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IDENTIFICATION OF CHERNOBYL FALL-OUT AS A NEW REFERENCE LEVEL IN NORTHERN HEMISPHERE GLACIERS

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ABSTRACT. Among the various artificial radioactive markers (mainly from atmospheric nuclear tests), the contamination from the Chernobyl accident has been found at five sampling sites on Northern Hemisphere glaciers. Total beta-activity measurements reveal a very high radioactive level. However, due to the short time of its occurrence, the temporal resolution of this event in the snow layers can be generally quite low and positive results require careful sampling. The size of the signal also depends on the trajectory of the contaminant cloud, the amount of precipitation, and the surface conditions during deposition.

INTRODUCTION

Until now, the greatest amount of deposition of artificial radioactivity on temperate glaciers and polar ice sheets came from atmospheric thermonuclear tests.

A significant number of these tests contaminated the stratosphere, leading to the world-wide spread of radionuclides. These are found in the annual snow layers, giving rise to well-known reference levels, and thus allowing accurate snow dating in both Northern and Southern Hemisphere glaciers (Picciotto and others, 1963; Crozaz, 1969; Hammer and others, 1978).

The radioactive pollution of glaciers by the nuclear power industry generally presents a more local pattern. The following is a chronological list of the most important accidents, including the failures of nuclear reactor-powered satellites:

October 1957. The Windscale (U.K.) accident dispersed 20 kCi of ^{131}I and 0.6 kCi of ^{137}Cs. The corresponding pollution may have reached the Alps, having been observed in West Germany, the Benelux countries, and Scandinavia (Gordon, 1979).

April 1964. The disintegration of the *SNAP-9A* satellite between 40 and 60 km altitude, at lat. 11°S. over the Indian Ocean, dispersed 17 kCi of ^{238}Pu. By 1970, 95% of this activity had been deposited on the Earth, leading in 1973 to a ^{238}Pu total amount deposited (in the

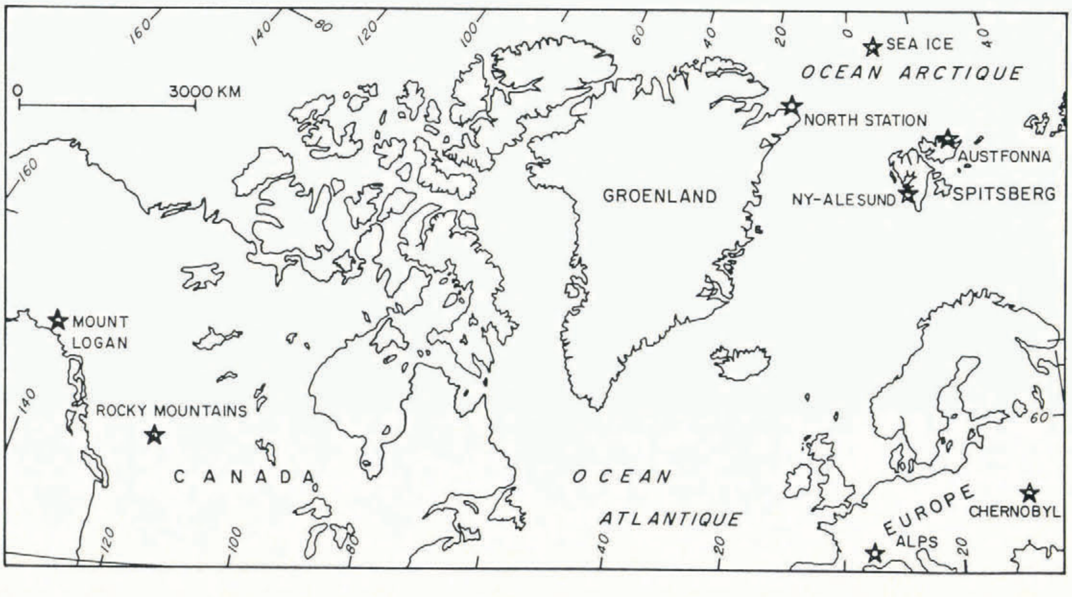

Fig. 1. Map of snow-sampling sites on Northern Hemisphere glaciers.

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TABLE I. BETA ACTIVITY OF SNOW SAMPLES WITH THEIR LOCATIONS AND DATES OF COLLECTION

Location	*Remarks*	*Beta radioactivity* Bq kg^{-1} *3 June 1986*[a]	*January 1987*[b]
Greenland			
Station Nord (lat. 81°36′ N., long. 16°40′ W.)	8 May snowfall (13.00–19.00 h GMT)	0.38[2]	
	12 May snow surface (11 May snowfall)	0.42	
Sea Ice Station (lat. 84°13′ N., long. 17°50′ E.)	12 May snow surface (11 May snowfall)	1.33[2]	0.84
Svalbard			
Austfonna (lat. 79°43′ N., long. 25°43′ W., 525 m)	4 May snow surface (old deposition)	0.15[2]	
	4 May snowfall	0.46[2]	0.59
	10–11 May snowfall	8.84[2]	5.47
	17–18 May snowfall	1.38[2]	0.88
	25 May snow surface (after blowing snow)	1.08[2]	0.67
Ny-Alesund	8 May snow surface (old deposition)	0.05[2]	
	13 May snow surface (after snowfall)	0.15[2]	
Alps			
Aiguille du Midi (Mont Blanc area, 3842 m)	16 May snow surface (~1 month of deposition)	0.19	
	21 May snowfall	8.78[c]	10.05
	6 June snowfall	0.25[c]	0.27
Col du Dôme (Mont Blanc area, 4250 m)	8 June snow surface (0–40 cm depth)	0.13	
	2 December ice core (200–210 cm)[1]		23.46
Mont de Lans glacier (Ecrins area, 3300 m)	25 May ice core (0–20 cm)[1]	5.79	4.08
North America			
Eclipse site (lat. 60°50′ N., long. 139°50′ W., 3017 m)	Summer 1986 ice core (80–100 cm)[1]		0.18
Seward Glacier (lat. 60°22′ N., long. 139°50′ W., 1830 m)	Summer 1986 ice core (100–120 cm)[1]		0.15
Mount Logan (lat. 60°35′ N., long. 140°35′ W., 5340 m)	Summer 1986 ice core (30–60 cm)[1]		0.04
Snow Dome (in the Rocky Mountains, Alberta, 3406 m)	9 November 1986 ice core (85–95 cm)[1]		0.13

(1) Maximum observed value of radioactivity of snow layer which may correspond to Chernobyl; (a), (b), (c): counting dates ((c) is October 1986).

(2) Pourchet and others, 1986 (published 23 October 1986).

Southern Hemisphere) of 12.4 kCi, composed of 10.8 ± 2.1 kCi from the satellite and 1.6 ± 0.3 kCi from thermonuclear tests (Hardy and others, 1973). This ^{238}Pu fall-out constitutes a chronological level in the Antarctic snow layers where the corresponding peak radioactivity values are as high as 1.5×10^{-3} Bq kg^{-1} at Dome C (East Antarctic plateau) (Cutter and others, 1979).

January 1978. The *Cosmos 954* satellite spread 50 kg of highly enriched uranium over northern Canada. This radionuclide has been identified in Greenland snow layers (Koïde and Golberg, 1983).

CHERNOBYL FALL-OUT IN SNOW

The Chernobyl accident (26 April 1986) (Pourchet and others, 1986) is of special concern in France, since the Chernobyl-dispersed ^{137}Cs deposited within the Alpine area (information to be published) represents 15% of the amount of the residual ^{137}Cs activity due to previous atmospheric nuclear tests.

Quantitative measurements of radioactive materials have been conducted on snow samples from several glaciers of the Northern Hemisphere: Greenland, Svalbard, North America, and the French Alps (Fig. 1). The snow samples, after melting and filtration (Delmas and Pourchet, 1977) were analysed for total beta activity using low-level counting equipment (Pinglot and Pourchet, 1979) and for gamma activity by spectrometry (using a specially designed low-background scintillation detector (Pinglot and Pourchet, 1981)) in order to identify the artificial radio-isotopes from the Chernobyl accident among the natural background radioactivity (short- or long-lived isotopes mainly from the decay products of uranium and thorium).

SNOW-SAMPLING SITES

Freshly fallen snow

The radioactive materials were mostly scavenged by the precipitation process and there was no dry deposition on the snow itself. Old snow (sampled on 8 May 1986 in Ny Alesund, Svalbard) was free of radioactivity, whereas the 10–11 May fresh snowfall at Austfonna was contaminated (Table I). The scavenging process was similar to that observed with wet precipitation (Fry and others, 1986); at the precise time of arrival of the Chernobyl pollution, as shown in Table I, the artificial radioactive levels show a great increase: 5.47, 10.05, and 4.08 Bq kg^{-1}, respectively, in Austfonna, Aiguille du Midi (Mont Blanc area, 3800 m), and Mont de Lans glacier (Ecrins area, 3300 m) (Fig. 2).

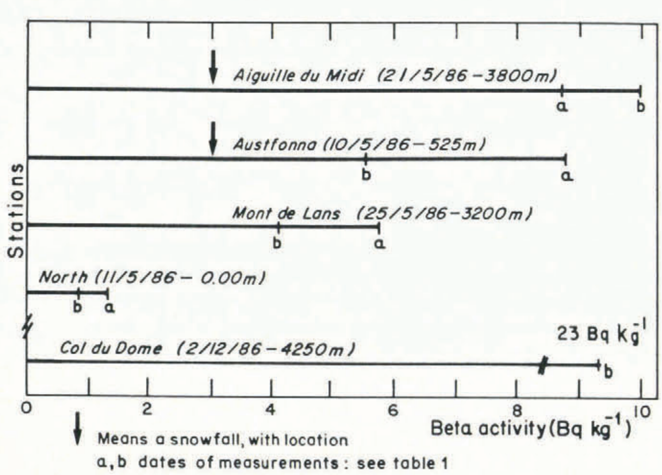

Fig. 2. Comparison of beta activity from several glaciers of the Northern Hemisphere.

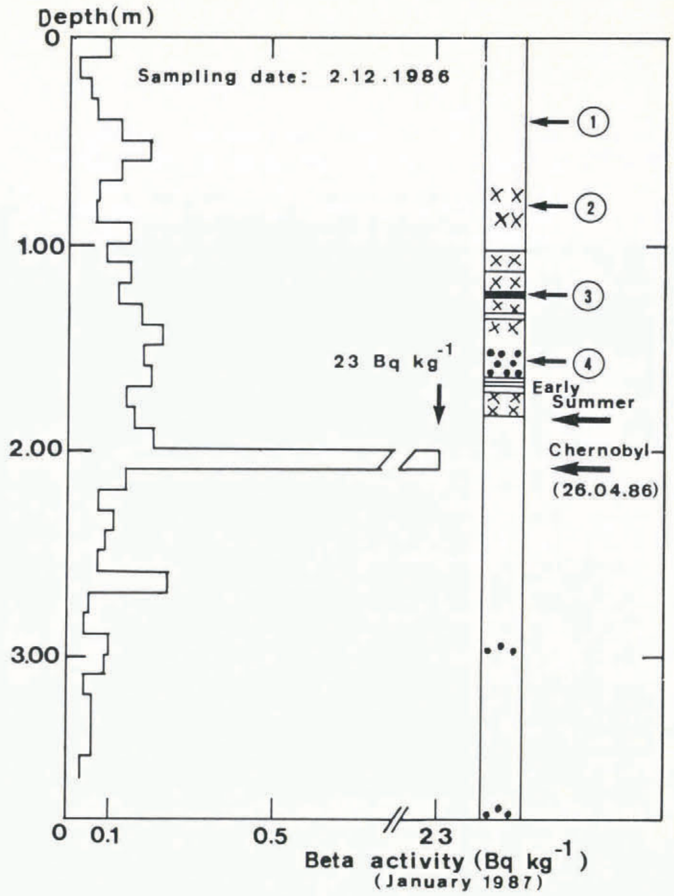

Fig. 3. Beta activity versus depth for Col du Dôme (Mont Blanc area, 4250 m; 2 December 1986 drilling; January 1987 measurements). (1) Small grain firn; (2) Rough firn; (3) Ice layer; (4) Ice lens.

French Alps

An ice core was drilled at Col du Dôme (Mont Blanc area, 4250 m) on 2 December 1986. This core (Fig. 3) shows a narrow layer of much enhanced beta activity (23 Bq kg^{-1}) between depths of 2.0 and 2.1 m, clearly deeper than the relatively high levels of natural radioactivity which prevail each summer due to a reduced snow-cover leading to the spreading of exposed soils by aeolian processes. The radioactivity peak is high compared to the previously measured values in the precipitation samples, despite the infrequent and light precipitation events in May 1986, as recorded at the nearby meteorological station (Les Contamines-Montjoie) (Association Météorologique de la Haute-Savoie, 1986) (Fig. 4), in addition to a Nivose automatic snow-cover station (Plan de l'Aiguille du Midi, elevation: 2403 m) (EERM/CEN, 1986). Based on the gamma-spectrometry measurements, the ^{137}Cs specific and deposited activities are respectively 10.4 Bq kg^{-1} and 538 Bq m^{-2} at the Col du Dôme station, which are in good agreement with the value determined on a sediment core

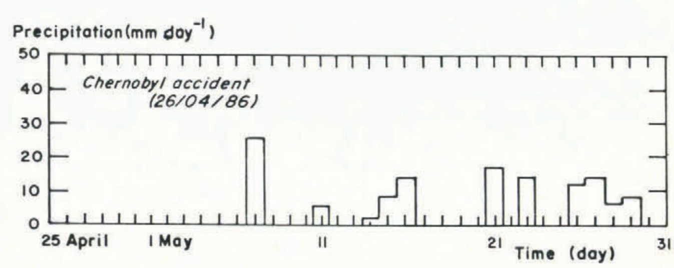

Fig. 4. Daily precipitation during April–May 1986 at Les Contamines-Montjoie meteorological station (Haute-Savoie, 1180 m).

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from the nearby lake Lérié (420 Bq m^{-2}) (Mélières and others, in press), and the value from the Mont de Lans glacier ice core (200 Bq m^{-2}), as discussed below.

A second ice core drilled on 25 May 1986 in Mont de Lans glacier (Ecrins area, 3300 m) clearly exhibits a very strong radioactive level due to the Chernobyl fall-out. This level (4.08 Bq kg^{-1}) is of the same order as that detected in the Col du Dôme ice core (23 Bq kg^{-1}). Due to the lower elevation of the temperate Mont de Lans glacier, melting and percolation occur, diffusing the Chernobyl layer down to a depth of 1.2 m (Fig. 5). As noted above, the ^{137}Cs deposited activity is 200 Bq m^{-2}, with a specific activity of 1.76 Bq kg^{-1}. Chernobyl fall-out is also well marked (2 Bq kg^{-1}) in another ice core, drilled in the summer of 1987 at Col des Ecrins-Glacier Blanc (Ecrins area, 3300 m) for snow-accumulation determination.

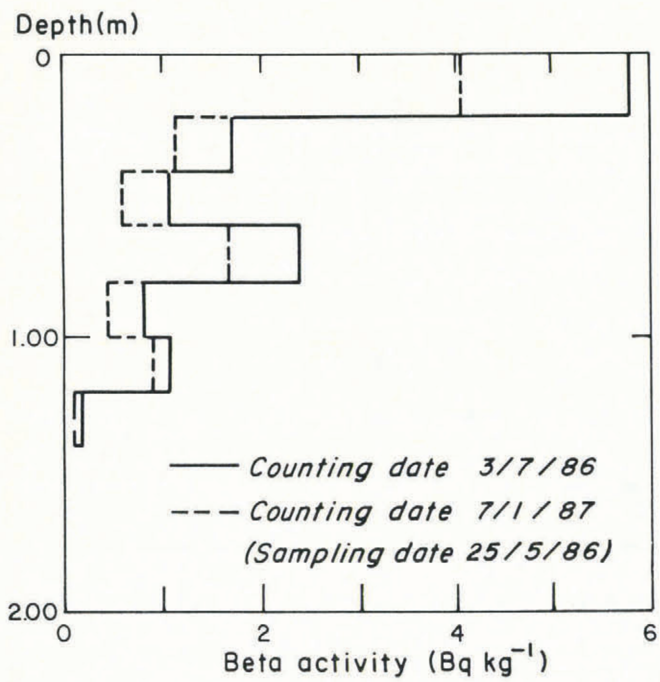

Fig. 5. Beta activity versus depth for an ice core from Mont de Lans glacier (Ecrins area, 3300 m; 25 May 1986 drilling).

North America

Other snow samples were collected in the summers of 1986 and 1987 in North America (Rocky Mountains, 3460 m; Mount Logan, Canada, 5340 m). Although air samples had reflected the Chernobyl accident (Gilbert, 1986), beta activity in the snow did not significantly exceed the natural radioactivity levels found at the five different sites. Samples of a greater weight should have been used to obtain a more accurate radioactive signal from Chernobyl. Moreover, these samples should have been subjected to a highly sensitive gamma-ray spectrometer, in order to identify the specific isotopes from Chernobyl.

DISCUSSION

The radioactivity increase shows an extensive and variable spatial distribution, including a large range of altitudes (from sea-level in Svalbard up to 5340 m on Mount Logan) and latitudes (from about lat. 45° to 90°N.) (Ambach and others, 1987; Davidson and others, 1987; Haeberli and others, 1988). This increase in total beta activity reached about 100 times the level of freshly deposited natural snow. Radioactive fall-out levels are highly dependent on the amount of precipitation and on the wind conditions, as shown by the Col du Dôme profile, and possibly the Mount Logan snow.

Surface conditions also lead to irregularities in the radioactivity profile (melting, wind scouring, etc.). Therefore, identification of the Chernobyl layer requires close sample spacing along each ice core.

The samples from several stations were combined for identification of ^{137}Cs and ^{134}Cs by gamma spectrometry (sensitivity of about 0.04 Bq) and for determination of the activity of each element deposited.

Moreover, these measurements led to the quantitative detection of ^{134}Cs and ^{137}Cs, among other isotopes, except in the North American samples. A subsequent decrease in radioactivity (as described by Picciotto and others (1971); (Table I, Figs 2–5)) has been observed for most Chernobyl-contaminated samples, except the snowfall from Aiguille du Midi (21 May 1986, 3800 m) (see Fig. 2); no clear interpretation can be given.

Despite this decrease, the ^{137}Cs activity (half life: 29.5 years) will still be a useful well-known level in snow at locations where Chernobyl fall-out occurred.

CONCLUSION

The Chernobyl accident gave rise to a very strong radioactive level in the snow deposited in Greenland, Svalbard, and the Alps. This new radioactivity peak is therefore suitable for dating the snow layers. However, the temporal resolution of this event is quite low and depends on the amounts of precipitation and surface conditions.

In North America, the detection of this new artificial radioactivity reference level will require snow samples of greater weights.

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