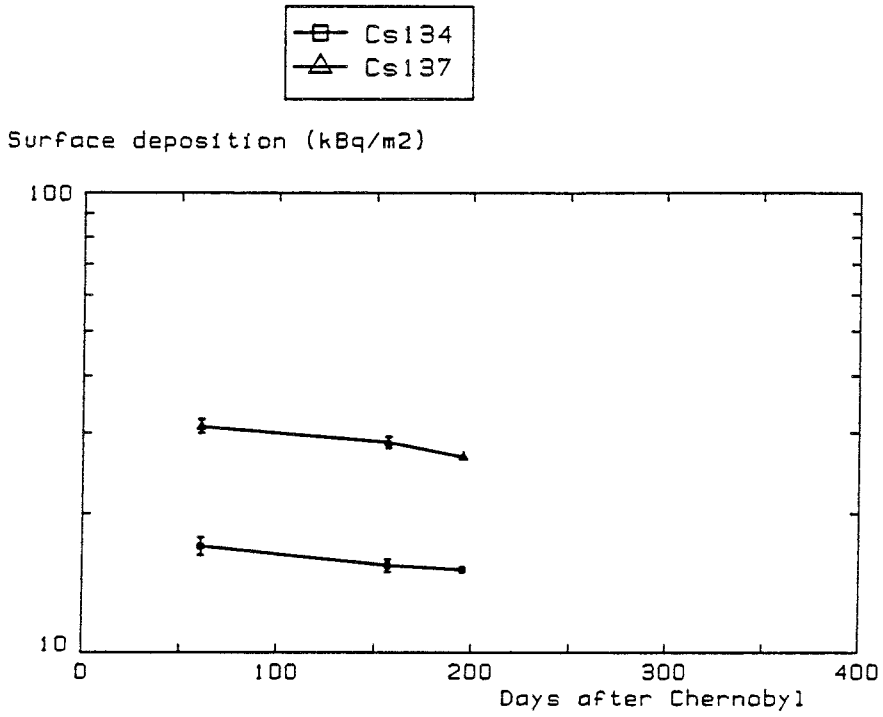

Figure 4.2.2 Gamma spectrometric measurement in situ at site F1 (Till), Finnsjön study site.

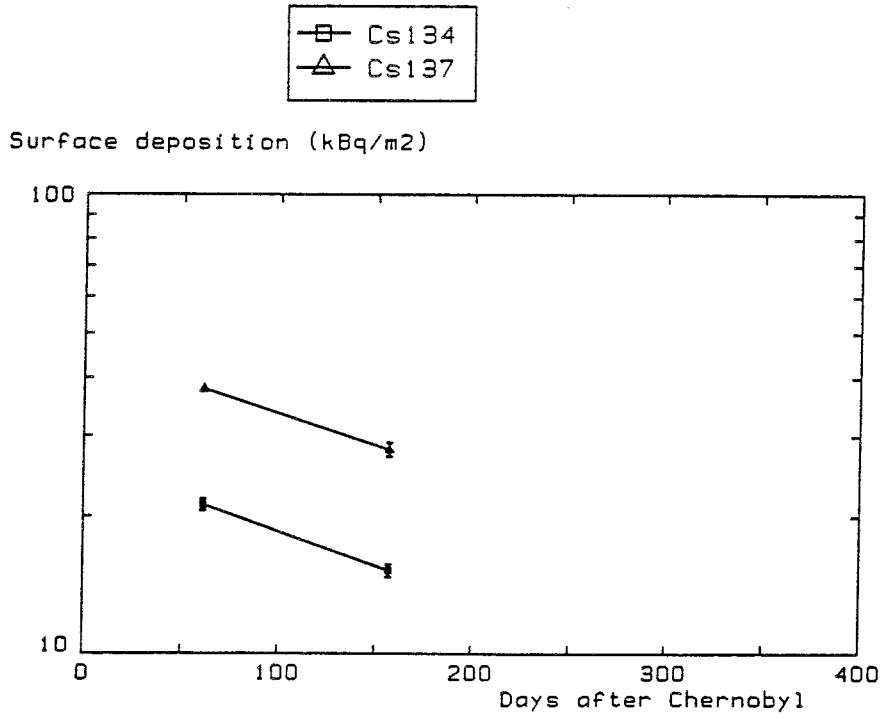

Figure 4.2.3 Gamma spectrometric measurement in situ at site F16 (Sand, clay), Finnsjön study site.

4.3 Soil profiles

Soil profile samples have been taken in June, October and November 1986. The location of the sampling sites are shown in Figure 4.3.1 and they are described in Table 4.3.1. Fifteen sites have been sampled of which 13 sites coinside with sites for gamma spectrometric measurements in situ.

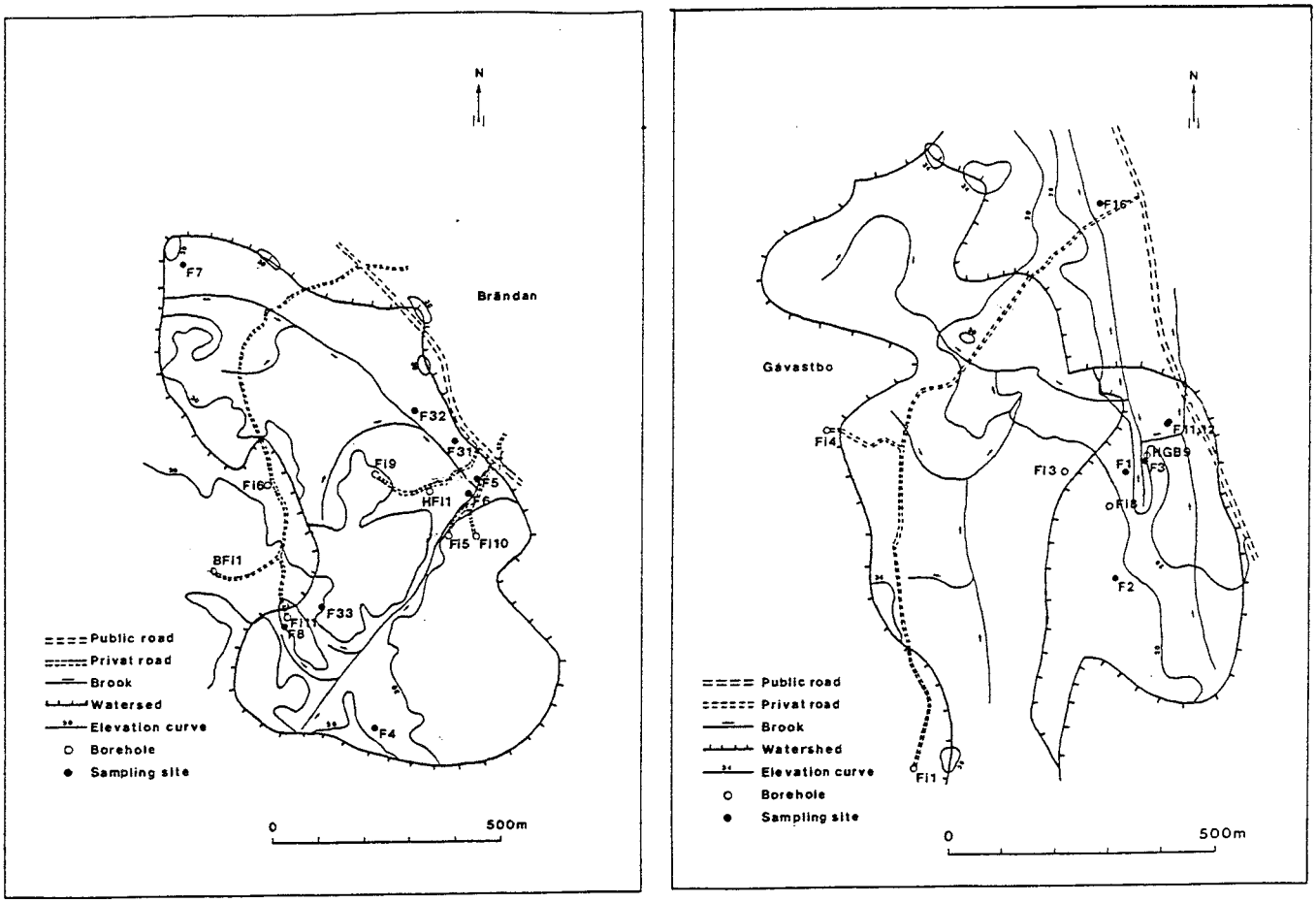

Figure 4.3.1 Soil profile sampling sites, Finnsjön study site.

The activity in the soil profile samples are presented in Tables 4.3.2 - 4.3.5. Among the radionuclides originating from the Chernobyl accident the following nuclides have been measured at depth in the soil profiles: Cs-137, Cs-134, Sb-125, Ru-106, Co-60, Ag-110 m, Zr-95 and Ce-144. The results are exemplified in Figures 4.3.2 - 4.3.8 showing soil activity profiles.

The results show that most of the nuclides are caught in the upper layer of vegetation and humus. Except for solitary recordings of Ru-106 and Cs-134 at 10-12 cm depth, only Cs-137 has been found below 10 cm depth in the soil profiles. This is very well demonstrated in the till profiles F1 and F2 (Figs. 4.3.2 and 4.3.3).

Concerning the nuclide/Cs-137 ratios the available data are unsufficient for any detailed interpretation. However, the present data indicate in some profiles a correlation between the Ru-106, Sb-125 and Cs-134 compared to Cs-137. This can be due to a common transport for all these nuclides, i.e. the observed difference of cesium compared to the other nuclides as observed in Gideå is not that pronounced within Finnsjön.

Table 4.3.1 Description of soil profile sampling sites.

Site	Description
F1	Till, forest old conifer
F2	Till, forest pine
F3	Muck soil, discharge area in forest opening
F4	Bog, recharge area with scattered pine trees
F5	Fen, moss-rich conifer forest with shrubs
F6	Fen, vegetation see F5
F7	Till, forest pine
F8	Outcrop, thin soil layer
F11	Clay, narrow forest opening
F12	Clay, forest conifer stand
F16	Sand clay, pasture
F30	
F31	Till
F32	Fen
F33	Outcrop, thin soil layer

The soil profile measurements from site F1 and F16 have been used for curve fitting with least square approximations to different analytical functions, exponential and power curve together with direct integration of the total activity in the different layers. The results are presented in Table 4.3.6.

Table 4.3.2 Activity in soil profile samples (Bq/kg d w) from Finnsjön study site. Sampling 1986-06-27--28. Reference date 1986-04-28.

No.	Site	Type	Depth (cm)	Area (m**2)	Water content (%, w w)	Zr-95	Ru-103	Ru-106	Ag-110m	I-131	Cs-134	Cs-136	Cs-137	Ba-140	Ce-141	Ce-144	Cs-134/Cs-137
10	F1**	Litter	0-3	0.045	16	3.03E2	4.11E2	1.37E2		4.70E3	2.95E2		6.63E2		3.39E2	2.42E2	0.44
11	F1**	Till	3-6		17		1.42E1				8.06E0		4.08E1				0.20
12	F1**	Till	6-10		13	2.93E1	1.09E1				9.16E0		2.85E1		2.12E1		0.32
13	F3**	Till	0-3	0.045	20	2.60E2	3.79E2	9.11E1			2.83E2		5.64E2		2.87E2	1.84E2	0.50
18	F8*	Moss	0-4	0.045	37	1.84E3	3.13E3	9.46E2	6.43E1	4.22E4	2.01E3		3.94E3		2.11E3	1.27E3	0.51
3	F16	Litter	0-3	0.045	25	2.62E2	5.39E2	2.20E2	1.78E1		3.18E2		6.10E2		3.63E2	1.86E2	0.52
4	F16	Sandy clay	3-6		15	2.02E1	2.29E1				1.43E1		5.19E1				0.27
5	F16	Sandy clay	6-10		13	1.44E1	1.88E1				9.76E0		3.35E1		4.52E1		0.29
6	F30	Litter	0-3	0.045	21	2.14E2	4.72E2	7.20E1			3.48E2		6.67E2	2.10E3	3.29E2	1.04E2	0.52
9	F31*	Litter	0-4	0.045	31	7.48E2	1.01E3	4.50E2		1.20E4	5.97E2		1.22E3		7.64E2	4.61E2	0.49
14	F32*	Bog	0-5	0.045	86	3.62E3	4.25E3	1.00E3			3.02E3		5.82E3		4.43E3	2.45E3	0.52
19	F32*	Till	0-3	0.045	47	1.17E3	1.87E3	5.79E2	5.50E1	2.57E4	1.47E3		2.87E3		1.20E3	8.84E2	0.51
20	F32*	Moss	0-3	0.045	76	1.44E3	1.86E3	3.10E2		1.16E4	9.56E2		1.74E3		1.39E3	1.12E3	0.55
21	F32*	Peat	3-10		80	9.65E1	1.61E2	7.70E1		4.42E3	1.03E2		2.31E2				0.45
22	F32*	Peat	10-20		88	9.13E1	2.30E2				2.64E1		7.35E1		7.39E1		0.36
8	F33*	Moss	0-4	0.045	57	8.08E2	1.75E3	4.17E2		3.20E4	9.26E2		1.77E3		1.12E3	6.61E2	0.52

** Gåvastbo area

* Brändan area

Table 4.3. 3 Activity in soil profile samples (Bq/kg d w) from Finnsjön study site. Sampling 1986-10-01--02. Reference date 1986-04-28.

No.	Site	Type	Depth (cm)	Area (m**2)	Water content (%, w w)	Ru-103	Ag-110m	Cs-134	Cs-137	Ce-141	Ce-144	Cs-134/Cs-137
106	F1**	Sedge			60		4.00E1	1.98E2	3.64E2		1.56E2	0.54
107	F1/0	Litter/humus	0-5	0.032	65			4.96E2	8.34E2		5.40E2	0.59
108	F1/3	Moss sphagnum	0-6	0.032	63			4.39E2	1.10E3		3.34E2	0.40
109	F1/3	Grass/clay	0-10	0.032	36			1.88E2	2.58E2		-	0.73
110	F1/3	Grass/clay	0-6	0.032	43			6.55E2	3.70E2		1.66E2	1.77
111	F1/8	Raw humus	0-5	0.032	34			2.08E2	3.71E2		-	0.56
112	F1/8	Raw humus	0-11	0.032	45			1.05E2	2.72E2		-	0.39
113	F1/8	Till	0-6	0.032	45			2.38E2	4.56E2		-	0.52
114	F1**	Till	0-3	0.045	83	4.30E3		1.13E3	2.13E3		9.45E2	0.53
115	F1**	Raw humus	5-9	0.045	83			3.08E1	6.19E1		-	0.50
120	F16	Pasture (non cut)		0.5	97			1.79E2	2.75E2			0.65
121	F16	Litter	0-3	0.040	40			2.96E2	5.35E2			0.55
122	F16	Sandy clay	3-6	0.025	28			1.97E1	5.13E1			0.38
123	F16	Sandy clay	6-11	0.020	24			8.80E0	2.48E1			0.35
124	F16	Sandy clay	12-17	0.005	22			1.68E1	2.56E1			0.66
102	F11**	Needle, spruce		0.45	56	3.97E3	8.77E1	2.35E3	4.26E3	3.06E3	1.93E3	0.55
103	F11**	Grass		0.5	79			4.75E2	9.02E2		7.48E2	0.53
101	F11**	Grassroots	0-3	0.04	38			3.47E2	6.28E2		2.15E2	0.55
105	F12**	Needle on ground		0.25	66	2.53E3	1.33E2	1.72E3	3.16E3		1.49E3	0.54
104	F12**	Raw humus	0-3	0.045	31			1.36E2	2.46E2			0.55

** Gåvastbo area

* Brändan area

Table 4.3.4 Activity in soil profile samples (Bq/kg d w) from Finnsjön study site. Sampling 1986-10-14--15. Reference date same as sampling date.

Number	Sample description:	Date of sampling	Date of analysis	Depth (cm)	Area (m2)	pH	% H20	Dry wght	Geom	Wght (g-a)
1	F1, Litter fall, incl. root carpet and surface vegetation (moss, grass).	861014	870210	0-3			71,20	106,20	M500	106,20
2	Rawhumus incl. gravelly till - bleached horizon.	861014	870210	3-10		4.8	25,20	332,10	B250	290,60
3	Normal till - bleached horizon.	861014	870210	10-20		4.7	16	498,70	B250	448
4	Normal till - enrichment layer.	861014	870211	20-30		5.2	23,70	426,50	B250	376,50
5	Normal till - parent material.	861014	870211	30-40		5.3	21,20	464,20	B250	464,20
6	Litter fall incl. surface vegetation.	861014	870209	0-2	,0625		67,90	80,50	M500	80,50
7	Rootcarpet, rawhumus	861014	870209	2-4	,0625		43,40	480,50	M500	399
8	Rawhumus	861014	870210	4-6	,0625	5.0	30,90	501,50	M500	501,50
9	Tube profile, vegetation - till	861014	870427	0-10	,0034		43,20	112,40	B60	39,20
10	Tube profile, vegetation - rawhumus	861014	870515	0-5	,0034		41	242,30	B250	230,80
11	F2, Litter fall incl. surface vegetation (moss, grass, twigs).	861014	870220	0-2	,0621		71	105,50	B250	55,30
12	Rootcarpet, rawhumus	861014	870220	2-4	,0621	4,45	71,60	135	B250	68
13	Rawhumus	861014	870221	4-5.5	,0621	4,35	71,50	178,50	B250	87,50
14	Rawhumus	861014	870222	5.5-8	,0621	4,25	72,60	236	B250	236
15	Rawhumus	861014	870221	8-10	,0621	4,30	69,50	197,20	B250	128
16	Sandy till, leached horizon.	861014	870222	10-12		4,40	27,70	385,10	B250	343,50
17	Sandy till, enrichment layer.	861014	870223	12-22		4,50	23,90	480,20	B250	430
18	Sandy till, enrichment layer.	861014	870221	22-32		4,60	32,70	505,50	B250	437,50
19	F4, Sphagnum sp.	861015	870218	0-5	,0625		96,30	26,30	M500	26,30
20	Sphagnum peat - degree of decomposition H2'.	861015	870218	5-7	,0625		94,20	36,60	M500	34,80
21	Sphagnum peat - degree of decomposition H2'.	861015	870218	7-10	,0625		95,30	46,50	M500	36
22	Sphagnum peat - degree of decomposition H2'.	861015	870217	10-12	,0225		93,20	46	M500	46
23	F6, Litter fall incl. surface vegetation.	861015	870223	0-3	,05		73,50	143,40	B250	67,40
24	Root carpet	861015	870223	3-6	,05		67	236,20	B250	126
25	Rawhumus incl. sandy till.	861015	870223	6-9	,05		52,70	1302,50	M500	588
26	F7, Litter fall incl. surface vegetation (grass, twigs).	861015	870217	0-4	,0625		72,30	27,20	B250	27,20
27	Root carpet	861015	870217	4-6	,0625		70	107	B250	107
28	Rawhumus incl. sandy till.	861015	870216	6-7.5	,0625	4,80	55,50	225,20	B250	215,80
29	Tube profile vegetation - till	861015	870217	0-15	,0034		25,50	353	B250	353

' According to von Post (1921).

Table 4.3.4 Activity in soil profile samples (Bq/kg d w) from Finnsjön study site. Sampling 1986-10-14--15. Reference date same as sampling date.

Number	K-40	Unc is	Mn-54	Unc is	Co-60	Unc is	Zr-95	Unc is	Ru-103	Unc is	Ru-106	Unc is	Ag-110m	Unc is	Sb-125	Unc is	Cs-134	Unc is	Cs-137	Unc is	Ce-144	Unc is
1	44,08	5,30	,41	79	1,57	25,90	32,50	4,80	16,26	24,60	45,05	10,80			11,86	15	213,70	,60	500,40	,40		
2	286,10	1,80									5,23	39,10					5,04	6,50	22,89	1,60		
3	406,70	1,40																	,86	25,70		
4	409,90	1,10																	,80	20,70		
5	495,40	1,40																	,34	82,10		
6	38,40	5,60	,83	46,30	1,45	27,50	35,85	4,20	18,36	24	53,39	10,40			10,80	16,10	228,40	,50	512,50	,40	93,78	8,70
7	293,10	1,60									5,63	23,70			2,48	29,80	31,83	1,50	107	,60		
8	489,40	,70					1,90	23,70	1,99	38,30	3,60	34,50			,88	29,90	11,26	1,70	54,98	,50		
9	970,92	3,50									56,68	34,20					119,36	3,10	352,04	1,40		
10	752,60	3,30									20,38	48					122,88	2,70	319,97	1,30		
11	38,88	7,90			,96	52	17,81	13,50			44,41	15,60	4,99	26,90	8,98	23,80	140	1,10	320,70	,70	84,80	13,20
12	30,40	8,80			,33	77,70					12,60	29,20			2,49	38,70	35,37	2,30	87,77	1,30		
13	36,43	8,10															10,03	4,80	31,47	2,20		
14	71,25	4,90					1,49	85,50			4,78	35,60			,90	65,10	8,90	4,10	30,79	1,80		
15	66,82	5,80															2,47	13,10	8,56	4,50		
16	331,80	2,20									4,11	61,80							8,27	4,20		
17	364,60	2																	2,66	11,10		
18	399,90	1,90																	1,37	20,10		
19	11,73	14,20			,55	43,50	9,52	22,20			17,19	18,40					47,11	1,40	113,60	,90		
20	7,68	15									2,34	28,30			,54	60,50	3,04	6,10	9,17	2,80		
21	8,89	6,30									,74	39,90					,92	7	4,86	1,80		
22	9,19	6,40															,79	6,90	4,71	2		
23	32,58	8			,87	52,30			29,47	23,90	76,93	10,60	8,50	40,60	10,45	20,60	151,90	1	363,70	,60	361,90	7
24	77,45	6,40			,64	75,30	6,91	48,20					3,30	88	4,25	41,60	69,03	1,90	164,40	1,10	141,80	17,60
25	439	,80			,22	74,70					7,14	18	,51	53,30	,78	41,90	13,41	1,80	47,06	,60		
26	17,98	11	,30	56,20	,69	25,40	,43	13,40	,12	7,20	113,80	3	1,82	9,40	10,32	11,70	107,70	,80	330,10	,50	221,50	5
27	46,41	6	,80	54,10	1,50	32,90	27,75	14,20	19,24	37,70	54,54	13,30	5,18	14,20	13,55	16,80	258	,70	574,60	,40	395,50	7,40
28	106,70	2,70			,68	34,30	7,73	12,10			14,30	14,30			3,63	20,60	64,31	,90	161,10	,50	64,45	13,60
29	315,80	2,30															23,38	2,70	64,80	1,30		

Table 4.3.5 Activity (Bq/kg d w) in soil profile samples from Finnsjön study site. Sampling 1986-11-06--07. Reference date 1986-04-28.

No.	Site	Type	Depth (cm)	Area (m**2)	Water content (%, w w)	Cs-134	Cs-137	Cs-134/Cs-137
221	F1**	Till	0-1		55	1.7E3	2.8E3	0.61
222	"	"	1-2		45	1.8E2	1.8E2	1.0
223	"	"	2-3		44	<5.0E1	1.9E2	-
224	"	"	3-4		30	<5.0E1	1.7E2	-
225	"	"	4-5		38	6.0E1	<5.0E1	-
226	"	"	5-9		47	<2.0E1	3.7E1	-
227	"	"	9-13		15	<2.0E1	2.1E1	-
228	"	"	13-17		20	<2.0E1	<2.0E1	-
229	"	"	17-21		23	<2.0E1	3.2E1	-
239	"	"	0-3	0.045		-	-	-
240	"	"	3-6			-	-	-
241	"	"	6-18			-	-	-
210	F3**	Peat	0-1		71	2.7E3	4.9E3	0.55
211	"	"	1-2		51	4.3E2	5.0E2	0.86
212	"	"	2-3		44	2.1E2	<1.0E2	-
213	"	"	3-4		43	2.1E2	2.6E2	0.81
214	"	"	4-5		40	2.3E2	3.3E2	0.70
215	"	"	5-9		36	6.0E1	1.1E2	0.55
216	"	"	9-13		32	2.0E1	<2.0E1	-
217	"	"	13-17		33	2.0E1	2.2E1	0.91
218	"	"	17-21		31	2.0E1	<2.0E1	-
219	"	"	0-3	0.045		5.3E2	9.9E2	0.54
220		"	3-8			4.0E1	9.0E1	0.44
202	F7*	Till	0-1		62	1.9E3	3.5E3	0.54
203	"	"	1-2		41	2.4E2	8.6E2	0.28
204	"	"	2-3		26	7.5E1	3.7E2	0.20
205	"	"	3-4		22	5.5E1	<6.5E1	-
206	"	"	4-5		16	8.0E1	<6.5E1	-
207	"	"	5-9		27	<2.0E1	4.0E1	-
208	"	"	9-13		24	<2.0E1	<2.0E1	-
209	"	"	13-17		20	<2.0E1	<2.0E1	-

** Gåvastbo area

Table 4.3.6 Soil profile evaluation. Spectrometer estimation of activity based on an efficiency with 1/alpha = 2.0. Least square approximation with large weights on upper layer points. A zero value of quotient SPEC/SAMP means that no spectrometer measurement was available.

SITE	TIME	NLAY	NUCL	EXPONENTIAL PROFILE SURF ACT. (BQ/KG)	D 1/2 (CM)	INT. ACT. (BQ/M2)	R2	POWER PROFILE SURF ACT. (BQ/KG)	D 1/2 (CM)	INT. ACT. (BQ/M2)	R2	DIRECT INTEGRATION INT ACT. (BQ/M2)	QUOT. SPEC/ SAMP
F 16	860627	3	CS134	2.26E+02	1.3	6.89E+03	.75	4.73E+02	1.4	6.54E+03	.96	1.36E+04	0.
			CS137	6.80E+02	1.5	2.41E+04	.84	8.66E+02	1.5	1.79E+04	.97	2.87E+04	0.
			RU103	8.33E+02	1.2	2.40E+04	.87	9.16E+02	1.4	1.32E+04	.96	2.30E+04	0.
F 1	860627	3	CS134	16.	4.7	1.69E+03	.11	59.	1.7	2.95E+03	.39	1.35E+04	1.3
			CS137	8.84E+02	1.4	2.86E+04	.85	1.13E+03	1.4	1.86E+04	.96	3.24E+04	.96
			RU103	8.26E+02	1.0	1.99E+04	.87	9.16E+02	1.3	9.76E+03	.96	1.85E+04	1.6
F 16	861001	4	CS134	53.	3.2	3.94E+03	.30	2.14E+02	1.5	4.96E+03	.78	1.19E+04	1.3
			CS137	92.	3.5	7.49E+03	.37	3.82E+02	1.6	1.12E+04	.85	2.28E+04	1.2

Table 4.3.7 Half value and quarter value depth in soil profiles,October 1986. Determined by curve fitting, with a logarithmic function, to experimental data from large area (25x25 cm) soil profile samples.

Site	Soil profile	# of points	Cs-134, 1/2-depth	1/4-depth	# of points	Ru-106, 1/2-depth	1/4-depth
F1	Till, medium, sandy (podsol)	5	1.3	2.0	5	1.0	1.9
F2	Till, medium, sandy (podsol)	5	1.6	2.7	4	1.5	3.2
F4	Peat	4	2.9	4.1	3	3.6	4.8
F6	Peat mixed with sand	3	2.8	3.7	2	2.4	3.3
F7	Till, medium, sandy (podsol)	3	3.9	5.3	3	3.0	3.8

The direct integration provides the best estimate of the total activity, used for comparison with the spectrometric measurements, and the power and exponential curve have been used for estimation of the half value depth. The power function provides the best fit to the experimental data, indicating other transport mechanisms than pure diffuson. The uncertainty in curve fitting is high, due to the limited number of points.

The half value depth, calculated for Cs-134, Cs-137 and Ru-103, is approx. 1.5 cm at sites F1 and F16.

Half value and quarter value depth have also been determined in the soil profiles F1, F2, F4, F6 and F7 from large area (25x25 cm) soil profile samples. Cs-134 and Ru-106 depth were calculated. The cesium isotope Cs-134 was shosen because it is not present in the soil before April 1986.

The depths have been determined by curve fitting to a logarithmic function which provided the best fit to the experimental data. The results are presented in Table 4.3.7. Cs-134 and Ru-106 shows nearly similar 1/2 and 1/4 value depths. The 1/2 value depth is approx. 1.5 cm in the profiles F1 and F2 in till (medium sandy, podsol). The 1/4 value depth is c. 2.5 cm. In the peat profiles F4 and F6 the 1/2 and 1/4 value depths is 3 cm and 4 cm respectively, i.e the migration is less dispersed than in the till profiles.

Surface activity at the sites F1,F4,F6 and F7 determined from large area (25x25 cm) soil profile samples is presented in Table 4.3.8. The relative distribution (per cent) between the uppermost layer and the entire profile is also given.

The activity of soil samples and some surface covering vegetation sampled in June 1986 is summarized in Table 4.3.9. The Cs-137 activity of the different soil layers (0-3 cm,3-6 cm and 6-10 cm), lichen, moss and fern is shown in the summary table, as well as the activity ratio in relation to Cs-134.

The mean surface activity of Cs-137 was in June 2100 Bq/kg d w, while the lichen had about 30 000 Bq/kg d w.

Table 4.3.8 Activity (kBq/m^2) in soil profile samples, taken 1986-10-14--15. Reference date is sampling date.

Site	Date	Area	Depth	Activity kBq/m^2 (sampling date) Zr-95	Ru-103	Ru-106	Ag-110m	Sb-125	Cs-134	Cs-137	Ce-144	Co-60	Mn-54	Ratio Cs-134/Cs-137
F1	861014	25x25 cm	0-6 cm	0.6	0.3	1.0		0.23	4.45	11.15	1.50	0.02	0.01	0.40
+			0-2 cm	95	90	84		74	82	74	100	100	100	
F4	861015	25x25 cm	0-12 cm	0.2		0.3		0.01	0.86	2.28	2.0	0.01		0.38
+			0-5 cm	100		83		0	88	80	100	100		
F6	861015	25x25 cm	0-9 cm	0.3	1.2	3.6	0.5	0.6	9.65	23.72	20.7	0.08		0.41
+			0-3 cm	0	100	91	71	70	67	65	74	44		
F7	861015	25x25 cm	0-7.5 cm	0.6	0.3	2.9	0.1	0.4	6.92	17.19	11.0	0.05	0.02	0.40
+			0-4 cm	1	1	62	26	37	25	31	32	24	28	

+ Percent of total activity within the first layer

Table 4.3.9 Activity (Bq/kg d w) in samples of soil and surface covering vegetation, taken 1986-06-25--26. Reference date 1986-04-28.

Type	No. of samples	Cs-137 Mean	CV (%)	Ratios to Cs-134 Cs-137	Zr-95	Ru-103	Ru-106	I-131	Ce-141	Ce-144
Soil (0-3 cm)	9	2 135	64	1.97	0.97	1.57	0.46	20	1.08	0.74
Soil (3-6 cm)	2	46	17	4.4	1.4	1.68	1.40			
Soil (6-10 cm)	2	31	11	3.3	2.3	1.28			3.50	
Lichen	1	29 400		1.91	0.96	1.40	0.35	10	1.14	0.69
Moss	1	3 020		1.93	1.20	1.41	0.33		1.47	0.81
Fern	1	960		2.52	3.6	2.2			3.4	3.7

The activity decreases rapidly, from 2100 in the upper 3 cm to about 50 Bq/kg d w in the layer of 3-6 cm. Compare this with Table 4.3.6, where the calculated half value depth is about 1.5 cm. At this depth the old bomb derived Cs-137 can also be seen, compare Cs-137/Cs-134 ratio 3 to 4 in deeper layers. The surface ratio is around 2.0.

Table 4.3.10 summarizes the results from the October measurements. The activity values are generally lower than in June. In November some single core samples were taken. More than 75 % of the total activity is found in the upper cm of the soil profile.

Table 4.3.10 Activity (Bq/kg d w) in samples of soil and surface covering vegetation, taken 1986-10-01--02. Reference date 1986-04-28.

Type	No. of samples	Cs-137 Mean	Ratios to Cs-137 Cs-137	Ru-103	Ce-144
Soil (0-3 cm)	4	885	1.83	1.3	0.7
Soil (3-6 cm)	1	50	2.6		
Soil (6-10 cm)	1	25	2.8		
Lichen	1	23 100	1.9	1.3	0.7
Moss	1	1 100	2.5	-	0.8

F1

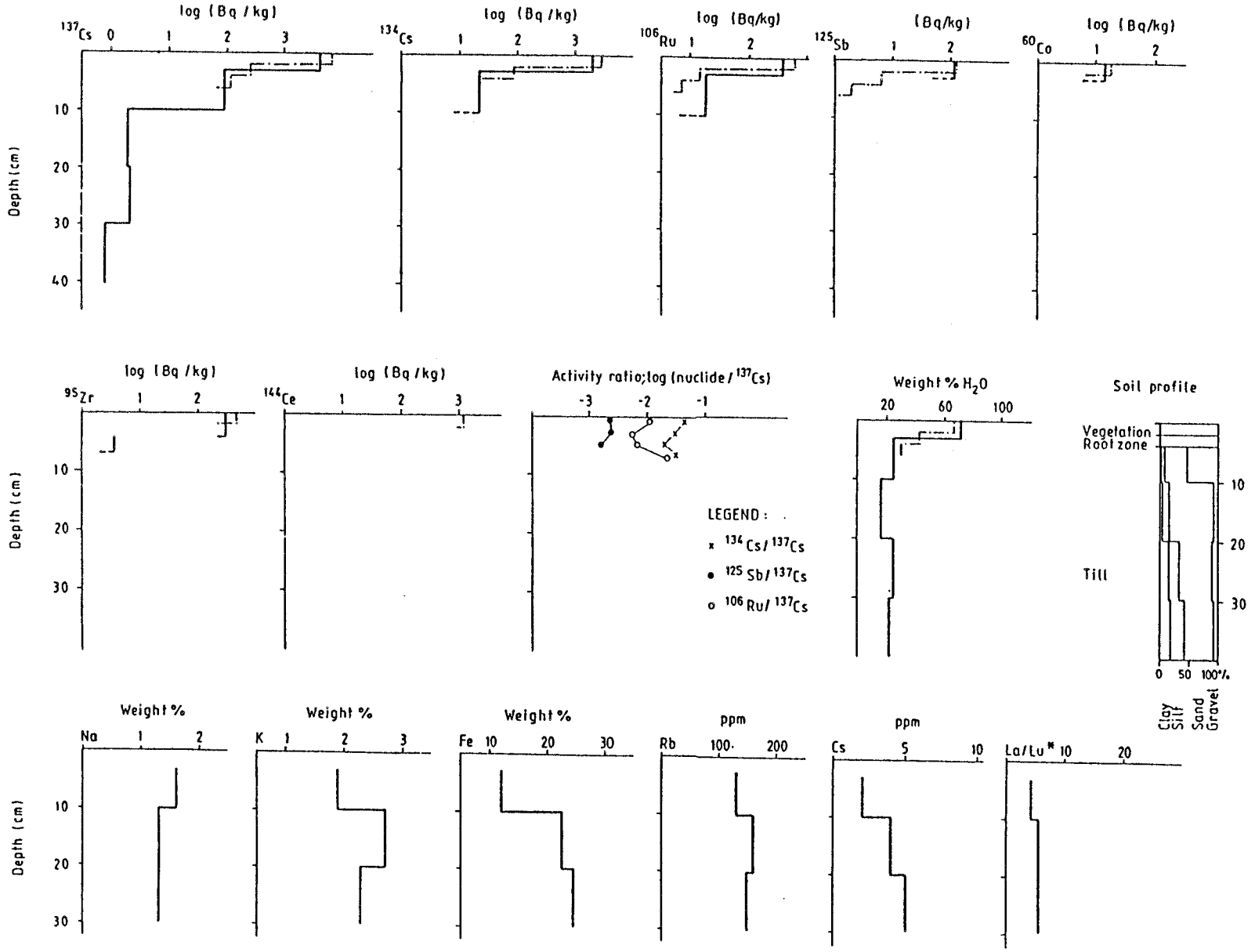

Figure 4.3.2 Soil activity profile (Bq/kg d w) in till, at site F1, recharge area, 1986-10-14.

F 2

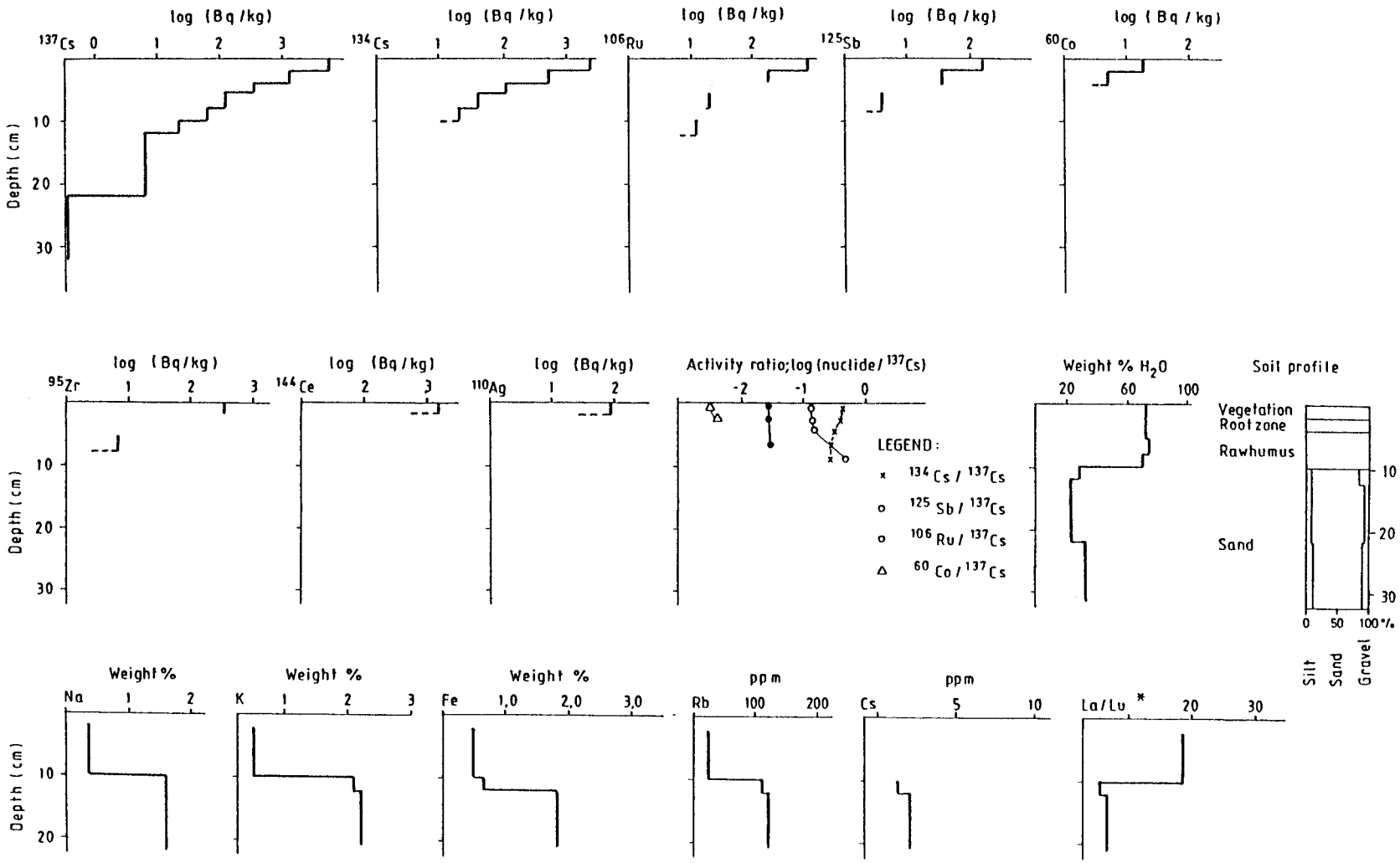

Figure 4.3.3 Soil activity profile (Bq/kg d w) in till, at site F2, recharge area, 1986-10-14.

F4

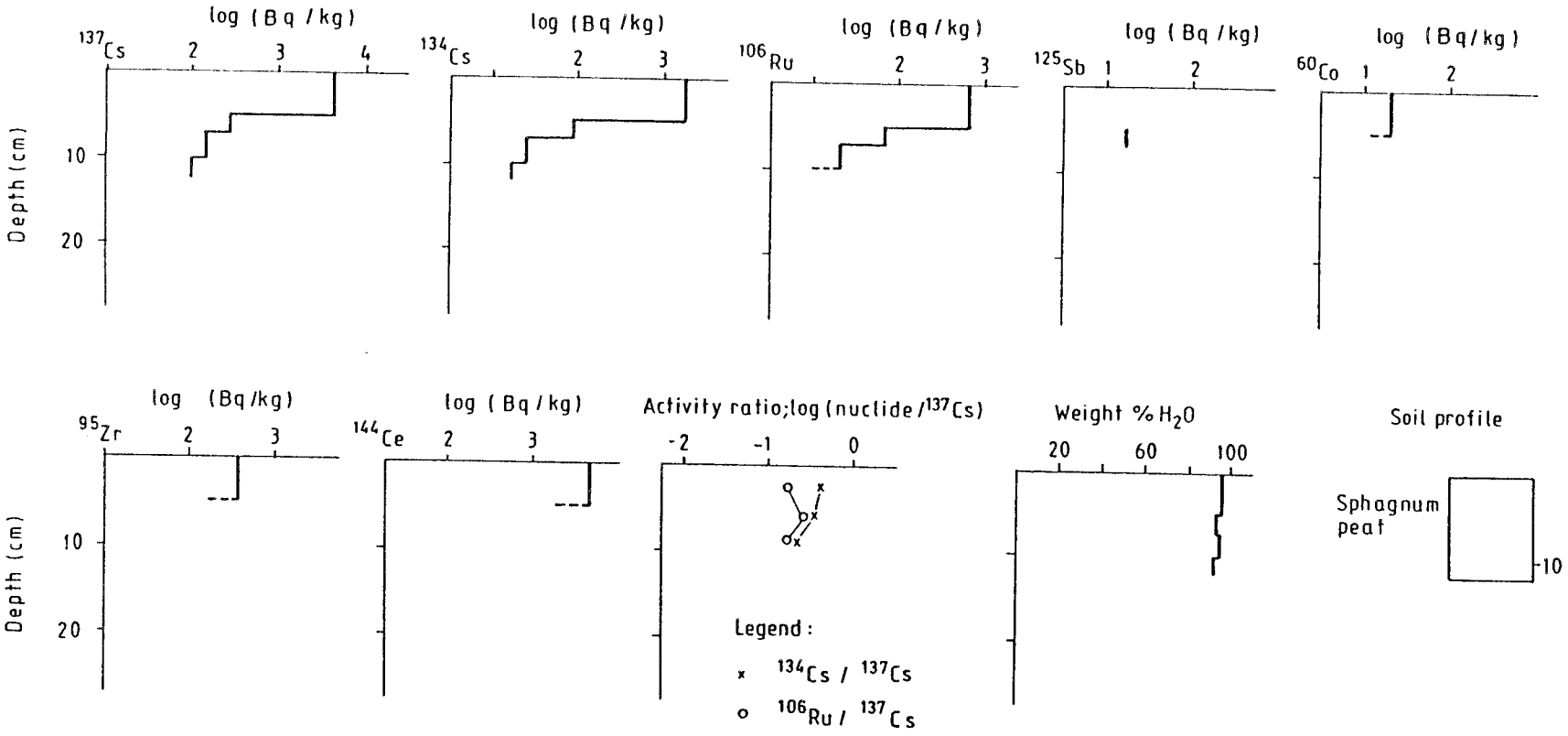

Figure 4.3.4 Soil activity profile (Bq/kg d w) in bog peat, at site F4, recharge area, 1986-10-15.

F 6

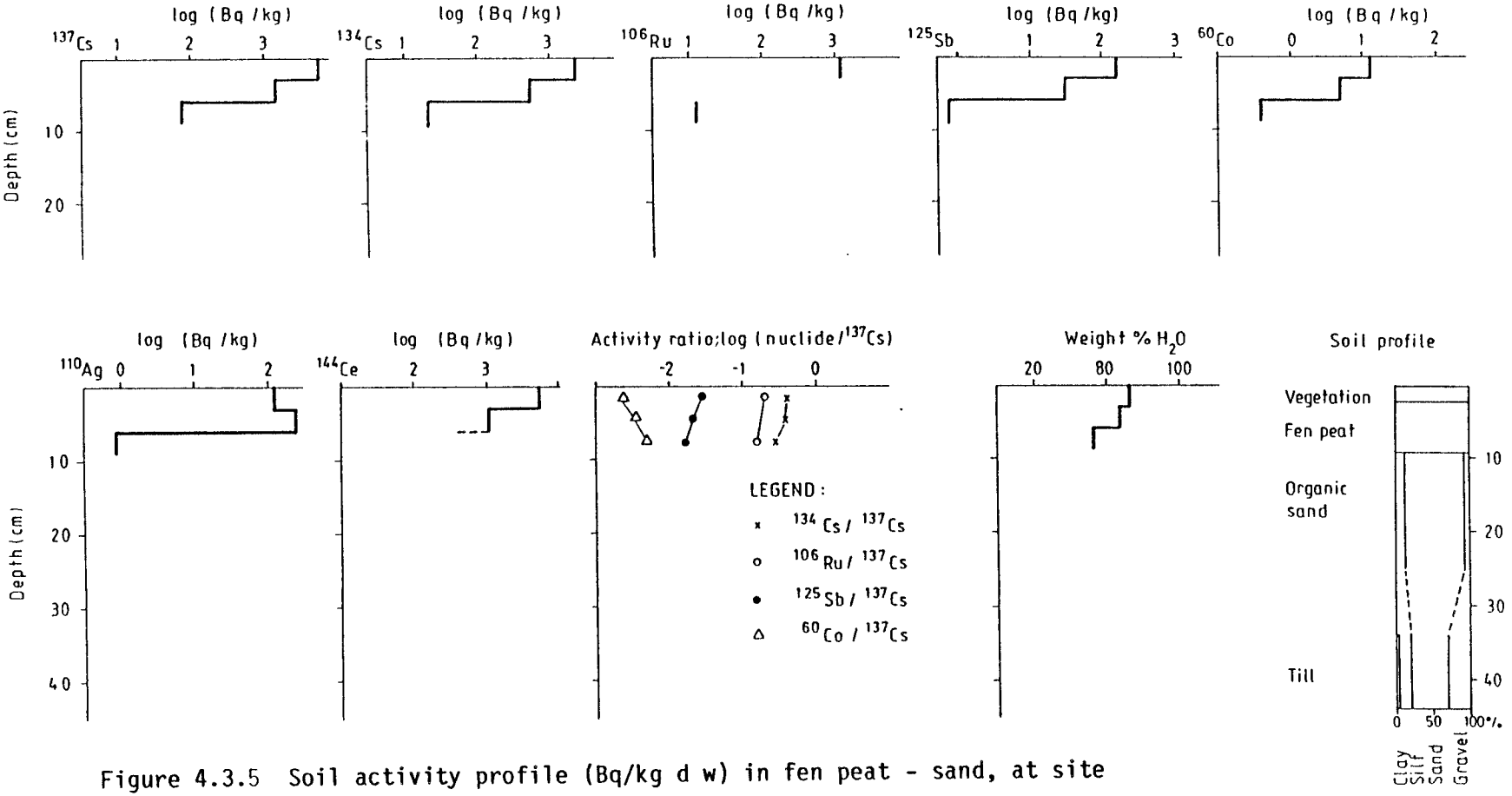

Figure 4.3.5 Soil activity profile (Bq/kg d w) in fen peat - sand, at site F6, discharge area, 1986-10-15.

F 7

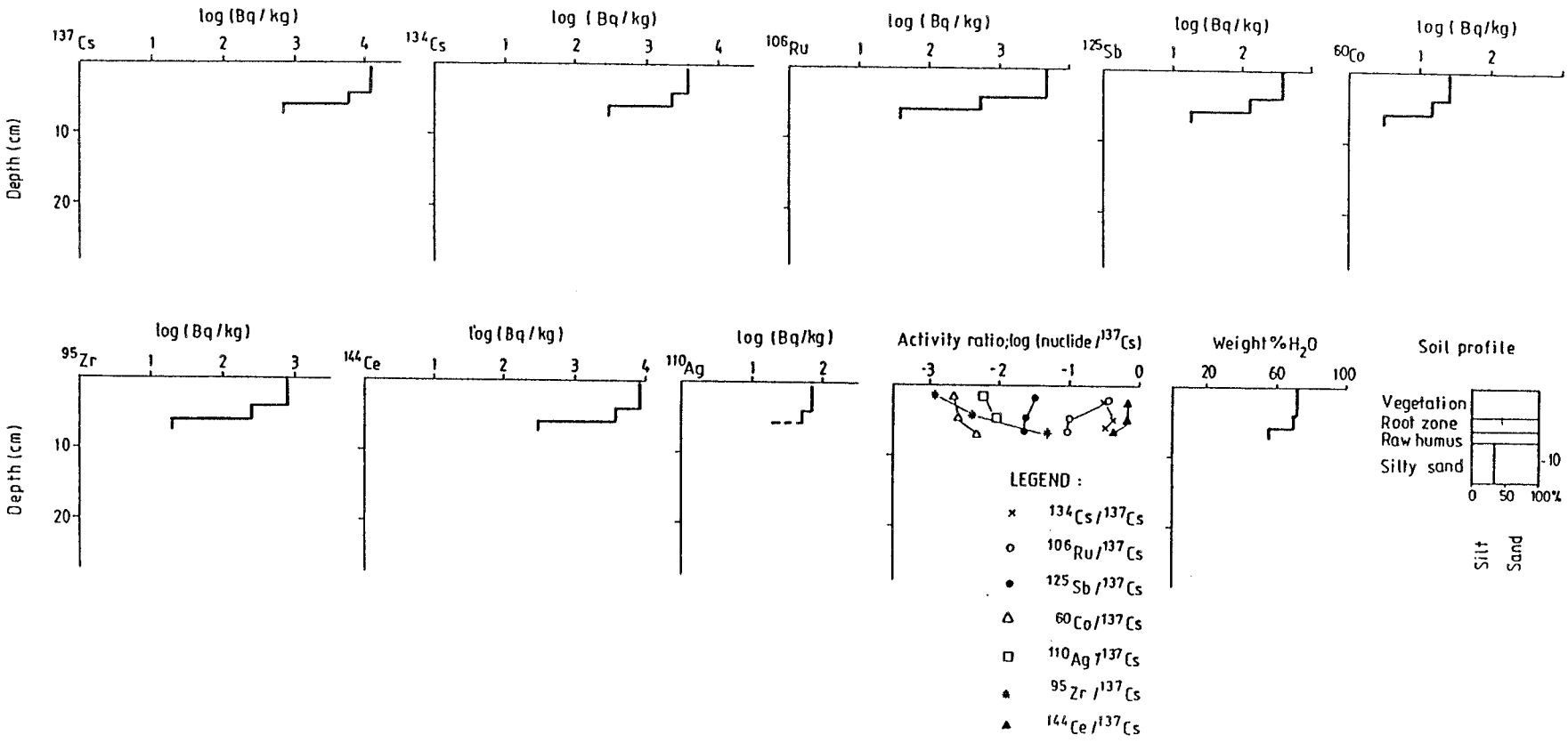

Figure 4.3.6 Soil activity profile (Bq/kg d w) in a thin till cover, at site F7, recharge area, 1986-10-15.

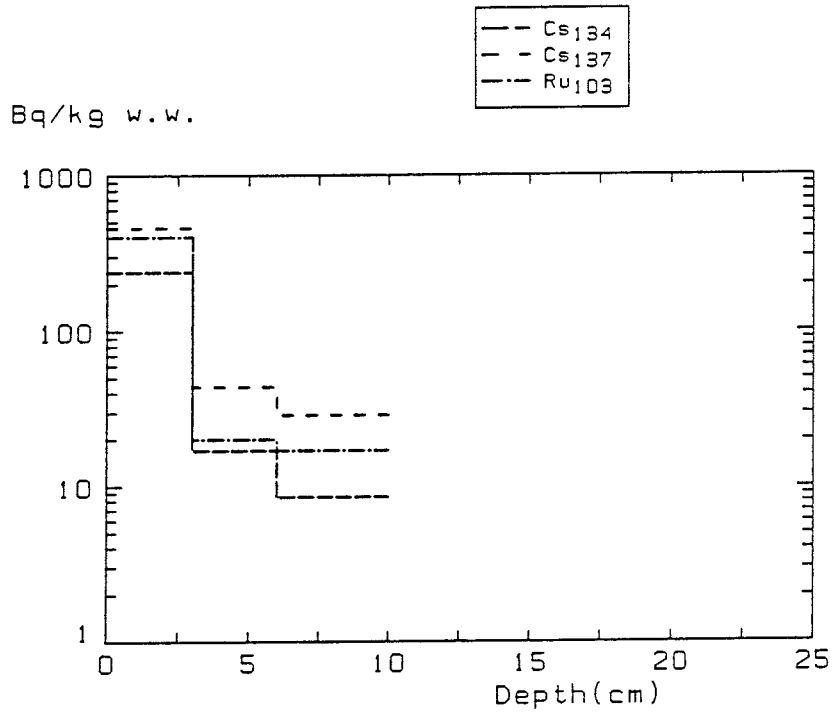

Figure 4.3.7 Soil activity profile (Bq/kg w w) in sand-clay (pasture), at site F16, 1986-06-27.

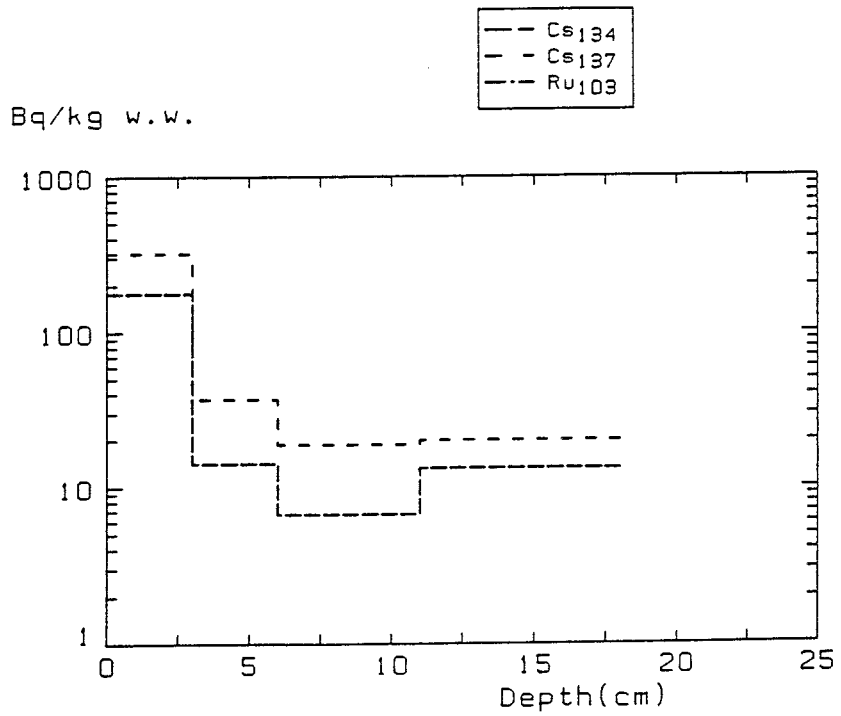

Figure 4.3.8 Soil activity profile (Bq/kg w w) in sand-clay (pasture), at site F16, 1986-10-01.

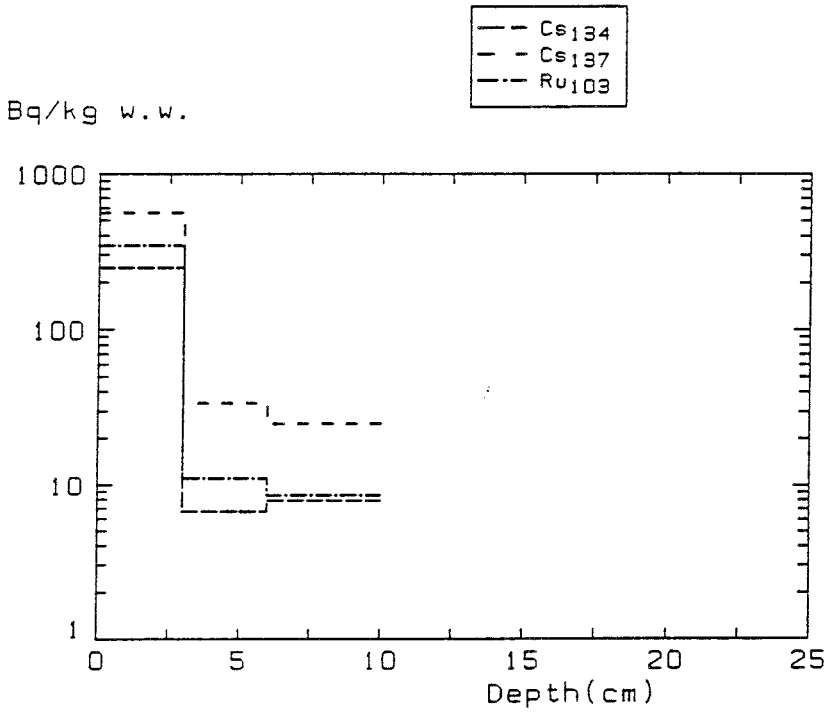

Figure 4.3.9 Soil activity profile (Bq/kg w w) in till, at site F1, recharge area, 1986-06-27.

4.4 Outcrops and fractures

Outcrops and fractures have been sampled at 4 sites, two within each sub-area. The location of the sampling sites is shown in Figure 4.4.1.

Within the Gåvastbo area five short drillcores have been collected of which two were drilled in open fractures in the outcrop. Furthermore, three surface samples were collected by hammer. All samples consist of granodioritic gneiss more or less red stained (hematized). One core was drilled in a metabasite inclusion in the granodiorite.

Within the Brändan area six short cores were drilled. Five of these include radioactive "hot spots" found with a portable detector. Also four samples of rock surfaces were collected by hammer. All samples consist of more or less red stained granodioritic gneiss.

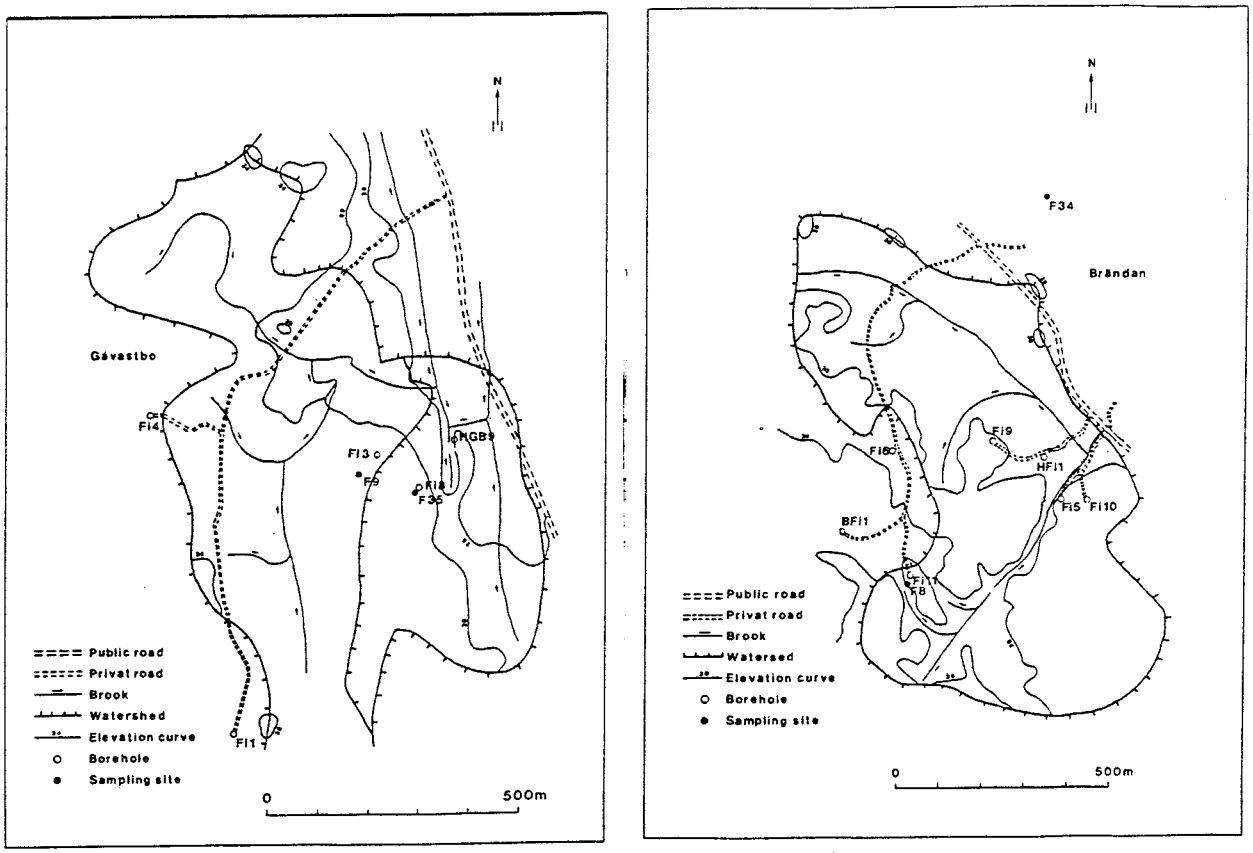

Figure 4.4.1 Drillcore and rocksurface sampling sites, Finnsjön study site.

The autoradiographic study of the rock surfaces from the Finnsjön area shows an even distribution of the radioactivity on the rock surfaces over-printed by a relatively high frequency of particles showing higher radioactivity. Results are presented in Table 4.4.1 and are also exemplified in Figure 2.6 and Appendix A.

The moss and lichen cover does not interfere with the particle distribution in contrast to the results found at the Gideå test site. A downward tranportation of radionuclides in a c. 1 mm wide fissure can be seen. The nuclides have penetrated at least 2-3 cm of the vertical fissure wall. No evident difference in radioactivity can be related to differences in mineralogical composition, grain size or degree of weathering.

Gamma spectrometric measurement in situ have been carried out on outcrops at five sites (cf. Table 4.2.1) and the result from the sites F8, F9, F10, F18 and F20 is summarized in Table 4.2.2. The exposure rate measured around the spectrometer sites is presented in Table 4.2.4. As can be seen, there are no systematic differences in nuclide composition or activity on the outcrops compared to soil surfaces.

Table 4.4.1 Results from drillcore and rock surface analyses.

Number	Sample description:	Date of sampling	Date of analysis	Lichen cover	Autoradiogram	Exposure time	Remarks:
1	F8, Drill core from flat rock.	861014	861103	No	Yes	1, 7.5, 18, 54.5 h	(1,2,3,4) Hot spot approx. 100-150 cps.
2	Drill core from flat rock.	861014	861103	No	Yes	1, 7.5, 18, 54.5 h	(1,2,3,4) Hot spot approx. 45-50 cps.
3	Drill core from flat rock.	861014	861103, 870205	No	Yes	360 h, 48 d	(1,2) Weak blackening with 1 strong and 1 weak black spot.
4	Drill core from flat rock.	861014	871013	No	Yes	298 d	Lost hot spot, weak blackening with spots.
5	Drill core	861014	861103,870205,871013	No	Yes	360 h, 48 d, 298 d	(1,2) Diffuse blackening. (3) Weak blackening with spots.
6	Drill core	861014	861103, 870205	No	Yes	360 h, 48 d	(1,2) No blackening on vertical side.
7	Rest from hot spot, on tape.	861014		No	No		
8	Rest from hot spot, on tape and Clenex.	861014		No	No		
9	Hammer rock sample.	861014	870205	Very little	Yes	48 d	Even background blackening plus about 10 black spots.
10	Hammer rock sample.	861014	861015	No	Yes	30 d	Even background blackening plus about 15 black spots.
11	Drill core from flat rock.	861014	861103, 871013	No	Yes	360 h, 298 d	(1) No blackening. (2) Weak blackening.
12	F9, Drill core, rock.	861014	861103, 870205	No	Yes	360 h, 48 d	(1) 2 small spots. (2) Weak blackening.
13	Drill core, rock.	861014	861103, 870205	No	Yes	360 h, 48 d	(1,2) Split in 5 parts, weak blackening, a few black spots.
14	Hammer rock sample.	861014	861103, 870205	No	Yes	360 h, 48 d	(1,2) Five black spots on horisontal top side, no blackening on vertical side.
15	Drill core, rock.	861014	861103, 871013	No	Yes	360 h, 298 d	(1) One weak black spot. (2) Weak blackening with a spot.
16	Drill core, rock.	861014	871013	No	Yes	298 d	Weak blackening with a spot.
17	Drill core, rock.	861014	870205	No	Yes	48 d	Grey blackening.
18	F34, Hammer rock sample.	861015	861103	Very little	Yes	360 h	One strong large spot.
19	Hammer rock sample.	861015	871013	Very little	Yes	209 d	Blackened with spots.
20							
21	F35, Hammer rock sample.	861014	861103, 870205	No	Yes	360 h, 48 d	(1,2) 2 powerful black spots and 4 weaker spots on horisontal top side.
22	Hammer rock sample.	861014	861103	No	Yes	360 h	The rock has an open fracture. 1 black spot and a few grey fields on top surface.

4.5 Water and Sediment

Water and sediment sampling have been concentrated to the Brändan catchment area. In this area 6 samples of surface water and one rainwater sample were taken on one of the first days (1986-04-28) of radionuclide deposition from the Chernobyl accident. This early investigation was followed by water and sediment sampling during June and October. Sediment was also sampled in November. The location of the sampling sites is shown in Figure 4.5.1 and they are described in table 4.5.1.

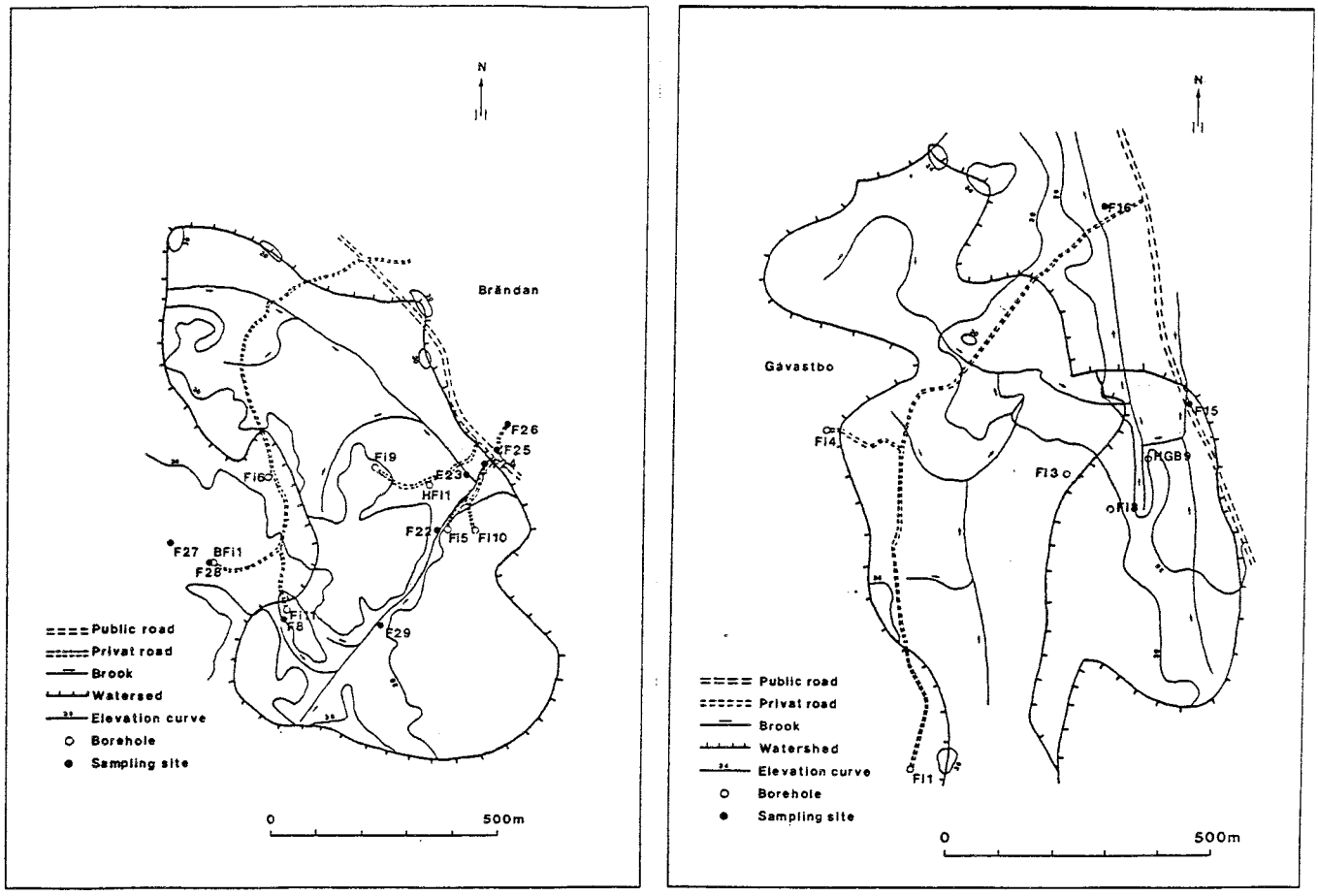

Figure 4.5.1 Water and sediment sampling sites within the Brändan and Gåvastbo areas, Finnsjön study site.

Nuclide activity in rainwater, stagnant water in bogs and a rock cavity, as well as activities in water samples collected in the brooks are presented in Tables 4.5.2 - 4.5.4.

Table 4.5.1 Description of water and sediment sampling sites within the Finnsjön study site.

Site	Description
F8	stagnant water in rock cavity
F15	brook, Gåvastbo area
F16	brook, 300 m north of Gåvastbo area
F22	brook, Brändan area
F23	"
F24	"
F25	"
F26	"
F27	bog, stagnant water F28
F28	rainwater, in steel container
F29	bog, stagnant water

In Table 4.5.5 and 4.5.6 nuclide activity in sediment samples from the creeks which drain the Brändan and Gåvastbo areas is presented.The analyses show that the activity of cesium is low compared to the soil activity, 150-550 Bq/kg d w and 2800-4900 Bq/kg d w respectively. However, the results also show a transportation by water of ruthenium and silver.

Tritium content was measured in the brook which drains the Brändan area (site F24). The content was 21 TU.

Table 4.5.2 Activity in water samples (mBq/l, sampling date) from the Finnsjön study site.

Number	Sample description:	Date of sampling	Date of analysis	Volume (l)	pH	Geom	Zr-95	Iunc Is	Ru-103	Iunc Is	Ru-106	Iunc Is	Ag-110m	Iunc Is	Sb-125	Iunc Is
1	F8, stagnant water from a cavity on a cleaned and scraped outcrop.	860429	860602	5		B60J			7110 #		2920 #					
2	stagnant water from a cavity on a cleaned and scraped outcrop.	860624	871027	10		B60J					157	29,90	32,30	36,60	20,10	33,60
3	stagnant water from a cavity on a cleaned and scraped outcrop.	861015	870304	50	6,50	M500			21,30	33,50	58	15,50	2,85	69,70	11,10	20,20
4	F22, brook, flowing water.	860429	860603	5		B60J			2360 #		2970#					
5	F23, relatively stagnant brook water.	861015	870306	50	6,10	M500					58,20	19,30	5,54	67,60	8,25	30,90
6	F24, brookwater, before passing under the road.	861015	870311	50	6,20	M500					36,90	29	9,86	32,50	3,39	83
7	F25, brookwater, after passing under the road.	861015	870315	50	6	M500					44,70	36,40	10,10	60	6,11	67,50
8	F27, stagnant water on the surface of a bog.	860429	860602	5		B60J	4390 #		13900 #		2910 #					
9	stagnant water on the surface of a bog.	860624	871029	10		B60J										
10	F28, rainwater in a steel container.	860429	860603	5		B60J	8350 #		20980 #		9210 #					
11	F29, stagnant water in the opening of a bog.	860429	860602	5		B60J			3620 #		2930 #					

Number	I-131	Iunc Is	Cs-134	Iunc Is	Cs-136	Iunc Is	Cs-137	Iunc Is	Ba-140	Iunc Is	Ce-141	Iunc Is	Ce-144	Iunc Is	Cs-134/Cs-137	Remarks
1	388400 #		5290 #		5420 #		10000 #		68790 #		2960 #		2170 #		,53	
2			95,90	5,70			201	2,20							,48	
3			23,80	4,60			64,80	2							,37	
4	67530 #		800 #		970 #		1730 #		5030 #						,46	
5			99,50	1,70			259	,90					209	31,20	,38	
6			40	4,10			121	1,70							,33	
7			56,90	5,20			163	2,40							,35	
8	257400 #		6430 #		3270 #		13500 #		67370 #		13780 #		7580 #		,48	
9			98,80	8,90			205	3,20							,48	
10	250470 #		13930 #		10530 #		27390 #		194690 #		46350 #		29910 #		,51	
11	103310 #		2110 #				4130 #		13900 #		710 #				,51	

Measured and analyzed by a 10% Ge(Li)-detector (FWHM 3.2 keV) connected to a 1024-channel MP-MCA, calibrated by a Eu-152 standard solution.

Table 4.5.3 Activity in water sampes (Bq/kg) from Finnsjön study site.
Sampling 1986-06-27--28. Reference date 1986-04-28.

No.	Site	Type	Depth (cm)	Area (m**2)	Water content (%, w w)	Zr-95	Ru-103	Ru-106	Ag-110m	I-131	Cs-134	Cs-136	Cs-137	Ba-140	Ce-141	Ce-144
25	F8*	Water (pit)				1.40E0	2.10E0				1.10E0		1.5			
23	F24*	" (in sed)									1.20E0		1.30E0			
24	F27	" (in peat)									1.10E0		0.80E0			
26	Finnsjön	" (lake)									-		0.8			

* Brändan area

Table 4.5.4 Activity in water samples (Bq/kg) from Finnsjön study site.
Sampling 1986-10-01--02. Reference date 1986-04-28.

No.	Site	Type	Depth (cm)	Area (m**2)	Water content (%, w w)	Ru-103	Ag-110m	Cs-134	Cs-137	Ce-141	Ce-144
128	F8*	Water (pit)							<1.0E0		
125	F16	Water (creek)							<1.0E2		

* Brändan area

Table 4.5.5 Activity in sediment samples, Finnsjön study site. Reference date same as sampling date.

Number	Sample description:	Date of sampling	Date of analysis	% H2O	Dry wght	Geom	Wght (g-a)	K-40	Unc %	Co-60	Unc %	Ir-95	Unc %
1	F8, Sediment from 0.5m depth, thin layer on outcrop. Area 0.04 m2 (Bq/m2).	861015	871123	93.0	4.5	B60	4.5	208,83	5,40				
2(1)	F23, Residue from water 2(3) (filter paper, retention 25 um) (Bq/l water).	861015	870422			B60		831,50	2,90				
2(2)	Residue from water 2(3) (glass fiber filter, retention 1,2 um) (Bq/l water).	861015	870427			B60		4625	4,50				
2(3)	Water collected together with sediment, filtrated.	861015	870806			B250	167.0	50,20	8,80				
2(4)	Sediment (sand and dead vegetation) collected at 0.2m depth.	861015	870806	12,90	475,50	B250	475.5	1004	1,50	1,30	62,30		
3(1)	Residue from water 3(3) (filter paper, retention 25 um) (Bq/l water).	861015	870407			B60		411,50	5,70				
3(2)	Residue from water 3(3) (glass fiber filter, retention 1,2 um) (Bq/l water).	861015	870408			B60		2884	8				
3(3)	Water collected together with sediment, filtrated.	861015	870814			B250	165.0	50,40	4,40	,60	25,40		
3(4)	Sediment (sand and dead vegetation) collected at 0.2m depth.	861015	870424	53,70	132,80	B60	58.8	1135,40	3,60	8,60	40,10	174,20	26,80
4(1)	Residue from water 4(3) (filter paper, retention 25 um) (Bq/l water).	861015	870415			B60		356,60	7,60				
4(2)	Residue from water 4(3) (glass fiber filter, retention 1,2 um) (Bq/l water).	861015	870511			B60		2179	5,90				
4(3)	Water collected together with sediment, filtrated.	861015	870818			B250	111.5	54,30	6,10				
4(4)	Sediment (sand and dead vegetation) collected at 0.2m depth.	861015	870423	82,50	75,30	B60	25.8	739,50	3,30	10,10	28,30	156,40	25,50
5(1)	F24, Residue from water 5(3) (filter paper, retention 25 um) (Bq/l water).	861015	870416			B60		600,80	17				
5(2)	Residue from water 5(3) (glass fiber filter, retention 1,2 um) (Bq/l water).	861015	870505			B60		3067,50	6,80				
5(3)	Water collected together with sediment, filtrated.	861015	870813			B250	101.5	42	18,80				
5(4)	Sediment (sand and dead vegetation, 1cm thick), collected at 0.1m depth.	861015	870424	83,40	47,70	B60	22.5	712,40	1,90	19,90	9,10	602,70	4,30
6(1)	F25, Residue from water 6(3) (filter paper, retention 25 um) (Bq/l water).	861015	870421			B60		1093,70	3,20				
6(2)	Residue from water 6(3) (glass fiber filter, retention 1,2 um) (Bq/l water).	861015	870512			B60		2724	6,90				
6(3)	Water collected together with sediment, filtrated.	861015	870805			B250	91.0	131,40	6,70				
6(4)	Sediment (sand and dead vegetation, surface layer), collected at 0.1m depth.	861015	870421	11,50	416,80	B60	129.0	855,80	,90	1,80	79,40		

Number	Ru-103	Unc %	Ru-106	Unc %	Ag-110m	Unc %	Sb-125	Unc %	Cs-134	Unc %	Cs-137	Unc %	Ce-144	Unc %	Cs-134/Cs-137	Remarks:
1									25,42	5,60	57,40	2,20				
2(1)			47,40	29,30					86,10	2,60	209,70	1,30				,41 Stagnant water, one sees a typical sedimentation (1st basin).
2(2)											33,80	49,30				
2(3)											,80	45,30				
2(4)					20	29,80			151,30	1,30	397,70	,60				,38
3(1)			31,60	41,20					209,40	1,40	676,30	,80	86	41,90		,31 Stagnant water, one sees a typical sedimentation (1st basin).
3(2)			351,20	56,40												
3(3)			3,20	78,90							1,40	12,10				
3(4)			247,40	10,80					962,40	1	2216	,60	261,40	30,70		,43
4(1)			54,80	41,70	3,90	72,30			3,40	70,80	9,70	19				,35 Stagnant water, 5m S F23 (2th basin).
4(2)					24,20	68,50					16,80	62,40				
4(3)			5,30	76,50							,50	65,30				
4(4)			266,20	15,50			44,50	25,30	1602,30	,50	3938	,30	373,30	18,80		,41
5(1)			125,30	26,60			30,70	1,90	283,80	1,90	686,50	1,10	130,70	61,70		,41
5(2)									31,40	63,40	55,20	26,60				,57
5(3)																
5(4)	235,40	26,10	755,60	3,80			94,80	8,20	2406,20	,20	5684,40	,10	2019,60	2		,42
6(1)			50,20	49,90					153,10	2,40	374,90	1,20				,41 Taken at the outlet of the basin. Waterflow approx. 1.5-2 l/s.
6(2)																
6(3)																
6(4)									281,20	1,20	648,80	,70				,43

Table 4.5.6 Activity in sediment samples (Bq/kg d w) from Finnsjön study site. Sampling 1986-11-06--07. Reference date 1986-04-28.

No.	Site	Type	Depth (cm)	Area (m**2)	Water content (%, w w)	Cs-134	Cs-137	Cs-134/ Cs-137
230	F15**	Sediment	0-2		59	1.0 E2	5.6 E2	0.18
231	"	"	3-5		31	-	-	
232	"	"	5-8		35	-	-	
233	"	"	8-10		45	6.3 E1	<2.0 E1	
234	"	"	10-16		30	-	-	
235	F26*		0-2		25	6.0 E1	1.6 E2	0.38
236	"	"	2-4		28	<2.0 E1	5.3 E2	
237	"	"	4-6		22	<2.0 E1	2.5 E1	
238	"	"	6-10		31	<2.0 E1	<2.0 E1	

** Gåvstbo area

* Brändan area

4.6 Vegetation

Surface vegetation, e.g. mosses, lichen and grass were analysed in the uppermost layer of the soil profiles (section 4.3) and the results are presented in Tables 4.3.2-4.3.5. As a complement, vegetation were sampled and analysed on additionally eight sites also including schrubs, needles and leaves. Some examples of the collected vegetation samples are specified in Table 4.6.1 and the activity is presented in Tables 4.6.2-4.6.4. In Tables 4.6.5 and 4.6.6 Cs-137 and ratios nuclide/Cs-134 in vegetation samples from June and October are presented.

Table 4.6.1 Example of vegetation samples collected within the Gåvastbo and Brändan areas, Finnsjön study site.

Mosses:	Polytricum juniperum
	Pleurozinum scheberi
	Sphagnum russowii
Lichen:	Cladina stellaris
	Cladina rangiferina
Schrubs:	Calluna vulgaris

The activity of Cs-137 in grass, schrubs, needles and leaves is in the order of 1000-5000 Bq/kg d w, while the lichens and mosses holds about 10.000 - 40.000 Bq/kg d w. There is no marked difference in Cs-137 activity between birch leaves and needles of spruce and pine, as observed in the Gideå study site. This can be explained by the fact that in Finnsjön the leaves were nearly fully developed at the time of nuclide deposition.

Table 4.6.2 Activity in vegetation samples (Bq/kg d w) from Finnsjön study site. Sampling 1986-06-27--28. Reference date 1986-04-28.

No.	Site	Type	Depth (cm)	Area (m**2)	Water content (%, w w)	Zr-95	Ru-103	Ru-106	Ag-110m	I-131	Cs-134	Cs-136	Cs-137	Ba-140	Ce-141	Ce-144
2	F9**	Lichen			6	1.48E4	2.16E4	5.39E3	4.95E2	1.50E5	1.54E4		2.94E4	4.30E4	1.75E4	1.06E4
1	F16	Grass		0.5	13	1.96E2	2.96E2				1.61E2		2.89E2		3.29E2	0.95
15	F32*	Needle, spruce			64	2.45E3	3.31E3	6.99E2			2.17E3		4.18E3		2.63E3	1.97E3
17	"	Fern			83	1.36E3	8.24E2				3.79E2		9.57E2		1.29E3	1.40E3
16	F33*	Needle, pine			64	5.64E3	7.23E3	1.79E3	1.91E2	3.85E4	4.25E3		8.09E3		6.29E3	4.23E3
7	"	Birch leaves			74	4.29E2	5.84E2				6.27E2		1.29E3		4.89E2	4.78E2

** Gåvastbo area
* Brändan area

Table 4.6.3 Activity in vegetation samples (Bq/kg d w) from Finnsjön study site. Sampling 1986-10-01--02. Reference date

No.	Site	Type	Depth (cm)	Area (m**2)	Water content (%, w w)	Ru-103	Ag-110m	Cs-134	Cs-137	Ce-141	Ce-144
126	F8*	Birch leaves			27	7.38E2	3.17E1	5.22E2	7.96E2		3.22E2
127	"	Needle, pine			48	2.87E3	9.87E1	1.56E3	2.84E3		1.24E3
117	F10**	Birch leaves			67	1.08E3	7.89E1	9.14E2	1.50E3		1.14E3
118	"	Heather			52	4.70E3	1.16E2	3.73E3	6.90E3	4.7E3	2.33E3
119	"	Needle, pine			34	1.50E3		7.61E2	1.45E3		7.42E2
116	"	Lichen	0-3	0.25	48	1.65E4	3.15E2	1.24E4	2.31E4	1.63E4	8.25E3
201	F20*+	Lichen	0-3	0.2	50			4.0E3	1.5E4		

** Gåvastbo area
* Brändan area
+ sampling 1986-11-06--07. Reference date 1986-04-28.

Table 4.6.4 Activity in vegetation samples (Bq/kg d w, sampling date) from Finnsjön study site.

Number	Sample description:	Date of sampling	Date of analysis	% H20	Dry wght	Geom	Wght (g-m)	K-40	Junc 1s	Mn-54	Junc 1s	Zr-95	Junc 1s
1	F8, Sphagnum	860624	870506	89,60	3,20	B60	3,20	1930	8,90			3741	15,90
2	F9, Polytrichum juniperium	861014	870317	65,30	24	B250	24	464	23	23	61,60		
3	Cladina stellaris	861014	870428	85,10	6,60	B60	6,60	834	19			3012	11,40
4	Cladonia arbuscula	861014	870317	72,20	54	B250	54	180	24,30	25	47,70		
5	Shagnum russowii	861014	870526	98,30	3	M500	3	1880	42,10				
6	Cladina rangiferina, old	861014	870504	81,70	9,50	B60	8,50	528	16,90			1561	14,70
7	Pleurozinum schreberi	861014	870323	80,70	15	B250	15	714	27,10				
8	Heather, perched, old and dry	861014	870405	0	38,80	B250	38,80	89	27,70				
9	Heather, alive	861014	870406	43,90	23,30	B250	23,30	384	11,40				
10	F27, Sphagnum girgensohnii (centrale)	860624	870602	88,90	5	B250	5	2040	21,90				

Number	Ru-103	Junc 1s	Ru-106	Junc 1s	Ag-110m	Junc 1s	Sb-125	Junc 1s	Cs-134	Junc 1s	Cs-137	Junc 1s	Ce-144	Junc 1s	Cs-134/Cs-137	Reaarks:
1			2732	12,70	282	16,30	385	19,30	5975	,90	12378	,60	16822	5	,48	
2	582	57,20	1332	17,10	530	21,80	318	20,30	4158	1,30	10738	,70			,39	Taken with roots.
3			3289	10,40			738	22,30	14944	,80	33682	,50	32818	4,50	,44	New for the year.
4	1191	21,80	2550	8,30	944	12,20	321	17,80	9219	,50	23204	,30	9096	5,30	,40	
5			10413	29,60	5687	31,10	1544	45,20	39667	1,60	107100	,80			,37	New for the year.
6			3112	7,40	319	24,40	659	17	12753	,60	28718	,40	6207	16,10	,44	
7			1422	16,60	1191	24,10	644	27	11867	1	29787	,60	89867	3,40	,40	
8	940	23,50	2170	5,70	1725	3,90	387	9,40	10064	,30	27320	,10			,37	
9			567	24,70	718	12,10	133	20,90	2780	,90	7824	,40			,36	
10			3892	37,70	2748	28,70	428	59	13560	1,80	31780	,90			,43	

4.7 Nuclide Deposition, Distribution and Migration; Summary

The radionuclide deposition within the Finnsjön study site is summarized in the following items:

Within the study site there was a deposition of different gamma emitting radionuclides which are possible to trace in a time perspective of several years(e.g Co-60, Ru-106, Ag-110m, Sb-125, Cs-134, Cs-137, Ce-144).

There was a high deposition of refractory elements (e.g La-140, Zr-95, Ru-103, Ru-106, Ce-144).

An essential part of the actvity was deposited as hot-spots (active particles), especially containing Ru-103 and Ru-106.

Substantial local variations in the ground surface deposition are observed.

The ground surface deposition, determined from gamma spectrometric and exposure rate measurements in situ and from laboratory measurements on large area (25x25 cm) soil profile samples are summarized in Tables 4.2.3, 4.2.4 and 4.3.8 - 4.3.10 where the following data is given.

- o The total surface deposition mean values were in June 1986 17 kBq/m^2 of Cs-134 and 31 kBq/m^2 of Cs-137, measured by gamma spectrometry in situ. The Cs-137 activity was within the range of 20-40 kBq/m^2 and the coefficient of variation (CV) was 30 %.

- o The mean activity of surface deposited refractory elements was in June 1986 58 kBq/m^2 of La-140, 17 kBq/m^2 Zr-95, 29 kBq/m^2 Ru-103 and 30 kBq/m^2 of Ce-144.

- o The mean activity of iodine, measured in June 1986 was 127 kBq/m^2.

- o In November 1986 the exposure rate was measured on 16 sites at a height of 0.7 m from the ground. The mean value was 16 uR/h.

In summary the disribution and migration of the radionuclides are described in the following items:

- o Soil profiles show that most of the nuclides are caught in the upper layer in the soil profiles, e.g. humus. Except for solitary recordings of Ru-106 and Cs-134 at 10-12 cm depth only Cs-137 has been found below 10 cm depth, remaining from atmospheric bomb tests in the 1960s´.

- o The mobility of cobolt and antimony in soil profiles is higher compared to that of cesium. Cerium, however, seems to be detained in the very upper layer of the soil, indicating that cerium exists as a cation.

- o The half value depth of Cs-134 and Cs-137 in soils has increased by about 60 % from June to November 1986, according to gamma spectrometric measurements in situ.

- o In October 1986 the 1/2- and 1/4-value depth in till (medium sandy, podsol)was approx. 1.5 and 2.5 cm respectively, for Cs-134 and Ru-106. In peat the 1/2- and 1/4-value depth were 3 and 4 cm respectively.

- o The autoradiographic study of rock surface samples shows an even distribution of the radioactivity over-printed by a relatively high frequency of particles showing higher radioactivity. The moss and lichen cover does not interfere with the activity distribution, as found in Gideå.

- o A downward transportation of radionuclides in a c. 1 mm wide fissure can be seen. The nuclides have penetrated at least 2-3 cm of the vertical fissure wall.

- Gamma spectrometric measurements in situ have been carried out on outcrops at five sites. As can be seen, there are no systematic differences in nuclide composition or activity on the outcrops compared to soil surfaces.

- Relatively high concentrations of radionuclides are found in water samples from the brooks which drain the studied area.

- The analyses of the sediment samples show that the activity of cesium is low compared to the soil activity, 150-550 Bq/kg d w and 2800-4900 Bq/kg d w respectively. However, the results also indicate a transportation by water of e.g. Zr-95, Ru-106 and Ag-110m.

- The activity of Cs-137 in grass, schrubs, needles and leaves is in the order of 1000-5000 Bq/kg d w, while the lichens and mosses holds about 10.000 - 40.000 Bq/kg d w. There is no marked difference in Cs-137 activity between birch leaves and needles of spruce and pine, as observed in the Gideå study site. This can be explained by the fact that in the Finnsjön the leaves were nearly fully developed at the time of nuclide deposition from the Chernobyl fallout.

5. SUMMARY AND CONCLUSIONS

The present study performed during 1986-87 shows that the radionuclide deposition from the Chernobyl accident is high enough within the Gideå and Finnsjön study sites to be used for field studies intended for radioecological and geohydrological migration modelling.

The fallout is different in the Finnsjön and Gideå areas with respect to radionuclide composition and the amount of activity, depending on the content in the plumes, deposition and surface conditions. For instance the Gideå study site was covered by approx. 0.5 m of snow at the time of radionuclide deposition, which seems to have influenced the chemical behaviour of different elements in the fallout. In contrast the Finnsjön study site was free from snow. However, many of the gamma emitting radionuclides deposited within the study sites are possible to trace in a time perspective of several years, e.g. Co-60, Ru-106, Ag-110m, Sb-125, Cs-134 , Cs-137 and in Finnsjön also Ce-144.

The cesium and iodine deposition was about twice as high in Gideå compared to Finnsjön, but in Finnsjön more refractory elements such as zirkonium, ruthenium and cerium were deposited. In Finnsjön also an essential part of the activity was deposited as hot-spots (active particles) especially containing Ru-103 and Ru-106.

The deposition of Sr-90 is low compared to what was already present since the nuclear bomb tests during the 1960´s.

The cesium-137 activity measured by gamma spectrometry in situ gave a range of 30-100 kBq/m^2 (CV 30%) in Gideå. Corresponding figures for Finnsjön were 20-40 kBq/m^2 (CV 30%). The mean values of exposure rate were 23 uR/h in Gideå and 16 uR/h in Finnsjön, measured in November 1986 at a height of 0.7 m above the ground.

An essential variation of radionuclide deposition has occurred even in the very local scale. As a consequence soil profiles taken close to each other can differ by a factor of two in radionuclude content.

Radionuclide migration and sorption have been observed within a wide variety of samples, e.g. soil profiles, vegetation, water, sediment and rock samples.

In the soil profiles a faster and different manner of migration is indicated for Sb-125, Ru-106 and Co-60 compared to cesium. In October 1986, five months after deposition, radionuclides are found at depths below 20 cm, indicating other transport mechanisms than only diffusion. The mean half value depth, in October 1986, of Cs-134 was in Gideå approx. 4 cm in the till and sand profiles and 7 cm in the peat profiles. Corresponding figures for Finnsjön are 1.5 cm and 3 cm.

Measurements on a drillcore sample, from a granodioritic outcrop in the Finnsjön area, show that radionuclides have penetrated at least 2-3 cm downward in a vertical fissure. In Gideå the snow cover also has influenced the redistribution of the nuclide deposition on the outcrops in such a way that the radioactivity is high on the lichen covered surfaces and very low on rock surfaces without moss and lichen.

Two different chemical forms of ruthenium seems to occur, one insoluble, which is detained on rock surfaces and in the uppermost layers of the soil profiles, and one that is very soluble in water which could already in February 1987 be detected in fairly deep groundwaters sampled in the artesian drill holes Gi 2 (97-106 m) and 20 (0-100 m) in the Gideå area. In a shallow well was also Co-60, Ag-110m, Cs-134 and Cs-137 found, besides Ru-106 in October 1986.

Relatively high concentrations of radionuclides are also found in surface waters (i.e. brooks, rock crevices etc.) and shallow ground waters sampled at the bottom of the dug pits remaining from soil profile sampling.

It is evident also from the sediment samples that an active transport of radionuclides (Ru-106, Ag-110m, Cs-134, Cs-137) has occurred by water.

Vegetation samples show that radionuclides have been absorbed in different types of vegetations.

The results from the deposition and migration measurements carried out in this study from April 1986 to February 1987 show that it is possible and worthwhile to continue the measurements of radionuclide redistribution and migration in both Gideå and Finnsjön study sites. However, the Gideå area is to prefer for radioecological and geohydrological migration modelling and budget calculations due to more easily geological and hydrological conditions. Despite the more complex environmental conditions it is valuable to continue studies also in Finnsjön because of a high concentration of refractory elements which will give information about different chemical species. This study can, however, be in a more moderate way compared with the Gideå studies.

In the continued study yearly sampling of water, some soil profiles and a separate rock surface/fissure is recommended. A more sparse time schedule is recommended for gamma spectrometric measuerements in situ. A few sites are proposed to be measured every year and all sites presented in this study are measured every third year.

Exposure rate is measured once a year at some of the sampling and spectrometer sites and also along the previous measured lines.

The data obtained from the distribution and migration measurements, will together with environmental conditions (geology, hydrology etc.) primarily constitute the basis for budget calculations of radionuclide redistribution and secondly radioecological and geohydrological migration modelling.

In the time perspective of decades it is feasible to compare the measured redistribution and migration with predictive

calculations based on laboratory experiments and previous performed tracer tests. Also comparison with real case histories from radionuclide deposits would give valuable knowledge about radionuclide migration in a natural complex environment.

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A P P E N D I C E S

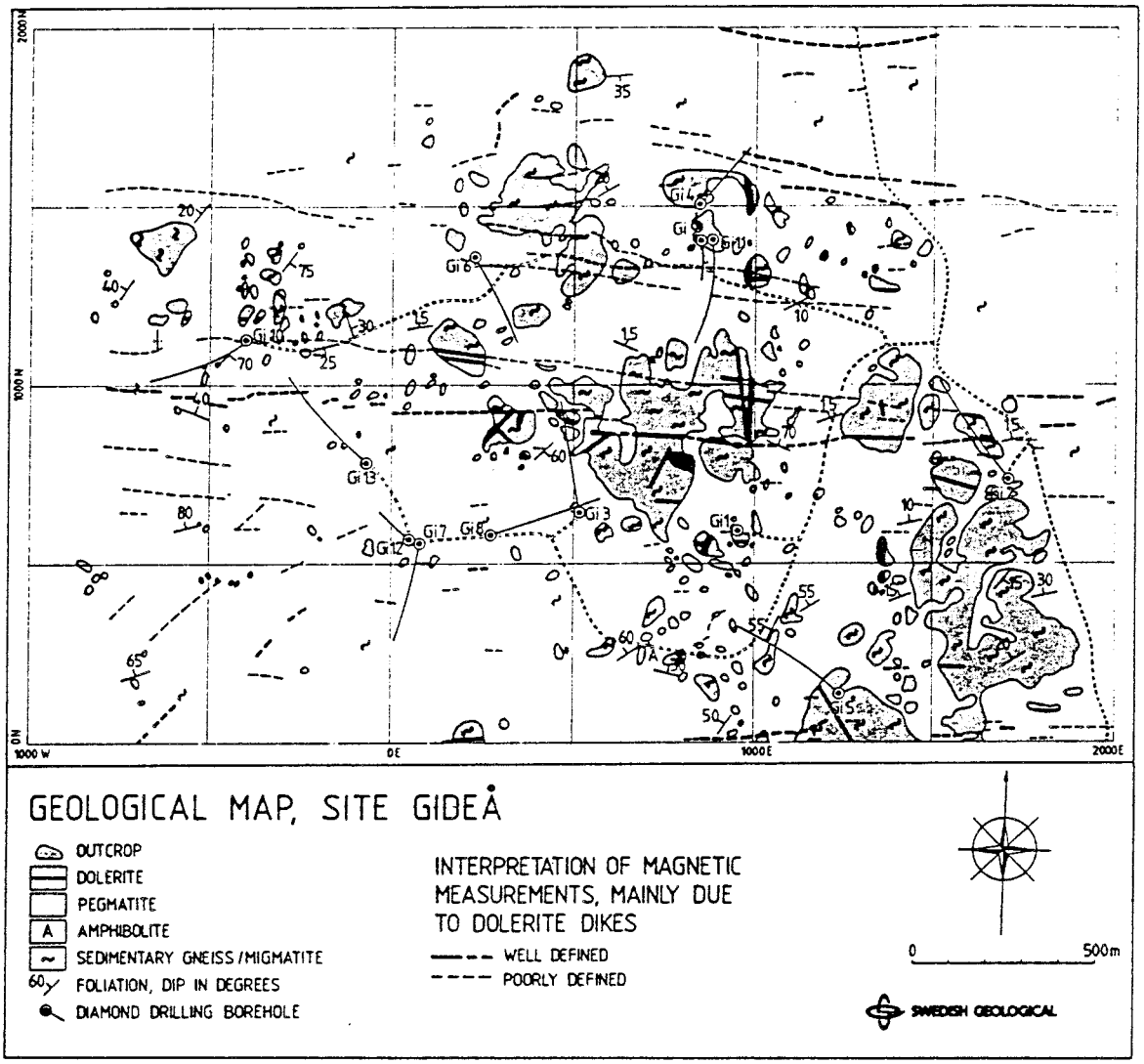
APPENDIX A

COMPLEMENTARY TABLES AND FIGURES

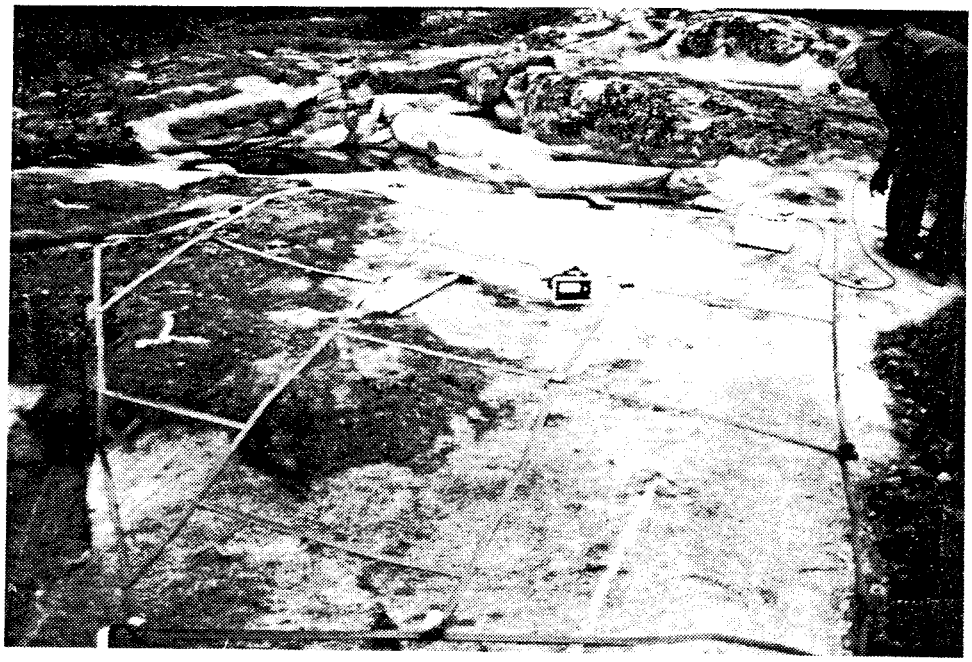
CONTENTS

Table A.1 Activity ratios to Cs-137 in soil samples from different places in Sweden. All activities are corrected for decay back to the sampling date. Activity ratio = Nuclide activity x 100 / Cs-137 activity.

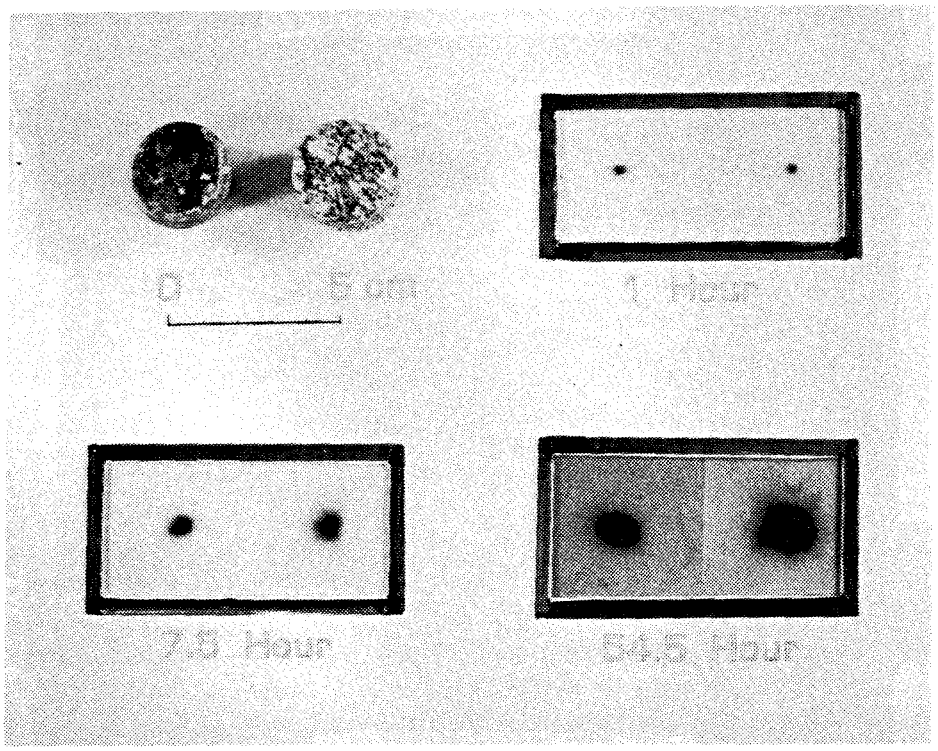
					Percentage of activity compared to the Cs-137 activity.						
Site	Place	Date	Area	Depth	Ru-103/	Ru-106/	Ag-110m/	Sb-125/	Cs-134/	Ce-144/	Co-60/
F1	Finnsjön	861014	25x25 cm	6 cm	3.0	9.1		2.1	40	13	0.18
F2	Finnsjön	861014	23x27 cm	10 cm		13	1.2	2.6	42	20	0.29
F4	Finnsjön	861015	25x25 cm	12 cm		14		0.44	38	88	0.44
F6	Finnsjön	861015	20x25 cm	9 cm	5.3	15		2.7	41	87	0.34
F7	Finnsjön	861015	25x25 cm	7.5cm	1.8	17		2.5	40	64	0.29
T1	Trödje	861016	50x50 cm	11 cm	1.8	5.7	0.9	1.9	40		0.30
B1	Brunne	861017	25x25 cm	10 cm	1.7	5.0	2.7	1.7	41		0.38
Ö1	Örnsköldsvik	861020	25x25 cm	2 cm		4.8	0.38	1.3	44		0.27
G1	Gideå	861018	25x25 cm	22 cm	2.6	9.2	0.96	2.5	42		0.32
G2	Gideå	861018	25x25 cm	12 cm	1.1	3.8		1.6	41		0.26
G3	Gideå	861018	25x25 cm	27 cm	0.70	7.6	0.56	2.7	43		0.28
G4	Gideå	861018	25x25 cm	16 cm	1.9	4.3	1.8	2.1	41		0.34
G6	Gideå	861019	25x25 cm	13 cm	0.92	3.5	0.05	1.5	44		0.28
G7	Gideå	861019	25x25 cm	4.5cm	0.33	2.2	0.53	0.45	44		0.20
G8	Gideå	861019	25x25 cm	60 cm		6.6	2.1	2.2	34		0.28
N1	N. Tannflo	861020	25x25 cm	8 cm		13	2.3	4.3	35		0.17
GE1	Gäddede	861021	25x25 cm	12.5cm		4.1	1.5	2.0	44	6.3	0.27
GE2	Gäddede	861021	25x25 cm	12.5cm		4.4	3.6	2.0	39	4.4	0.39
GE3	Gäddede	861021	25x25 cm	9 cm		3.7	3.5	1.6	39		0.23
GE4	Gäddede	861021	25x25 cm	8 cm		2.5	1.5	1.5	43		0.31



Geological map for the Gideå study site.



Picture showing an outcrop of 9 m^2 during a search for active particles, Finnsjön sampling site F8 (October 1986).



Picture showing two drill cores (middle) from Finnsjön (sampling site F8), and autoradiograms with exposure time 1, 7.5, 18 and 55 hours.

APPENDIX B

SOIL PROFILE CHARACTERIZATION

CONTENTS

Table B.1 Gideå, soil profile characterisation. Texture and trace element composition.

Number	Sample description:	Date of sampling	Date of analysis	Depth (cm)	Area (m2)	pH	% H2O	Dry wght	Geom	Wght (g-m)
1	G1, Litter fall incl. surface vegetation (moss, grass, twigs).	861018	870207	0-7	,0625		82,30	53,90	M 500	48,60
2	Root carpet, rawhumus	861018	870207	7-10	,0625	4,45	80,90	87,60	M 500	73,90
3	Rawhumus	861018	870207	10-12	,0625		77,60	134,30	M 500	126
4	Rawhumus	861018	870208	12-14	,0625		78	283,40	M 500	138
5	Rawhumus incl. gravelly till.	861018	870313	14-16	,0625		72	334	M 500	198
6	Gravelly till	861018	870313	16-22	,0225	4,45	34,90	1190,60	M 500	657,80
7	G2, Litter fall incl. surface vegetation (grass).	861018	870216	0-4	,0625		77,30	109	M 500	96,50
8	Root carpet, rawhumus	861018	870217	4-7	,0625		68,50	242,50	M 500	189,70
9	Rawhumus	861018	870214	7-10	,0625	4,50	52	356,80	M 500	329,60
10	Sand - bleached horizon	861018	870214	10-12	,0625		20,20	980	M 500	781
11	Litter fall incl. surface vegetation (grass)	861018	870215	0-10		4,50	47,30	295,70	M 500	295,70
12	Sand - bleached horizon	861018	870227	10-17		4,60	11,70	908,90	B 250	479
13	Sand - bleached horizon	861018	870228	17-25		4,90	27	753,40	B 250	457,20
14	Sand - enrichment layer	861018	870228	25-37		4,90	24,30	753,60	B 250	482
15	Sand - enrichment layer	861018	870301	40-48		5,10	56,90	430,30	B 250	380
16	Sand - bleached horizon	861018	870302	50-51		5,10				
17	G3, Sphagnum sp. incl. vegetation (heather, twigs).	861018	870213	0-8	,0625		94,30	44	M 500	37
18	Sphagnum peat	861018	870213	8-15	,0625		92,50	110,50	M 500	45
19	Sphagnum peat - degree of decomposition H3	861018	870214	15-18	,0625		92,10	153,80	M 500	62,30
20	Sphagnum peat - degree of decomposition H3	861018	870216	18-22	,0625		94	116,50	M 500	86
21	Sphagnum peat - degree of decomposition H3	861018	870215	22-27	,0625		95,70	91,70	M 500	88
22	Water sample from groundwater surface.	861018	870326	27-		4	100		M 500	363
23	Residue* from water sample above (22) presented in (Bq/l water).	861018	870328	27-					B60	363
24	G4, Litter fall incl. surface vegetation (grass, moss and lingonberry twigs).	861019	870218	0-4	,0625		73,40	86,20	M 500	77,40
25	Root carpet incl. some stones, rawhumus	861019	870219	4-8	,0625	4,60	51,20	470	M 500	248,50
26	Rawhumus	861019	870219	8-12	,0625	4,70	49,50	699,30	M 500	328
27	Stony sandy till - enrichment layer	861019	870219	12-16	,0625		19,40	1074	M 500	806
28	Stony sandy till - enrichment layer	861019	870219	14-24		4,90	12,80	1063,20	M 500	982
29	G5, Sphagnum sp.	861019	870223	0-10	,0225	3,60	95,10	44,40	M500	30
30	Sphagnum peat - degree of decomposition H2-H3	861019	870222	10-20	,0225		93,60	44	M500	44
31	Sphagnum peat - degree of decomposition H2-H3	861019	870222	20-30	,0225		94,90	39,30	M500	39,30
32	Sphagnum peat - degree of decomposition H2-H3	861019	870221	30-50	,0225		95,70	37	M500	35
33	Sphagnum peat - degree of decomposition H2-H3	861019	870220	50-70	,0225		95,70	39,60	M500	39,60
34	Sphagnum peat - degree of decomposition H2-H3	861019	870219	70-90	,0225		96,70	32	M500	32
35	G6, Litter fall incl. surface vegetation (lichen, moss, heather twigs).	861019	870211	0-2	,0625		35,50	234	M 500	114
36	Rootcarpet, rawhumus	861019	870211	2-4	,0625		58,70	170,30	M 500	161
37	Rawhumus	861019	870216	4-5	,0625		45,10	205,90	B 250	187,60
38	Sandy till - bleached horizon	861019	870212	5-6	,0625	4	20,10	717,80	M 500	676,80
39	Sandy till - bleached horizon	861019	870212	6-8	,0625		21,40	898,90	M 500	780
40	Sandy till - (bleached horizon) + enrichment layer.	861019	870325	8-10	,0625	3,90	21,10	1399	M 500	684
41	Gravelly till - enrichment layer.	861019	870324	10-13	,0625	4,80	17,40	1379	M 500	831
42	Gravelly till - enrichment layer.	861019	870213	11-21			10,20	1180	M 500	1072,80
43	G7, Litter fall incl. vegetation (lichen).	861019	870220	0-2	,0625		74	182,70	B 250	115,50
44	Rawhumus.	861019	870220	2-3.5	,0625		56,30	389	B 250	223
45	Rawhumus	861019	870220	3.5-4.5	,0625	4,20	48,60	470,70	B 250	243,50
46	G8, Sphagnum peat - cultivated, drained.	861019	870301	0-10	,06		79,70	478,40	M 500	90,40
47	Sphagnum peat - cultivated, drained.	861019	870225	10-20	,0625		78,40	642,60	M 500	76,60
48	Sphagnum peat - cultivated, drained.	861019	870301	20-30	,0625		86,50	413	M 500	76,40
49	Sphagnum peat - cultivated, drained.	861019	870302	30-40	,04		88,50	343,20	M 500	100,30
50	Sphagnum peat - cultivated, drained.	861019	870227	40-50	,04		87,60	398	M 500	172
51	Sphagnum peat - cultivated, drained.	861019	870226	50-60	,04	3,70	85,40	447,30	M 500	241,30

Table B.1 cont. Gideå, soil profile characterisation. Texture and trace element composition.

Number	As	Ba	Br	Ca %	Ce	Cs	Cr	Co	Eu	Hf	Fe %	La	Lu	Nd	K %	Rb	Se	Sc	Na %	Ta	Tb	Th	Zn	Zr	Yb	Clay	Silt	Sand	Gravel	Ignition loss %	Remarks:
1						,50									,35	15	,03		,01				40								
2			11		15	1,30	10	3,70	,20	1	,30	6					1	1,60	,18			1,50	110		,20						
3			10		9		6	2,30		,30	,17	4					,90	,80	,05			,70	60								
4			15		16	,60		1,90	,30		,44	9			,12		1,40	1,50	,04			,80	50								
5			15		23	1,50	8	1,50	,50	1,50	,49	12	,10		,29	25	1,90	2,20	,54			3	50								
6		400			55	2,90	7	1,30	,80	4,50	,52	22	,10	20	2,50	125	4	2,30	1,70	,30		11	35	100	,90	1	2	28	69	15,90	
7																															
8		300	6		17	1,10	9	1,20	,20	1	,24	9	,40		,79	40	2	1,20	,51		,30	3	110		23						
9		300	6		18	1,50	9	1,20	,30	2,70	,28	8	,20		,80	50	1,50	2,80	,65	,30		3	120		,80						
10																															
11																															pH measured on earth approx. 6-10 cm.
12		450			14	2,20	7	,50	,60	3,40	,16	6	,10		2,30	115	1,10	1,30	1,50	,30		2,70		250	,70	1	2	95	2	1,10	pH measured at approx. 10-17 cm. Soil contents, ignition loss valid for 10-25 cm.
13		450		1,40	25	2,80	14	1,10	,60	4	,50	12	,10		2,20	130	1,80	2,50	1,80	,60		6		150	,70						
14		500		1,30	24	2,90	15	1,90	,70	2,80	,68	10	,10		2,20	130	1,80	2,70	1,80	,40		4,50			,80	1	1	96	2	2,10	
15		500			35	2,40	21	2	,80	3,50	,83	13	,20		1,90	115	3	3,40	1,80	,40	,50	5			1	0	1	99	0	2,50	
16		500		1,30	35	2,70	19	2	,80	2,30	,71	13	,20		2,10	130	2,50	3	1,80	,40	,20	5			,80						
17																															
18			9		8			3,50			,28	4					,80	,40	,01				70								
19																															
20																															
21	3,50		35		10			1,70	,20		,39	5					,80	,90	,01			,50	35								
22																															
23																															Sampelvolume 1 l
24			7		10	,60		5	,10		,10	7			,34		,90	,40	,02				90								
25		400	7		28	5	24	29	,70	1	1,10	15	,10		1,60	65	2,50	3,30	,87			3	65		,20						
26			25		40	2,50	17	27	,60	1,30	1,50	20	,10		,30	30	2,70	3	,37			2,50	100		,90						
27		400	10		40	8,50	35	27	,70	3	2,60	20	,20		1,40	110	3	6	1,20	,50		7	90		,90						
28																										1	4	62	33	5,70	
29			8					,60										,10	,02				40								
30																															
31																															
32											,08							,20	,01												
33																															
34																															
35																															
36			8		10	1	9	,80	,10	1,50	,23	5			,58	40	,80	1,20	,35			3	65								
37		400			25	1,50	8	,60	,50	4	,18	10	,10		1,60	95	1,80	1,70	1,10	,40		4,50	35		,80						
38		450			35	1,70	7		,60	4	,21	15	,30	20	2,40	125	3	2,10	1,20	,40	,40	9			1,60						
39		600			50	6	15	,90	,70	7	,38	20	,30	30	3,30	220	3,70	3,70	1,40	,70	,40	10		150	1,30	2	14	69	15	3,70	Soil contents and ignition loss valid for 6-11 cm depth.
40		800		,82	65	3,20	17	1,20	,80	6	,75	27	,10	30	3,30	145	4,50	3,30	1,40	,70	,40	11			,80						
41																															
42		800			40	4	40	4,80	,90	4	2,30	16	,20		2,90	150	2,80	6	1,80	,60	,30	11	50	200	1,10	0	3	36	61	9,70	
43																															
44																															
45																															
46																															
47																															
48																															
49																															
50																															
51																															

Table B.2 Finnsjön, soil profile characterisation. Texture and trace element composition.

Number	Sample description:	Date of sampling	Date of analysis	Depth (cm)	Area (m2)	pH	I H2O	Dry wght	Geom	Wght (g-m)
1	F1, Litter fall, incl. root carpet and surface vegetation (moss, grass).	861014	870210	0-3			71,20	106,20	M500	106,20
2	Rawhumus incl. gravelly till - bleached horizon.	861014	870210	3-10		4.8	25,20	332,10	B250	290,60
3	Normal till - bleached horizon.	861014	870210	10-20		4.7	16	498,70	B250	448
4	Normal till - enrichment layer.	861014	870211	20-30		5.2	23,70	426,50	B250	376,50
5	Normal till - parent material.	861014	870211	30-40		5.3	21,20	464,20	B250	464,20
6	Litter fall incl. surface vegetation.	861014	870209	0-2	,0625		67,90	80,50	M500	80,50
7	Rootcarpet, rawhumus	861014	870209	2-4	,0625		43,40	480,50	M500	399
8	Rawhumus	861014	870210	4-6	,0625	5.0	30,90	501,50	M500	501,50
9	Tube profile, vegetation - till	861014	870427	0-10	,0034		43,20	112,40	B60	39,20
10	Tube profile, vegetation - rawhumus	861014	870515	0-5	,0034		41	242,30	B250	230,80
11	F2, Litter fall incl. surface vegetation (moss, grass, twigs).	861014	870220	0-2	,0621		71	105,50	B250	55,30
12	Rootcarpet, rawhumus	861014	870220	2-4	,0621	4,45	71,60	135	B250	68
13	Rawhumus	861014	870221	4-5.5	,0621	4,35	71,50	178,50	B250	87,50
14	Rawhumus	861014	870222	5.5-8	,0621	4,25	72,60	236	B250	236
15	Rawhumus	861014	870221	8-10	,0621	4,30	69,50	197,20	B250	128
16	Sandy till, leached horizon.	861014	870222	10-12		4,40	27,70	385,10	B250	343,50
17	Sandy till, enrichment layer.	861014	870223	12-22		4,50	23,90	480,20	B250	430
18	Sandy till, enrichment layer.	861014	870221	22-32		4,60	32,70	505,50	B250	437,50
19	F4, Sphagnum sp.	861015	870218	0-5	,0625		96,30	26,30	M500	26,30
20	Sphagnum peat - degree of decomposition H2*.	861015	870218	5-7	,0625		94,20	36,60	M500	34,80
21	Sphagnum peat - degree of decomposition H2*.	861015	870218	7-10	,0625		95,30	46,50	M500	36
22	Sphagnum peat - degree of decomposition H2*.	861015	870217	10-12	,0225		93,20	46	M500	46
23	F6, Litter fall incl. surface vegetation.	861015	870223	0-3	,05		73,50	143,40	B250	67,40
24	Root carpet	861015	870223	3-6	,05		67	236,20	B250	126
25	Rawhumus incl. sandy till.	861015	870223	6-9	,05		52,70	1302,50	M500	588
26	F7, Litter fall incl. surface vegetation (grass, twigs).	861015	870217	0-4	,0625		72,30	27,20	B250	27,20
27	Root carpet	861015	870217	4-6	,0625		70	107	B250	107
28	Rawhumus incl. sandy till.	861015	870216	6-7.5	,0625	4,80	55,50	225,20	B250	215,80
29	Tube profile vegetation - till	861015	870217	0-15	,0034		25,50	353	B250	353

* According to von Post (1921).

Table B.2 cont. Finnsjön, soil profile characterisation. Texture and trace element composition.

Number	As	Ba	Br	Ca %	Ce	Cs	Cr	Co	Eu	Hf	Fe %	La	Lu	Nd	K %	Rb	Sm	Sc	Na %	Ta	Tb	Th	Zn	Zr	Yb	Clay	Silt	Sand	Gravel	Ignition loss %	Remarks:
1																															
2		400			30	2	18	3,10	,50	3	1,20	13	,30		1,90	130	2,50	4,50	1,60	,50		6	50		1,50	1	9	35	55	10	
3		600	8		65	4	45	7	,70	8	2,50	21	,40		2,70	160	4	9	1,30	,70	,20	10	85	250	2	3	16	53	28	10	
4	5	500	9		70	5	50	9	,80	5	2,70	22	,40		2,30	150	4	9	1,30	,90	,90	10	90		2	15	25	52	8	9,80	
5																										16	17	46	21	4,70	
6																															
7																															
8																															
9		400			30	2	18	3,10	,50	3	1,20	13	,30		1,90	130	2,50	4,50	1,60	,50		6	50		1,50						
10																															
11																															
12																															
13																														65	Soil contents is missing, ignition losses are valid for 2-10 cm.
14																															
15		150	18		45		4	2,70	,50	,60	,46	24	,13		,51	25	3,50	1,90	,34		,30	2,30	40		,80						
16		500			20	1,20	11	1,50	,60	2,50	,63	8	,15		2,10	110	1,50	2,50	1,60	,20		2,50	40		,80	1	6	77	16	5,10	
17		600	7		30	2	13	2,70	,60	3,50	1,80	13	,20		2,20	120	2	4	1,60	,40		6	35		1,30	1	6	74	19	5,80	
18																										1	9	68	22	7,60	
19																															
20			12					,70			,13							,10	,01				45								
21																															
22																															
23																															
24		400	14	1,90	100	2	35	10	1,10	3,50	2	40	,40	25	1,50	85	9	8	1,10	,50	,80	11	80		2	1	12	81	6	22,50	Soil contents and ignition losses are valid for a depth of 2-24 cm
25																															
26																															
27																															
28		200		,88	20	,80	13	1,80	,40	2,50	,87	8	,20		,78	40	1,50	3,50	,75	,40		2,50	75		1,30						pH was measured at 8 cm depth.
29																										2	28	70	0	7,60	Soil contents and ignition losses are valid for a depth of 4-13 cm

APPENDIX C

SAMPLING, ANALYSIS AND MEASUREMENT TECHNIQUES

CONTENTS

C.1 Gamma Spectrometric Measurements in situ

The measurements were made with a Ge-detector. The detector position was 1.0 metre above the ground, and its position was carefully marked, so that repeated measurements could be made with the same geometry. Figure C.1.1 shows a spectrum, obtained at Finnsjön.

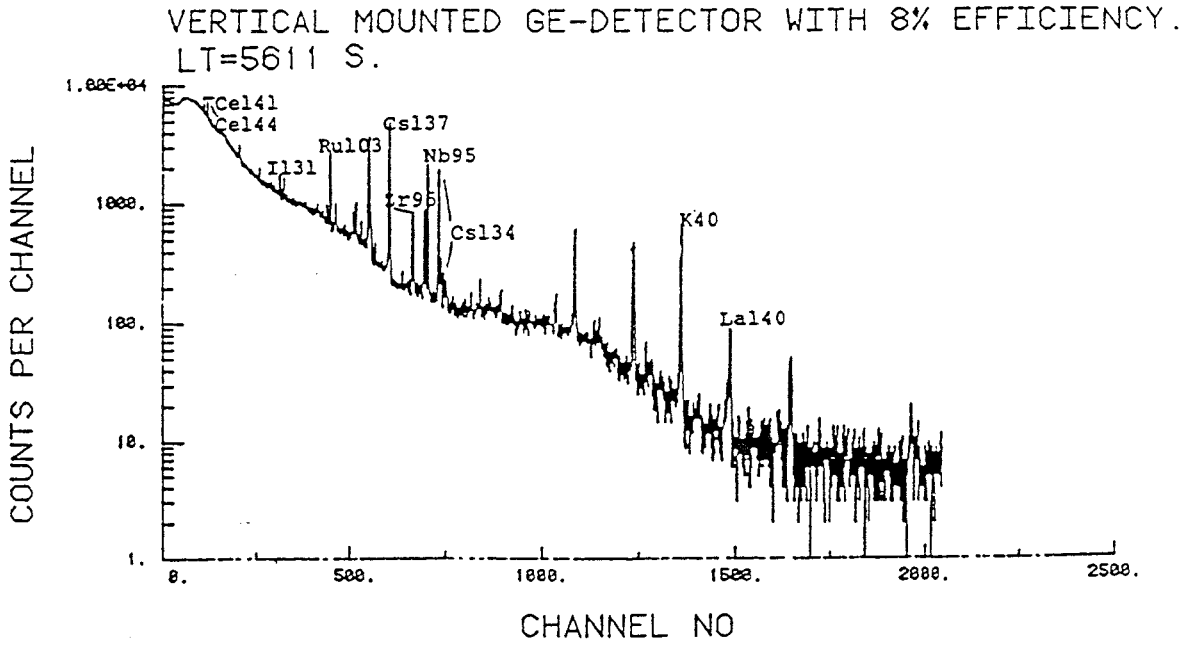


Figure C.1.1 Ge-spectra from Finnsjön, site F1.

C.1.1 Calibration of spectrometer

For the estimation of the relative decrease of ground contamination due to migration effects, the count-rate of the full energy peaks can be used, and no calibration of the spectrometer is necessary. In order to estimate the absolute surface contamination, calibration must, however, be carried out.

The Ge-detector is of coaxial type and can be mounted vertically or horizontally. The detector was calibrated by using standard point sources of Am-241, Ba-133 and Eu-152. The angular response of the detector is shown in Figure C.1.2. The response was symmetric with respect to the length axis.

Since the measurements were carried out over relatively plane surfaces, the efficiency was expressed as counts per second in the full energy peak per Bq/m^2 (γ-yield one) on an infinite, plane, smooth surface.

The count rate, N_f, for a full energy peak with energy E, from such a disc source, is given by

$$N_f(h) = \frac{S \cdot f}{2} \int_0^{90^o} \frac{\tan \theta \cdot \exp(-\mu \cdot h)}{\cos \theta} \varepsilon(\theta)\, d\theta \qquad \text{(Eq A.1)}$$

where

S = source (Bq/m^2)
f = gamma yield of energy E
μ = linear attenuation coefficient in air (m^{-1})
$\varepsilon(\theta)$ = angular dependent absolute efficiency -($cps/phot\ m^{-2}\ s^{-1}$)
h = height above disc source (m)
θ = the azimuthal angle

This equation was integrated numerically for the different calibration energies, by the use of polynominal fits of the angular responses. Figure C.1.3 shows the resulting efficiency of the detector, mounted vertically 1 m above ground.

Since the decrease of contamination (excluding decay) is a rather slow process, and only small differences between measurements can be expected, the spectra must be evaluated with high precison and with good knowledge of the uncertainties.

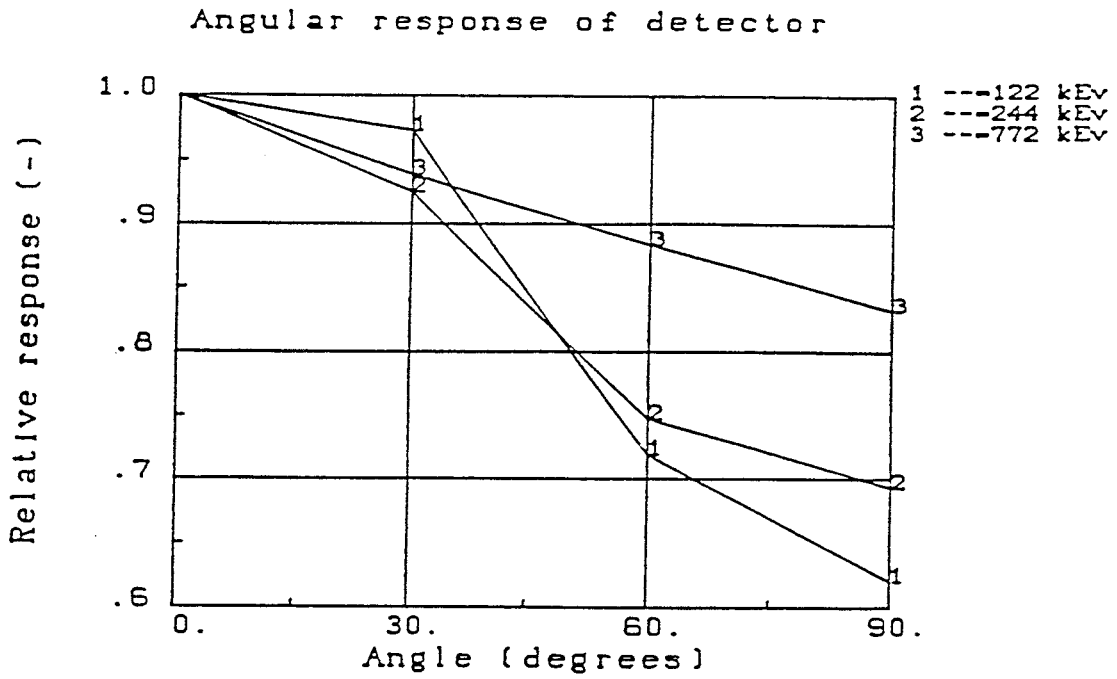


Figure C.1.2 Angular response of detector.

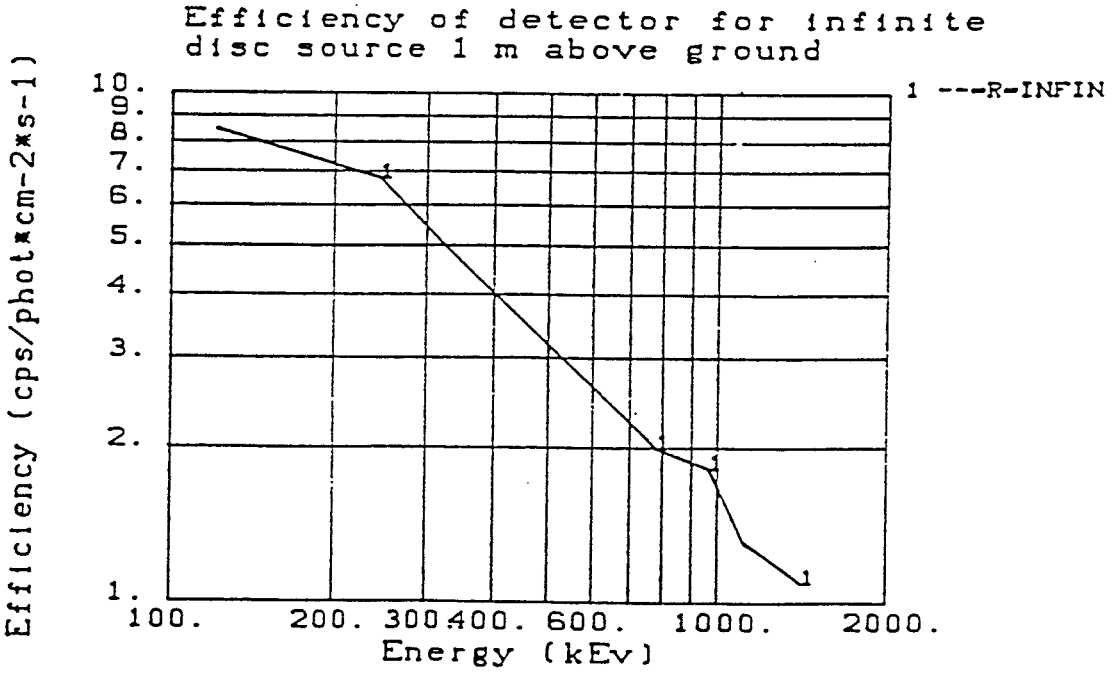


Figure C.1.3 Resulting efficiency of detector.

The spectra were initially recorded on cassette tape, than transferred to a Cyber computer and analyzed with the JANE code (Shubriger et al, 1978). This code, originally designed for neutron activation analysis, has the capability of carrying out peak serach, peak fit and isotope identification with a high degree of precision. A nuclide library, with about 20 nuclides, was established by using Jülich data (Erdtmann, 1973). The efficiency data, fitted to a linear curve in log-log scale, was read into the code and then the spectra were analyzed.

The code was also tested with respect to accuracy and precision, by using test spectra. These spectra were achieved from IAEA and they were mathematically manipulated measured spectra with known intensities. The JANE code was found to be in statistical control with respect to both accuracy and precision, i.e. the uncertainties predicted by JANE were in agreement with those observed.

When using this technique for estimating the surface contamination for multi-energy nuclides, such as La-140 and Cs-134, the measured photon fluences were found to be significantly higher for higher energies (typically 30-40 % higher for 1596 keV peak than for the 328 keV peak of La-140), than predicted by the infinite plane source geometry.

The explanation for this is the obvious influence of the migration of the activity and the shielding from the surface roughness.

An initial discussion of this problem and a method to compensate for this effect is presented below.

C.1.2 Compensation for surface roughness and migration of activity

No measuring sites are "infinite, plane, smooth surfaces". They suffer from varying surface roughness. They are finite in area and are seldom completely plane.

The effect on a finite area is shown in Figure C.1.4, where the efficiency for disc source with radius R, relative to infinite radius is plotted versus energy. As could be seen,~60 % of the count rate arises from activity within 10 m from the detector, and ~90 % from activity within 60 m. Since the behaviour of the nuclides does not differ much for different types of surfaces, the influence of "wrong" surfaces at distances greater than 10 m is small.

The surface roughness will act as a shielding for the radiation, and will be more dominant for larger source-detector distances. Nielsen (1977) has studied this effect when carrying out measurements in situ on naturally occurring isotopes. He indicates a method to compensate for this effect.

The surface roughness is simulated with a fictitious depth distribution of the activity (or, on porous surfaces, to assume a deeper distribution then the actual one). The fictitious depth distribution will affect the radiation in a similar way as a plane surface distribution with a surface roughness. The fictitious depth distribution is assumed to be exponential

$$S(x) = S_o \exp(-x \cdot \alpha)$$

where

$S(x)$ = activity concentration at depth x (Bq/m^3)
S_o = surface concentration (Bq/m^3)
α = the reciprocal of the fictitious relaxation length (m^{-1})

The total contamination S_A is then given by

$$S_A = \int_0^\infty S(x)dx = S_o / \alpha$$

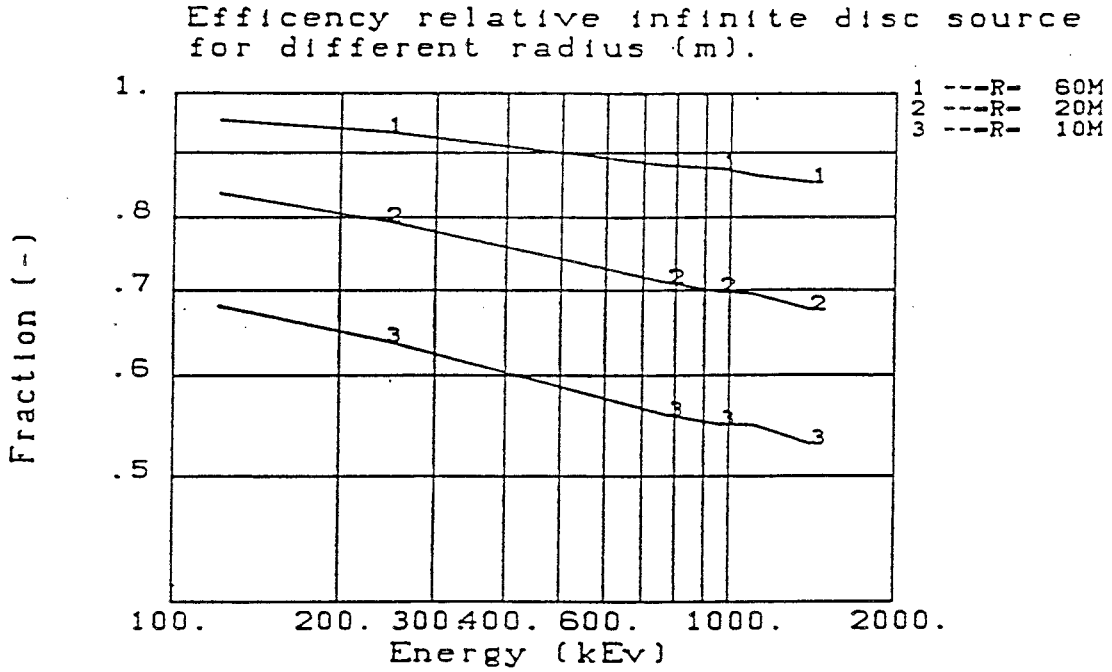


Figure C.1.4 Efficiency relative infinite disc source.

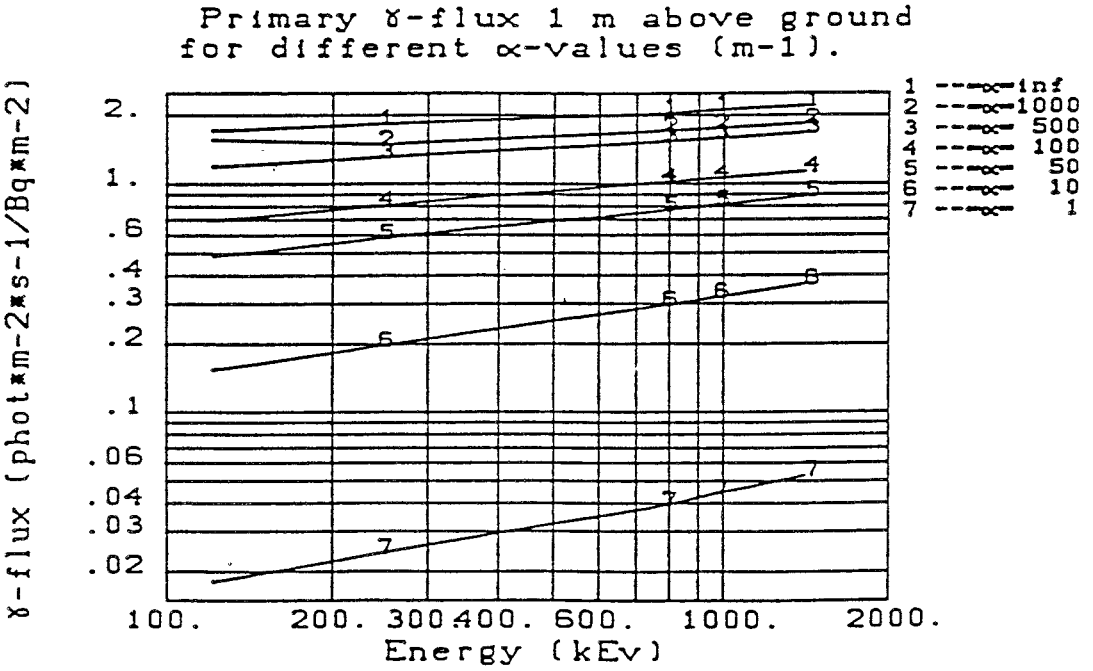


Figure C.1.5 Photon flux from a depth distributed infinite plane source.

The photon flux from the depth distributed infinite plane source at height h is given by

$$\phi(h) = \int_0^\infty \frac{S_0 \sin\theta \cdot \exp(-\mu_a \cdot h/\cos\theta)\, d\theta}{2(\alpha \cos\theta + \mu_s)} \qquad \text{(Eq A.2)}$$

where

μ_s = linear attenuation in the surface material (m^{-1})

Figure C.1.5 shows the evaluation of this equation for different values of α. A value of $\alpha = 1\,000$ gives a half-value of 0.69 mm and $\alpha = 10$ gives a half value of 6.9 cm.

For μ_s, values for soil with 10 % water content and a density of 1.6 g/cm^3 have been used. The relation between α, the photon flux for 661 keV relative the photon flux for $1/\alpha = 0$ and the corresponding quotient of photon flux for 1596/328 keV relative to corresponding quotient for $1/\alpha = 0$, were found with least square approximation accoring to

$$\phi/\phi_0(661 \text{ keV}) = 0.481 - 0153 \ln 1/\alpha \qquad \text{(Eq A.3)}$$

$$Q/Q_0(1596 \text{ keV}/328 \text{ keV}) = 1.14 + 0.134 \ln 1/\alpha \qquad \text{(Eq A.4)}$$

C.1.3 Comparison with field measurements

As indicated in section C.1.2 the measured photon flux was significantly higher for higher energies when the infinite disc source with $1/\alpha = 0$ was used. Table C.1.1 summarizes the measured quotient Q/Q_0 between 1596 and 328 keV for Cs-134 and La-140 at different sites in the Gävle, Finnsjön and Gideå areas. The quotients were found by error weighted least square fitting. Figure C.1.6 also shows an example for La-140 at 5 sites, with error bars for two of the sites. The curves are normalized to the lowest energy and to γ-yield. Figure C.1.7 shows corresponding model calculation.

Table C.1.1 Measured photon flux dependence of energy expressed as the quotient between 1596 and 328 keV for different surfaces and different times, during 1986.

Surface	Cs-134 May	Cs-134 June	Cs-134 Sept
Grass, Furuvik	1.27	1.05	1.25
Grass, old camping	-	1.20	1.15
Gravel, Furuvik	1.20	1.20	1.18
Paving stones	1.28	1.03	1.21
Concrete plates	1.00	1.15	1.12
Asphalt	1.14	1.10	1.20
G9, gravel		1.20	1.38
G10, boulder soil		1.10	
G11, outcrop		0.95	1.10
G12, bog		1.65	1.00
G13, moor		1.15	1.13
G15, moor		1.30	1.18
G22, till		0.62	1.15
F1, till			1.21
F16, clay		1.07	
F17, till			2.27
F20, outcrop			1.33
F7, till			2.33
F6, moor			1.13

Average statistical error < 10%

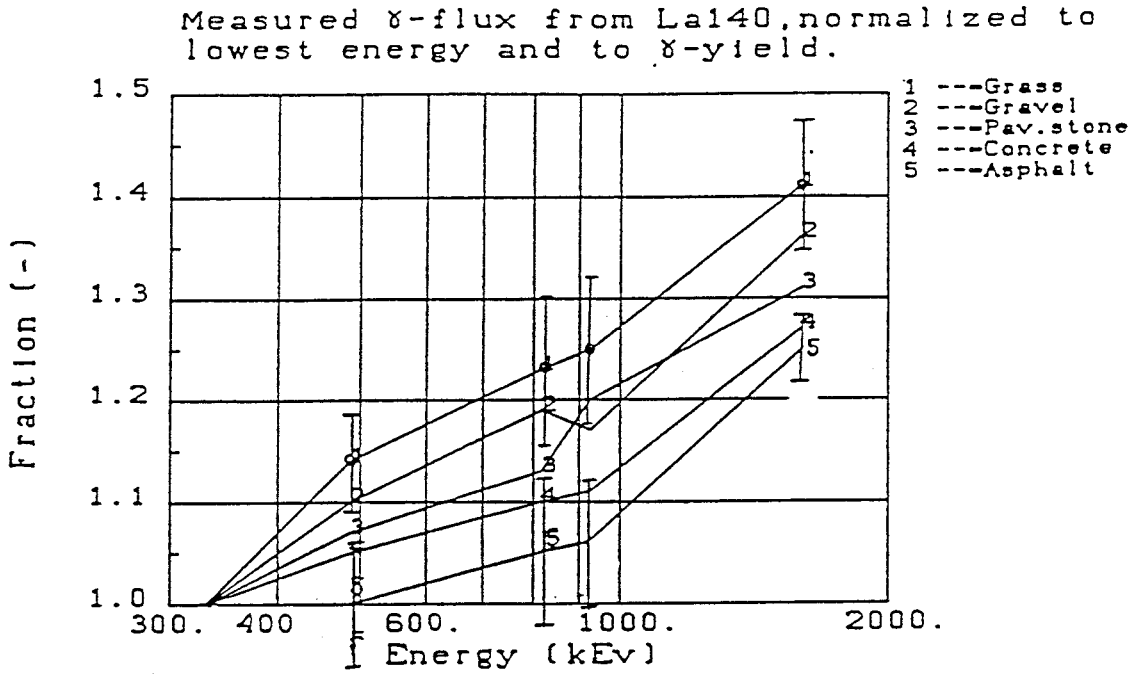


Figure C.1.6 Measured gamma flux from La-140.

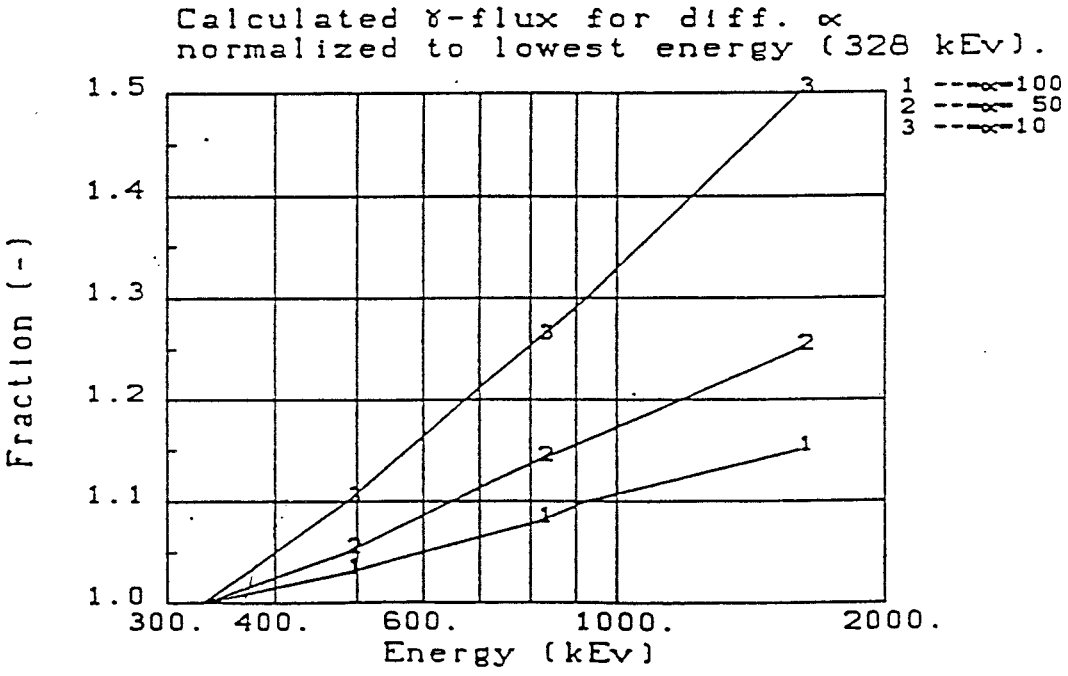


Figure C.1.7 Calculated gamma flux.

No regular pattern could be recognized in the measured data presented in Table C.1.1, an irregular variation with time and surface seems to exist. The variation could not be explained by counting statistics only. For the hard surfaces (pavement) in Gävle, the explanation must be a source pattern changing with time caused by rain water, road sweeping etc. At the porous surfaces in Finnsjön and Gideå the statistical errors are larger and the variation with time could be accounted for by these errors and by the influence of the water content of the soil and other phenomena.

If good estimations of the quotients were available (the 1365 keV of Cs-134 must be detected), individual compensation at each site would be possible. Since this is not the case, an average compensation has been made.

The mean of the existing quotients at Finnsjön and Gideå is 1.27 with a CV of 30 %. This corresponds to an $1/\alpha$ value of 2.67 cm (α= 38 m^{-1}) according to Eq A.4 and a reduction of the photon flux at 661 keV of 0.33 according to Eq A.3. A mean value of the corresponding quantity, found by comparison with the soil samples, was 0.39 (section C.1.2, 3.3 and 4.2). A $1/\alpha$ value of 2 cm was therefore selected for the detector efficiency calculation, givinig a reduction factor of 0.37 to be used for all sites.

It is now possible to estimate the increase of the $1/\alpha$ value at succeeding measurement occations, with use of Eq A.3 and a measured reduction of the photon fluence. The $1/\alpha$ value of 2 cm and the reduction factor 0.37 correspond to the shielding effect of both the activity soil profile and the surface roughness.

From the observed soil profiles, Tables 3.3.4 and 4.3.6, a 1/ value of 2 seems to be accouned for by the soil profile only. This is probably due to a sharp decrease of soil density at the upper centimetres of soil, so that the shielding is not so effective as assumed in the theoretical model (most measuring sites have a high humus content in the upper layer).

So, if we use a $1/\alpha$ value of 2 as a start value, the increase of $1/\alpha$ is given by

$$\Delta 1/\alpha = 22 \cdot \exp(-6.5 \cdot (d \cdot d_o))$$

where d_o is the initial reduction of 0.37, d is observed reduction between two measurement occasions. A 10 % reduction will then give an increase of relaxation length with 24 %, and a 20 % reduction with 50 % etc.

These estimates will be more accurate when the activity has migrated to larger depths, and must be used in comparison with direct observation by soil sampling. Since these estimations, however, provide averages over relatively large areas and are relatively cost effective, this technique is useful, specially in budget calculations.

C.1.4 Exposure rate

The exposure rate has been measured with a scintillation detector, type ALNOR 2414, with a plastic crystal 3*6 inches (NE102A). The measuring height has been 0.7 meter above ground, if nothing else is mentioned.

C.2 Soil Profile Sampling and Analysis

C.2.1 Sampling techniques

Sampling, preparation and handling of soil samples require a great precaution against cross contamination. To avoid contamination and to obtain representative samples in a fast and convenient way four different sampling techniques were used and are described below.

In technique 1 soil profile samples were collected by cutting out an area of 25x25 cm with a knife. Each layer (approximately 2-5 cm thick) was carefully removed to avoid contamination of the underlying soil (Fig. C.2.1). Between each layer all tools were cleaned and plastic gloves were changed. The sample was packed in plastic bags or containers and labelled. Data about the sample site, hydrological and geological properties were noted in the diary.

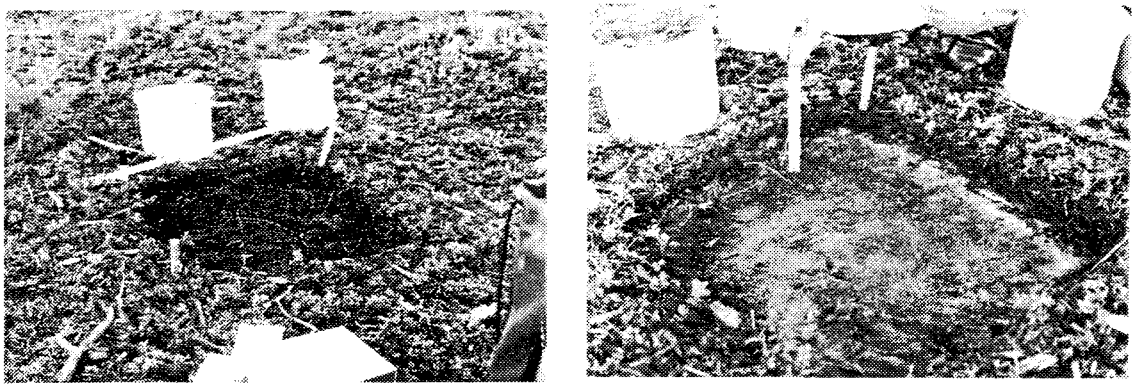


Figure C.2.1 Picture sequence of the working routine for 25x25 cm areal profile sampling.

In technique 2 the soil profile samples were taken with a plain shuffle from the side in a dug hole. The sample weight was approximately, 1.5 kg, corresponding to a one litre sample. The area was kept fairly constant and equal at 4.5 dm^2 which gives a sample thickness of around 2 cm. At greater depths, samples were taken at 10 cm intervals.

Attention was paid to the problem of cross contamination from upper soil layers. This was avoided by removing an additional area around each sample, thus making contamination from upper soil layer improbable.

In technique 3, used in fine soil areas, soil profile samples were collected by hammering down a plastic tube (diameter 0.067 m) into the soil (Fig. C.2.2). Samples were also taken with a sharp iron tube, with approximately 10 cm^2 area.

Figure C.2.2 Soil profile sampling using a PVC cylinder in fine soil areas.

This technique is fast and permits a more accurate soil depth resolution, but the disadvantage is the relatively small sample volume and to know which part of the soil profile is compressed during the pressure obtained. Development of this sampling method will be continued.

Technique 4 was used to collect peat profile samples. A standard Russian peat sampler was used (Fig. C.2.3) and made it possible to collect peat profiles down to 1 m depth. Peat type and degree of decomposition (according to L von Post) is determined in the field.

Figure C.2.3 Peat profile sampling, with a standard Russian peat sampler.

C.2.2 Sample preparation

Preparation of a sample is done by drying it in 105°C until constant weight. The sample is then homogenized and transferred to an analysis beaker with well defined geometry. The most used geometry is 600 ml Marinelli, but 60 ml, 250 ml and 500 ml plastic containers are also used.

If samples were taken with a PVC cylinder the sample was frozen to -30°C to avoid water transportation of radionuclides during the time between sampling and analysis. The PVC cylinder was cut lengthwise and the two halves were taken apart. The soil profile was then cut into horizontal layers and the sample was dried the same way as mentioned above.

Soil profiles collected with the sharp iron tube were cut into 1-2 cm layers and transferred to sample containers, on site, immediate after sampling.

C.2.3 Analysis

This study concentrates on the γ-emitting nuclides (Co-60, Ru-103, Ru-106, Ag-110m, Sb-125, Cs-134, Cs-137, and Ce-144) which can be found in such concentrations that it will be possible to follow their behaviour in a perspective of several years.

Measurements of the fallout from Chernobyl showed a very small amount of alfa-emitting nuclides and Sr-90, compared to what could be found after the nuclear weapon tests in the 60´s.

Gamma spectrometric measurement was performed with a HPGe-detector with relative effectivity of 30.3% and a resolution of 1.76 keV (1322 keV). The detector was connected to a PC-based multi channel analazer (ORTEC MCB 918). For evaluation of the gamma-spectrum the software GELIGAM from EG&G Ortec was used together with a nuclide library TJE1, modified at the Dept. of Nuclear Chemistry, Chalmers University of Technology. The detector was energy and effeiciency calibrated against a mixed standard (Amersham QCY 44 R7/5/103) and a Cs-137 standard (CDZ 24 S4/19/164) for different measuring geometries.

The measurements are decay corrected back to the sampling date.

C.3 Outcrop Samling and Analysis

C.3.1 Sampling techniques

Rock samples from outcrops were collected in two different ways: 1) diamond drilling (fig C.3.1) and 2) by hammering. The drillcore samples were drilled on flat outcrops and in open fractures where radionuclide migration and sorption are to be studied. In the Finnsjön area "hot spots" (active particles with considerably activity) were found on outcrops. By drilling, several of these "hot spots" could be removed (cf. sec 2.5). The rock samples picked by hammer represent a larger area than a drillcore sample.

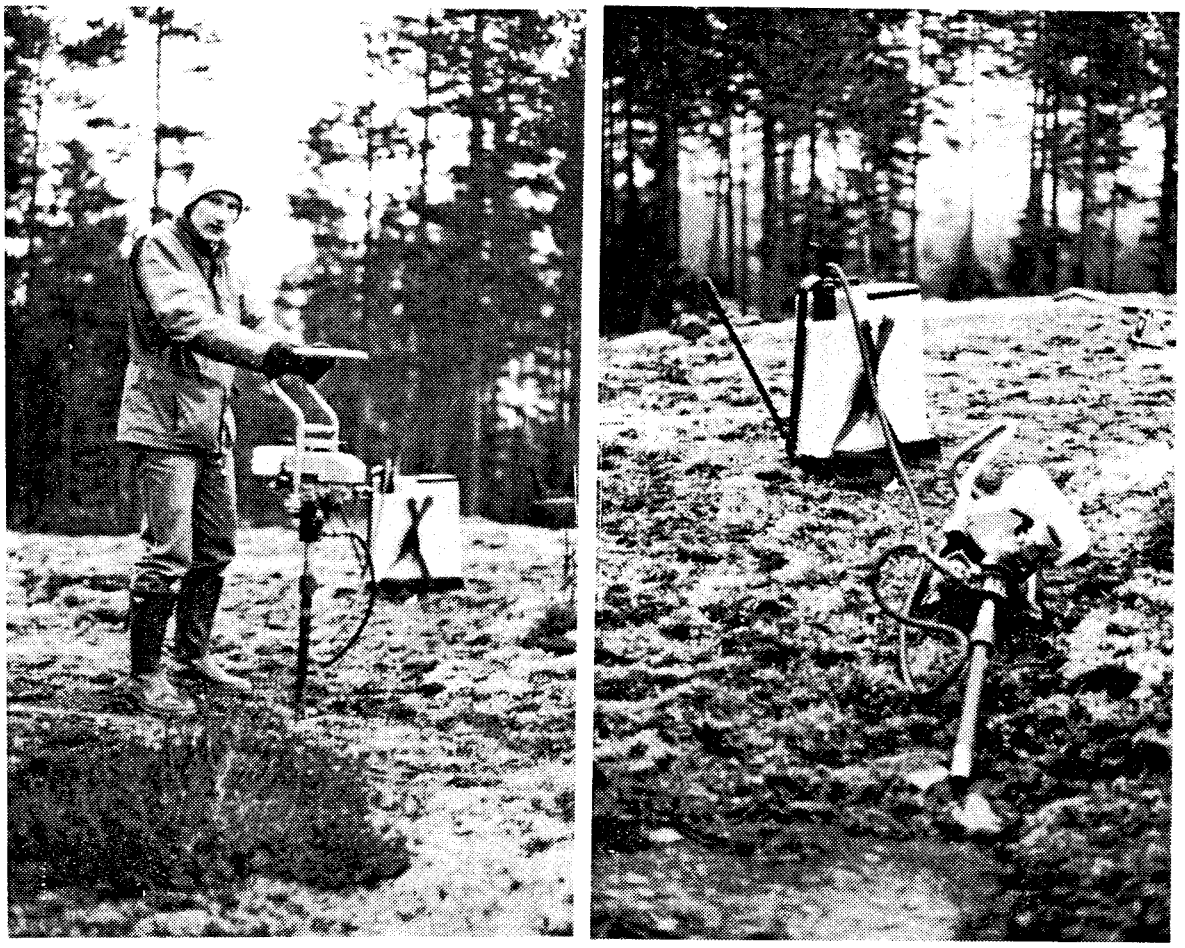


Figure C.3.1 Picture showing the portable drilling equipment.

C.3.2 Analysis

"Hot spot" samples were analysed in respect of their radionuclide content and in some cases also the chemical form. The rock samples were investigated to see if the fallout was deposited as particles or as an even distribution (cf. sec. 2.5-2.6). Of certain interest was also whether the fallout was concentrated to surfaces covered by lichen, moss or uncovered rock surfaces or if the radionuclides were washed away.

Analysis of the activity distribution on the outcrops was performed by using autoradiography. The time of exposure was approx. 1-1.5 months, except for the "hot spots" which gave strong blacking already after 1 hour exposure time. The film used, Cea Reflex 15, is a film especially designed for applications where high sensitivity for direct X-ray exposure is needed. The film has also a very low sensitivity to light to prevent fogging during handling in darkroom. The analysis after development of the autoradiogram was ocular. No characterization of different types of radiation were determined, but it is possible to get a rough estimation of the total quantity of activity. The distribution of the radionuclides can by this method be well estimated in the very small scale.

Attempts were also made to determine the chemical form of a "hot spot". Following efforts were made:

a/ the particle was placed in an oven in 200^{o}C for 1 h.
b/ - " - ultra sonic bath for 12 h.
c/ dissolving the particle in 1 M $MgCl_2$ for 12 h.
d/ - " - 0.01 M HNO_3 for 12 h.
e/ - " - conc. HNO_3 for 12 h.
f/ - " - aqua regia for 12 h.

The activity was in neither case possible to remove or dissolve.

C.4 Water Sampling and Analysis

Groundwater samples were taken in a shallow dug well and from discharging artesian drill holes. Surface water samples were taken in fens and brooks, draining the study sites. A few soil water/shallow groundwater samples were taken at the bottom of some of the pits remaining from the soil profile sampling.

During the water sampling procedure a great contamination risk comes from solid particles carried by water into the containers. In most cases the sample volumes varied between 25-150 l, to get an acceptable activity.

The water sample was tapped off into 25 l PVC-cans and acidified with nitric acid (to pH=2, to stop the biological activity). Since the PVC-material can act as a good ion exchanger, trace quantity (approx. 2 umol/l water) of inactive Sr, Cs, and Y was added to equilibrate with the radionuclides. The detection limit was lowered through concentration by destillation and evaporation of the water sample to approx. 500 ml.

Surface water contains high concentration of humic substances which can, with its large active surface, physically absorb ions and complexes. Therefore surface waters were analyzed with respect to radionuclide concentrations before as well as after filtration of humic substances. For gamma spectrometric measurements 600 ml Marinelli beakers were used.

C.5 Sediment Sampling and Analysis

To be able to estimate the removal of radionuclides by water from the study sites not only water but also sediment samples were collected. This was done by selecting a place down stream the brook (outside the area) were the water velocity was slow enough to allow suspended particles to settle out. A known area of the sediment was taken by carefully removing the fresh sediment and the upper layer of the more compact sediment. This was done on several places to give a statistical significance.

In laboratory the samples were filtrated to separate the coarse material from the fine in the water part. The compact sediment was dried and all different fractions were analyzed separately.

Sediment profile samples were collected by forcing a PVC-tube down through the sediments. The cylindric samples obtained were cut into 1-2 cm layers and transferred to sample containers, on-site, directly after sampling.

C.6 Vegetation Sampling and Analysis

Vegetation samples were taken to give a rough estimation of the uptake of radionuclides in vegetation at this early stage. Samples were also taken and treated to determine the effect of sorption of radionuclides on vegetation during the fallout. The aim of these studies is in a perspective of several years to see how uptake in vegetation can influence the total migration of radionuclides through the soil.

The collected vegetation consisted of lichen, moss, shrub vegetation and trees. In laboratory these samples were treated in the same way as for example soil samples.

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