Band 18 (1982), Heft 1, Seite 37—45

ZEITSCHRIFT FÜR
GLETSCHERKUNDE
UND GLAZIALGEOLOGIE

DATING OF ICE CORES FROM VERNAGTFERNER (AUSTRIA) WITH FISSION PRODUCTS AND LEAD-210

By HANS R. VON GUNTEN, Bern, ELFRIEDE RÖSSLER, Würenlingen, and HEINZ GÄGGELER, Darmstadt

With 2 figures

ABSTRACT

Fission product (^{90}Sr—^{90}Y, ^{137}Cs, total beta) and ^{210}Pb—^{210}Po activities were measured in core samples from the temperate Vernagtferner (3150 m altitude, Oetztal Alps, Austria). The results show that the investigated fission products are transported with water resulting from melting processes, and are sorbed on dust or dirt horizons. These products are, therefore, not suited for dating temperate glaciers.

^{210}Pb is also transported with water and displaced from its original deposition. However, despite large fluctuations, the specific activity of ^{210}Pb decreases with depth, and can be used to estimate accumulation rates and the age of the ice. The average annual accumulation rate amounts to about 80 cm water equivalent, and the deepest sample (81 m i. e. ≈ 65 m w. e.) was deposited in the beginning of this century. These results agree with data obtained from other observations on this glacier and show that the ^{210}Pb-method is suitable to date temperate glaciers, if the ice cores cover a time interval of about 100 years (i. e. ≈ 4 half-lives of ^{210}Pb). The surface activity of ^{210}Pb was found to be 5 ± 1 dpm per kg of ice in agreement with other locations in the Alps and with measurements of fresh snow.

DATIERUNG VON EISKERNEN AUS DEM VERNAGTFERNER (ÖSTERREICH) MIT SPALTPRODUKTEN UND BLEI-210

ZUSAMMENFASSUNG

An Firn- und Eisproben einer Kernbohrung auf dem temperierten Vernagtferner (3150 m Meereshöhe, Ötztaler Alpen, Österreich) wurden Spaltprodukte (^{90}Sr—^{90}Y, ^{137}Cs, Gesamt-Beta) und ^{210}Pb—^{210}Po-Aktivitäten bestimmt.

Die Ergebnisse zeigen, daß die untersuchten Spaltprodukte mit dem Schmelzwasser transportiert und an Staub- und Schmutzhorizonten adsorbiert werden. Diese Spaltprodukte sind deshalb nicht für die Datierung temperierter Gletscher geeignet.

^{210}Pb wird ebenfalls mit dem Schmelzwasser transportiert und dadurch aus seiner ursprünglichen Ablagerungsschicht verschleppt. Die spezifischen Aktivitäten von ^{210}Pb nehmen jedoch trotz großer Schwankungen mit der Tiefe ab und können somit zur Abschätzung von Akkumulationsraten und des Eisalters herangezogen werden. Die mittlere jährliche Akkumulationsrate beträgt angenähert 80 cm Wasseräquivalent. Die tiefste Probe aus 81 m Tiefe (entsprechend ≈ 65 m Wasseräquivalent) wurde zu Beginn unseres Jahrhunderts abgelagert. Diese Ergebnisse stimmen mit anderen Untersuchungsergebnissen auf diesem Gletscher überein und belegen damit, daß die ^{210}Pb-Methode zur Datierung temperierter Gletscher geeignet ist, wenn die Eiskerne einen Zeitraum von ungefähr 100 Jahren, d. h. ≈ 4 Halbwertszeiten von ^{210}Pb, umfassen. Die Oberflächenaktivität für ^{210}Pb wurde zu 5 ± 1 dpm kg^{-1} Eis bestimmt und steht in Übereinstimmung mit anderen Alpengletschern sowie mit Meßwerten für Neuschnee.

INTRODUCTION

In the course of the extensive investigation of the Vernagtferner (Oetztal Alps, Austria) which is described in detail in this volume, an attempt was made to date ice core samples from this glacier.

Recent accumulation rates and ages of firn or ice samples can, in principle, be measured with fall-out radioactivity remaining from the extensive testing of nuclear weapons during the 1950's and 1960's which culminated in 1962/63. In temperate glaciers like the Vernagtferner this dating approach is, however, problematic due to transport and sorption of fall-out products occurring during melting processes which lead to a redistribution and smear-out of the deposited activity. Ambach et al. (1971) demonstrated, with total beta activity measurements in ice cores from the neighbouring Kesselwandferner (Austria), a significant correlation of the activity with summer ablation horizons. Thus, melting processes may strongly alter the initial distribution of fission products in the ice.

The ^{210}Pb method was proposed by Goldberg (1963) to determine recent accumulation rates on arctic glaciers. ^{210}Pb (half-life 22.3 years) is a late decay product of ^{222}Rn which emanates from the ground into the atmosphere. ^{210}Pb then is adsorbed on aerosols which are washed out from the atmosphere by precipitation. If the ^{210}Pb concentration in fresh snow is assumed to be constant, this nuclide can be applied for dating purposes. Based on its half-life a time period of about 100 years is accessible with this method.

First attempts to apply the ^{210}Pb method to date a temperate glacier were undertaken by Picciotto et al. (1967). These authors used firn cores originating from the accumulation zone of the Kesselwandferner (Austria) which were recovered at about 3200 m altitude and represented a time interval of about 10 years only. The ^{210}Pb activities varied by more than a factor of two from sample to sample around a mean value of 4.3 dpm per kg of ice and showed no decrease with depth. Schotterer et al. (1977) found very large fluctuations (up to a factor of 100) in the specific activity of ^{210}Pb in firn samples from the Plaine Morte (2750 m altitude, Switzerland). The high activities could be attributed to dirt horizons. Samples from the Jungfraujoch Ice Cap (3470 m altitude, Switzerland) also showed an irregular distribution of the ^{210}Pb activity and no decrease of the activity with depth of the samples (Schotterer et al., 1977). However, these ice cores covered only a period of about 20 years.

In contrast to these attempts to date temperate alpine glaciers von Gunten and Rössler (1979), and Gäggeler et al. (1983) demonstrated on ice cores from the Colle Gnifetti (4450 m altitude, Switzerland) that fission products as well as ^{210}Pb are suitable tools to date cold alpine glaciers at higher elevation. Since the firn and ice cores drilled on the Vernagtferner (Oerter et al., 1982) reached to much larger depths than those taken before from other temperate alpine glaciers it seemed justified to try the ^{210}Pb method once more. Based on these measurements, which were expected to cover a time interval of roughly 100 years, it should be possible to judge the general applicability of the ^{210}Pb method for ice dating. Besides this main object of the present investigation additional information on the distribution pattern of fission products in a temperate glacier was obtained.

EXPERIMENTS

A. SAMPLES

The cores were drilled in 1979 at an elevation of 3150 m on the Vernagtferner (see Oerter et al., 1982). They were transported and stored in deep-frozen condition. Samples from two different cores were used in this investigation:

i) Drill core I with a total length of 81.35 m (coordinates on map "Vernagtferner 1969": 37461.7/93977.4) was used for the ^{210}Pb—^{210}Po dating. The core was cut at the GSF-Institut für Radiohydrometrie (Munich) in 4 sections parallel to the drilling axis. Our samples had a length of about 60 cm each and corresponded to about 10 % of the total core weight. About 10 % of each of these 60 cm long samples was taken for our measurements.

ii) Selected sections of 60—70 cm length of drill core II (coordinates: 37374.3/93850.4) were used for the measurements of ^{90}Sr—^{90}Y, ^{137}Cs and the total beta activity. These samples covered the core region where the 1962/63 fall-out activity was expected based on a significant peak in the tritium activity observed in core I at this depth (Oerter and Rauert, 1982).

B. MEASUREMENT OF FISSION PRODUCT ACTIVITIES

Radiochemical methods (Flynn, 1975) were used for the determinations of ^{90}Sr—^{90}Y, and ^{137}Cs in the ice of core II samples 42, 43, 44 and 45. About 1 kg of ice was melted in a polyethylene beaker, having 10 ml of concentrated nitric acid and 10 mg each of Sr-, Y-, and Cs-Carriers present. The resulting water was filtered (Schleicher-Schüll No. 589[3]) and evaporated to a volume of $\approx$ 10 ml.

Strontium was precipitated with fuming nitric acid and redissolved in water. A barium chromate precipitation (addition of 1 mg Ba) removed radium. After several additional cleaning steps [$Fe(OH)_3$-scavengings] strontium was precipitated as carbonate. A low-background proportional counter ($\approx$ 1 cpm) was used to follow the ingrowth of ^{90}Y into the sample.

Yttrium was extracted from the remaining solution with 2-diethylhexylorthophosphoric acid in heptane, and backextracted with hydrochloric acid. Yttrium was precipitated as hydroxide, dissolved in nitric acid and finally precipitated as yttrium oxalate. The decay of ^{90}Y was followed on a low-background proportional counter.

Cesium was precipitated from the remaining solution with silico-tungstic acid. The precipitate was dissolved in sodium hydroxide. The final precipitation was cesium perchlorate. The 662 keV γ-line was measured on a Ge(Li)-detector.

The chemical yields for the determination of these elements were 80—90 %. Computer programs were used to analyze the growth and decay of ^{90}Y and the γ-ray spectra.

Total beta and ^{137}Cs: About 1 kg of ice was melted and filtered for the determination of total beta and ^{137}Cs activities. The activity on the filters was measured on a low-background ($\approx$ 1 cpm) proportional counter and on a Ge(Li)-detector.

C. MEASUREMENTS OF ^{210}Pb—^{210}Po

The α-radiation of ^{210}Po which is in radioactive equilibrium with ^{210}Pb was used for these determinations. Ten 60 cm core I sections, corresponding to about 6 m core

length and to a total weight of 140—230 g were combined and melted, having 5 ml concentrated hydrochloric acid per 100 g of ice, and ^{208}Po tracer present. Sulfur dioxide gas was bubbled for 3 minutes through the solution at a temperature of 90—95° C. Polonium was deposited on a silver disk (diameter 15 mm) which was suspended in the hot solution (Figgins, 1961). An almost quantitative deposition was achieved in about 7 hours. The chemical yield was measured relative to the ^{208}Po tracer. The samples were counted on Si(Li) surface barrier detectors (ORTEC, 300 mm^2) having an α-energy resolution of about 20 keV full width at half maximum at 5.486 MeV. The efficiency for the 5.3 MeV α-line of ^{210}Po was about 18 %.

After plating ^{210}Po the solutions were filtered and the weight of the dirt was determined. The two largest dirt samples were dissolved using HF and HNO_3. ^{210}Po was plated from these solutions according to the procedure given above.

RESULTS AND DISCUSSION

A. MEASUREMENTS OF FISSION PRODUCTS

The results of the total beta and ^{137}Cs radioactivity measurements in the dirt filtered-off from the melted samples of core II are shown in table 1 and are presented in

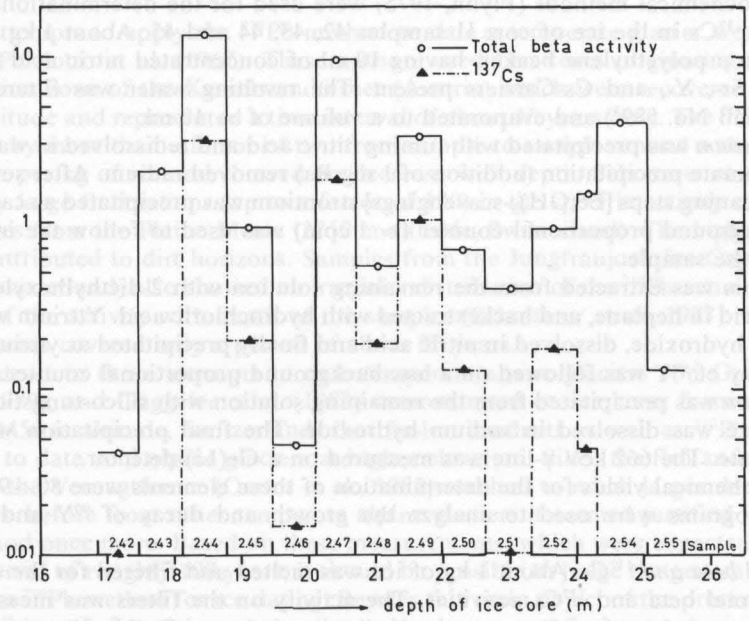

Fig. 1: Total beta and ^{137}Cs activities measured in dust and dirt of core II from the Vernagtferner (Austria, 3150 m altitude). The core section was selected around the expected location of the 1962/63 fall-out horizon. Several activity peaks were found; the fall-out horizon of the year 1962/63 can not be identified. A high correlation exists between total beta und ^{137}Cs activities (correlation coefficient 0.95) and activities and amount of dust (0.74)

fig. 1. Since the detectors were not calibrated for these measurements relative activities (cpm) are given. The distribution of the activity within these dirt samples is very irregular, and large fluctuations are observed between adjacent samples leading to several correlated peaks of ^{137}Cs and of the total beta activity. On the other hand, in the filtrate of the melted samples the activities of the radiochemically isolated ^{90}Sr, ^{90}Y and ^{137}Cs were found to be negligible. In addition, no significant decay (^{90}Y) or increase ($^{90}Sr/^{90}Y$) was observed in growth and decay analyses. This distribution pattern is in sharp contrast to the very pronounced activity peak found in the bomb fall-out of the years 1962/63 which is well conserved in samples recovered at 4500 m altitude on the cold Colle Gnifetti glacier (von Gunten and Rössler, 1979). The magnitude of many of the activity peaks in the samples from the Vernagtferner is correlated with the amount of dirt; this supports earlier observations (Ambach et al., 1971; Schotterer et al., 1977). The correlation of the activity with dirt horizons indicates that radionuclides are transported by percolating water and are sorbed on these dust and/or dirt horizons in the ice. The very low concentrations of dissolved fall-out products in the filtrate of the samples support the conclusion that fission products are strongly sorbed on dirt particles. Therefore, the observed activities do not allow to locate the place of initial deposition of the nuclides, and dating of temperate glaciers with fission products is not feasible or involves at least very large uncertainties. This conclusion disagrees with the interpretation of in situ measurements in borehole I of natural gamma-ray activity performed by Drost and Hofreiter (1982) who attribute activity peaks to the years 1953, 1962, 1963 and 1977.

Table 1: Total beta and ^{137}Cs activities in filtered dirt horizons from Vernagtferner (Austria). Samples of core II

Sample No.	Depth m	Mass of ice g	Mass of dirt mg	Total beta activity cpm	^{137}Cs cpm
2.42	16.85—17.46	997.7	3.01	0.04	0.01
2.43	17.46—18.11	1072.8	6.98	2.02	—
2.44	18.11—18.77	1213.2	40.91	13.71	3.07
2.45	18.77—19.45	1219.5	1.47	0.94	0.20
2.46	19.45—20.10	1176.5	0.83	0.05	0.01
2.47	20.10—20.68	1066.5	17.63	9.60	1.80
2.48	20.68—21.33	1186.6	2.80	0.56	0.19
2.49	21.33—21.98	1204.8	6.63	3.27	1.02
2.50	21.98—22.63	1263.7	6.11	0.69	0.14
2.51	22.63—23.31	1222.7	5.91	0.40	0.01
2.52	23.31—23.99	1231.9	6.27	0.93	0.17
2.53	23.99—24.30	693.2	5.32	1.50	0.04
2.54	24.30—25.05	1241.0	46.14	4.01	—
2.55	25.05—25.65	1059.6	2.93	0.13	—

B. MEASUREMENTS OF $^{210}Pb-^{210}Po$

The results of the $^{210}Pb-^{210}Po$ measurements in the samples of core I are given in table 2. A graphical presentation of these data together with an indication of the most

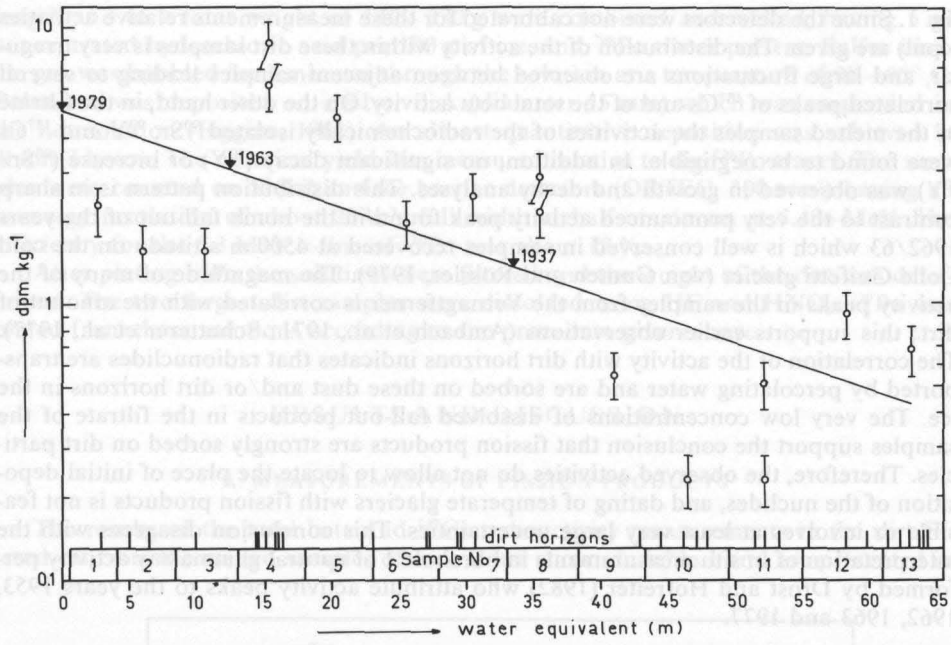

Fig. 2: ^{210}Pb—^{210}Po measurements in core I from the Vernagtferner (Austria, 3150 m altitude). The points correspond to 6 m long core sections. The large fluctuations in the measured activities are probably due to transport and sorption on dirt. The most expressed dirt horizons are indicated. However, no obvious correlation between dust and activity can be established. The ^{210}Pb activity at the surface of the glacier amounts to ~5 dpm and the mean accumulation rate to 0.8 m w. e. The deepest measured sample originates from the beginning of this century. The years indicated on the regression line correspond to the surface (1979), the maximum in nuclear testing (1963) and to a year (1937) with high amounts of dust from the Sahara desert. The positions of the year-marks are based on ^{210}Pb dating. Error bars correspond to statistical counting errors (1σ).

important dirt horizons is shown in fig. 2. The ^{210}Pb measurements scatter very much, despite the fact that 6 m long core samples were used which cover several yearly deposits. Double determinations demonstrate that the variations between different samples are not due to the precision of the method. Furthermore, we found that the annual mean values of ^{210}Pb in air samples were quite constant ($1.2 \pm 0.4 \times 10^{-2}$ pCi m^{-3} air) over the last 9 years (von Gunten and Wegmüller, 1983). The variations in activity are, therefore, not the result of variations in the input of ^{210}Pb. The observed scatter of the ^{210}Pb values is probably also produced by transport and sorption processes on the glacier. A significant correlation with dirt horizons is, however, not obvious. Similar ^{210}Pb measurements in samples from the cold glacier on the Colle Gnifetti (Monte Rosa) do not show these large fluctuations in the ^{210}Pb activities (Gäggeler et al., 1983).

The specific ^{210}Pb activities decrease, however, with increasing depth of the core. A least squares fit through the data (solid line of fig. 2) leads to a surface activity on the firn of 5.0 ± 1.0 dpm kg^{-1}. This value is in good agreement with ^{210}Pb surface activities observed on other alpine glaciers and with the radioactivity of fresh snow: Picciotto et

Table 2: ^{210}Pb measurements in core I from the Vernagtferner (Austria)

Sample No.	Depth m	Depth water equivalent m	Mass of ice g	Mass of dirt mg	Activity and estimated errors dpm per kg of ice
1	2.30— 8.08	1.06— 4.24	143.7	0.42	2.22±0.44
2	8.08—14.08	4.24— 8.38	176.1	—	1.59±0.32
3	14.08—19.84	8.38—12.90	199.1	—	1.58±0.32
4/1	19.84—25.73	12.90—17.85	223.1	0.70	6.19±1.23
4/2	19.84—25.73	12.90—17.85	213.3	2.73*	8.75±1.75
5	25.73—31.88	17.85—22.94	211.5	1.50	4.78±0.96
6	31.88—37.97	22.94—27.96	230.4	0.84	1.97±0.39
7	37.97—44.08	27.96—32.88	210.6	3.55*	2.49±0.50
8/1	44.08—50.33	32.88—38.32	218.0	1.04	2.88±0.58
8/2	44.08—50.33	32.88—38.32	213.4	0.48	2.14±0.43
9	50.33—56.38	38.32—43.58	166.1	0.23	0.55±0.11
10	56.38—62.79	43.58—49.50	183.0	—	0.23±0.05
11/1	62.79—69.18	49.50—55.00	229.5	0.04	0.23±0.05
11/2	62.79—69.18	49.50—55.00	228.3	0.59	0.51±0.10
12	69.18—75.25	55.00—61.40	223.5	0.81	0.92±0.18
13	75.25—80.24	61.40—65.70	174.5	1.06	0.68±0.14

* The ^{210}Pb activity measured in the remaining dirt after plating of ^{210}Pb was found to be 0.03—0.04 dpm mg^{-1} of dirt (see text).

al. (1967) found 4.3 dpm kg^{-1} on the neighbouring Kesselwandferner, Schotterer et al. (1977) determined a value of 4.7±0.3 dpm kg^{-1} on the Plaine Morte (Switzerland), and Gäggeler et al. (1983) ≈ 4 dpm kg^{-1} of ice on the Colle Gnifetti (Monte Rosa). Thus, the mean surface activity of ^{210}Pb seems to be practically independent on location and altitude. This result is rather surprising, since different sources and source strengths are expected to be responsible for the ^{210}Pb activities of locations which are geographically quite far apart and well separated by mountain ranges and valleys.

Based on the least squares fit through the data from this more than 80 m long core one arrives at a mean accumulation rate for the Vernagtferner of ≈ 80 cm w. e. year^{-1}. This value agrees well with accumulation rates derived from direct measurements of annual snow heights at the same location. The correlation coefficient of the linear regression is only ≈ −0.6. Therefore, the accuracy reached for this temperate glacier is not very high, but the measurements are nevertheless useful for many applications: e. g. the age of the deepest sample can be estimated to be about 80 years.

Our measurements demonstrate for the first time that the ^{210}Pb method may successfully be used to date temperate glaciers if the ice cores are long enough to cover a time span which averages out large local fluctuations. Furthermore, one has to assume that ^{210}Pb is not transported over very long distances, thus carrying younger ^{210}Pb to older (deeper) places in the glacier. The ^{210}Pb method is, therefore, generally applicable to all types of glaciers, i. e. cold (Gäggeler et al., 1983) and temperate (this paper) alpine glaciers, and polar glaciers (Goldberg, 1963; Picciotto et al., 1964) as well.

CONCLUSIONS

The ^{210}Pb method is universally applicable to date glaciers. Temperate glaciers may be dated if the recovered samples cover a period of about 100 years (corresponding to about 4 half-lives of ^{210}Pb) or more.

The surface activities of ^{210}Pb on alpine glaciers are about 4—5 dpm per kg of ice independent of different locations and altitudes.

Dating of temperate glaciers with fission products is not possible due to their transportation and sorption by percolating water.

The sorption of ^{90}Sr and ^{137}Cs on dirt horizons seems to be more expressed than that of ^{210}Pb.

ACKNOWLEDGEMENT

The authors are indebted to H. Moser and H. Oerter for a very good cooperation and for supplying the ice samples. They thank A. Grütter for many constructive discussions. Part of the work was supported by the Swiss National Science Foundation.

REFERENCES

Ambach, W., H. Eisner, F. Prantl, and M. Url, 1971: Zum Abbau radioaktiver Spaltprodukte im Firn eines Alpengletschers. Arch. Met. Geophys. Biokl.: Ser. A. Vol. *20:* 277—288.

Drost, W. and G. Hofreiter, 1982: Natural gamma logging of bore hole I on Vernagtferner (Oetztal Alps, Austria). Z. Gletscherk. Glazialgeol. *18* (1): 49—54.

Figgins, P. E., 1961: The radiochemistry of polonium. U. S. Atomic Energy Commission, NAS-NS 3037: 29—30.

Flynn, K. F., 1975: Radiochemical procedures and techniques. Argonne National Laboratory Report ANL-75-24.

Gäggeler, H., H. R. von Gunten, E. Rössler, H. Oeschger and U. Schotterer, 1983: ^{210}Pb-Dating of Cold Alpine Firn / Ice cores from the Colle Gnifetti. J. Glaciology, *29* (101): 165—177.

Goldberg, E. D., 1963: Geochronology with ^{210}Pb. In: Proc. Symp. Radioactive Dating, IAEA, Vienna: 121—131.

Oerter, H., O. Reinwarth and H. Rufli, 1982: Core drilling through a temperate Alpine glacier (Vernagtferner, Oetztal Alps) in 1979. Z. Gletscherk. Glazialgeol. *18* (1): 1—11.

Picciotto, E., G. Crozaz, and W. de Breuck, 1964: Rate of accumulation of snow at the South Pole as determined by radioactive measurements. Nature *203* (4943): 393—394.

Picciotto, E., G. Crozaz, W. Ambach and H. Eisner, 1967: Lead-210 and strontium-90 in alpine glaciers. Earth and Planet. Sci. Lett. *3* (3): 237—242.

Oerter, H. and W. Rauert, 1982: Core drilling on Vernagtferner (Oetztal Alps, Austria) in 1979: Tritium contens. Z. Gletscherk. Glazialgeol. *18* (1): 13—22.

Schotterer, U., R. Finkel, H. Oeschger, U. Siegenthaler, M. Wahlen, G. Bart, H. Gäggeler and H. R. von Gunten, 1977: Isotope measurements on firn and ice cores from alpine galciers. In: Proc. Symp. Isotopes and Impurities in Snow and Ice, Grenoble 1975, IAHS Publ. No. *118:* 232—236.

von Gunten, H. R., and E. Rössler, 1979: Datierung eines Eis-Bohrkerns vom Colle Gnifetti (Monte Rosa) mit ^{90}Sr, ^{90}Y und ^{137}Cs. EIR-internal report, unpublished.

von Gunten, H. R., and F. Wegmüller, 1983: In „25 Jahre KUER". Editor O. Huber, Eidg. Amt für Gesundheitswesen.

Manuscript received December 27, 1982

Authors' addresses: H. R. von Gunten
Anorganisch-chemisches Institut Univerisität Bern
CH-3000 Bern 9, and
Eidgenössisches Institut für Reaktorforschung
CH-5303 Würenlingen, Switzerland

E. Rössler
Eidgenössisches Institut für Reaktorforschung
CH-5303 Würenlingen, Switzerland

H. Gäggeler
Gesellschaft für Schwerionenforschung
D-6100 Darmstadt, FR Germany