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VERTICAL DISPERSION OF CHERNOBYL-FALLOUT BY MELTWATER IN A TEMPERATE ALPINE GLACIER

Abstract: AMBACH W., REHWALD W., BLUMTHALER M., EISNER H. & BRUNNER P., *Vertical dispersion of Chernobyl-fallout by meltwater in a temperate alpine glacier* (ISSN 0084-8948, 1989).

Gross-beta-activity of snow samples from 10 vertical profiles was measured with respect to their contamination by fallout from the Chernobyl reactor accident. Samples were collected on Kesselwandferner (Ötztal Alps, Austria) in the years 1986, 1987 and 1988. Peak activity concentrations decrease from >100 Bq/kg (1986) to <10 Bq/kg (1988), however, a dispersion of the contaminated range to depths of about 11 m is observed, while the contamination per unit area remained almost constant. With gamma-spectroscopy the isotopes ^{137}Cs and ^{134}Cs were detected as dominant.

KEY WORDS: Chernobyl accident, Radioactive fallout, Alpine glaciers.

Riassunto: AMBACH W., REHWALD W., BLUMTHALER M., EISNER H. & BRUNNER P., *Dispersione verticale della nube radioattiva di Chernobyl in un ghiacciaio alpino temperato* (ISSN 0084-8948, 1989).

Sono state misurate le attività radioattive (particelle beta) di campioni di neve su 10 profili nella zona di Kesselwandferner (Alpi di Ötztal, Austria) negli anni 1986, 1987 e 1988 in relazione alla contaminazione seguita alla formazione della nube radioattiva di Chernobyl e alla sua ricaduta. La concentrazione diminuisce da >100 Bq/kg (1986) a <10 Bq/hkg (1988) e comunque è stata osservata una dispersione dell'intervallo contaminato, alla profondità di circa 11 m. La contaminazione per unità di superficie è rimasta invece quasi costante. Per mezzo della spettroscopia gamma si è osservata una dominanza degli isotopi ^{137}Cs e ^{134}Cs.

TERMINI CHIAVE: Incidente di Chernobyl, Caduta di povere radioattiva, Ghiacciai alpini.

INTRODUCTION

This study was carried out to investigate vertical profiles of radioactive contamination from Chernobyl fallout in snow and their temporal changes. Layers of snow within the accumulation area of a glacier are well suited for such studies as displacement occurs within a sufficiently great depth range. In contrast, such measurements of vertical dispersion of radioactive fallout in soil are more difficult because displacement of isotopes occurs there very slowly and only within a range of some centimeters. Due to the coarse structure of soil layers vertical profiles do not have great significance.

Kesselwandferner (Ötztal Alps, Austria) was chosen as the site of measurement because from this glacier glaciological and micrometeorological data are available for the last 35 years. Kesselwandferner is a temperate glacier, where in summer meltwater percolates through snow. The site of measurement is located in the center of the accumulation area within an area of 10.000 m².

Measurements of the contamination of glaciers in the French Alps (POURCHET & *alii*, 1988) show the gross-beta-activities per area lower by a factor of about 10 compared with the present paper while in North America activity in snow does not exceed the natural radioactivity levels. Radioactive cesium resulting from the Chernobyl accident has also been detected in Greenland snow (POURCHET & *alii*, 1986) and in the Greenland Ice Sheet (DAVIDSON & *alii*, 1987). In contrast to the Greenland Ice Sheet, Kesselwandferner is a temperate glacier where vertical dispersion of contamination occurs by meltwater percolation.

METHODS

On Kesselwandferner, at an altitude of 3250 m a.s.l., 14 snow profiles were drilled in July 1986, 9 profiles in August 1987 and 10 profiles in July 1988. The depth of

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the profiles reached from the surface to 1 m in 1986, from 2.5 to 6 m in 1987 and from 3.5 to 11 m in 1988. Each profile consisted of samples of some 15-20 cm thickness. Because of limitations in the organization of sampling it was not possible to reach greater depth than 6 m in 1987 and 11 m in 1988. Therefore any displacement of fallout into greater depths is not detected.

The samples were evaporated to their dry residues and their gross-beta-activities were measured in August 1986, September-December 1987 and September-December 1988, respectively, using a low-level flow-type counting system (Type BF100L, Berthold Analytic Instruments, FRG), calibrated with ^{40}K. Therefore gross-beta-activities were obtained as ^{40}K equivalents.

The isotopes were identified using a high-purity Ge-detector (PGT, Princeton Gamma-Tech, FRG) with a resolution of 1.3 keV and a relative efficiency of 30% for the 1.33 MeV line of ^{60}Co. Gamma — spectra were stored in an 8 k — channel analyzer (model CATO, SILENA, Italy), calibrated with an ^{152}Eu standard. A SILENA supplied program (SILGAMMA) was used for qualitative and quantitative spectrum analysis.

RESULTS AND DISCUSSION

For comparison fig. 1 shows typical vertical profiles of gross-beta-activity from the years 1986-1988 demonstrating three effects:

- Contaminated snow layers immerse from year to year in greater depth corresponding to annual accumulation rates
- The depth range contaminated disperses from year to year due to displacement of fallout by meltwater percolation
- Peak activity concentrations decrease from > 100 Bq/kg (1986) to < 10 Bq/kg (1988).

Activities indicated are values at the respective times of measurement. The observed decrease of activities results from physical decay and from vertical dispersion of the contamination.

The various patterns of activity concentrations of 10 vertical profiles taken in 1988 are shown in fig. 2. Activities indicated are values at the respective times of measurement. It can be seen that the peak values of gross-beta-activity scatter from 3 to 46 Bq/kg. No regular pattern of vertical distribution occurs within the contaminated depth range. Most peak values are found in the top layers of the contaminated range but can also be seen in deeper layers. Samples from above the contaminated range show only neglibile small activities corresponding to the natural background. Thus a distinct level of the change in contamination results. It is possible to use this layer as a reference horizon for dating representing the time of the deposition of the Chernobyl fallout (AMBACH & *alii*, 1987). The lower boundary of the contaminated depth range is not expressed as distinctly as the upper boundary. This can be explained by the influence of percolating meltwater.

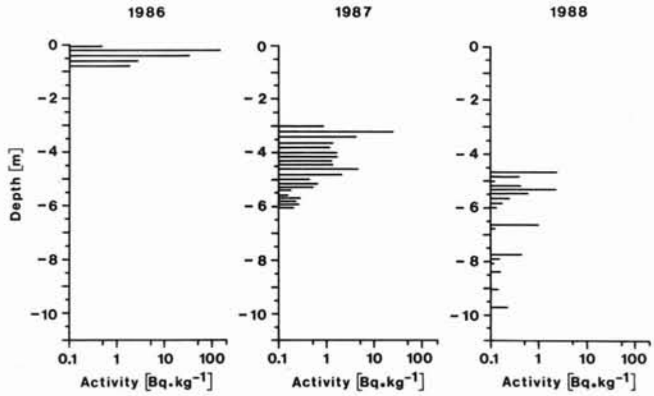

FIG. 1 - Gross-beta-activity of representative vertical snow profiles in the years 1986, 1987 and 1988 on Kesselwandferner (Ötztal Alps, Austria). Depth zero represents the surface at the respective times of sampling. Dates of sampling: July 1986, August 1987, July 1988, dates of measurement: August 1986, September-December 1987, September-December 1988.

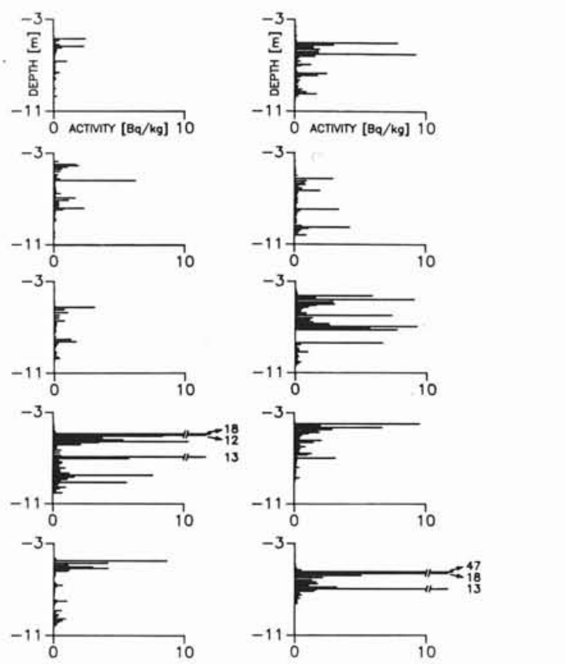

FIG. 2 - Vertical profiles of gross-beta-activity taken within an area of about 10.000 m² on Kesselwandferner (Ötztal Alps, Austria). Date of sampling: July 1988, date of measurement: September-December 1988.

The most remarkable characteristics are the irregularities in the vertical distribution of peak activities and the great local differences within a relative small area of sampling. It is concluded that meltwater percolation is of major importance for fallout displacement. From detailled studies it is known that meltwater does not percolate homogeneously through snow but in distinct channels ("channelling flow").

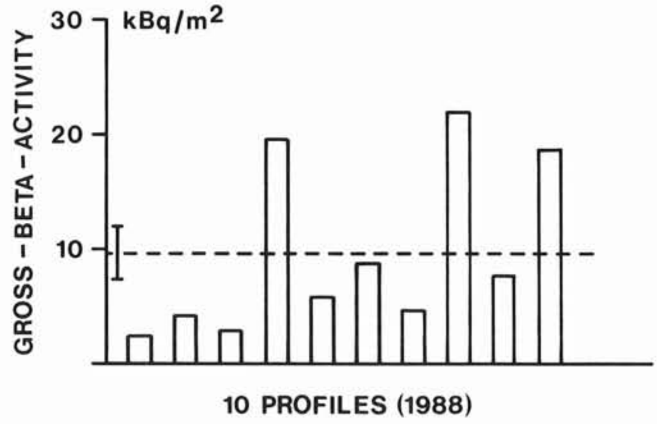

FIG. 3 - Gross-beta-activities per unit area of 10 vertical profiles from Kesselwandferner (Ötztal Alps, Austria). Profiles are the same as in fig. 1. Activities are corrected to May 1, 1987.

Integration of activities along a vertical profile gives the surface contamination in Bq/m^2. To distinguish between the effect of radioactive decay and migration of fallout by meltwater percolation the gross-beta-activity per unit area was corrected to a common date, May 1, 1987. A comparison of values therefore only shows the influence of leaching out of fallout from the contaminated depth range. Mean values of the gross-beta-activities per unit area and their corresponding SEM's are calculated as 10.4 ± 1.5 kBq/m^2 for 1986, 6.6 ± 2.4 kBq/m^2 for 1987, and 9.7 ± 2.4 kBq/m^2 for 1988. Values for the various profiles taken in 1988 are given in fig. 3. The gross-beta-activity per unit area is in the same order of magnitude as obtained in Swiss Alps by HAEBERLI & *alii*, 1988. From fig. 3 also great local variations of activity per unit area can be seen with differences of a factor of 10 within 100 m distance.

Activities per unit area do not differ significantly from 1986 to 1988. Thus it is concluded that the profiles cover the respective ranges of contamination. The correction of activities to May 1, 1987 was carried out using the power function $A(t) = A_o . t^{-0.226}$ where A denotes gross-beta-activity and t time in days. The power of 0.226 is not identical to the power in Way-Wigner's law as discussed by ADERHOLZ & WAGNER (1987). The value of 0.226 has been determined from measurements of the dry residue of samples over a period of 600 days (AMBACH & *alii*, 1988b).

The activity concentration of a sample can be expressed either by the activity per sample mass (Bq/kg) or by the activity per mass of dry residue (Bq/mg). These two activity concentrations are correlated by the concentration of dry residue in sample mass (mg/kg). The respective mean values and their corresponding SEM's and the peak values are given in tab. 1. As each of the peak values occurs in a different profile they have to be regarded as outliers.

TABLE 1

MEAN VALUES AND PEAK VALUES OF GROSS-BETA-ACTIVITY CONCENTRATION IN VERTICAL PROFILES FROM KESSELWANDFERNER (ÖTZTAL ALPS, AUSTRIA).

	Activity per sample mass [Bq/kg]	Activity per mass of dry residue [Bq/mg]	Dry residue per sample mass [mg/kg]
Mean activity	1.14 ± 0.16	0.08 ± 0.02	11.6 ± 0.7
Peak activity	46.99	1.27	204

Gamma-spectrum analysis was carried out with samples from 1986, 1987, and 1988. Besides the dominant isotopes ^{137}Cs and ^{134}Cs the isotopes ^{95}Zr, ^{95}Nb, ^{103}Ru, $^{106}Ru/Rh$, ^{110m}Ag, ^{125}Sb and ^{144}Ce were detected with significance in 1986 (AMBACH & *alii*, 1988a). Gamma-spectrum analysis of samples taken in 1988 from the depth ranges 3.5-6 m and 6-11 m, respectively, show that in both sets of samples ^{137}Cs and ^{134}Cs are dominant with the ratio $^{137}Cs/^{134}Cs$ being 4.9 and 5.6. Besides ^{137}Cs and ^{134}Cs in the upper set the isotopes $^{106}Ru/Rh$, ^{110m}Ag and ^{125}Sb are detected as traces without significance, in the lower set only traces of $^{106}Ru/Rh$ occur without significance (December 1988). Isotopes with half-lives shorter than that of ^{110m}Ag (250 d) are not detected.

REFERENCES

ADERHOLZ M. & WAGNER S., (1987) - *Das Abklingen der ß-Aktivität des Tschernobyl-Fallouts.* Physik. Blätter, *43*(6), 159-165.

AMBACH W., REHWALD W., BLUMTHALER M. & EISNER H., (1987) - *Chernobyl fallout on Alpine glaciers.* EOS, *68*(45), p. 1577.

AMBACH W., REHWALD W., BLUMTHALER M., EISNER H. & BRUNNER P., (1988a) - *Radioactive fallout on Alpine glaciers from the Chernobyl nuclear accident.* Zeit. Gletsch. Glazialgeol., *23*(2), 123-129.

AMBACH W., REHWALD W., BLUMTHALER M., EISNER H. & BRUNNER P., (1988b) - *Displacement of Chernobyl fallout in snow layers of temperate Alpine glaciers.* Total Environment, *76*, 101-107.

DAVIDSON C.I., HARRINGTON J.R., STEPHENSON M.J., MONAGHAN M.C., PUDYKIEWICZ J. & SCHELL W.R., (1987) - *Radioactive Cesium from the Chernobyl Accident in the Greenland Ice Sheet.* Science, *237*, 633-634.

HAEBERLI W., GAEGGELER H., BALTENSPERGER U., JOST D. & SCHOTTERER U. (1988) - *The signal from the Chernobyl accident in high-altitude firn areas of the Swiss Alps.* Ann. Glaciology, *10*, 48-51.

POURCHET M., PINGLOT J.F. & GASCARD J.C. (1986) - *The northerly extent of Chernobyl contamination.* Nature, *323*, p. 676.