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Radiometric studies in the Meråker region. Environmental implications of anomalous levels of ^{137}Cs

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RAPPORT

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Radiometric studies in the Meråker region: Environmental implications of anomalous levels of ^{137}Cs.

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Sammendrag:

Airborne and ground-based radiometry surveys in the Meråker region have revealed unusually high concentrations of ^{137}Cs in a bog to the north of Meråker. These anomalies were originally identified in Airborne Total count data, where they could not be correlated with Uranium, Potassium or Thorium anomalies. A ^{137}Cs map was generated by extracting a cesium window from the Total count data which again revealed the presence of these anomalies and provided an indication that they might be due to the presence of anomalous concentrations of ^{137}Cs.

A limited programme of ground-based measurements, carried out to confirm the presence of these anomalies, reveal that ^{137}Cs concentrations across the region as a whole generally lie within the range 2 to 6 kBq/m^2 but rise to approx. 42 kBq/m^2 in the bog at Fundaunn. Despite the limited nature of the ground measurements a general correlation is noted between the nature of the terrain and the ^{137}Cs concentrations measured, with the highest concentrations found in areas of dry and vegetated peat.

Emneord: Geofysikk	Radiometri	Bakkemåling
		Fagrapport

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1. INTRODUCTION

This report describes the interpretation of a Gamma-Ray Spectrometry survey in the area of Meråker, Nord-Trøndelag. The area was the subject of an Airborne Gamma-Ray Spectrometry survey in the summer of 1991 (Mogaard & Blokkum, 1992) and four contoured radiometric maps were produced from the data accquired in this survey: a Total Count radiometric map, a Uranium count radiometric map, a Potassium count radiometric map and a Thorium count radiometric map.

A preliminary interpretation of these maps was made by Mac Niocaill (1992), in an NGU internal report. A number of prominent anomalies in the Total Count radiometric map were identified that appeared to have no correlatives in the Uranium, Potassium or Thorium maps. As these anomalies could not be correlated with the Uranium, Potassium and Thorium radiometric data the author tentatively proposed the possible presence of anomalous concentrations of radiocesium.

Therefore two approaches were used to try to identify the source and areal extent of these anomalies:

1. A ^{137}Cs map was generated by retrieving the original helicopter data and extracting a ^{137}Cs window (Walker & Smethurst, in prep).

2. A limited programme of ground-based measurements was carried out in Meråker at the sites of these anomalies, using a portable Gamma-ray spectrometer, including measurements of ^{137}Cs, in an attempt to verify the presence and source of these anomalies.

The results of this follow-up work are detailed in this report, preceded by a brief summary of the Airborne data and followed by recommendations for further work.

2. SYNOPSIS OF RESULTS OF AIRBORNE RADIOMETRY

The acquisition and processing of the data used in this study is reported in Mogaard & Blokkum (1992) and, rather than repeating their work here, the reader is referred to their work for more details.

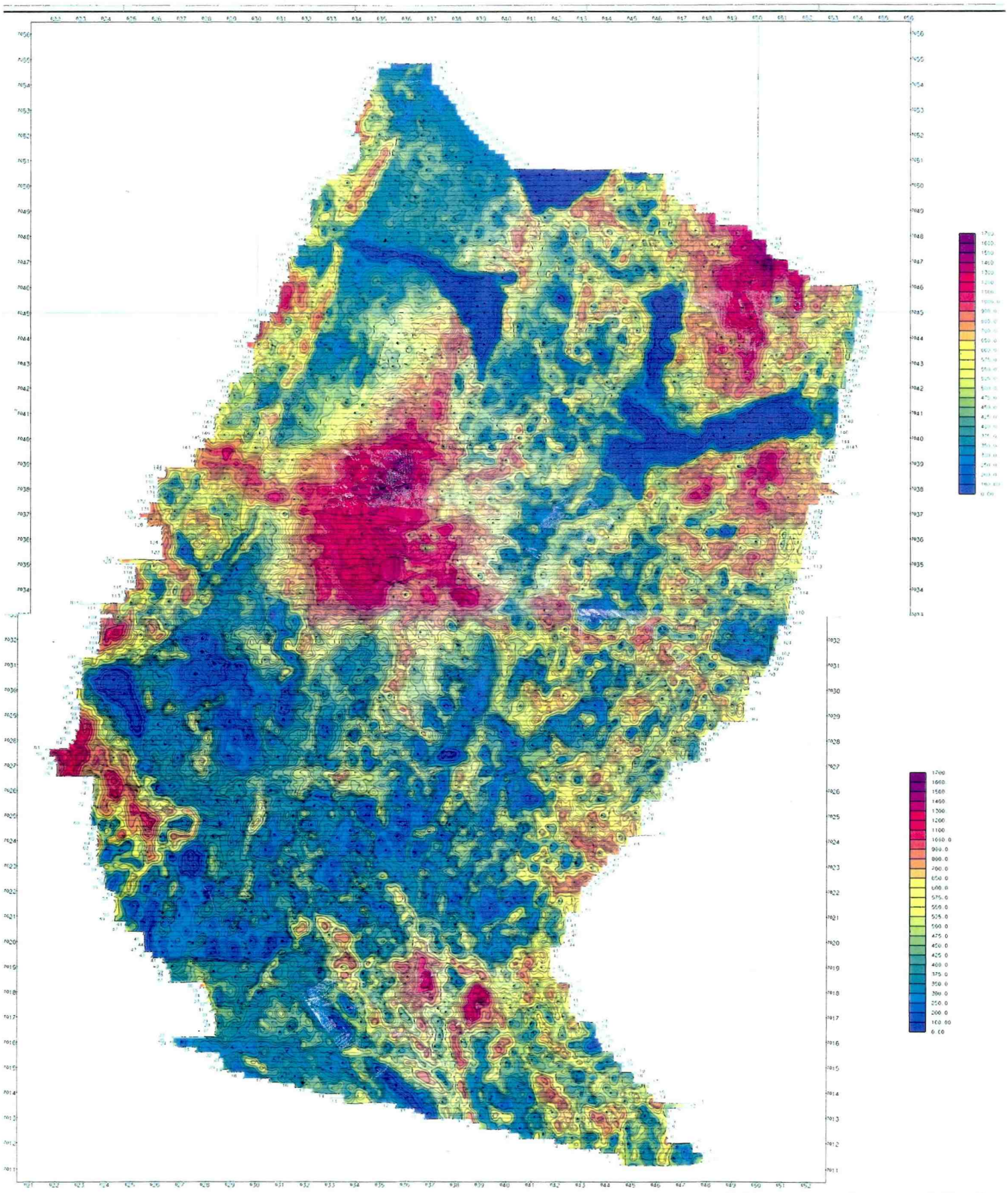
A number of anomalies were identified in the Total Count map (Fig. 1) most of which could be correlated with regional geological features. A number of these geological features also were reflected in Uranium, Potassium and Thorium anomalies. However two anomalies proved to be enigmatic in the sense that they did not appear in the Uranium, Potassium or Thorium windows and could not be related to the regional geology. These were centred to the north and south of Meråker. As there was no correlation between them and the local geology or the other radiometric data it was concluded that they might possibly be due to radiocesium from the Chernobyl fall-out as measurments made in 1986, in the aftermath of the accident at Chernobyl, had revealed the presence of significant radiometric anomalies in the area (Lindahl & Håbrekke, 1986), though the source of those anomalies had not been positively identified.

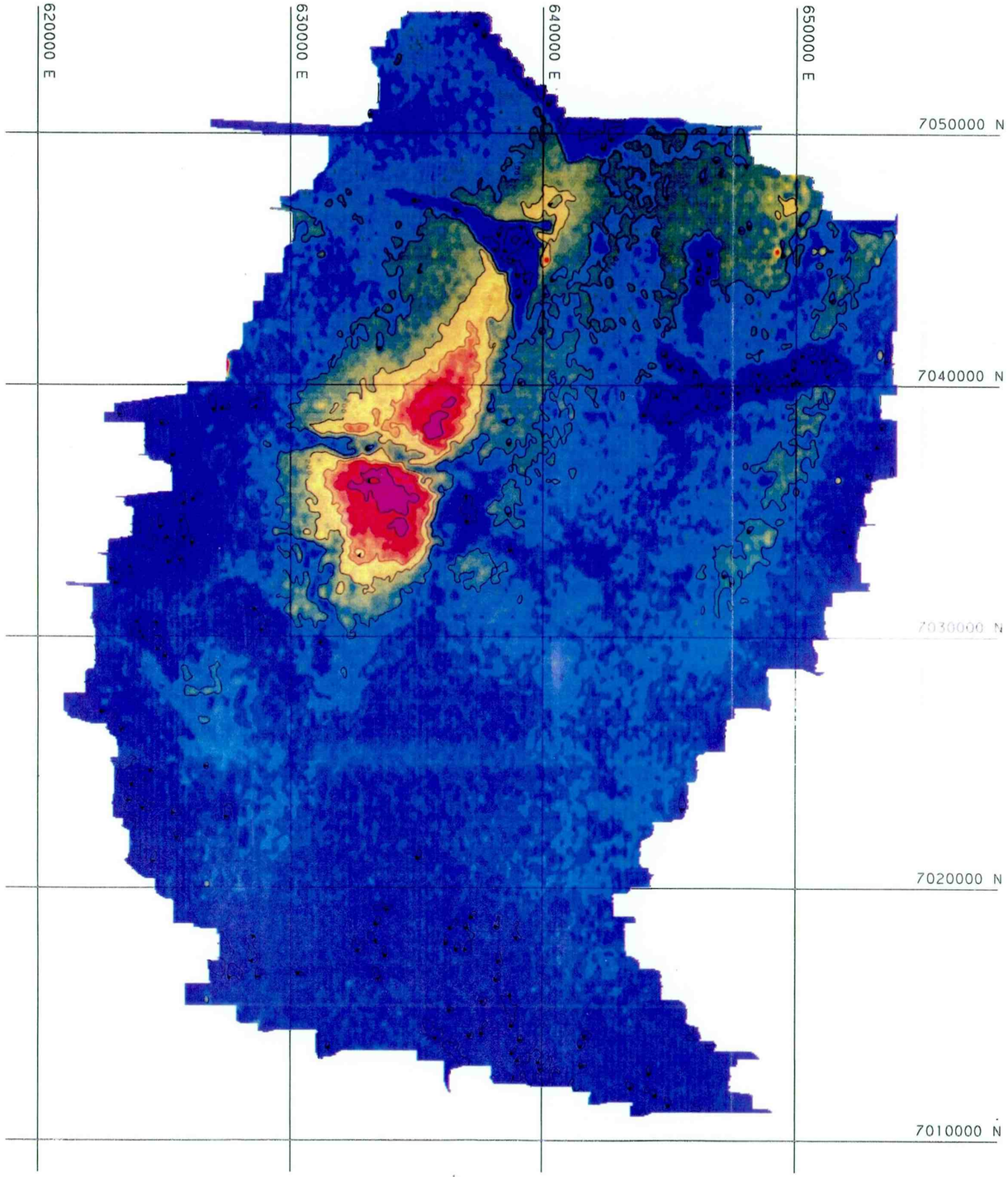
3. ^{137}Cs MAP

In an attempt to further delimit the extent of the anomalies lying outside the Potassium, Uranium and Thorium windows a cesium map has been generated using a specially developed algorithm which 'extracts' a cesium window from the total count. A detailed description of the method of production of this map lies outside the scope of this report, given that its purpose is primarily the interpretation of these anomalies, and a separate report is currently being prepared on this topic (Walker & Smethurst, in prep).

Figure 2 shows the ^{137}Cs map. The main features are the pronounced anomalies in the bog at Fundaunn and in the area to the south of Meråker and which appear to be greatest on eastward facing slopes. Since this map only covers the ^{137}Cs window it indicates that the source of the anomalies to the north and south of Meråker is indeed cesium (^{137}Cs). What is also noteworthy is that all the anomalies in the Total Count map that have correlatives in the Uranium, Potassium or Thorium windows have no correlatives on this map, indicating that this seems to be localized feature. Factors affecting the concentration of ^{137}Cs in natural environments are discussed in a later section.

Fig.1 Total count anomaly map.





NORGES GEOLOGISKE UNDERSØKELSE
Geological Survey of Norway

N

Cesium Tellinger

Cesium 137 kanalen
Ei tellinger / sekund

Kartkonturene er multiplum av
de som er listet nedenfor

100 t/s

500 t/s

Farger distribuert etter en fargeskala
som vist til venstre

Fig 2. 137Cs Map

NORD TRØNDELAG PROGRAMMET

RADIOMETRI CESIUM KANALEN
KONTURER OG FARGER

MERAAKER

NORD TRØNDELAG

MÅLESTOKK 1 : 100.000

0 1000 2000 5000 10 KILOMETERS

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TEGNING NR: 93.045-01

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4. GROUND-BASED RADIOMETRY

4.1 Data-acquisition

A preliminary ground-based survey was carried out in the Meråker region, in august 1992, using a 256-channel portable spectrometer (an Exploranium GR-256) with a 7.6 x 7.6cm Sodium Iodide (Thalium) activated crystal detector. This instrument was chosen because it can be used to record up to 8 user-specified windows located anywhere in the Gamma-Ray spectrum. Five 'windows' were recorded for this study: Total Count, Uranium, Potassium, Thorium and Cesium. The spectrometer also includes a spectrum stabilization feature to protect from gain shifts due to temperature changes which could possibly have adversely affected the results. This feature uses a cesium source which was inserted for stabilization but removed and kept well away from the detector during all measurements. Background measurements were carried out from a boat on lake Funnsjöen.

Measurements were made along two main profiles, one to the north of Meråker (Fig. 3a), in the bog at Fundaunn at one of the anomalies, and the second some 10km to the east of Meråker, in a traverse across the river Teola, where no such anomaly was present (Fig. 3b). The results from these two profiles are presented in this section.

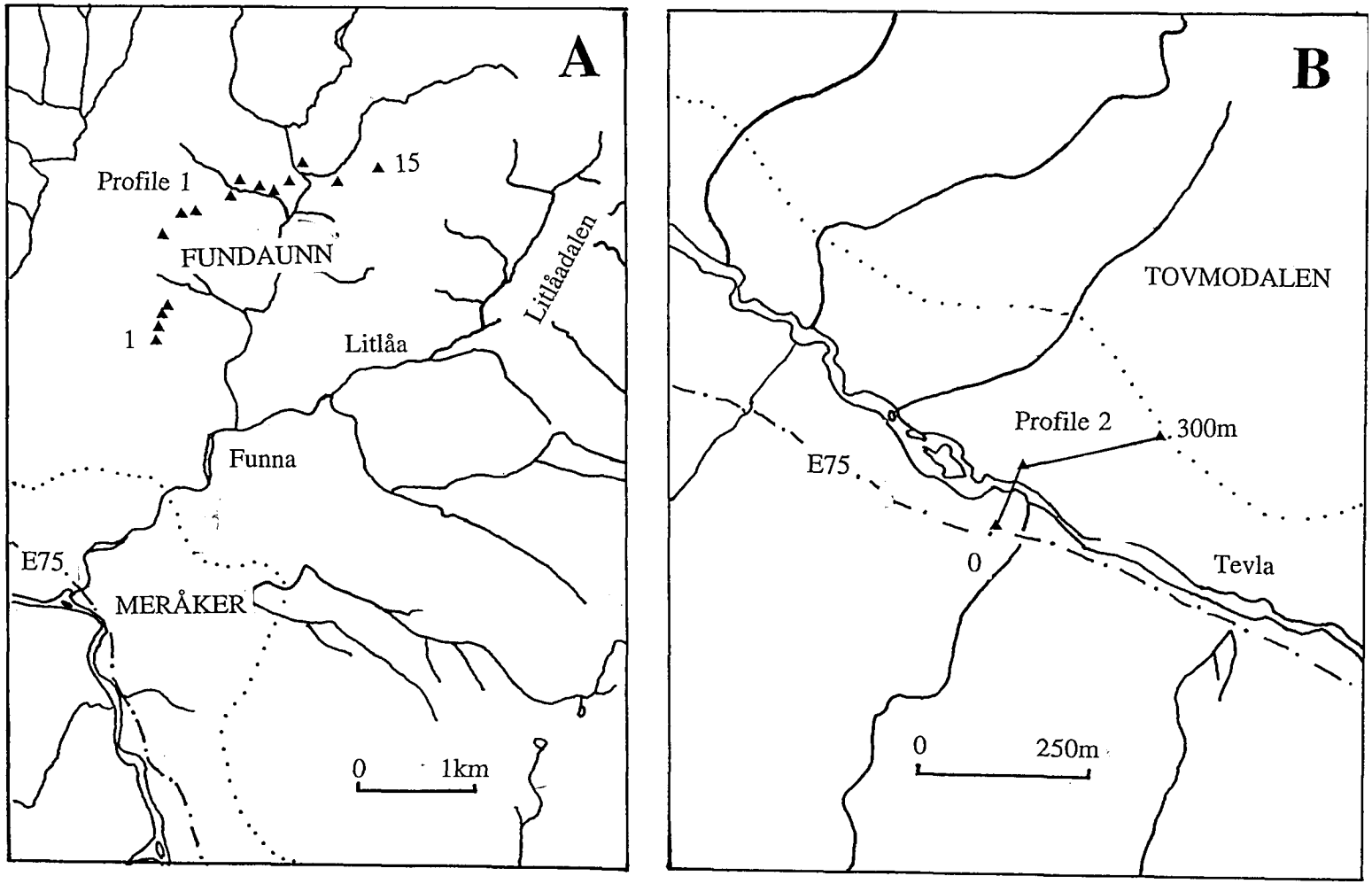

Fig.3 Simplified map showing the location of profiles 1 (A) and 2 (B).
Numbers on profile 1 refer to station numbers.

4.2 Data-Processing

The raw data was converted to counts per second (c.p.s.) and the background counts were subtracted giving the background corrected count rate. The background corrected count rates, n_K, n_U and n_{Th}, are the sums of the individual count rates from Potassium, Uranium and Thorium (respectively) in the ground. Because the spectra of the Uranium, Potassium and Thorium overlap, in a phenomenon known as the Compton effect, the count rates were then 'stripped' to remove the spectral overlap between the windows using the following equations:

$$n_{KK}=\frac{n_{Th}(\alpha\gamma-\beta)+n_U(a\beta-\gamma)+n_K(1-a\alpha)}{A} \quad (1)$$

$$n_{UU}=\frac{n_{Th}(g\beta-\alpha)+n_U(1-b\beta)+n_K(b\alpha-g)}{A} \quad (2)$$

$$n_{ThTh}=\frac{n_{Th}(1-g\gamma)+n_U(b\gamma-a)+n_K(ag-b)}{A} \quad (3)$$

where A has the value:

$$A=1-g\gamma-a(\alpha-g\beta)-b(\beta-\alpha\gamma) \quad (4)$$

This yields the count rate for each window originating from the element in that window: ie. n_{UU} is the count rate in the Uranium window attributable to Uranium. Alpha (α), Beta(ß), Gamma (γ), a, b and g are stripping ratios derived from measurements made with the spectrometer of concrete calibration pads with known radioelement concentrations. (Appendix A.)

To remove the effect of Potassium, Thorium and Uranium from the Cesium 'window' these stripped values were then used to calculate the 'normalized' cesium count using the following equation:

$$C_{Cs}=C_{Cso}-(Cs/K)n_{KK}-(Cs/Th)n_{ThTh}-(Cs/U)n_{UU} \quad (5)$$

where C_{Cs} is the normalized cesium count rate and C_{Cso} is the background corrected cesium count rate. Cs/K, Cs/Th and Cs/U are the stripping ratios for Potassium, Thorium and Uranium into Cesium respectively (Appendix A).

Cesium concentrations, in KBq/m^2, were then calculated from the 'normalized' count cesium count rate, using a concentration co-efficient determined in the laboratory at N.G.U.(a $1KBq/m^2$ ^{137}Cs source yielded 157.25 counts per minute using the GR-256 spectrometer).

5. RESULTS OF GROUND-BASED RADIOMETRY

5.1 Profile 1.

This profile was undertaken in the bog at Fundaunn where one of the anomalies was located. The highest concentrations of ^{137}Cs identified during the ground survey area were found here, with ^{137}Cs concentrations rising to some 42 KBq/m^2 (Fig. 4). It is clear from Fig. 4. that there are large variations in ^{137}Cs concentrations, even over a very small area (See for example stations 4 & 6). However a qualitative correlation can be made between ^{137}Cs concentrations and the nature of the terrain. In general the highest values were recorded on the eastward-facing slopes in areas of dry vegetated peat and the lowest recorded on dry outcrops with no vegetation (Fig. 4). There also seems to be a general decrease in ^{137}Cs concentration along the profile to the east; away from the bog. It is important to note here that the above comments are qualitative in nature and we have, as yet, no way of quantifying what the factors controlling the ^{137}Cs distribution. However, we can state that, as with the ^{137}Cs map, the ground measurements suggest that the anomaly can be directly attributed to the presence of anomalous concentrations of ^{137}Cs in the vicinity of the bog. It also raises the possibility that there is some process operating in the bog which is concentrating the ^{137}Cs above the general 'regional' level.

5.2 Profile 2.

A second profile was carried out across the river Teola at Tovmodalen (Fig. 3b) where no major anomaly had been identified in the airborne data. This profile revealed much lower concentrations of ^{137}Cs than did profile 1. In general ^{137}Cs concentrations were within the range 4-8 KBq/m^2 (Fig. 5). Again a general correlation can be seen between the nature of the terrain and the ^{137}Cs concentrations, with the highest values recorded in mossy-woodland and over dry peat. Measurements made on outcrops were typically in the range of 2-3 KBq/m^2. This we take to be the general ^{137}Cs concentration across the region.

Meraker Radiometry Survey

Caesium Profile No 1

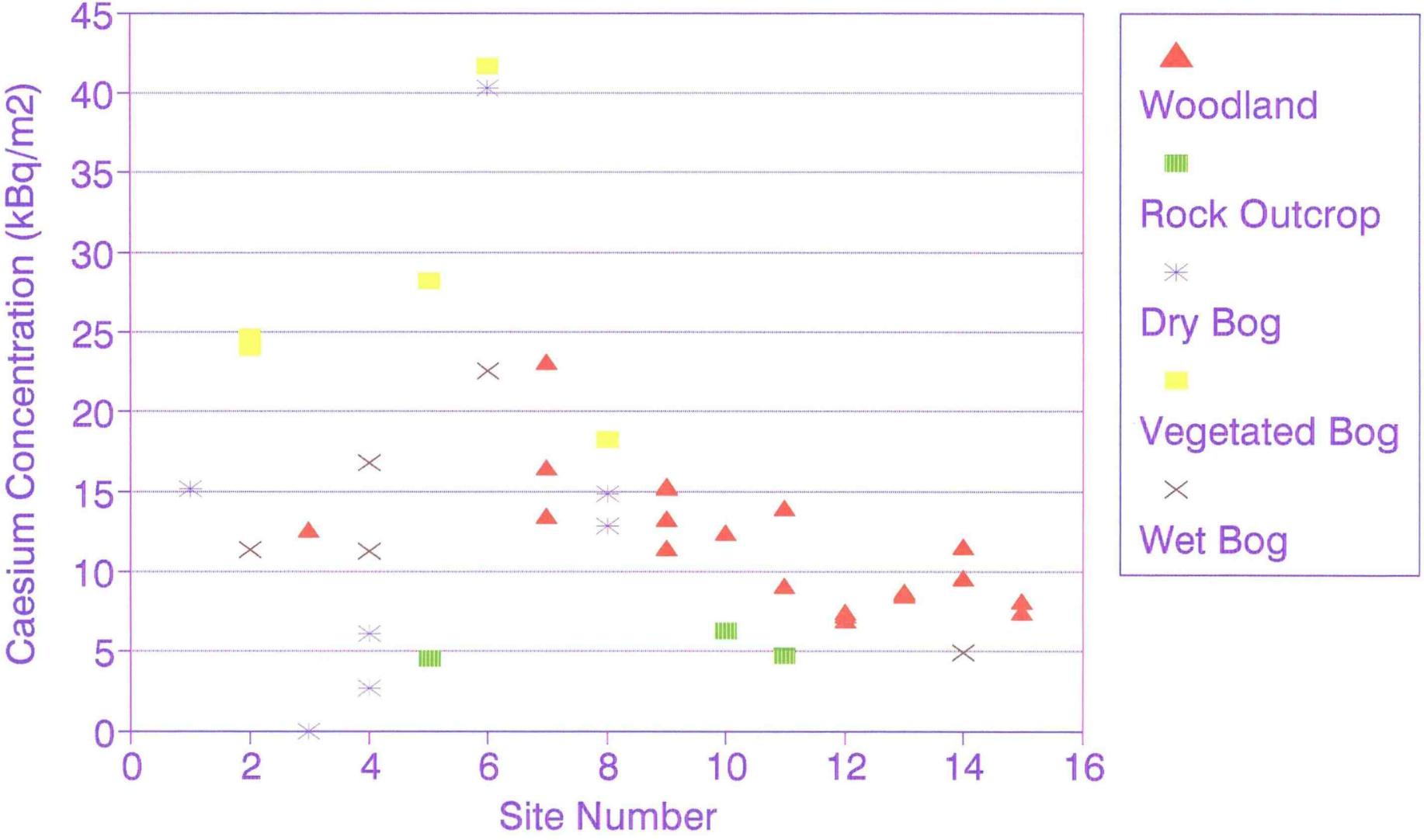

Figure 4 Results from Profile 1

Meraker Radiometry Survey

Caesium Profile No 2

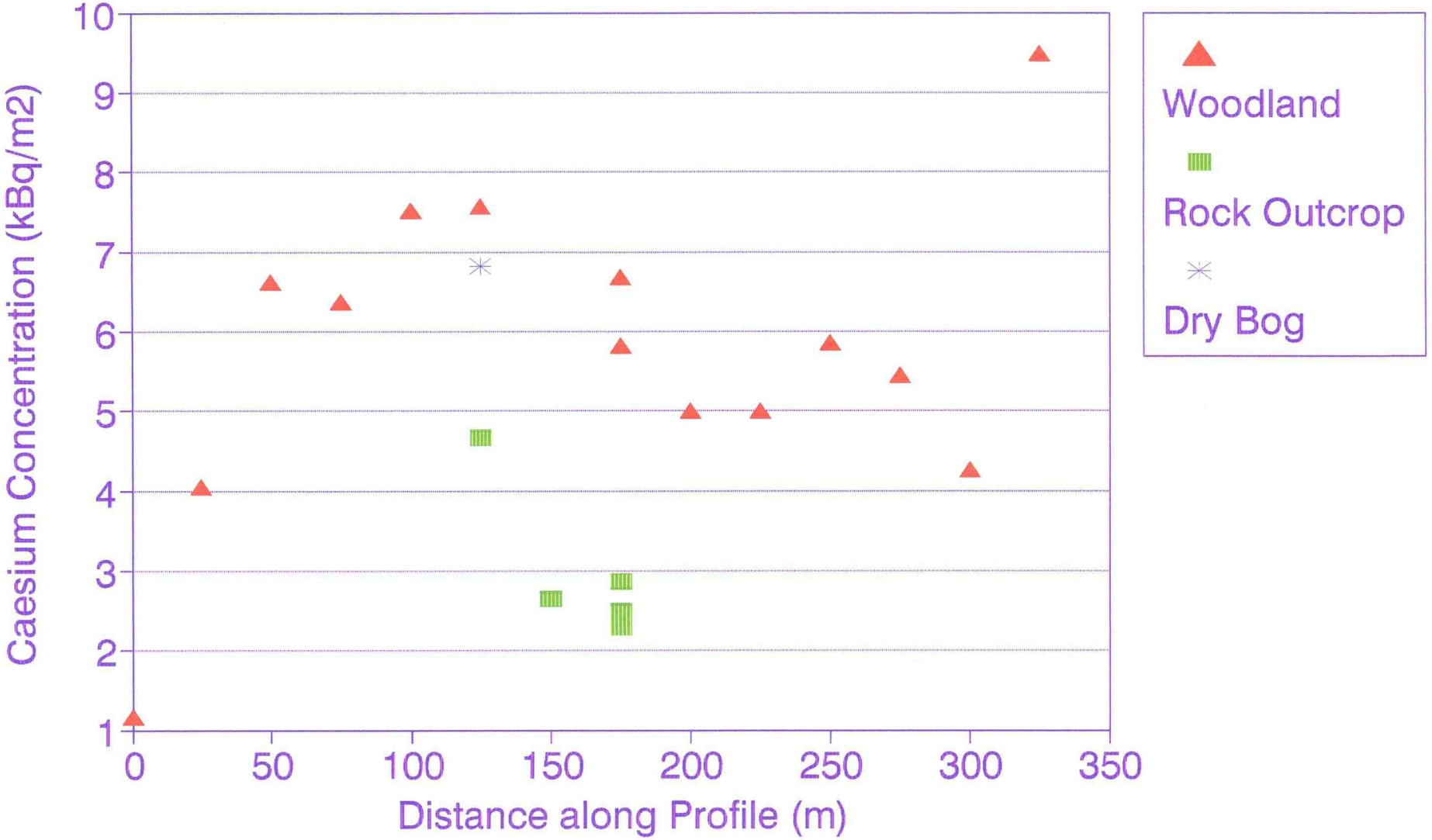

Figure 5 Results from Profile 2

6. FACTORS AFFECTING THE DISTRIBUTION OF RADIOCESIUM

It is immediately obvious that levels of ^{137}Cs show great variation in concentrations, even over the space of a few metres (Figs. 4 & 5). A general correlation was noted in both profiles between the ^{137}Cs concentration and the nature of the terrain, with the highest concentrations occuring in areas of dry and/or vegetated peat. Bare rock out-crops yielded the lowest cesium concentrations. The generally lower values obtained over wet peat must be treated with caution as the presence of water attenuates or 'damps' the Gamma-ray spectra and these lower values could be an artifact of signal 'damping' rather than lower ^{137}Cs concentrations. Indeed at one locality (locality 4, profile 1, Fig.4) higher values were recorded for damp peat than for the dry peat!

Other studies (Schimmack & Bunzl 1992, Salbu et al. 1992, Gerzabek et al. 1992) have also noted correlations between radiocesium concentrations and ground conditions. The concentration of ^{137}Cs in soils is dependent on a number of factors including the composition and extent of soil cover, the nature of the vegetation, topography and atmospheric effects (McGee et al. 1992).

6.1 *Soil Composition.*

Gerbzabek et al. (1992) noted that the composition of the soil has an important effect on the availibility of cesium (ie. how readily it is released to plants). In a study of two different soil types in Austria, they found that increasing organic matter in the silt fraction of soils yielded a corresponding increase in the ratio of ^{137}Cs activity to total activity in the soil. The soils with a higher organic silt content also yielded the highest ^{137}Cs soil-to-plant transfer factors. Therefore radiocesium transfer from soil-to-plants was faster in organic-rich soils.

6.2 *Nature of vegetation.*

In general the cesium availibility to plants increases with time (Salbu et al. 1992), indicating a higher degree of root uptake and a reduction in surface contamination of soil. This yields a corresponding decrease in cesium availibility in soils (Schimmack & Bunzl 1992). However the residence time of cesium in soils also varies according to the nature of the vegetation. Schimmack and Bunzl (1992) report Chernobyl-derived radiocesium in soils

under spruce having a residence time of 15 years and Chernobyl-derived radiocesium in soils under pine having a residence time of 4 years. In organic layers of soil the residence half-time was found to be approximately 4-6 years. However, radionuclide mobility tends to be much higher in peatlands, such as that at Fundaunn, with enhanced bioavailability under acidic conditions, where mineral content is low (Sanchez et al. 1988, Frissel et al. 1990). Investigations of cesium bioavailibility in peatlands (Cremers et al. 1990) show enhanced plant uptake under these conditions. Therefore cesium in peatland tends to be transferred to plants at higher rates than in other soil types, with corresponding implications for the measured concentrations.

6.3 *Migration of cesium.*

One other factor that must be taken into account is the possibility of vertical and lateral migration of cesium within the soil. Obviously, if any cesium present in the soil has migrated to below the root zone it is not available for plant uptake, remains in the soil for considerably longer and is therefore not part of the food-chain. Results from western Norway (Selnaes & Strand 1992) indicate that vertical migration of cesium is very slow, with some 85% of Chernobyl radiocesium fallout still present in the upper 5cm of soil, though this result is of course applicable only to the soils studied. However it is noteworthy that Beckmann and Faas (1992) reported similar values from Lower Saxony in Germany, with some 60% of Chernobyl-derived radiocesium still present in the top 2cm of soil in January 1989, almost three years after the accident at Chernobyl. Bergman et al. (1991) have studied the effects of lateral migration of radiocesium in peatland in Sweden and report that although leakage by run-off from the peat bog in 1986 was 7%, this declined in subsequent years to about 0.2%. They attribute the higher value for the first year to the melting of snow that had covered the area at the time of the Chernobyl cesium deposition. The results for subsequent years indicate that lateral migration is very slow and that depletion of cesium in peat soils will take several years.

Therefore the general correlation noted in this study between the ^{137}Cs concentration and the nature of the terrain may possibly to be related to the presence of organic layers within the peat, plant-uptake of cesium from the soil and the presence or absence of vegetation. However ascertaining whether this is or is not the case lies outside the expertise

of these authors. Evaluating the relative roles of all the above parameters, and possibly others that we are not aware of, requires the co-operation of soil-scientists, botanists, hydrogeologists and isotope geologists and chemists. We would like to point out, however, the area has great potential for a truly multi-disciplinary approach to the problem of the occurence and mobility of ^{137}Cs in a natural ecosystem.

7. CONCLUSIONS AND RECOMMENDATIONS

1. The Airborne total-count map has contains an anomaly that is not evident in the Uranium, Thorium and Potassium windows. However, the production of a ^{137}Cs map has indicated that the source is cesium.

2. Preliminary ground-based measurements carried out with a portable Gamma-ray spectrometer confirm that anomalous concentrations of cesium are present in the vicinity of this anomaly.

3. There seems to be a correlation in the ground-based measurements between the nature of the terrain and the ^{137}Cs concentration, with the highest ^{137}Cs concentrations occuring in areas of dry or vegetated peat. However, given the limited nature of the survey, this conclusion must await verification by a more detailed study. However it is possible that this increase in measured ^{137}Cs could be due to the concentration of cesium in organic peat layers and in plants, due to its higher bioavailability in the peat.

4. There is an urgent need for further work to be done in this area to constrain the precise occurence of the cesium. This work would involve:

a. A more complete programme of ground-based measurements, with repeat measurements taken at 'base stations' to try to better constrain the temporal and spatial variations in the levels of cesium.

b. The collection of peat cores, soil samples and plant samples at various topographic levels and at various levels within the bog with a view to the laboratory measurement of the ^{137}Cs content. This would yield further information as to whether the anomalous cesium levels within the bog can be related to the soil type, the nature of vegetation, topography or other factors.

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9. APPENDIX A.

Calibration constants used in calculating n(kk), n(ThTh) & n(UU) (section 4.2, Equations 1,2,3 & 4):

α= 0.53 ß= 0.58

τ= 0.98 g= 0.10

a= 0.05 b= 0.004

Calibration constants for calculating the stripping ratios of potassium, Thorium and Uranium into Cesium (respectively). These are then used to calculate ^{137}Cs concentrations (section 4.2, Equation 5.):

Cs/k= 0.48

Cs/Th= 2.22

Cs/U= 3.44