Strålevern Rapport 2006:10

Terrestrial Monitoring in Øvre Dividalen

Statens strålevern

Norwegian Radiation Protection Authority
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Key words:
Øvre Dividalen, terrestrial, soil, vegetation, animals.

Abstract:
This report details the monitoring of radioactivity by the Norwegian Radiation Protection Authority in Øvre Dividalen. Results indicate that the contamination with anthropogenic radionuclides is currently low. Estimates of dose rates from ^{137}Cs are made for reindeer, willow ptarmigan and voles.

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Emneord:
Øvre Dividalen, terrestrisk, jord, vegetasjon, dyr.

Resymé:
Denne rapporten beskriver resultater fra Strålevernets overvåkning av radioaktiv forurensning i Øvre Dividalen. Resultatene viser at de nåværende konsentrasjonene av menneskeskapt radionuklider er lave. Doserater fra ^{137}Cs er beregnet på rein, rype og jordrotter.

Head of project: Tone Bergan.
Approved:

Per Strand, Director, Department for Emergency Preparedness and Environmental Radioactivity.

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Terrestrial Monitoring in Øvre Dividalen

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Norwegian Radiation
Protection Authority
Østerås, 2006

Contents

1 Introduction

The Norwegian terrestrial environment has been affected by the fallout of artificial radionuclides from atmospheric nuclear weapons testing in the 1950-60's and from the Chernobyl accident in 1986. The Norwegian Radiation Protection Authority (NRPA) carries out monitoring of the concentrations of radionuclides in the marine and terrestrial environments and of radiation doses to the population and biota. The terrestrial monitoring program includes regular monitoring of food products, farm and wild animals, freshwater fish, soil and vegetation across Norway, including Svalbard and Jan Mayen.

This report describes and characterises a new terrestrial monitoring site that was established in northern Norway in 2004 as part of NRPA's terrestrial monitoring programme. The results of the initial sampling carried out in 2004 reported here provide a comprehensive baseline for future monitoring efforts. The relatively large number of soil analyses characterise the spatial distribution and variability of radionuclides in the surface soil. In addition, the analysis of vegetation, animal faeces and water samples provide information on the behaviour and transfer of radionuclides through the terrestrial system.

The site is located in the same area as one of seven terrestrial monitoring sites in Norway that were set up by the Norwegian Directorate for Nature Management (DN) in order to monitor possible impacts of long-range air pollution in northern boreal and alpine ecosystems. At these sites, regular bird and small mammal population surveys are combined with chemical analyses of vegetation. The co-location of these monitoring sites allows for the integration of future monitoring efforts as well as improved interpretation and correlation of the results.

2 Regional background

2.1 Dividalen National Park

Øvre Dividalen national park is located in the municipality of Målselv in the eastern part of Troms along the Swedish border (Figure 1). The national park, which has an area of 750 km^2, was established in 1971 and includes the upper reaches of Divielva and the surrounding mountain areas up to the Swedish border. The park represents a typical northern Norwegian inland mountain landscape with steep high mountains of up to 1700 m, deep ravines, open plateaus, pine and birch forest, bogs and lakes. The valleys are covered with old growth pine and birch forest while a varied geology supports a rich alpine flora on the high mountain plateaus. The national park has a rich variety of animal life and is an important habitat for predators such as the lynx (*Lynx lynx*).

The climate in the area is sub-continental with mean temperatures (between 1961 and 1990) in the coldest (January) and warmest (July) months of -9.4°C and 12.8°C, respectively (Aune, 1993). The mean annual precipitation over the same period was 282 mm at the meteorological station in Dividalen (Førland, 1993).

2.2 Geology and geomorphology

The bedrock geology in the Dividal area can be divided into three main groups (e.g. Møller, 2004) (Figure 2). The basement rocks, which are mostly present in the upper parts of the Dividalen valley and towards the Swedish border, are of Precambrian age (ca 1700 million years old) and are characterized by red granites and banded gneiss. The Precambrian basement is overlain by several hundreds of meters thick layers of Precambrian-Cambrian (ca 600 million years) sedimentary rocks (Dividal Group), which were deposited directly on top of the basement in a period when the region was below sea level. The Dividal Group consists of often strongly deformed conglomerate,

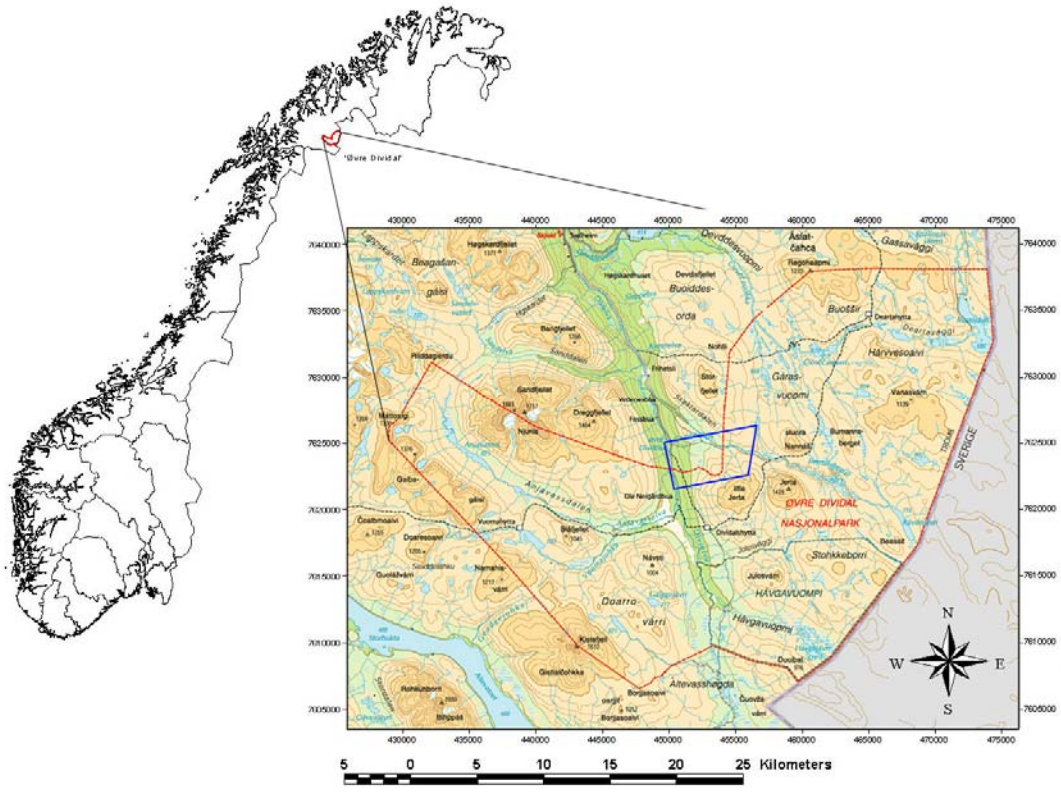


Figure 1. Location of Øvre Dividalen national park (red outline) and study area (blue outline). Grid coordinates in UTM 34W.

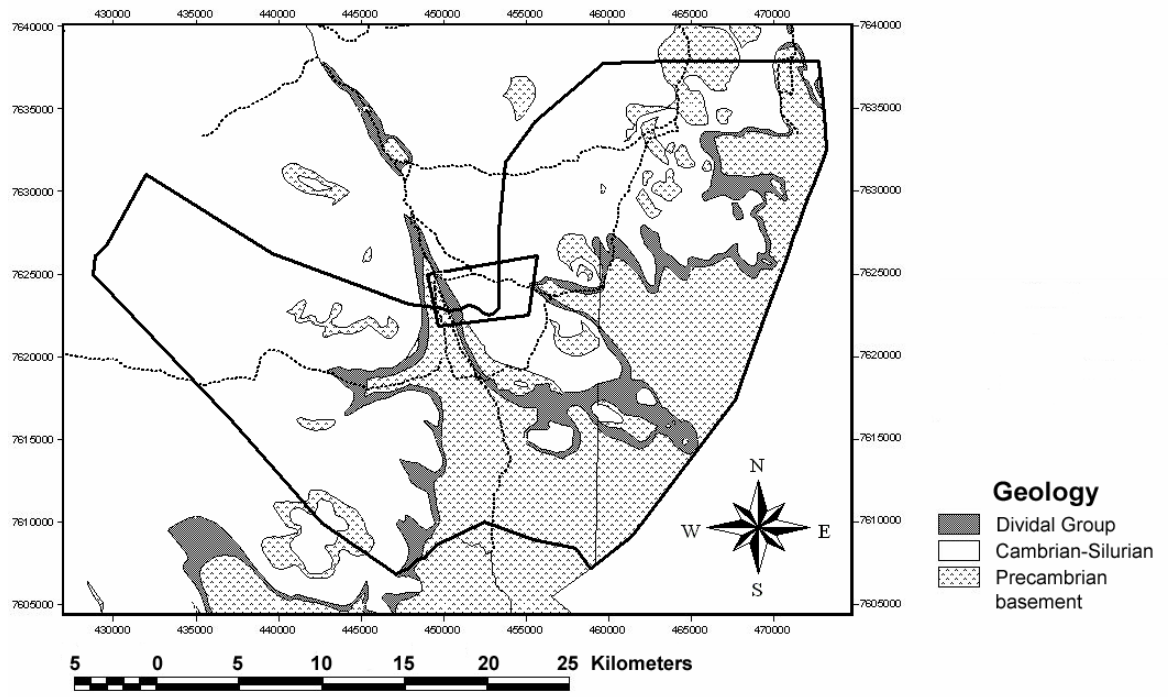


Figure 2. Simplified geological map of Dividalen. Grid coordinates in UTM 34W.

sandstone, slate and minor limestone and can be found mostly in the steep valley sides of Dividalen. While soil formed on the Precambrian basement rocks is acidic and nutrient-poor, soil formed on Dividal Group rock types is typically nutrient-rich. The rock layers that overlie the Dividal Group are Cambrian-Silurian (600-400 million years) metamorphic rocks, which consist mainly of schist, gneiss, quartzite and amphibolite. These rocks were placed on top of the Dividal Group during the Caledonian deformation event ca 400 million years ago when North America-Greenland collided with Scandinavia and now form the highest mountain tops in the region.

The current landscape has been shaped by several periods of glacial activity with typical glacial U-shaped valleys, narrow gorges and glacial deposits such as Quaternary glacial river deposits and moraines covering most of the area. Most of the Quaternary glacial sediments were presumably deposited during the melting of the last land ice, 9000-8500 years ago (Møller, 2004).

2.3 Vegetation

The area can be divided into three main regions: the boreal forest zone is found in the valleys up to 700 m elevation, the low-alpine zone with extensive mountain plateaus between 700 m and 1100 m and the middle- to high-alpine zone above 1100 m (Vorren, 1974). The boreal zone includes open pine or mixed pine/birch forest with an undergrowth of mainly heather, moss and lichen species in the valleys up to ca 450 m (open pine forest, heather pine forest). At higher elevations, on the steeper sides of the valleys, the area is dominated by birch forest with dwarf birch (*Betula nana*) and heather and moss species on nutrient poor substrates (crowberry/birch forest) and downy birch (*Betula pubescens*) with an undergrowth of heather, fern and moss species on the more nutrient rich substrates (blueberry/birch forest). In the wetter parts of the boreal zone, peat bogs are dominated by willow (*Salix* sp.), heather and moss species (birch swamp, nutrient poor swamp) or grass and sedge species (grassy swamp). More open vegetation types such as those dominated by dwarf birch, willow and heather species (dwarf birch mountain heath) and by heather and sedge species

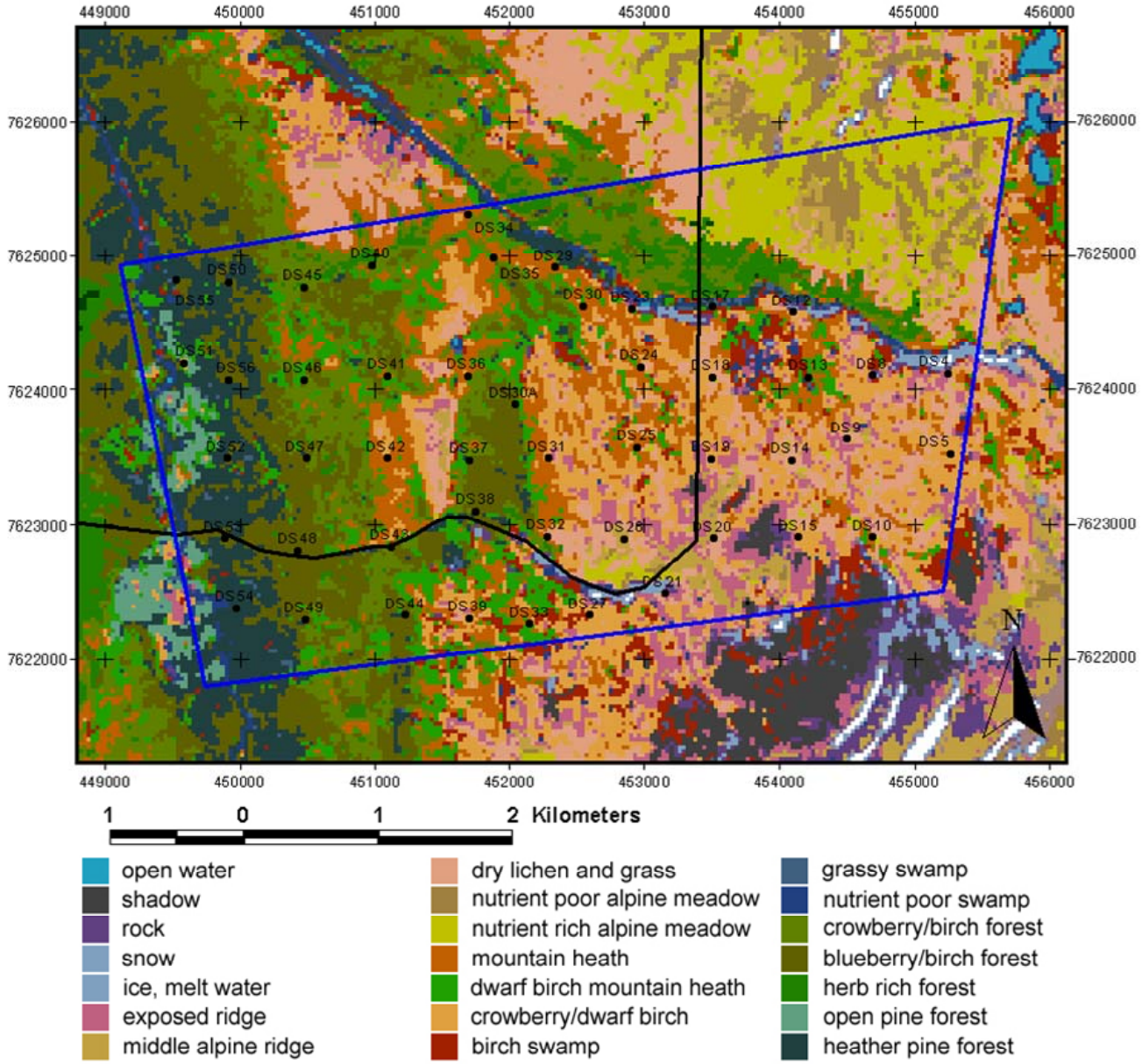


Figure 3. Extract of the vegetation map by Johansen et al. (1995) showing the vegetation types in and around the study area (study area boundary in blue, national park boundary in black). The map is based on Landsat satellite imagery. Grid coordinates in UTM 34W.

(mountain heath) are present both in the boreal zone and in the low-alpine zone. Other vegetation types present in the low-alpine zone are mountain heaths with dwarf birch and crowberry (*Empetrium nigrum*; crowberry/dwarf birch) and mountain meadows with grasses and herbs (dry lichen and grass). Exposed mountain ridges in the middle-alpine zone are dominated by high alpine grass and sedge species (exposed ridge).

2.4 Animals

Dividalen national park has a rich variety of animal life with most of Norway's large mammals present. The area has resident populations of Scandanavian brown bear (*Ursus arctos*), European lynx (*Lynx lynx*), wolverine (*Gulo gulo*), red fox (*Vulpes vulpes*) and arctic fox (*Alopex lagopus*), while both moose (*Alces alces*) and Norwegian reindeer (*Rangifer tarandus tarandus*) graze in the area during the summer months. Brown bears spend most of their time

in the forest area, while lynx, wolverine and fox can be found both in the forest as well as higher up in the mountains. Reindeer grazing in the Dividalen area during the summer months belong to Swedish reindeer herders; the Norwegian reindeer herders from Senja, who have been allocated Dividalen as their winter pastures, have not used the area in recent years. Additionally, Dividalen contains resident populations of several species of rodents, in particular arctic hare (*Lepus timidus*), the northern red-backed vole (*Clethrionumys rutilus*), grey red-backed vole (*C. rufocanus*), and field voles (*Microtus agrestis*) (Kålås and Framstad, 2001). The population of willow ptarmigan (*Lagopus lagopus*) was 37 individuals per km^2 in 2000 (Kålås and Framstad, 2001), an increase compared to 1999, while a strong reduction in the number of passerine birds was observed in 2000 compared to 1999. Common passerine birds in Dividalen include the willow warbler (*Phylloscopus trochylus*), brambling (*Fringilla montifringilla*), meadow pipit (*Anthus pratensis*), redwing (*Turdus iliacus*) and redstart (*Phoenicurus phoenicurus*) (Kålås and Framstad, 2001).

2.5 TOV program

Øvre Dividalen is the location of one of the Norwegian Directorate for Nature Management (DN) terrestrial monitoring areas (TOV area). The terrestrial monitoring program was established by the Norwegian Institute for Nature Research (NINA) in 1990 in order to monitor the possible effects of atmospheric contaminants on flora and fauna (Framstad and Kålås, 2001). The program is based on integrated monitoring in seven permanent TOV areas throughout Norway; the TOV area in Øvre Dividalen, which was established in 1993, is currently the only TOV area in northern Norway. The integrated monitoring includes analyses of contaminants in precipitation and in selected organisms, soil mineral contents, changes in vegetation communities and in population sizes of birds and small mammals. The work is carried out by NINA in cooperation with Statskog.

2.6 Sources of radionuclides

The main sources of anthropogenic radionuclide contamination in the Dividal area are fallout from nuclear weapons testing in the 1950's-1960's and fallout from the Chernobyl accident in 1986. These sources are extensively described in a number of publications, for example AMAP (1997, 2002), UNSCEAR (2000) and Gwynn *et al.* (2004). For the 60-70° northern hemisphere latitude band, UNSCEAR (2000) reported mean integrated deposition densities as result of atmospheric weapons testing of 1740 Bq/m^2 for ^{90}Sr, from which mean integrated deposition densities of 2650 Bq/m^2 for ^{137}Cs and 30 Bq/m^2 for $^{239+240}Pu$ can be derived using the reported relative quantities of the dispersed radionuclides. Wright *et al.* (1999) estimated the ^{137}Cs and ^{90}Sr deposition in December 1985 in the eastern part of Troms at 1920-2200 Bq/m^2 and 1200-1370 Bq/m^2, respectively. The data is based on the predicted spatial distribution of ^{137}Cs deposition in the Arctic which was derived from combining the spatial variability of the annual precipitation with a known relationship between deposition and precipitation as measured at the Norwegian Meteorological Institute in Tromsø. Deposition from the Chernobyl accident in eastern Troms is poorly constrained with an estimated range of 0-5000 Bq/m^2 (Strålevern Info 5:01), or 1000-10000 Bq/m^2 (AMAP, 1997). A report on the long term consequences of potential radioactive contamination in the northern areas by the Joint Russian-Norwegian Expert Group (JRNEG, 2002) reported deposition values of 350-3120 Bq/m^2 in the county Troms for 1998, of which the measured deposition values in natural pastures, ranging between 770-3120 Bq/m^2, were higher than those for cultivated fields, which varied between 350-900 Bq/m^2.

2.7 Previous work

Previous work that was carried out in Øvre Dividalen includes the population monitoring of, and the analysis of metals, ^{137}Cs and organic contaminants in arctic fox, arctic hare, small rodents, and willow ptarmigan (Kålås *et al.*, 1994). In addition, the populations of passerine

Table 1. Average and range (in parentheses) of ^{137}Cs concentration (Bq/kg d.w.) reported in different vegetation types from Dividalen (Gaare, 1994) and from Troms (JRNEG, 2002).

Vegetation	Dividalen (1993) ^{137}Cs	Troms (1998) ^{137}Cs
Herbs	59 (42 - 111)	127 (21 - 387)
Grasses/sedges	65 (45 - 78)	120 (72 - 159)
Shrubs	41 (13 - 144)	77 (29 - 116)
Mosses	92 (41 - 155)	-
Lichens	116 (95 - 137)	68

birds were monitored and the concentrations of ^{137}Cs and metals in vegetation, in particular reindeer fodder, were analysed (Gaare, 1994). Other data relevant to the current study are presented in the JRNEG (2002) report. This report discusses the results of soil, vegetation and food analyses from the counties Troms and Finnmark, and although none of the samples were taken from the immediate vicinity of the Dividalen area, the results provide a regional context for the data discussed in the current report.

Table 1 summarises both the 1993 ^{137}Cs concentrations in vegetation reported by Gaare (1994) as well as the 1998 data compiled for Troms (JRNEG, 2002) per vegetation type. Some of the variation in concentrations between the two reports is the result of different species sampled.

Table 2. Average (±SD) ^{137}Cs concentrations (Bq/kg d.w.) in individual species of vegetation from Dividalen in 1993 (Gaare, 1994).

Species	n	^{137}Cs
Herbs		
Solidago virgaurea	2	111 ± 56
Vaccinium myrtillus	6	42 ± 79
Grasses/sedges		
Deschampsia flexuosa	2	45 ± 67
Shrubs		
Betula nana	5	31 ± 44
Salix glauca	6	53 ± 31
Mosses		
Hylocomium splendens[1]	6	41 ± 36
Hylocomium splendens[2]	6	46 ± 34
Lichens		
Cladonia rangiferina[3]	2	137 ± 38
Cladonia rangiferina[4]	2	95 ± 9

1. Older than last year's shoots; 2. last year's shoots; 3. living parts and 4. dead parts of the plant.

The concentrations measured in Dividalen in 1993 are lower than the average concentrations in Troms, apart from the concentrations in lichen. The results for some of the individual species, those that were also analysed in the current study, are summarized in Table 2. Cs-137 activity concentrations of these species ranged from 31-137 Bq/kg dry weight (d.w.) with the highest concentrations found in lichen species and in the flowering plant golden rod (*Solidago virgaurea*).In addition, 2-5 samples of the grey red-backed vole, willow ptarmigan, and arctic hare were analysed for ^{137}Cs (Table 3). Cs-137 concentrations range from 70-150 Bq/kg d.w. with willow ptarmigan showing the lowest concentration and grey red-backed vole the highest.

Table 3. Average (±SD) ^{137}Cs concentrations (Bq/kg d.w.) in small animals from Dividalen (Kålås et al., 1994).

Species	no	^{137}Cs
Grey red-backed vole	2	150 ± 70
Willow ptarmigan	5	70 ± 7
Arctic hare	3	100 ± 13

3 Methods

3.1 Sample area

The study area is situated in the south-eastern part of Dividalen, approximately between Hagembekken and Skakterelva, and from Divielva up towards Litle Jerta (68°42'N-68°44'N, 19°45'E-19°54'E) (figure 1). This is immediately adjacent to one of the seven TOV areas (see 1.5) where NINA carries out monitoring of small rodents, vegetation and soil (Figure 1). The area has an elevation between ca 200 m and 1000 m and a surface area of ca 20 km^2 and currently lies on and outside the border of Øvre Dividalen national park. However, the regional government has recently recommended that the park should be extended by an extra 30 km^2 to include Skakterdalen, and the study area may thus reside entirely within the park boundaries in the future. The site comprises the full range of vegetation communities that are present in the national park, from pine- and birch forests in the valleys (northern boreal forest), low-alpine heather and moorlands, to high-alpine vegetation (Figure 3). The treeline lies at an elevation of ca 600 m. Sampling was carried out in August 2004.

3.2 Sampling and handling

3.2.1 Soil Sampling

A regular grid across the sampling area, with a spacing of 600 m between sample sites, was used as a guideline for the choice of sampling locations in the field. In the field, the majority of soil samples were taken within 50 m of the guideline grid sites although some soil samples were taken at greater distances (up to 250 m) due to terrain difficulties (Figure 4). All soil sample locations were recorded by GPS, with an accuracy of <10 m. A total of 48 surface soil samples were obtained across the sampling area. Surface soil samples, including surface vegetation, were taken by using a heavy plastic tube with a diameter of 7 cm and a length of about 30 cm (Figure 5). The tubes were hammered into the soil with a plastic mallet and a wooden cover over the tubes and each soil sample with its surface vegetation was subsequently packed in a polyethylene ziplock bag and labelled. The soil cores varied in length between 10 and 22 cm. The length of the soil core was determined by measuring the depth of the core hole and the thickness of the surface vegetation. All soil samples were frozen immediately after arrival back in Tromsø.

In order to determine the approximate depth of the bedrock at each sampling location, a 1 m long metal rod was hammered as far as possible into the ground and the above-ground length was measured at 3 points at each sampling location.

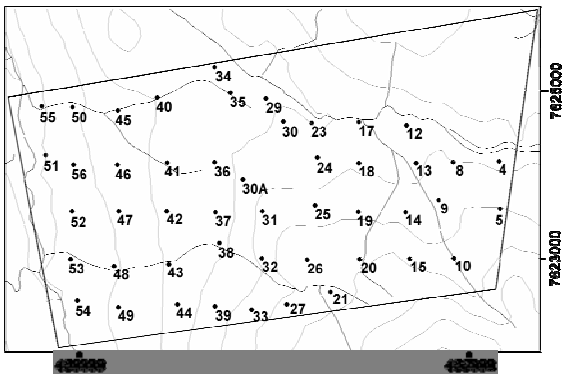


Figure 4. Actual sampling locations.

Figure 5. Soil sampling.

3.2.2 Vegetation Sampling

Vegetation samples were collected throughout the whole area, but always within 20 m of a soil sampling location for which GPS coordinates were recorded. A total of 48 samples were collected, of which 4 samples of berries, 2 samples of fungi, and 42 samples of other vegetation. The 13 species sampled (2 lichen, 1 moss, 3 grass/sedge, 3 herb, 2 shrub and 2

fungus species) are all common to the area and many of the species were sampled at more than one location. The species sampled were selected such that they represented the range of different vegetation types common to the area and included several species that were sampled and analysed for ^{137}Cs previously (Section 1.7; Gaare, 1994). Most species were identified in the field, but digital photographs were taken of all species to confirm and aid identification of unknown species. Figures 6a-c show some examples of the vegetation sampled.

Sampling was carried out by hand and care was taken to limit each sample to a single species. Apart from the shrub species (*S. glauca/lapponum* and *B. nana*), the whole plant, including the root system was sampled. For shrub species, only the above ground parts (branches, leaves and flowers) were sampled using garden clippers. Each sample represents a bulked collection of several individual plants. The fungi samples were packed in a paper bag and were processed (dried and ground) immediately after identification back in Tromsø. Berries were packed in plastic M-geometries, whilst all other vegetation samples were bagged in polyethylene ziplock bags and labelled. The samples were frozen immediately after arrival back in Tromsø.

3.2.3 Sampling of animal faeces

Sampling of animal faeces was carried out in an opportunistic fashion. Faeces of 5 different animal species were collected: moose, reindeer, willow ptarmigan, fox or wolverine, and small rodent (species unknown). Apart from the small rodent faeces, all faeces samples represent the faeces of an individual animal. Samples were collected by hand and bagged in polyethylene ziplock bags. The samples were labelled, the positions recorded and digital photographs were taken.

Figure 6a. Hylocomium splendens.

Figure 6b. Lactarius rufus.

Figure 6c. Solidago virgaurea.

3.2.4 Water sampling

Water samples were taken from the two main rivers that flow through the sample area, Divielva and Skakterelva, although the actual water sampling locations were both outside the sample area due to difficulties in accessing the rivers within the sampling area. At each location 200 l of water was taken using a bucket and 8 x 25 l plastic water cans. The water was not filtered on site. The cans were labelled and the position of the sampling locations recorded.

3.3 Sample preparation

Soil, faeces and vegetation samples were dried at 105°C in a fan-assisted oven for a period of 24 hours or more to constant mass. All dried samples were homogenised using a stainless steel laboratory blender, sieved through a stainless steel sieve of 2 mm aperture size and packed to defined fill heights in standardised counting geometries of volumes between 14 - 550 ml in both simple cylinder and Marinelli configurations.

3.4 Analysis

Gamma analysis was conducted on terrestrial samples for the measurement of gamma emitting isotopes including ^{137}Cs, ^{40}K, U and Th isotopes. The detection system used was an electrically cooled p-type coaxial high purity germanium detector constructed of low background materials. Nominal resolution and efficiency of the system was 1.9 keV at 1332 keV and 40 %. The detector was connected to an Inspector 2000 (Canberra) MCA (8k channels) utilising Genie 2000. Spectra were obtained between 50 and 2000 keV for periods between 24 and 72 hours and were corrected for a laboratory background counted for 3 months. The detector was calibrated using internationally traceable standard single isotope solutions for each geometry in an aqueous matrix. Differences between the calibration source and the samples, with respect to both density and composition, were corrected for via the calculation of efficiency correction factors using GammaTool (AEA Technology) with attenuation coefficients taken from Hubbell (1982). The system is subject to the normal QA procedures of the laboratory, involving participation in international and national intercomparisons with sample batches containing splits, duplicates, blanks and spikes. Cs-137 was determined from its characteristic emission at 661 keV, ^{40}K via 1461 keV.

3.4.1 Cs-137: Analysis in water

The low level of ^{137}Cs in water necessitates a pre-concentration step to obtain a detectable analytical signal. This was achieved using cotton filters impregnated with a copper hexacyanoferrate, as a Cs selective exchange resin. 200 l of water was pumped at a speed of ca 5 l per minute over one clean filter and two impregnated filters in series. These filters were then air dried and ashed. The ash from each filter was then packed into standard fill height geometries and counted as for solid samples.

3.4.2 Pu and Am: Analysis

Concentrations of ^{238}Pu, $^{239+240}$Pu and ^{241}Am were determined using alpha spectrometry. Samples consisted of ca 10 g of dried soil. Recovery was determined by using ^{242}Pu and ^{243}Am as yield tracers. Different radiochemical separation techniques were applied to separate plutonium and americium from other nuclides using solvent extraction with 10% TIOA/xylene solution and ion-exchange chromatography with a BIO-RAD AG1-X4 (100 – 200 mesh) column. Purified plutonium and americium fractions were then electroplated onto stainless steel planchettes and counted on semiconductor silicon detectors. As the resolution of such detectors is insufficient to resolve emissions from ^{239}Pu and ^{240}Pu, these nuclides are quoted as a single result.

4 Results

4.1 Cs-137 in soil

A total of 48 soil cores of between 10 and 22 cm in length were taken across the area. Fourteen of the cores showed little variation in the soil profile and were analysed as one sample. The remaining 34 cores were divided into 2 samples according to the different horizons present while 3 of these cores (13, 40, 54) had an additional distinguishable moss layer which was analysed separately. The soil cores were separated into an organic-rich surface layer (A-horizon), which often included a litter cap (O-horizon), of 1-10 cm thick, and the white/brown sandy soil or clay soil below this (B-horizon). The individual analyses were decay corrected for the sampling date and reported in Bq/kg d.w.. A mean integrated activity concentration per core is calculated by combining the individual analyses. Inventories or deposition density values, in Bq/m^2, were calculated by combining the individual analyses per soil core and using the fixed core diameter of 7 cm (core surface area of 0.0038 m^2). Results for soil samples are summarised in Table 4, with results for individual cores given in Table 6.

Cs-137 activity concentrations in individual samples (divided core sections and undivided core samples) ranged from <0.19 to 135 Bq/kg, while mean integrated ^{137}Cs activity concentrations in the cores ranged from 0.3 to 73 Bq/kg, with an average of 15 ± 15 Bq/kg (Table 5).

Of the soil cores that were divided into an organic-rich layer and a clay or sandy soil layer, the top organic rich layer was between 1 and 10 cm thick with an average thickness of 4 cm. Cs-137 activity concentrations in the organic-rich layers were higher than those in the underlying layer of clay or sandy soil. Cs-137 activity concentrations in the organic-rich layer ranged from 14.6 to 135 Bq/kg with an average of 61 ± 27 Bq/kg, while in the clay or sandy soil values varied between <0.19 and 31.2 Bq/kg, with an average of 4.9 ± 6.8 Bq/kg (Table 4). Undivided soil cores yielded ^{137}Cs activity concentrations between 3.1 and 73.2 Bq/kg, with an average of 24 ± 22 Bq/kg. Of these soil cores, those that consisted mostly of peat showed higher average activity concentrations than those that were mostly clay or sand, 48 ± 20 Bq/kg and 10.4 ± 6.9 Bq/kg, respectively. The observed accumulation of ^{137}Cs in top organic-rich layers and limited vertical mobility is consistent with results from other studies and has been attributed to fixation to clay minerals present in the organic layer or uptake by soil organisms (e.g. Kruyts *et al.*, 2004; Kruyts and Delvaux, 2002; Rühm *et al.*, 1999; Valcke and Cremers, 1994).

Table 4. Mean (±SD) and range of ^{137}Cs activity concentrations (Bq/kg d.w.) in soil cores.

	n	^{137}Cs (Bq/kg d.w.)	
		Mean ±SD	Range
Divided Cores			
Top	34	59.2 ± 28.5	14.6 - 135
Bottom	34	5.0 ± 6.8	<0.19 - 31.2
Undivided Cores			
All	14	23.7 ± 22.2	3.1 - 73.2
Peat	5	47.8 ± 19.5	27.5 – 73.2
Sand/ clay	9	10.4 ± 6.9	3.1 – 23.6

Figure 7 shows the results of the 3 cores with a moss top that was analysed separately. The results suggest an inverse relationship between the ^{137}Cs activity concentration in the moss cover and the top organic rich layer.

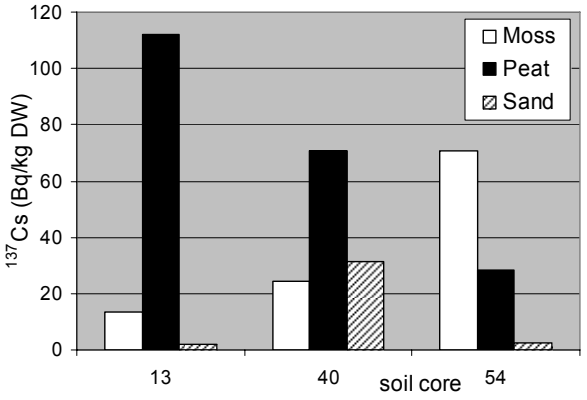
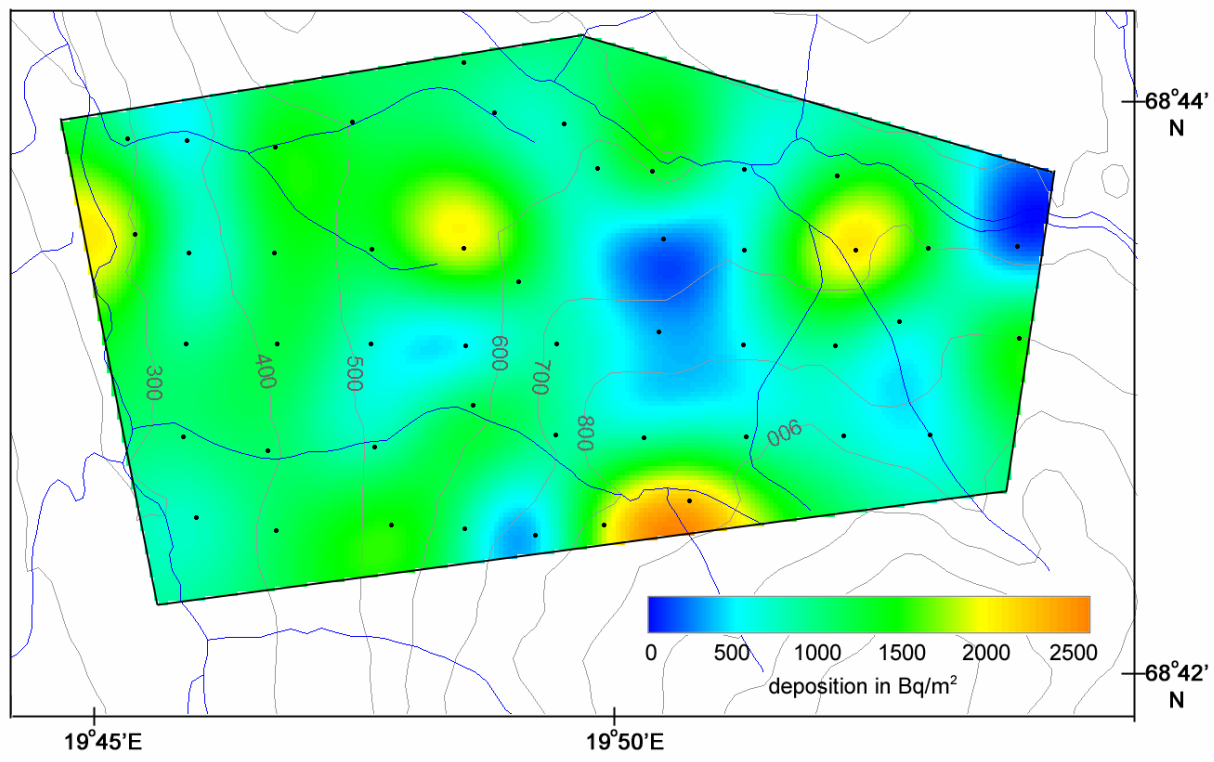


Figure 7. Distribution of ^{137}Cs in moss, organic and sand/clay layers in 3 soil cores.



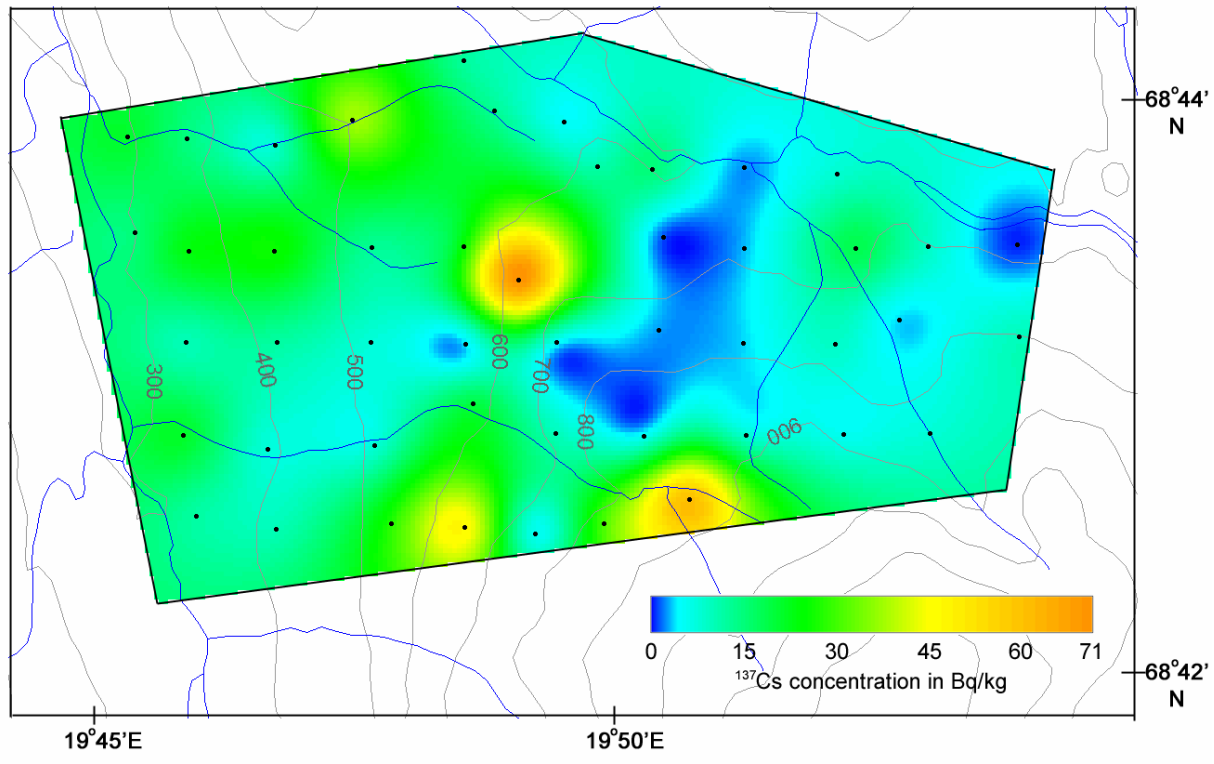


Figure 8. Interpolated ^{137}Cs soil deposition (Bq/m^2) and activity concentration (Bq/kg d.w.) maps of the study area. Black dots indicate soil sampling locations.

Calculated deposition density values for the study area ranged from 213 Bq/m^2 to 2325 Bq/m^2, with an average of 1025.5 ± 463.5 Bq/m^2 (Table 5). These values are well within the range of deposition values of 771-3119 Bq/m^2 for natural pastures in the county Troms in 1998, as reported by JRNEG (2002). Deposition and activity concentration values calculated for each of the 48 soil cores were subsequently interpolated using a regularised

Table 5. Details of individual cores, ^{137}Cs and ^{40}K activity concentrations (Bq/kg d.w.), intergrated mean ^{137}Cs activity concentrations per soil core (Bq/kg d.w.) and calculated deposition density (Bq/m^2).

Field ID	Depth (cm)	Description	^{40}K (Bq/kg d.w.)	^{137}Cs (Bq/kg d.w.)	Mean ^{137}Cs (Bq/kg d.w.)	Deposition (Bq/m^2)
DS4	0-2.5	brown sandy soil	913 ± 28	1.5 ± 0.1	0.3	930
	2.5-19	brown sandy soil	1078 ± 33	0.2 ± 0.1		
DS5	0-4.5	peat	539 ± 22	92.0 ± 3.0	10.0	1470
	4.5-19	clay	867 ± 26	2.5 ± 0.2		
DS8	0-4	litter/peat/clay	626 ± 25	82.5 ± 2.5	9.2	1279
	4-12	clay	741 ± 23	0.6 ± 0.1		
DS9	0-3.5	litter/peat/clay	522 ± 21	57.0 ± 1.7	3.8	735
	3.5-22	clay	836 ± 25	<0.2		
DS10	0-5	litter/peat	352 ± 14	29.3 ± 1.2	7.9	538
	5-17	clay	622 ± 19	1.9 ± 0.2		
DS12	0-2.5	litter/peat	654 ± 26	75.4 ± 2.3	8.2	1249
	2.5-18.5	loam	736 ± 22	0.5 ± 0.1		
DS13	0-1.5	moss	202 ± 39	13.4 ± 1.3	18.8	2166
	1.5-9	peat	282 ± 14	111.9 ± 3.3		
	9-19	grey sandy soil	898 ± 27	2.2 ± 0.1		
DS14	0-9	litter/peat/clay	496 ± 15	25.5 ± 0.8	9.2	924
	9-15.5	clay	796 ± 24	2.5 ± 0.2		
DS15	0-3.5	litter/peat/loam	316 ± 16	68.0 ± 2.7	5.7	713
	3.5-19	loam	893 ± 27	0.5 ± 0.1		
DS17	0-1.75	peat/brown sandy soil	807 ± 24	31.9 ± 1.3	2.5	606
	1.75-18	brown sandy soil	931 ± 28	0.5 ± 0.1		
DS18	0-2.5	litter/peat	698 ± 28	45.3 ± 1.8	3.2	643
	2.5-22	clay	887 ± 27	0.1 ± 0.1		
DS19	0-3	litter/clay	243 ± 15	47.3 ± 1.9	3.8	539
	3-16.5	clay	895 ± 27	0.6 ± 0.1		
DS20	0-1.5	peat/brown sandy soil	664 ± 20	63.8 ± 1.9	8.0	803
	1.5-13.5	brown sandy soil	916 ± 25	1.0 ± 0.1		
DS21	0-10	peat	547 ± 17	61.4 ± 1.8	61.4	2325

Table 5 continued.

Field ID	Depth (cm)	Description	^{40}K (Bq/kg d.w.)	^{137}Cs (Bq/kg d.w.)	Mean ^{137}Cs (Bq/kg d.w.)	Deposition (Bq/m^2)
DS23	0-3	litter/peat/loam	629 ± 25	101.3 ± 3.0	15.5	1438
	3-15	loam	741 ± 22	2.7 ± 0.2		
DS24	0-1	litter/peat	832 ± 33	14.6 ± 0.6	1.3	213
	1-14	clay	862 ± 26	0.5 ± 0.1		
DS25	0-2	litter/clay	175 ± 20	59.5 ± 2.4	2.9	383
	2-21	clay	757 ± 31	0.9 ± 0.1		
DS26	0-18	clay	925 ± 28	4.7 ± 0.2	4.7	798
DS27	0-16.5	peat/clay	775 ± 23	30.7 ± 0.9	30.7	1860
DS29	0-1.5	litter/peat	379 ± 19	67.0 ± 2.7	5.1	809
	1.5-13	brown sandy soils	922 ± 28	2.3 ± 0.1		
DS30	0-7.5	litter/peat	515 ± 21	34.8 ± 1.4	11.0	857
	7.5-19	clay	723 ± 22	1.9 ± 0.2		
DS30A	0-10.5	peat	215 ± 11	73.2 ± 2.2	73.2	1183
DS31	0-3	litter/peat	791 ± 24	45.4 ± 1.4	5.5	850
	3-16	clay/sandy soil	882 ± 27	0.5 ± 0.1		
DS32	0-14.5	litter/clay	658 ± 20	10.2 ± 0.4	10.2	920
DS33	0-13	loam	611 ± 19	5.2 ± 0.2	5.2	307
DS34	0-2	litter/peat	548 ± 22	60.8 ± 1.8	12.5	1062
	2-12.5	white sandy soil	887 ± 27	5.6 ± 0.2		
DS35	0-3	litter/ sandy soil	<56.9	31.0 ± 1.3	13.1	816
	3-10	brown sandy soil	992 ± 30	8.3 ± 0.4		
DS36	0-4	peat/white sandy soil	727 ± 22	30.5 ± 1.2	23.7	2024
	4-13.5	white sandy soil	1018 ± 31	22.0 ± 1.8		
DS37	0-15	clay/sandy soil	841 ± 26	3.1 ± 0.2	3.1	415
DS38	0-17.5	sandy soil	728 ± 22	19.4 ± 0.6	19.4	1195
DS39	0-12	litter/peat	67 ± 7	47.7 ± 1.4	47.7	914
DS40	0-2	moss	<334	24.4 ± 2.4	38.0	1175
	2-5	peat	238 ± 15	70.8 ± 2.1		
	5-10	white sandy soil	1054 ± 32	31.2 ± 0.9		

Table 5 continued.

Field ID	Depth (cm)	Description	^{40}K (Bq/kg d.w.)	^{137}Cs (Bq/kg d.w.)	Mean ^{137}Cs (Bq/kg d.w.)	Deposition (Bq/m^2)
DS41	0-2.5	litter/peat	818 ± 25	76.9 ± 2.3	13.0	1239
	2.5-15	white sandy soil	1154 ± 37	7.2 ± 0.3		
DS42	0-15	grey sandy soil	1030 ± 31	7.8 ± 0.3	7.8	695
DS43	0-3	litter/peat	111 ± 13	90.5 ± 2.7	7.4	804
	3-18.5	clay	916 ± 28	3.2 ± 0.2		
DS44	0-12	peat/white sandy soil	979 ± 30	27.5 ± 0.8	27.5	1532
DS45	0-2.5	litter/peat	622 ± 25	96.0 ± 2.9	8.1	1442
	2.5-18	white sandy soil	1067 ± 32	3.4 ± 0.2		
DS46	0-3	litter/peat	322 ± 23	134.9 ± 4.0	26.0	1301
	3-13	loam	848 ± 26	13.8 ± 0.6		
DS47	0-17	clay/sandy soil	847 ± 26	12.1 ± 0.5	12.1	1244
DS48	0-20	brown sandy soil	708 ± 21	7.6 ± 0.3	7.6	1096
DS49	0-4	peat/white sandy soil	480 ± 19	51.5 ± 1.6	10.2	1113
	4-10	white sandy soil	1111 ± 34	4.7 ± 0.2		
DS50	0-5.5	litter/peat	174 ± 14	55.4 ± 2.2	14.8	517
	5.5-15	loam	635 ± 19	3.0 ± 0.3		
DS51	0-4	peat/white sandy soil	354 ± 18	60.6 ± 2.4	15.0	1783
	4-16	white sandy soil	986 ± 30	10.7 ± 0.4		
DS52	0-3	peat/brown sandy soil	<71	64.8 ± 2.0	10.3	956
	3-17	Brown sandy soils	1030 ± 31	4.6 ± 0.2		
DS53	0-6	litter/peat	306 ± 16	48.4 ± 2.0	21.6	1017
	6-14	white sandy soil	692 ± 21	14.5 ± 0.6		
DS54	0-2	moss	<221	70.6 ± 2.8	12.0	743
	2-12	peat	423 ± 13	28.3 ± 0.8		
	12-18	white sandy soil	1139 ± 34	2.4 ± 0.2		
DS55	0-5	litter/peat	372 ± 19	72.6 ± 2.9	21.2	954
	5-14	white sandy soil	881 ± 27	8.9 ± 0.4		
DS56	0-16	litter/white sandy soil	912 ± 28	23.6 ± 1.0	23.6	650

Table 6. Pu-238, $^{239,240}Pu$, and ^{241}Am activity concentrations (Bq/kg d.w.) and $^{238}Pu/^{239,240}Pu$, $^{241}Am/^{239,240}Pu$, $^{239,240}Pu/^{137}Cs$ activity ratios in soil samples.

Field ID	Depth (cm)	^{238}Pu (Bq/kg d.w.)	$^{239,240}Pu$ (Bq/kg d.w.)	^{241}Am (Bq/kg d.w.)	$^{238}Pu/^{239+240}Pu$	$^{241}Am/^{239,240}Pu$	$^{239,240}Pu/^{137}Cs$
DS13	1.5-9 (peat)	0.047 ± 0.014	1.93 ± 0.16	NA	0.024	-	0.017
	9-19 (sand)	<0.004	0.03 ± 0.01	0.01 ± 0.01	-	0.55	0.012
DS14	0-9 (peat)	0.028 ± 0.010	0.89 ± 0.08	0.34 ± 0.04	0.032	0.38	0.035
	9-15.5 (clay)	<0.006	0.02 ± 0.02	0.03 ± 0.01	-	1.42	0.007
DS21	0-10 (peat)	0.031 ± 0.011	1.24 ± 0.11	0.47 ± 0.06	0.025	0.38	0.020
DS30A	0-10.5 (peat)	0.051 ± 0.015	1.94 ± 0.17	0.66 ± 0.07	0.026	0.34	0.027
DS36	0-4 (peat)	0.030 ± 0.010	0.84 ± 0.08	0.48 ± 0.05	0.036	0.56	0.028
	4-13.5 (sand)	<0.005	0.05 ± 0.01	0.03 ± 0.01	-	0.60	0.002
DS47	0-17 (clay)	0.005 ± 0.005	0.23 ± 0.03	0.09 ± 0.02	0.023	0.41	0.019
DS54	2-12 (peat)	0.029 ± 0.012	0.95 ± 0.10	0.39 ± 0.06	0.031	0.41	0.033
	12-18 (sand)	<0.002	0.02 ± 0.01	0.02 ± 0.01	-	1.16	0.007
DS56	0-16 (sand)	0.029 ± 0.011	0.76 ± 0.08	0.25 ± 0.04	0.037	0.32	0.032

spline with tension spatial interpolation method (Figure 8). This method is formally equivalent to the geostatistical method universal kriging (e.g. Cressie, 1993), but is a deterministic rather than a stochastic method. This means that it is based on a physical model with flexibility rather than statistical techniques. The tension parameter that determines the flexibility was chosen based on the minimization of the root mean square error estimated by cross-validation procedures. The measured spatial variability is likely to be the result of differences in soil type and chemistry or in the spatial distribution of the original fallout rather than the effect of topography or vegetation type.

4.2 Pu-238, ^{239,240}Pu and ^{241}Am in soil

Thirteen individual samples from eight soil cores were selected for further analysis of the levels of actinides in the soil. The samples were selected to represent both a range in ^{137}Cs deposition densities as well as a range in vegetation types. The results are summarized in Table 6.

Analyses of the 4 cores that were divided into an organic-rich top layer and a lower layer of clay or sand show that 83-96% of the ^{239,240}Pu and 82-90% of the ^{241}Am is contained in the top organic-rich layer. The activity concentrations in the soil range from 0.21 - 1.94 Bq/kg (with an average of 0.66 Bq/kg) for ^{239,240}Pu and from 0.09 – 0.66 Bq/kg (with an average of 0.26 Bq/kg) for ^{241}Am, which correspond to deposition values of 17.9 – 47.1 Bq/m^2 and 1.44 – 18.0 Bq/m^2, respectively.

This is in good agreement with the mean integrated deposition density of 30 Bq/m^2 for ^{239,240}Pu in the 60-70° latitude band reported by UNSCEAR (2000). The ^{238}Pu/^{239,240}Pu ratio is fairly constant with an average of 0.029, which indicates that the actinides originate dominantly from the global fallout from weapons testing. For those cores that were divided into an organic-rich top layer and a clay/sandy lower layer, the ^{241}Am/^{239,240}Pu ratio is higher and the ^{239,240}Pu/^{137}Cs ratio is considerably lower in the lower clay/sandy layer than in the top organic-rich layer. This is in agreement with other studies which reported that ^{239,240}Pu is more strongly associated with organic matter than ^{137}Cs (Bunzl *et al.*, 1998; Lee and Lee, 2000).

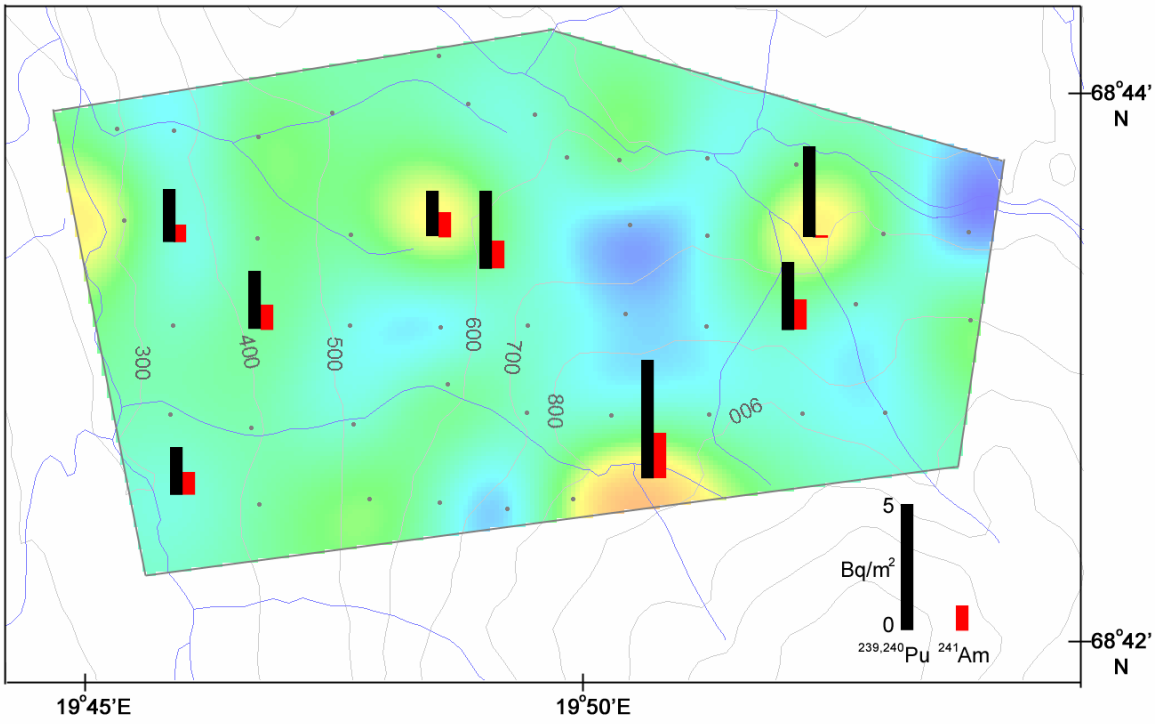


Figure 9. Pu-239,240 and ^{241}Am soil deposition density values (m^2/kg); For comparison, actinide values are superimposed over the ^{137}Cs soil deposition density map from Figure 7.

4.3 Cs-137 in vegetation

The vegetation that was sampled and analysed included 2 shrub, 3 herb, 3 grass/sedge, 2 moss, 3 lichen and 2 fungus species. In each case, the whole plant including the root system was sampled, with the exception (root systems not sampled) of the 2 shrub species (*S. glauca/lapponum* and *B. Nana*). Samples of these shrub species were sub-divided into woody material and leaves/buds, while samples of *Empetrium nigrum* were sub-divided into berries and remaining plant material. The individual analyses were decay corrected for the sampling date and reported in Bq/kg dry weight (d.w.). Results are summarized for each species and vegetation type in Table 7.

Figure 10 shows that grass/sedge, shrub, moss and herb species all contained typically low average ^{137}Cs activity concentrations of between 11 ± 6 and 27 ± 40 Bq/kg, with shrub and herb species displaying a higher variation between the individual species than grass/sedge and moss species. Lichen and fungus species contained considerably higher average concentrations of ^{137}Cs at 110 ± 86 and 288 ± 137 Bq/kg respectively, with large variations between specimens.

Cs-137 activity concentrations in grass and sedge species ranged from 2.9 Bq/kg to 24.6 Bq/kg with an average of 11 ± 6 Bq/kg. All grasses showed higher ^{137}Cs activity concentrations than sedges, with an average value for grasses of 13.4 ± 5.1 Bq/kg compared to an average value of 4.8 ± 1.8 Bq/kg for sedges. Cs-137 activity concentrations in shrub species ranged from 1.3 Bq/kg to 108.8 Bq/kg with an average of 20 ± 29 Bq/kg. In both *S. glauca/lapponum* and *B. Nana* ^{137}Cs activity concentrations were higher in leaves and buds compared to woody material (37.8 ± 48.3 and 18.0 ± 19.6 Bq/kg for *S. glauca/lapponum*, 6.6 ± 2.5 and 5.2 ± 2.3 Bq/kg for *B. nana*). Herb species yielded ^{137}Cs activity concentrations between 1.3 Bq/kg and 152.3 Bq/kg, with an average of 27 ± 40 Bq/kg. Berries from *E. nigrum* showed higher average ^{137}Cs activity concentrations than observed in the plant itself (leaves and woody material combined). Of all herb species sampled, the highest activity concentrations were observed in *S. virgaurea* (average concentration of 82.2 ± 62.8 Bq/kg), albeit with a high variation between individual samples. Moss species yielded ^{137}Cs activity concentrations of between 9.1 and 59.6 Bq/kg with an average of 23 ± 16 Bq/kg, while lichen species yielded higher concentrations ranging from 28.4 to 205.3 Bq/kg. However, large

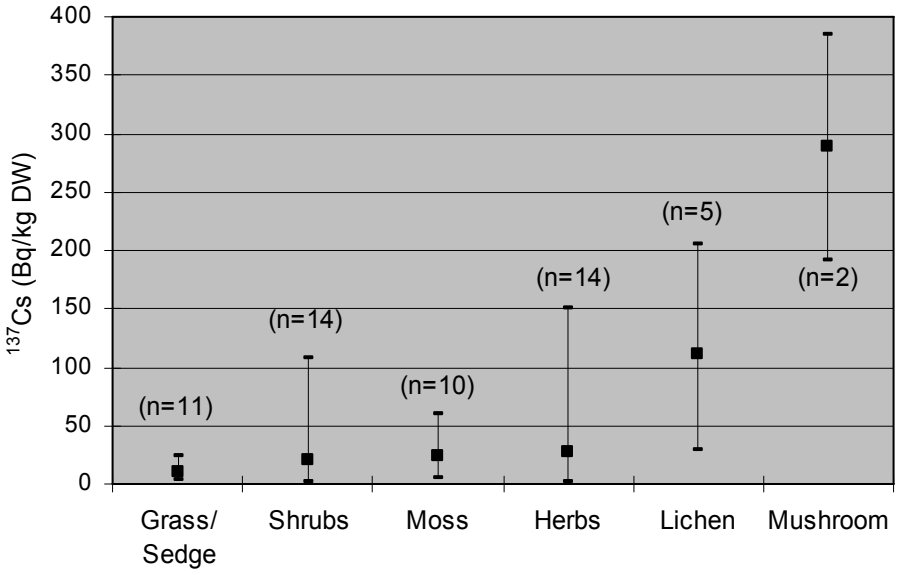


Figure 10. Mean ^{137}Cs activity concentrations (Bq/kg d.w.) in different vegetation types and concentration ranges of the individual specimens.

Table 7. Mean (±SD) and range of ^{137}Cs activity concentrations and mean Transfer Factor (TF) and Tag values for vegetation samples.

Species	Part	n	^{137}Cs (Bq/kg d.w.)		TF value (Bq kg^{-1}/Bq kg^{-1})	Tag value (m^2/kg d.w.)
			Mean ±SD	Range		
Shrubs						
Betula nana	Twigs	3	5.2 ± 2.3	3.1 - 7.6	8.6 ± 11.6	0.035 ± 0.041
Betula nana	Leaves	3	6.6 ± 2.5	4.4 - 9.2	10.6 ± 14.0	0.044 ± 0.049
Salix glauca/lapponum	Twigs	4	18.0 ± 19.6	<2.9 - 46.3	17.3 ± 23.4	0.074 ± 0.080
Salix glauca/lapponum	Leaves	4	37.8 ± 48.3	1.3 - 108.8	22.6 ± 33.9	0.100 ± 0.120
Herbs						
Cassiope tetragona		4	10.5 ± 3.8	5.7 - 14.5	1.6 ± 1.2	0.011 ± 0.006
Solidago virgaurea		3	82.2 ± 62.8	31.4 - 152.3	10.4 ± 9.5	0.093 ± 0.066
Empetrum nigrum	Berries	4	16.5 ± 16.5	1.3 - 44.0	1.8 ± 1.4	0.020 ± 0.020
Empetrum nigrum	Plant	3	9.7 ± 4.5	4.5 - 12.3	1.6 ± 2.0	0.013 ± 0.006
Grasses/sedges						
Deschampsia flexuosa		7	13.9 ± 5.3	10.1 - 24.6	2.0 ± 3.4	0.015 ± 0.012
Undefined grass		1	9.8 ± 1.0		1	0.009
Carex sp.		3	4.8 ± 1.8	2.9 - 6.6	0.7 ± 0.4	0.007 ± 0.002
Mosses						
Hylocomium splendens		9	23.9 ± 16.9	9.1 - 59.6	2.6 ± 2.4	0 021 ± 0.012
Sphagnum sp.		1	17.3 ± 3.1		50.1	0.187
Lichens						
Cladina sp.		2	183.4 ± 30.9	161.6 - 205.3	15.2 ± 2.7	0.172 ± 0.042
Cladina sp.		1	46.5 ± 2.3		3.7	0.044
Cladina arbuscula		1	28.4 ± 3.4		0.7	0.024
Mushrooms						
Lactarius rufus		1	191 ± 8			
Russula paludosa		1	385 ± 12			

differences were observed between different lichens, with the one sample of *Cladina arbuscula* containing considerably less than the other *Cladina* spp. sampled. The two fungi analysed, *Lactarius rufus* and *Russula paludosa*, which are both edible and can form part of the diet of reindeer, contained ^{137}Cs activity concentrations of 191 Bq/kg and 385 Bq/kg, respectively.

The majority of these values are in good agreement with those reported by Gaare (1994), allowing for decay-correction, although the activity concentrations for dwarf birch, 6.6 and 5.2 Bq/kg, are lower than the decay-corrected value from 1993 of 24 Bq/kg.

4.4 Transfer Factor and Tag values

Transfer factor (TF) values were calculated by dividing the measured ^{137}Cs concentrations in the vegetation (Bq/kg d.w.) by the intergrated mean soil ^{137}Cs concentration (Bq/kg d.w.) from the closest soil core. Aggregated transfer (Tag) values were calculated for all vegetation species by dividing the measured ^{137}Cs concentrations in the vegetation (in Bq/kg d.w.) by the deposition value calculated from the closest soil core (in Bq/m^2). Mean TF and Tag values are summarised for each species in Table 7.

The leaves and buds of *S. glauca/lapponum* and *B. nana* showed higher TF and Tag values than the woody parts, while *S. virgaurea* showed considerably higher TF and Tag values compared to other herb species.

The Tag values calculated here are in the same order of magnitude as those reported by JRNEG (2002). The calculated mean Tag value for shrub species in this study is a factor of 2 higher, and for herb and grass/sedge species a factor of 2-4 lower than those reported in JRNEG (2002), but these differences could be attributed to the different individual species that were analysed, as well as differences in soil type in the sampling areas. The data reported in JRNEG (2002) were from samples taken from grazing pastures, while the samples described in this report were taken from an alpine environment.

Although all vegetation samples were sampled within 20 m of a soil core, they are not strictly co-located. As the spatial variability of the soil type and its ^{137}Cs activity are not known the Tag values should be considered with caution.

4.5 Cs-137 in faeces

Table 8 shows that there are considerable differences in the radionuclide concentrations between the faeces of the various animal species sampled. The highest ^{137}Cs activity concentrations were found in the faeces of reindeer (170.3 Bq/kg) and of an unknown rodent species (40.2 Bq/kg). Faeces of moose and willow ptarmigan contained less ^{137}Cs yielding ^{137}Cs activity concentrations of 4.3 and 5.9 Bq/kg d.w., respectively. A sample of faeces from either a (arctic) fox or wolverine contained a ^{137}Cs activity concentration of 12.9 Bq/kg d.w..

Differences in diet between the various species can explain much of the observed variation in radionuclide concentration. The radionuclide concentrations in faeces are controlled by a range of factors of which the radionuclide concentrations in the diet, the digestibility of the diet species and the fractional gastrointestinal absorption of the radionuclides

Table 8. Mean and range of ^{137}Cs and ^{40}K activity concentrations (Bq/kg d.w.) in faecal samples.

Species	n	^{137}Cs (Bq/kg d.w.)	Range	^{40}K (Bq/kg d.w.)	Range
Moose	3	4.3 ± 1.1	3.0 – 5.6	23.7 ± 5.2	<21 - 31
Reindeer	2	170.3 ± 7.8	162.5 - 178.0	307 ± 23	284 – 330
Fox /wolverine	1	12.9 ± 1.7		203 ± 57	
Willow ptarmigan	2	5.9 ± 0.3	5.6 – 6.1	74 ± 39	35 - 113
Small rodent	2	40.2 ± 8.9	31.3 – 49.1	<380	

are the most important. In Dividalen, reindeer feed on grasses, flowering plants, mosses and lichens (e.g. Mathiesen, 1999), while moose feed mainly on leaves from coniferous and deciduous trees, with a important proportion of aquatic plants in summer, and a minor component of leaves and twigs of other deciduous trees (Shipley *et al.*, 1998). In summer and autumn, willow ptarmigan typically feed on berries (for example berries from *E. nigrum*), herb and *B. nana* leaves (Pedersen *et al.*, 1998) while small rodents feed on a variety of seeds, nuts, berries, roots and insects.

4.6 Cs-137 in water

Samples of water from the Divielva and Skakterelva rivers contained similar ^{137}Cs activity concentrations, with values of 0.23 ± 0.03 and 0.20 ± 0.03 Bq/m^3, respectively.

5 Discussion

5.1 Dose assessment

5.1.1 Introduction

The soil deposition densities and the activity concentrations in vegetation reported in the previous section are low compared to for example areas in central Norway, where deposition densities of 4200-190000 Bq/m^2 were reported for 2002-2003 (Skuterud *et al.*, 2005). Consequently, the doses to local biota in Dividalen would be expected to be significantly lower than in central Norway and well below recommended dose rate limits. In this section we will estimate the doses from anthropogenic radionuclides to biota in the Dividalen environment, assess the spatial variability across the study area and compare the estimated doses to dose rate limits recommended by international authorities.

5.1.2 Recommended dose rate limits

It was suggested by the IAEA (1992), UNSCEAR (2002) and in a report to the UK Environment Agency by Copplestone *et al.* (2001) that radiation at chronic dose rates of ≤ 10 mGy/day is unlikely to cause any observable effects in populations of terrestrial plants. Similarly, they suggested that radiation at chronic dose rates of ≤ 1 mGy/day is unlikely to cause any observable effects to populations of terrestrial animals. These values of 10 mGy/day for populations of terrestrial plants and 1 mGy/day for populations of terrestrial animals were used by Higley *et al.* (2003a) and DOE (2002) as recommended dose limits in order to derive limiting soil activity concentrations at which these dose limits would be reached.

5.1.3 Dose coefficients and dose to biota

DOE (2002) and Higley *et al.* (2003b) presented general external and internal dose coefficients for a range of radionuclides in order to calculate dose rates to aquatic and terrestrial biota. The dose coefficients were further refined for a number of terrestrial reference organisms of varying sizes, and taking into account the different external exposure conditions for organisms living in the ground and those living on the ground, by Taranenko *et al.* (2004). A selection of those dose coefficients (Taranenko *et al.*, 2004) relevant to the discussion in this chapter is given in table 9. External dose coefficients are given in Gy year^{-1}/Bq·kg^{-1} and allow for the calculation of dose rates from external exposure per unit concentration of radionuclides in environmental media. Above ground dose coefficients are based on a uniform distribution of radionuclides in the top 10 cm of the soil, and in ground dose coefficients on a uniform distribution of radionuclides in a 50 cm thick soil layer around the organism. Internal dose coefficients, which are given in Gy year^{-1}/Bq·kg^{-1} fresh weight (f.w.), were calculated on the assumption that the radionuclides were homogeneously distributed throughout the tissue.

With these dose coefficients the total dose to terrestrial biota can be calculated by adding the external and internal doses. For example, the dose from ^{137}Cs:

$$Dose_{Cs} = Dose_{ext,Cs} + Dose_{int,Cs} = C_{soil,Cs} \times DC_{ext,soil,Cs} + C_{int,Cs} \times DC_{int,Cs} \quad (1)$$

Table 9. Dose coefficients for internal (DC_{int}) and external ($DC_{ext,soil}$) exposure from ^{137}Cs in a terrestrial environment (Taranenko et al., 2004).

	Mouse	Large bird	Deer
DC_{int} ^{137}Cs (mGy·day^{-1}/Bq·kg^{-1} f.w.)	3.8×10^{-6}	4.8×10^{-6}	6.2×10^{-6}
$DC_{ext,soil}$ ^{137}Cs (above ground) (mGy·day^{-1}/Bq·kg^{-1} d.w.)	2.6×10^{-6}	2.4×10^{-6}	1.8×10^{-6}
$DC_{ext,soil}$ ^{137}Cs (in ground) (mGy·day^{-1}/Bq·kg^{-1} d.w.)	7.0×10^{-6}	-	-

Total dose of all present radionuclides i is

$$\sum(Dose_{ext,i} + Dose_{int,i})$$

While activity concentrations have been measured for soil and for a range of vegetation species in the study area, few recent data are available for internal activity concentrations in animals in the study area and these will therefore be estimated through documented transfer coefficients and generic models.

5.1.4 Intake and assessment of internal body concentrations

We will look at 3 animal species: reindeer, willow ptarmigan and voles. Feeding experiments with reindeer and other ruminants have provided a considerable, albeit highly variable, amount of information on the bioavailability of ^{137}Cs in a range of food products and ^{137}Cs transfer coefficients. For reindeer, the internal body concentration will therefore be estimated according to the information on relative bioavailability (28%, 100%, and 25% for ^{137}Cs in lichen, vascular plants, and soil, respectively, relative to ionic CsCl) and transfer coefficients (F=0.74) reported by Skuterud *et al*. (2004) and Mayes *et al*. (1996). For willow ptarmigan and vole, internal body concentrations will be estimated using generic allometric models such as those proposed by DOE (2002), Higley *et al*. (2003b), Brown *et al*. (2003) and Beresford *et al*. (2004) together with estimated intake.

Using the diet composition in Table 10 together with the mean ^{137}Cs activity concentrations in the sampled vegetation and the estimated daily intake (Table 11) a total intake of 81 Bq/day of ^{137}Cs can be estimated for reindeer in summer, of which 57 Bq/day would be expected to be bioavailable. With a transfer coefficient value of F=0.74 (in Bq·kg^{-1} f.w./Bq·day^{-1}), the summer ^{137}Cs activity concentration in reindeer can be estimated at 42 Bq/kg f.w.. In comparison, Eikelmann *et al*. (2005) reported mean winter ^{137}Cs concentrations, which tend to be higher due to a higher intake of high ^{137}Cs forage such as lichen (e.g. Åhman and Åhman, 1994), of 79 Bq/kg and 152 Bq/kg f.w. in adult reindeer from two different regions in Finnmark. The most recent available late summer data from the Dividalen area itself yielded 144 Bq/kg in 1996 (Åhman, unpublished data). Values for apparent absorption ((intake – faecal excretion) / intake) of 17% for lichen (Skuterud *et al*., 2004) and 60% for other vegetation (Mayes *et al*., 1996) suggests a daily faecal excretion of 47 Bq; with the ^{137}Cs content in reindeer faeces in Dividalen measured at 170.3 Bq/kg d.w. (section 3.5), this would indicate a daily excretion of ca 0.27 kg d.w. faeces. Skuterud *et al*. (2004) reported daily faeces production of ca 0.3 kg for reindeer with a body mass of about 50 kg fed with a mixed lichen/concentrate diet.

Table 10. Reindeer diet compositions based on stomach content analyses by Mathiessen (1999) and data by Gaare and Staaland (1994); Willow ptarmigan diet from Pedersen et al. (1998). Vole diet from Sample and Suter (1994). Mean ^{137}Cs activity concentration, Tag and TF values taken from table 4.

	Grass	**Herbs**	**Woody plants**	**Lichen**	**Moss**	**Soil**
Mean ^{137}Cs (Bq/kg)	*11*	*27*	*20*	*110*	*23*	*15*
Mean Tag (m^2/kg)	*0.012*	*0.032*	*0.066*	*0.103*	*0.038*	
Mean TF (Bq·kg^{-1}/Bq·kg^{-1})	*1.5*	*3.5*	*15.4*	*8.7*	*7.4*	
Reindeer Summer (%)	45	25	15	10	5	
Reindeer Winter (%)	30		25	40	5	
Willow Ptarmigan Summer (%)		60 (+10% berries)	30			
Willow Ptarmigan Winter (%)		30 (+20% berries)	50			
Vole (%)	50	50				

Species specific parameters	
Reindeer	
mean body weight	70 kg
mean daily food intake summer	3 kg[1] d.w.
mean daily food intake winter	1.5 kg d.w.
soil ingestion	2% of food intake[4]
Red-backed vole	
mean body weight	0.030 kg[3,4]
mean daily food intake	0.005[4] kg d.w.
soil ingestion	2%[4]
Willow ptarmigan	
mean body weight	0.6 kg[5]
mean daily food intake	0.055 kg[2] d.w.
excreta	0.02 kg d.w.
soil ingestion	10%[4]

Table 11. 1. Golikov (2001); 2. Pedersen et al. (1998); 3. Kålås et al. (1994); 4. Sample and Suter (1994); 5. terrestrial monitoring program, NRPA. Measures of soil ingestion are rare; here the soil ingestion is estimated based on data from other related species with a similar diet and body weight reported by Sample and Suter (1994).

For willow ptarmigan and voles, the total daily intake in summer is estimated at 0.8 Bq/day (excluding *S. virgaurea* from the herbs) and 0.1 Bq/day, respectively. The internal activity concentration varies with time according to the following standard equations (e.g. DOE (2002), Higley *et al.* (2003b), Brown *et al.* (2003), Beresford *et al.* (2004)):

$$\frac{dC_{int}(t)}{dt} = \frac{f_1 \times I}{M} - \lambda_{eff} C_{int}(t) \qquad (2a)$$

$$C_{int}(t) = \frac{f_1 \times I}{\lambda_{eff} M}\left(1 - e^{-\lambda_{eff} t}\right) \qquad (2b)$$

Where:

$C_{int}(t)$ = the body concentration in Bq/kg f.w.

f_1 = fractional absorption (assumed to be 1 for ^{137}Cs (Coughtrey and Thorne, 1983))

I = the intake rate in Bq/day

λ_{eff} = the effective decay constant in day-1 (λ_{eff} is the sum of the biological, λ_{bio}, and radiological, λ_{rad}, decay constants)

M = the body mass in kg fresh weight

With time, the body concentration $C(t)$ will reach an equilibrium concentration at:

$$C_{int}(t) = \frac{f_1 \times I}{\lambda_{eff} M} \qquad (2c)$$

The biological decay constant can be estimated through the generic allometric relationship for ^{137}Cs excretion (Brown *et al.*, 2003):

$$\lambda_{bio,Cs} = \frac{ln\,2}{13.22 M^{0.237}} \qquad (3)$$

For a willow ptarmigan with a body mass of 0.6 kg (Table 11) and a total daily intake of 0.8 Bq/day, the equilibrium internal activity concentration is estimated at 22.5 Bq/kg f.w.. This estimate is somewhat higher than previously published and unpublished data, suggesting a lower ^{137}Cs diet than used in the calculations or a fractional absorption of ^{137}Cs of < 1. The ^{137}Cs activity concentration in the breast muscle of willow ptarmigan sampled in Dividalen in August 1993 was 70 Bq/kg d.w., or 18.6 Bq/kg f.w., using the mean dry weight percentage of 26.6% (Kålås *et al.*, 1994). More recent analyses from nearby areas in inner Troms gave breast muscle concentrations of 22-39 Bq/kg d.w., corresponding to 5.8-10.4 Bq/kg f.w., in the year 2000 (terrestrial monitoring program, NINA/NRPA).

For a vole with a body mass of 0.03 kg (table 11) and a total daily intake of 0.1 Bq/day, the equilibrium internal activity concentration is estimated at 27.5 Bq/kg f.w. This is in agreement with the ^{137}Cs activity concentration measured in whole grey red-backed voles sampled in Dividalen in August 1993 of 150 Bq/kg d.w., or 45 Bq/kg f.w. using the mean

dry weight percentage of 30.1% (Kålås *et al.*, 1994).

5.1.5 Cs-137 dose rate to biota in Dividalen

The mean ^{137}Cs concentration in the soil is 14.9 Bq/kg d.w.. Using the internal and external dose coefficients in Table 10 and the estimated internal activity concentrations, equation 1 can now be used to estimate the mean dose rate to reindeer, willow ptarmigan and voles in the study area. The results show that the dose rates in the study area are well below the recommended dose rate limits.

Reindeer:

Dose rate ^{137}Cs = $(35 \times 6.2 \times 10^{-6} + 14.9 \times 1.8 \times 10^{-6}) = 0.24 \times 10^{-3}$ mGy/day.

Willow ptarmigan:

Dose rate ^{137}Cs = $(22.5 \times 4.8 \times 10^{-6} + 14.9 \times 2.4 \times 10^{-6}) = 0.14 \times 10^{-3}$ mGy/day.

Vole:

Dose rate ^{137}Cs = $(27.5 \times 3.8 \times 10^{-6} + 14.9 \times 0.5 \times (2.6 \times 10^{-6} + 7.0 \times 10^{-6})) = 0.39 \times 10^{-3}$ mGy/day.

5.2 Mapping of dose rates

The internal tissue concentration in animals can be estimated directly from the activity concentration in the soil if soil-vegetation uptake values are used to determine activity concentrations in vegetation. This would then enable the mapping of dose rates across an area based on a soil contamination map such as shown in Figure 8. Two commonly used values are transfer factors (TF in Bq·kg^{-1} d.w. vegetation / Bq·kg^{-1} d.w. soil) and the Tag value (m^2/kg d.w.) (Section 3.6), which relate the radionuclide concentration in vegetation to the soil concentration through the following relationships:

Dep is the deposition density value in Bq/m^2. Substituting equation 4a for the activity

$$C_{veg,i} = CF_i \times C_{soil} \quad (4a)$$

$$C_{veg,i} = Tag_i \times Dep \quad (4b)$$

concentration in vegetation (using TF values in Table 11) gives a relationship between the ^{137}Cs internal tissue concentration of reindeer and the ^{137}Cs activity concentration in soil (equation 5) of $C_{int} = 9.6 \times C_{soil}$, and hence a ^{137}Cs dose rate (equation 6) of $(9.6 \times C_{soil}) \times DC_{int} + C_{soil} \times DC_{ext,soil} = 6.18 \times 10^{-5} \times C_{soil}$ mGy/day. This relationship has been mapped out in Figure 11. It should be kept into mind that the uncertainties on the TF and Tag values in Tables 8 and 11 are large due to the limited number of samples.

To perform a similar assessment for willow ptarmigan and voles, equation 4a needs to be substituted into equation 2c.

DMI is the daily dry matter intake and P_i and P_{soil} are the percentages of the daily dry matter intake of the different vegetation types and soil. From equation 6 follows then also the relationship between dose rate and activity concentration in the soil:

For willow ptarmigan, the relationship between the ^{137}Cs internal tissue concentration and the ^{137}Cs activity concentration in soil becomes $C_{int} = 8.5 \times C_{soil}$, which leads to a ^{137}Cs dose rate of $(8.5 \times C_{soil}) \times DC_{int} + C_{soil} \times DC_{ext,soil} = 4.3 \times 10^{-5} \times C_{soil}$ mGy/day (Figure 12).

$$C_{int}(t) = \frac{\left(\sum (CF_i \times P_i) + P_{soil}\right) \times DMI}{\lambda_{eff} M} \times C_{soil} \quad (5)$$

$$Dose \cdot rate = \left[\frac{\left(\sum (CF_i \times P_i) + P_{soil}\right) \times DMI}{\lambda_{eff} M} \times DC_{int} + DC_{ext} \right] \times C_{soil} \quad (6)$$

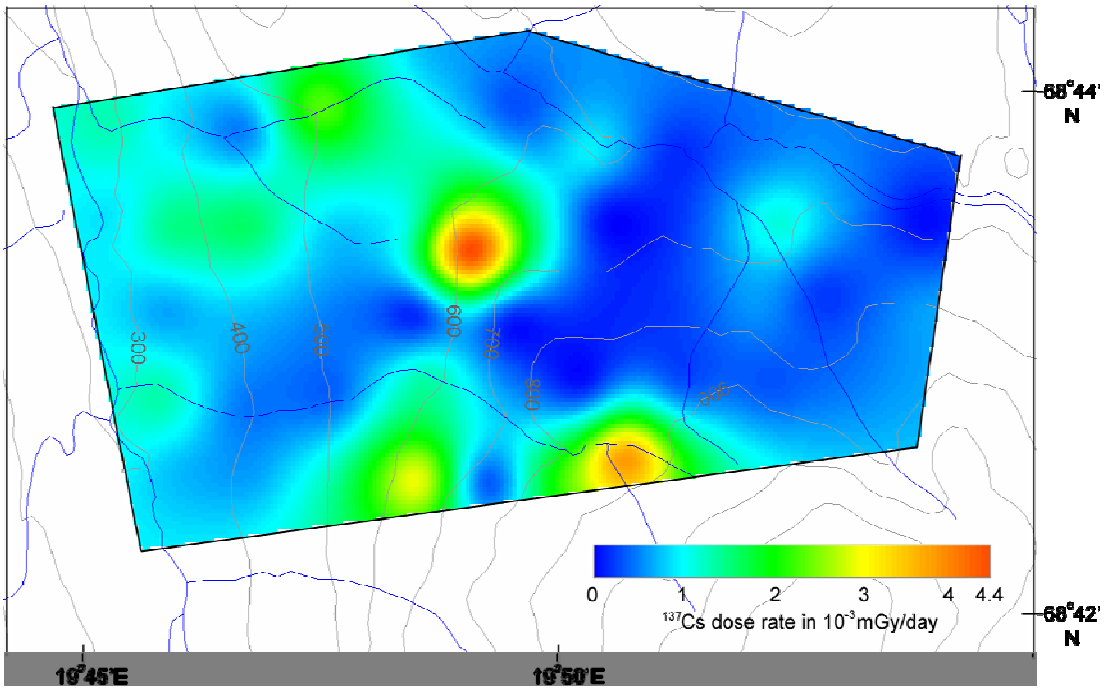


Figure 11. Map of the dose rates from ^{137}Cs to reindeer.

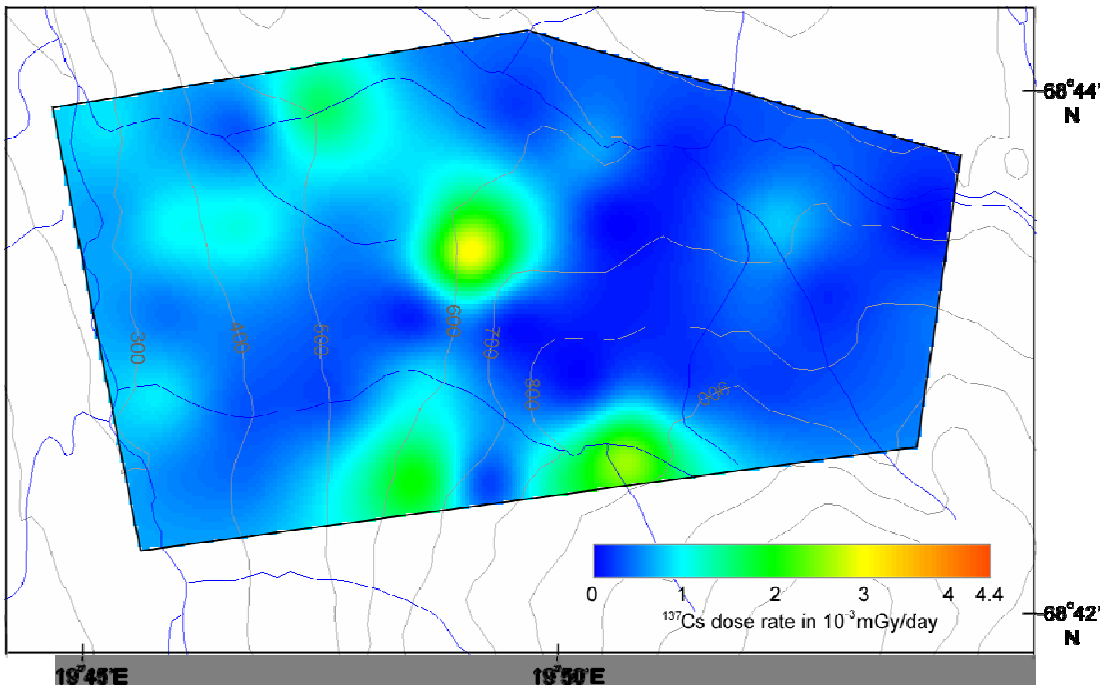


Figure 12. Map of the dose rates from ^{137}Cs to ptarmigan.

For voles, the relationship between the ^{137}Cs internal tissue concentration and the ^{137}Cs activity concentration in soil becomes $C_{int} = 3.5 \times C_{soil}$, which leads to a ^{137}Cs dose rate of $(3.5 \times C_{soil}) \times DC_{int} + C_{soil} \times DC_{ext,soil} = 1.8 \times 10^{-5} \times C_{soil}$ mGy/day (Figure 13).

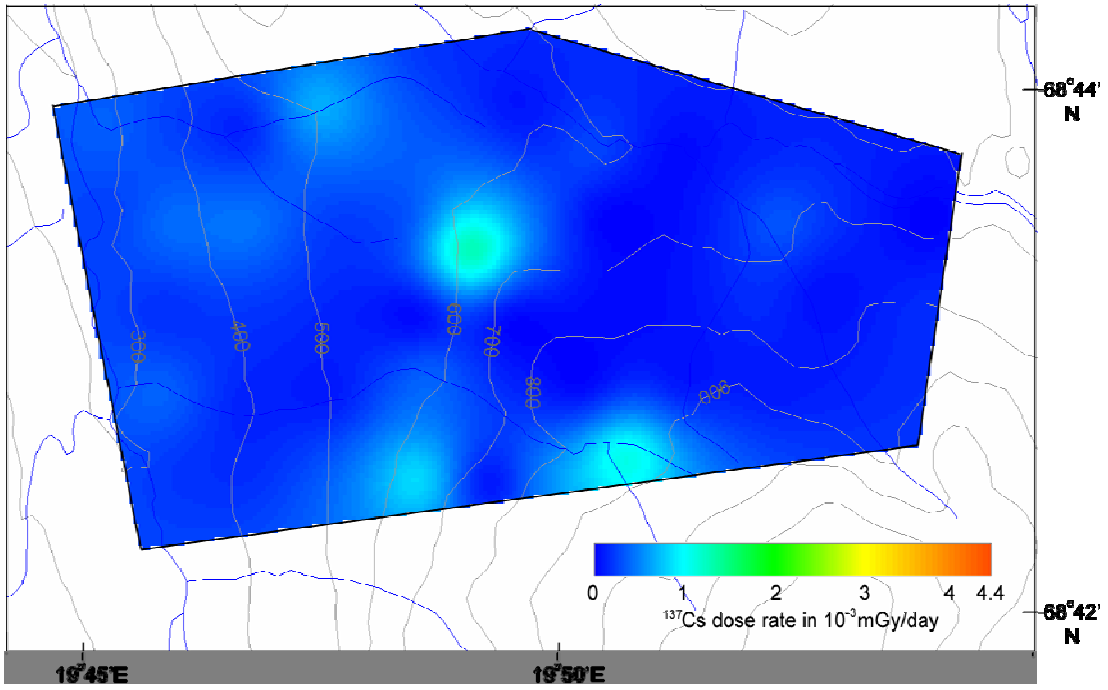


Figure 13. Map of the dose rates from ^{137}Cs to voles.

6 Conclusions

This study has characterised the radiological environment of the newly established terrestrial monitoring site in Dividalen in northern Norway. Results indicate that levels of anthropogenic radioactive contamination at the site are generally low and typical for northern Norway.

The soil is contaminated with ^{137}Cs, ^{241}Am and Pu isotopes. Am and Pu isotope ratios indicate that these radionuclides are primarily derived from the deposition following the atmospheric weapons testing programmes. Most of the radioactive contamination is contained in the organic-rich layer in the top ≤10 cm of the soil. The results indicate a ten-fold variation in the ^{137}Cs deposition density across the study area.

The levels of ^{137}Cs are notably higher in fungi and lichens than in herbs, grasses, shrubs and mosses. As a result of the varying food intake and preferences between different animal species, there are considerable differences in the ^{137}Cs activity concentrations in the faeces of these animal species. Reindeer faeces contain some 40 times higher levels of ^{137}Cs than moose faeces. Due to the choice of food products with higher ^{137}Cs levels by reindeer, this species will receive higher radiation doses than other animal species present in the area. However, estimated dose rates for different animal species indicate that the doses received are well below recommended dose limits for terrestrial wildlife.

6.1 Future sampling

NINA plans to carry out sampling and chemical analysis of vegetation, small mammals and birds in the Dividalen TOV area once every 5 years. It would be beneficial to coordinate future monitoring and sampling efforts such that the datasets can be combined and interpretations improved. With the current low levels of contamination in soil, vegetation and water, and only a slowly decreasing trend expected, a 5 year interval for regular terrestrial monitoring purposes would be sufficient.

For research purposes, however, further investigation would be desirable to enhance understanding of radionuclide transport processes through the sub-arctic environment. Dose assessment was carried out based on published food intake, bioavailability and radionuclide absorption. Further investigation is required into the actual activity concentrations in the various animal species to verify and improve these calculations. Investigation into the effect of various soil properties on the activity concentrations, bioavailability and vertical distribution of radionuclides in soil would help understand the spatial distribution of radionuclides in both soil and vegetation.

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