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Assessment of the radiological impacts of historical coal mining operations on the environment of Ny-Ålesund, Svalbard

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Abstract

Mineral extraction activities, such as those conducted by oil, gas and coal industries, are widespread throughout the Arctic region. Waste products of these activities can result in significant contributions to the radioactive burden of the surrounding environment due to increased concentrations of naturally occurring radioactive materials (NORM) to levels that would not normally be found in the environment. Coal mining operations commenced in the early 1900s on Svalbard and have been conducted at a variety of locations on the archipelago since then. Coal contains radionuclides of the uranium and thorium series as well as ^{40}K. Extraction and processing of coal can result in releases of these radionuclides to the broader environment with subsequent impact on the human and non-human inhabitants of the area. This paper presents the results of a study on environmental radioactivity resulting from historical coal mining operations conducted at Ny-Ålesund, Spitsbergen, in the Svalbard archipelago. Activity concentrations of radionuclides found in materials associated with these operations are presented as well as the results of a spatial dosimetric survey conducted over an area affected by coal mining.

Keywords: Arctic; Coal mining; Dosimetric survey; NORM; Thorium; Uranium; Svalbard

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1. Introduction

The arctic archipelago of Svalbard (78°00 N, 20°00 E) remains vulnerable, as does the arctic region in general, to radioactive contamination from a variety of sources, an introduction to which may be found in Strand et al. (2002). A possible source of radioactive contamination which has received little attention however, is the coal industry which is situated at a variety of locations on the archipelago. Commercial coal mining began on Svalbard in the early 1900s with mines in and around Longyearbyen and at Sveagruva at the head of Van Mijenfjord. Russian mining operations are centred at Barentsburg, 45 km to the west of Longyearbyen, with some activity at Pyramiden in Billefjorden. Ny-Ålesund, lying at 78° 55′ N, 11° 56′ E (Fig. 1), is the world's most northerly settlement and, given its location, is an area of special environmental interest. The first buildings were constructed at Ny-Ålesund in 1901 with coal mining commencing in 1916. Activities continued to varying extents over the following years until a large accident in 1962 resulted in the cessation of operations in 1963. Evidence of the operations at Ny-Ålesund remains to this day and takes the form of machinery, equipment and piles of waste materials from the mines.

The environmental impacts of coal mining with respect to heavy metals have been studied for a long time, recent examples being Teixeira et al. (2001) and Tiwary and Dhar (1994). In addition to heavy metals, coal also contains radionuclides of

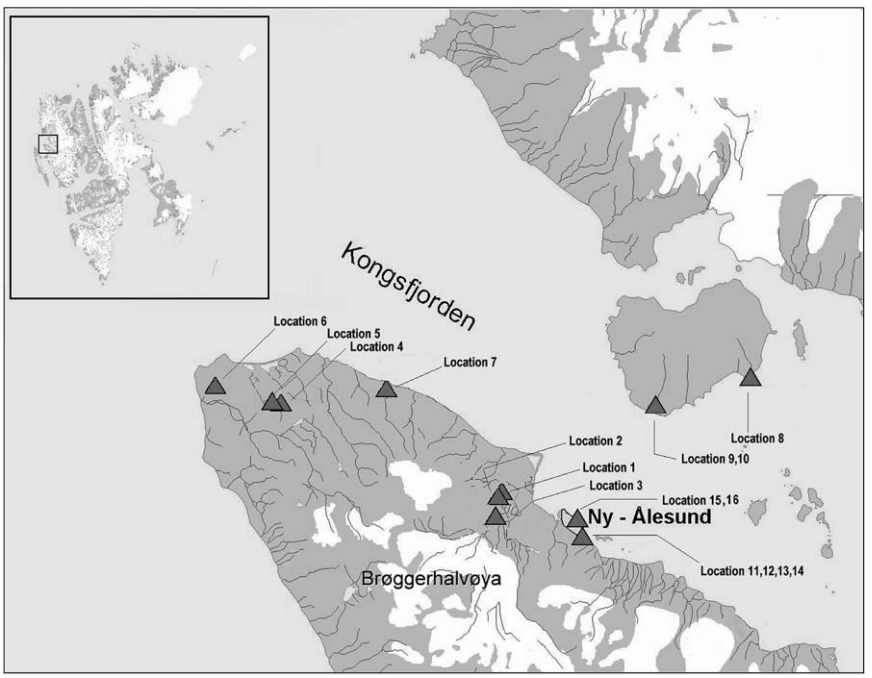

Fig. 1. Location of soil sampling sites within the Kongsfjord area, Spitsbergen.

the uranium and thorium series, together with ^{40}K. Typical concentrations of these nuclides in a variety of coals have been collated by Beck et al. (1980) and indicate that coal may contain between less than 0.2–25.2 mg kg^{-1} U (<2.4–304 Bq kg^{-1} ^{238}U) and from 0.62 to 47.8 mg kg^{-1} Th (2.5–191 Bq kg^{-1} ^{232}Th) depending on the coal type. The activity concentrations of radionuclides in the ash produced by combustion of these coals are significantly higher than those in the raw coal. The radioactivity associated with coal slags and waste materials has been examined by Trautmannsheimer et al. (1998), Somlai et al. (1998, 1996) and Bodizs et al. (1993). In fly ash, in particular, enhancement of radionuclide activity concentrations can be considerable, Baxter (1993) indicating enrichment factors for 5, 10, 12 and 46 for ^{40}K, ^{238}U, ^{226}Ra and ^{210}Pb, respectively.

The arctic remains susceptible to ongoing radioactive contamination from a number of sources of anthropogenic radioactivity, both local and long-range. However, of all contaminant radionuclides, either anthropogenic or naturally occurring, the nuclides that contribute the greatest portion of the radiation dose in arctic areas are ^{210}Pb and ^{210}Po (Gilman et al., 1997) which both arise from the ^{238}U decay series. These nuclides are daughter products of the radioactive gas radon (^{222}Rn). They typically occur as, or attached to, airborne particulates and settle on vegetation at which point they can enter the food web. ^{210}Po enters the kidneys and liver and the air-lichen-reindeer-human pathway that can predominate in the Arctic, and to some extent, diets high in shellfish and fish, can result in high body burdens of this radionuclide (Beasley and Palmer, 1966; Persson, 1972). ^{210}Po is a daughter product of ^{210}Pb and the relatively short half-life of the polonium isotope (138 days) combined with the slow growth of lichens in arctic ecosystems means that significant levels of ^{210}Pb can build up in these plants over the course of one growing season. The behaviour of ^{210}Pb differs slightly from ^{210}Po in that it resides primarily in bone tissue as it substitutes for calcium in the mineral apatite, although ^{210}Po will build up over time in these tissues as ingrowth from the parent proceeds. Any activity which increases the amount of ^{238}U or ^{226}Ra in the environment will increase the amount of these isotopes in the ecosystems of that environment and hence the radiological impact to the organisms within those ecosystems. The radionuclide content of coal and its waste products therefore poses a potential radiological hazard to areas contaminated via its input of ^{210}Pb and ^{210}Po to the local ecosystems.

Of lesser concern, but worthy of consideration nonetheless, is the physical nature of the coal mining related waste materials. Radon emanation from soil has been shown to be related to soil properties such as compaction (Goh et al., 1991) and climatological conditions such as freezing (Nason and Cohen, 1987). The coal waste piles at Ny-Ålesund consist of relatively non-compacted loose material which is located above the permafrost layer. Given equal activities of ^{226}Ra, it appears likely that this material could conceivably contribute more ^{210}Pb and ^{210}Po to the surrounding area than the compacted frozen surrounding soil, due to increased radon emanation from the coal wastes. In addition to radon emanation, radionuclides in coal wastes contribute directly to the ambient dose rate of the surrounding areas via the emission of gamma radiation. The primary sources of terrestrial gamma radiation are ^{40}K and the nuclides of the ^{232}Th and the ^{238}U decay chains which exist naturally

in soils and rocks. In addition to the naturally occurring radionuclides, the presence of the primary gamma emitting anthropogenic contaminant ^{137}Cs also contributes to the ambient dose rate. Thus, the kinetic energy released in matter (kerma) rate above soils containing elevated levels of any of these radionuclides is expected to be higher than in areas with 'normal' radionuclide activity concentrations in soils.

Although environmental impact assessments of human activities in the Ny-Ålesund area have been completed (Shears et al., 1998; Krzyszowska, 1988) the subject of radioactivity in general, and radioactivity generated by mining activities in particular, was not addressed in these earlier studies. The work reported in this study aimed to determine whether historical mining operations in the environment around Ny-Ålesund have resulted in any enhanced environmental radioactivity and, if so, whether this has increased radioactive dose rates in the area. This involved the sampling of soils and mine wastes from within and outside the Ny-Ålesund area and the analysis of these samples for natural and anthropogenic gamma emitting radionuclides. In situ kerma rate measurements were also performed in and around Ny-Ålesund, and at a control site, in order to examine the dose distribution on a smaller spatial scale. The relative contributions of the natural and anthropogenic components of the ambient dose rate were calculated and assessment is made of the impact of coal mining wastes around Ny-Ålesund.

2. Methods

2.1. In situ dosimetric survey

An in situ spatial survey of kerma rate ($\mu Gy\ y^{-1}$) was carried out in July 1999 at the former coal workings adjacent to the settlement of Ny-Ålesund. The survey area was centred approximately 1 km due south of the centre of Ny-Ålesund, as shown in Fig. 2. In situ measurements were taken 1 m above the ground surface using a Mini Instruments Environmental Radiation Meter Type 6-80 coupled to a Type MC-71 Geiger–Müller tube which has a response range of 0.05–75 $\mu Gy\ h^{-1}$. Repeated measurements (5–10) were obtained at each node of a 200 m regular grid. Where visible remains of coal mining activity were missed by this grid spacing a nested grid pattern was adopted at 100 m grid spacing, as shown in Fig. 2. In total, 640 individual measurements of in situ kerma rate were made. At the same time, as kerma rates were measured (Table 1), the degree of degradation of the ground surface was recorded on an arbitrary scale of 1–6 based on the visual criteria shown in Table 2. A score of 6 was given to areas in which the ground was completely covered by tundra vegetation typical of unpolluted and physically undisturbed locations in the Ny-Ålesund area. Conversely, a score of 1 was given to areas in which there was no evidence of natural vegetation cover remaining. Intermediate scores were assigned to areas in which the state of the ground surface was judged to be between these two extremes.

Point measurements of the spatial distribution of in situ kerma rate and ground

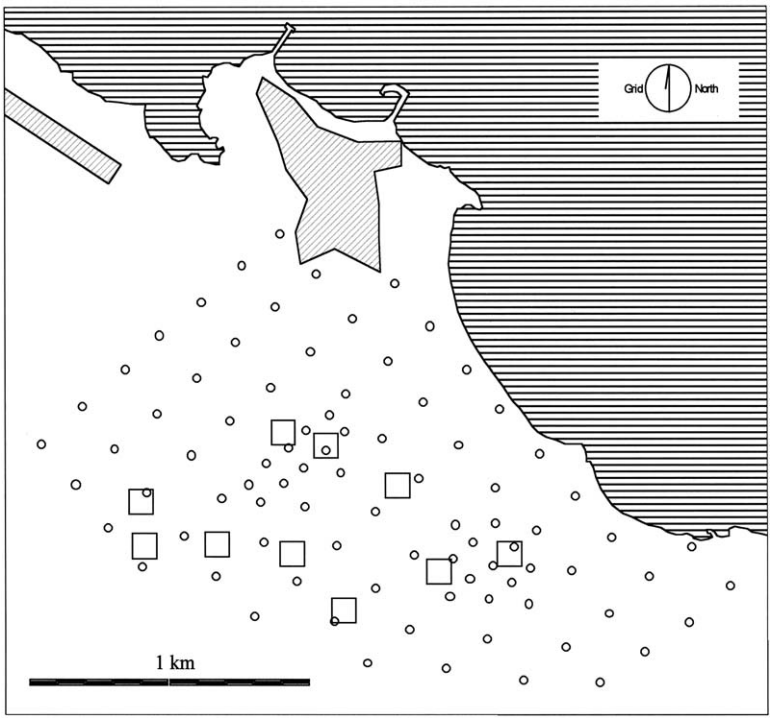

Fig. 2. Grid at Ny-Ålesund used for the survey of in situ kerma rate in 1999. The open circles show survey points while the solid black circles show former coal workings. The shaded areas indicate the present day settlement and airstrip at Ny-Ålesund.

Table 1
Kerma rate 1 m above the surface of a soil containing specified activity concentrations of ^{40}K, ^{238}U and ^{232}Th in secular equilibrium with daughter nuclides (modified from Beck, 1972)

Radionuclide	Soil activity concentration (Bq kg^{-1})	Kerma rate 1 m above soil surface (μGy y^{-1})
^{40}K	37	14
^{238}U + daughters in secular equilibrium	37	139
^{232}Th + daughters in secular equilibrium	37	216

degradation were interpolated using a distance-weighted least squares routine within the Idrisi 32 Geographic Information System.

A ‘clean’ control area was also surveyed for in situ kerma rate. The Brøgger peninsula (Brøggerhalvøya) to the north-west of Ny-Ålesund (Fig. 1) has a similar geology (Carboniferous and Permian) to the mined area in Ny-Ålesund but is unaffected by coal wastes. A limited number (54) of measurements of in situ kerma rate

Table 2
Arbitrary scoring system used to assess the degree of degradation of the ground surface at individual measurement locations within the Ny-Ålesund survey area

Score	Description
1	Severely degraded: no natural ground cover remaining.
2	Very degraded: <25% natural ground cover.
3	Degraded: 25–50% natural ground cover.
4	Partially degraded: 50–75% natural ground cover.
5	Minimal degradation: 75–100% natural ground cover.
6	Natural tundra: no evidence of degradation.

within this area therefore provided a control data set against which the kerma rates from Ny-Ålesund could be compared.

2.2. Collection of samples for ex situ radiometric analysis

Soil and substrate samples were taken from along the Brøgger peninsula at positions of increasing distance from Ny-Ålesund in late May 2001 (Fig. 1). Due to adverse climatic conditions, samples were taken at locations where snow cover permitted. Samples consisted of surface samples (0–3 cm depth) and some depth cores to the upper edge of the seasonal frost (approximately 12–15 cm). Depth cores were taken by incrementally sampling one side of an excavated pit. Within the Ny-Ålesund settlement itself samples were taken of soil and of coal wastes located within the area. Samples of coal and soil were also taken at the mining facilities in Longyearbyen. These samples were placed in polyethylene sacks and frozen prior to transport to the laboratories of the Norwegian Radiation Protection Authority at Tromsø, Norway. One sample (location 16), consisted of a form of coal slag distributed throughout a contaminated soil. This was separated from the soil by sieving and analysed separately. Several coal samples were taken from mine 7 at Longyearbyen and from the Svea mines. A sample of disturbed soil was also taken near to the mine 7 workings.

2.3. Radiometric analysis

Radionuclide activities within the samples taken were determined using a high purity germanium detector (Canberra) of nominal relative efficiency of 40% and with a resolution of 0.87 FWHM at 122 keV. Samples were dried at 110 °C, crushed to less than 2 mm, homogenised and packed into standard geometries with volumes between 40 and 500 ml. Quantitative analysis of the nuclides was based, where appropriate, on primary photon emissions (661 and 1460 keV for ^{137}Cs and ^{40}K, respectively). In the case of ^{226}Ra, whose primary emission is interfered with by ^{235}U, correction was made by establishing the ^{238}U content via the emissions of ^{234}Th (which is always in secular equilibrium with its parent in terrestrial matrices) and correcting the ^{226}Ra peak for the ^{235}U contribution using the known activity ratio of

^{238}U:^{235}U. ^{232}Th was determined via its grand-daughter, ^{228}Ac. All measurements were conducted in accordance with the quality assurance procedures of the laboratory which involve International Reference Materials, splits, duplicates and blanks. Count times were sufficient to ensure 2σ errors of less than 20%.

2.4. Dosimetric calculations based on ex situ analyses

Calculations were performed to obtain an estimate of the dose rates received at a point 1 m above the surface based on the contributions of the ^{238}U and ^{232}Th series, ^{40}K and ^{137}Cs as determined by gamma ray spectrometry. Using methods originally devised by Hultqvist (1956) and further developed by Beck (1972), it is possible to estimate the kerma rate at a specified height above the soil surface by establishing the activity concentrations of these radionuclides in soils. The dose rate conversion factors used were those derived by Clouvas et al. (2000). These factors incorporate 300 different photon emissions for each series and, for the purpose of calculation, it was assumed that the density of the soil was 1.3 g cm^{-3} and that the nuclides were uniformly distributed to a depth of 1 m. Secular equilibrium was assumed to exist between radionuclides and their progeny within each series. At locations where depth cores were taken, the dose was calculated on the average activities of the nuclides over all depths sampled.

3. Results and discussion

3.1. In situ dosimetric survey

Fig. 3 shows the interpolated surface of in situ kerma rate within the survey area at Ny-Ålesund. Contours obtained for the fitted surface are overlain to emphasise the spatial distribution of kerma rate. Several points with high in situ kerma rates can be observed and the most prominent three of these are labelled. Points 1, 2 and 3 had average in situ kerma rates of 1195, 983 and 963 μGy y^{-1}, respectively. It can be seen from Fig. 4(a) that these kerma rates lie at the upper end of the overall frequency distribution of kerma rates measured across the site as a whole. A normal distribution gave the best fit to the observed distribution of kerma rates, but only when individual kerma rates greater than 1093 μGy y^{-1} (the 99th percentile value) were treated as outliers and omitted from the distribution. Thus, the kerma rates measured at points 2 and 3 can be considered to occupy the higher percentiles of the general distribution for the site. However, the kerma rates measured at point 1 are evidently outliers, lying above the 99th percentile of the fitted distribution. The ground surface at point 1 was characterised by coal ash deposits which were the result of either the deliberate or spontaneous combustion of coal wastes, a mechanism which results in significant concentration of radionuclides from the raw coal (Baxter, 1993). Each of the three points at which high kerma rates were measured were associated with severe degradation of the ground surface, as defined in Table 2, evidently due to mining activity and the presence of coal wastes in the form of coal,

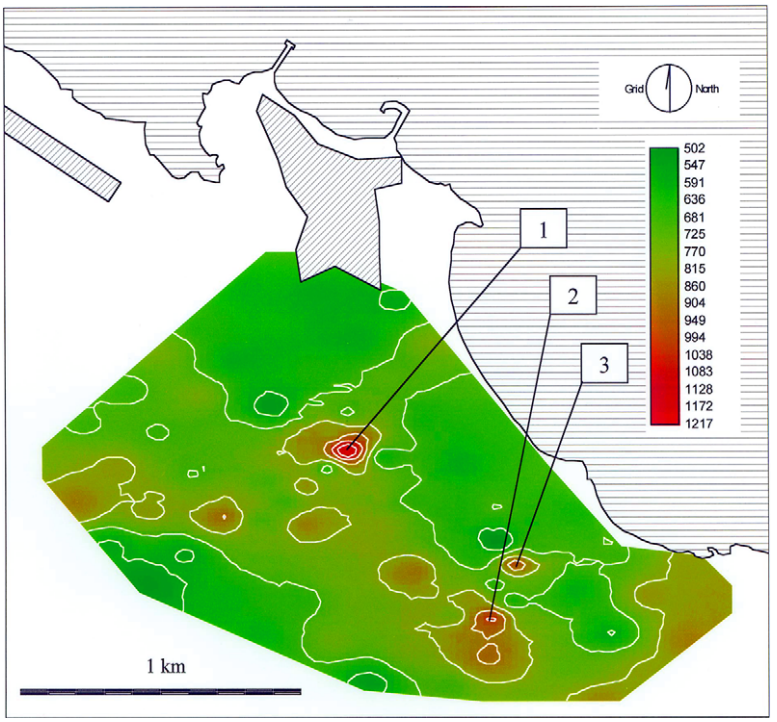

Fig. 3. Interpolated surface of in situ kerma rate (μGy y^{-1}) 1 m above the ground surface within the Ny-Ålesund survey area.

coal ash or fragments of the host rock from which the coal was extracted. Thus, the in situ dosimetric survey indicated a clear relationship between locally elevated kerma rates and past coal mining activities. This relationship is shown graphically in Fig. 5 in which the interpolated surface of ground degradation (as defined in Table 2) is overlain by the contours of interpolated in situ kerma rate obtained from Fig. 3 to indicate the correspondence between ground surface degradation and enhanced kerma rate.

The in situ measurements at the Brøgger control site, though fewer in number than those at the Ny-Ålesund survey area, yielded an approximately normal distribution of kerma rates (Fig. 4(b)) with an arithmetic mean of 663 μGy y^{-1} and an arithmetic standard deviation of 87 μGy y^{-1}. A *t*-test showed the mean kerma rate (outliers excluded) at the Ny-Ålesund survey area to be significantly higher than that at the Brøgger control site ($p < 0.001$), thus providing further evidence that historic coal mining operations at Ny-Ålesund have resulted in locally elevated in situ kerma rates.

3.2. Radiometric analyses of soil and substrate samples

Radionuclide activity concentrations of the soil and substrate samples collected from the locations indicated in Fig. 1 are presented in Table 3. The major source of

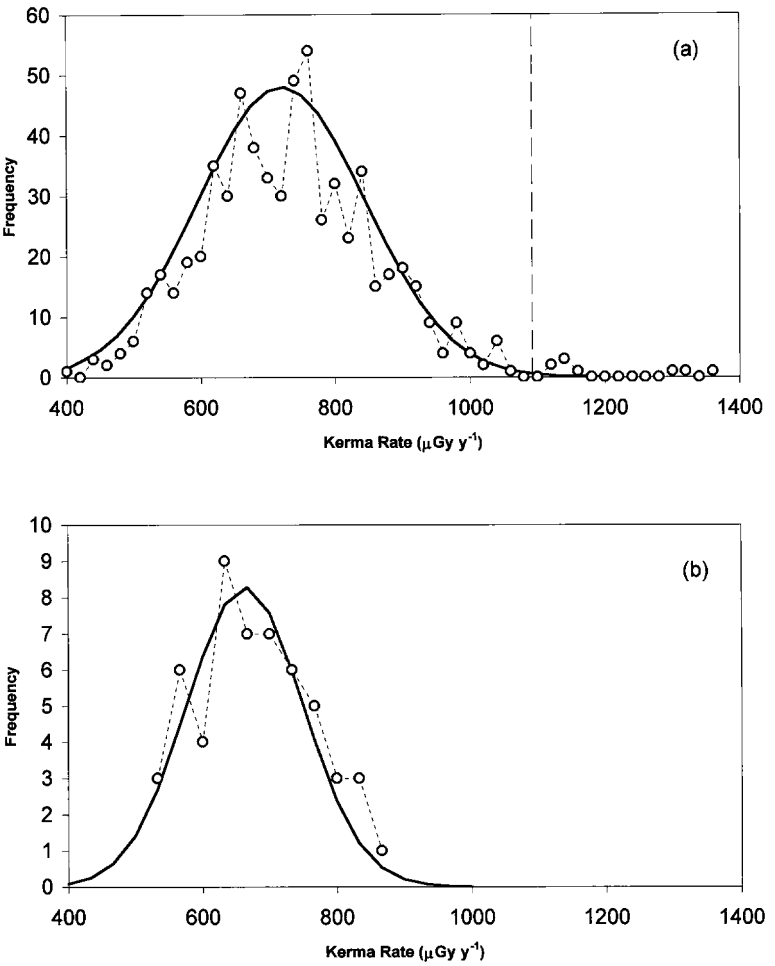

Fig. 4. Frequency distribution of in situ kerma rates 1 m above the ground surface within the Ny-Ålesund survey area (a) and corresponding frequency distribution for kerma rates at the Brogger control site (b). The arithmetic mean ($\bar{x}$) and standard deviation (σ) are 721 and 124 μGy y^{-1}, respectively. The smooth curve represents an idealised normal distribution: the vertical dashed line indicates the 99th percentile ($\bar{x} + 3\sigma$ = 1093 μGy y^{-1}) of this distribution above which measured kerma rates can be considered to be statistical outliers.

radioactivity within all samples is ^{40}K, with activity concentrations ranging from 114 to 860 Bq kg^{-1}. In most samples, the activity concentrations of ^{137}Cs are substantially lower than those of ^{40}K as well as ^{238}U, ^{232}Th and ^{226}Ra. The four naturally occurring radionuclides were more or less uniformly distributed with soil depth whereas ^{137}Cs showed a pronounced maximum at the soil surface: this suggests that the sole source of ^{137}Cs in soils and substrates in the area is atmospheric deposition.

The soil and substrate activity data set was subdivided into two groups, one group (samples 1–10) consisting of samples taken from outside of the environs of Ny-

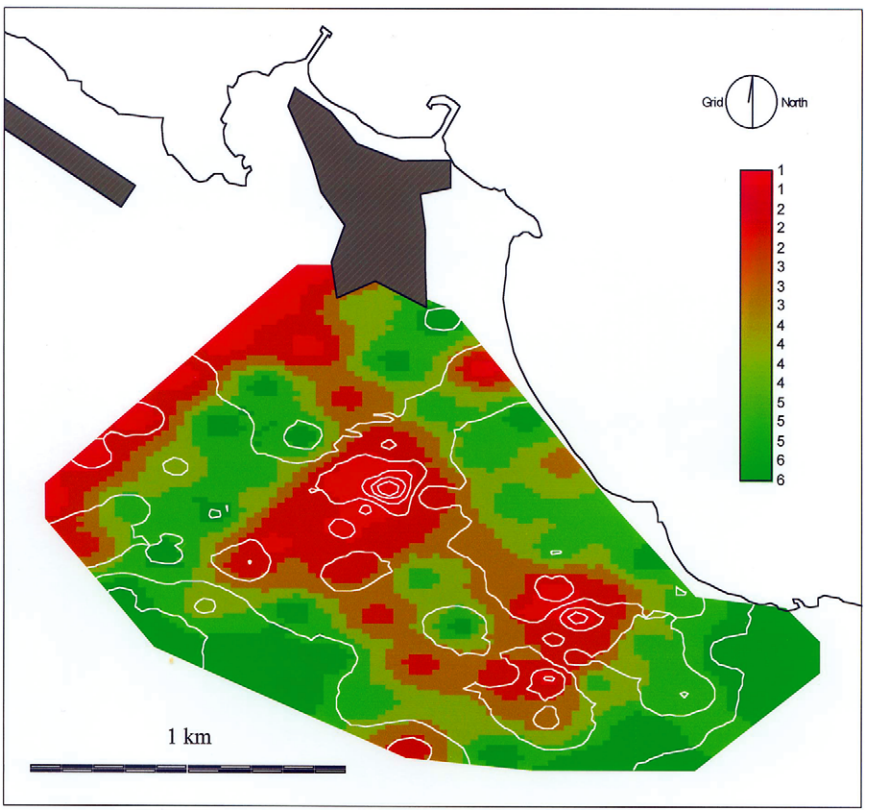

Fig. 5. Interpolated surface of ground degradation (see Table 2) within the Ny-Ålesund survey area. The contours of interpolated in situ kerma rate from Fig. 3 are overlain to indicate the correspondence between ground degradation and enhanced kerma rate.

Ålesund, the other (samples 11–16) consisting of samples taken from within the settlement. The second group consisted of both soil and coal waste samples. The summary statistics for these two groups are presented in Table 5.

Examination of the summarised data sets (Table 4) indicates that average activity concentrations of all the natural radionuclides determined are higher in samples taken from Ny-Ålesund than in samples taken from areas outside of the settlement and mining areas. This suggests that contamination of soils and substrates by mining activities within Ny-Ålesund has increased the activity concentrations of naturally occurring radionuclides on the ground surface, a result which explains the small but significant enhancement of in situ kerma rate observed in the dosimetric survey described above. The most marked difference in mean activity concentration between the two data sets in Table 4 is exhibited by ^{40}K with the arithmetic mean value for samples taken within Ny-Ålesund being some 26% greater than the arithmetic mean value outside the area.

Table 5 shows kerma rate estimates calculated from the data obtained on soil and

Table 3
Activity concentrations of radionuclides in soil and substrate samples taken from within and around Ny-Ålesund. Activity concentrations are all reported in Bq kg^{-1} dry weight

Location	Material	Depth (cm)	^{238}U	^{226}Ra	^{232}Th	^{40}K	^{137}Cs
Outside Ny-Ålesund							
1	Soil	0–3	20	32	15	220	34.6
		3–6	26	30	18	250	5.8
		6–9	46	47	28	359	1.0
		9–12	49	42	32	384	0.5
2	Soil	0–3	47	35	34	413	11.5
		3–6	43	47	35	441	1.2
		6–9	48	47	32	390	0.3
3	Soil	0–3	34	42	35	558	14.5
		3–6	40	35	36	523	0.8
		6–9	45	46	43	614	0.6
4	Soil	0–3	38	49	14	205	9.7
		3–6	41	56	16	214	0.7
		6–9	31	62	14	213	0.6
5	Soil	0–3	24	45	15	215	5.4
		3–6	27	36	16	218	1.2
		6–9	41	40	17	227	0.3
		9–12	37	40	16	231	0.5
6	Soil	0–3	23	46	10	115	5.2
		3–6	25	40	9	117	1.1
7	Soil	0–4	21	47	26	431	1.8
		4–7	22	40	25	460	1.6
		7–11	31	23	26	432	0.9
8	Soil	0–5	23	18	20	274	3.1
9	Soil	0–3	17	21	19	435	21.5
		3–6	23	17	21	473	0.3
		6–9	24	15	21	431	0.3
		9–12	17	18	21	427	0.4
		12–15	19	23	22	468	0.3
10	Soil	0–3	34	22	31	499	39
		3–6	36	32	34	489	1.2
		6–9	31	34	33	486	0.3
Inside Ny-Ålesund							
11[a]	Disturbed soil	0–3	22	51	35	564	1.3
		3–6	53	19	35	577	3.2
		6–9	44	29	36	643	1.2
		9–20	37	31	30	575	0.3
12[a]	Coal wastes	0–5	39	60	51	694	0.3
13[a]	Coal wastes	0–5	39	54	39	599	0.4
14[a]	Coal wastes	0–5	62	69	61	860	0.7
15[a]	Disturbed soil	0–3	68	70	52	156	0.9
	Disturbed soil	3–6	66	85	48	114	1.8
	Disturbed soil	6–9	69	73	51	123	2.0
	Disturbed soil	9–12	61	80	47	135	1.4
16[a]	Coal slag	0–12			38	140	<2.7

[a] Samples taken from near historical mining operations or waste piles.

Table 4
Summary statistics for soil and substrate samples taken from within and outside Ny-Ålesund (all data are Bq kg^{-1} dry weight: AM and ASD are arithmetic mean and arithmetic standard deviation, respectively)

	$^{238}U_{out}$	$^{226}Ra_{out}$	$^{232}Th_{out}$	$^{40}K_{out}$	$^{238}U_{in}$	$^{226}Ra_{in}$	$^{232}Th_{in}$	$^{40}K_{in}$
AM	31.7	36.4	23.7	361.7	50.9	56.5	44.1	458.2
Min	17.0	15.0	9.0	115.0	22.0	19.0	30.0	114.0
Max	49.0	62.0	43.0	614.0	69.0	85.0	61.0	860.0
ASD	10.1	12.1	8.9	135.8	15.6	22.0	9.6	271.4

Table 5
Total kerma rate (μGy y^{-1}) and percentage contributions to total kerma rate calculated from activity concentrations of ^{137}Cs, ^{238}U, ^{232}Th and ^{40}K in soil or substrate at each sampling location. Where depth-wise samples were taken, the kerma rate was calculated from activity concentrations averaged over the depth of sampling

Site	Total	^{137}Cs (%)	^{238}U (%)	^{232}Th (%)	^{40}K (%)
1	335	3	35	32	30
2	448	1	34	34	31
3	497	1	27	35	37
4	262	1	47	25	27
5	255	1	42	28	29
6	166	2	48	27	23
7	353	2	23	33	42
8	264	1	29	35	35
9	315	1	22	30	47
10	439	3	26	34	37
11[a]	484	0	27	32	41
12[a]	590	0	22	39	39
13[a]	506	0	26	35	39
14[a]	770	0	27	36	37
15[a]	490	0	45	46	9

[a] Samples taken from near historical mining operations or waste piles.

substrate activity concentrations of ^{137}Cs, ^{238}U, ^{232}Th and ^{40}K. The highest estimated kerma rates occur over the coal waste piles in Ny-Ålesund, where rates are some two to three times higher than those calculated for locations further away from Ny-Ålesund. The ^{232}Th series and ^{40}K appear to contribute most to the overall kerma rate within Ny-Ålesund. However, at one location, 15, within the settlement, the ^{40}K activity concentration was relatively low and hence its contribution dropped substantially to less than 10% of the total kerma rate compared with 30–40% contribution in other samples.

The mean kerma rate calculated from ex situ measurements of samples was 568 μGy y^{-1}, which is significantly lower ($p < 0.01$) than the mean kerma rate measured in the in situ dosimetric survey at Ny-Ålesund. The calculated mean kerma rate is

not significantly different from the mean in situ kerma rate of 663 μGy y^{-1} determined on the Brøgger peninsula, however, suggesting that the use of dose conversion coefficients to estimate in situ kerma rates from ex situ spectrometric analyses of substrate samples is a reasonable technique to make estimates of external radiation dose in situations in which field surveys of in situ kerma rate are not feasible.

The estimates of kerma rate, based on ex situ gamma ray spectrometry of soil and substrate samples, further emphasise that coal mining activities have modified the radiological situation at Ny-Ålesund. It is reasonable to assume that similar coal mining activities in other areas of Spitsbergen, and throughout the Arctic, have had a similar effect on the local environment. While analyses of ^{210}Pb and ^{210}Po were not made a part of this study, it is evident that activity concentrations of these two naturally occurring radionuclides are also likely to be enhanced in soils and substrates affected by coal mining activities in the Arctic. The dosimetric implications of enhancement of ^{210}Pb and ^{210}Po activity concentrations are certainly worthy of further study. On the other hand, the very low contribution of ^{137}Cs to the total kerma rate at all sites (Table 5) from which samples were obtained in this study underscores the relatively small radiological impact that the civil and military nuclear power and weapons programmes have had on terrestrial ecosystems in this area of the Arctic.

4. Conclusions

Results from an in situ dosimetric survey within the settlement of Ny-Ålesund, and an adjacent control area, have shown that a small but significantly enhanced radiation kerma rate can be determined at locations at which severe degradation of the ground surface has resulted from historic coal mining operations. Ex situ gamma spectrometric analyses of soil and substrate samples from within Ny-Ålesund and from several control sites outside of the settlement have indicated enhanced activity concentrations of ^{40}K and the ^{238}U and ^{232}Th series radionuclides within those samples obtained in areas of Ny-Ålesund contaminated with coal wastes. In situ kerma rates can be estimated from these activity concentrations using appropriate dose conversion factors and these indicate the importance of the naturally occurring radionuclides in coal wastes to the overall kerma rates within Ny-Ålesund and in ‘clean’ locations outside of the settlement. Evidently, ^{137}Cs from atmospheric deposition plays a minor role in external radiation exposures in Svalbard when compared with potential exposures to naturally occurring radionuclides resulting from coal mining.

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