ENVIRONMENTAL RADIATION AND RADIOACTIVITY FROM THE CERN HIGH-ENERGY ACCELERATORS

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1. INTRODUCTION

High-energy accelerators used for investigating the nuclear structure of matter are sources of secondary stray radiation and of induced radioactivity.

Stray radiation and induced radioactivity are created in materials through which the primary beam of accelerated or secondary particles pass. Induced radioactivity production depends on the radiation intensity, the exposure duration, the material itself, and the time after exposure.

To protect the environment of high-energy accelerators against the risk from stray radiation and induced radioactivity, precautions are taken. The accelerators are shielded with concrete and earth, or located underground. Water used for cooling magnets or other accelerator units becomes radioactive and is therefore recycled in closed circuits to avoid environmental contamination. Radioactive dust in air inside the accelerator building is trapped on filters.

In spite of these precautions some radiation and radioactivity originating from accelerator operation escapes into the environment. This report presents the results of measurements of stray radiation at several locations on the CERN site together with measurements of radioactivity in air, precipitation, and effluent water leaving the CERN site.

These measurements are used at CERN to control radiation exposure of individuals not belonging to the category of radiation workers (people who in their work are exposed to radiation) and therefore not individually monitored by film badges. Further, the measurements are also used to ensure that the environmental radiation and radioactivity levels from operating the Laboratory are kept within acceptable limits.

2. RADIATION AND RADIOACTIVITY MONITORING PRACTICE

The CERN Laboratory site covers 80 hectares at the French-Swiss border, 8 km northwest of Geneva, and is the seat of a 600 MeV synchro-cyclotron and a 28 GeV proton synchrotron, as well as a 50 MeV linear accelerator used as an injector to the synchrotron, and the intersecting proton storage rings.

A site monitoring system to measure the environmental radiation levels from the accelerators and other radiation sources within the Laboratory has been in operation since 1964. This system is based on a time integration of the radiation level using a 5 litre 20 atm Ar/air-filled ionization chamber for gamma radiation and charged particles, and a moderated BF_3 counter for neutron radiation. The locations of the measuring stations within the Laboratory are indicated in Fig. 1.

Radioactivity of air, precipitation, and effluent water is also continuously monitored since 1969 by measurements of total beta and gamma activities. Alpha-activity controls of environmental samples show isotopes of only natural origin.

An automatic air monitoring station, a sheltered hut with a precipitation collector on its roof, operates on the CERN Health Physics Building. The location can be seen from Fig. 1. This point, selected after air-activity and wind-condition studies, is considered representative for the CERN site. The stray radiation background from accelerator operation is relatively low and stable at this point.

The monitor draws air at a mean suction rate of 12 m^3/h through a continually moving filter tape of glass fiber material. The tape speed is 4 mm/h. Two GM counters for total beta-activity measurements installed above the filter tape at a distance from each other allow measuring immediately after and with a delay of 100 hours after aerosol collection; the latter to discriminate against natural Rn- and Tn-daughter radioactivity. The mean counter background is 18 cpm. The counter efficiency for energies above 1 MeV is 30%. The data are printed out and computer processed.

Precipitation is collected into an inox funnel of 1 m^2 catchment area. This collector was installed recently to replace the initially used plastic tray of 0.4 m^2 collecting surface. The tray let the water through a hole in its middle into a screwed-on bottle underneath. During winter a heating under the tray melted the snow and avoided sample freezing. The collector operated from December 1968 to May 1969. Due to plastic aging under the field conditions it had to be replaced. The reported data refer to the tray sampler.

The funnel sampler is fitted with a tube through which precipitation enters a container inside the air monitor hut. An overflow tube on the container collects into a bottle.

The precipitation sample is acidified, evaporated to dryness, and the residue transferred into counting planchets. A rest sample is available for chemical analyses.

Total beta activity is measured with a low-level anticoincidence methane flow counter. For 2" planchet diameter the mean background value is 2 cpm. The counter is K-40 calibrated in function of the sample weight. The counter efficiency at 10 mg/cm^2 is 49%, and drops to 30% at 100 mg/cm^2.

The CERN drainage water leaves the Laboratory site at three different points indicated in Fig. 1. The drainage system collects surface, secondary cooling and operating water, and to some extent ground and spring water. Effluents 1 and 2 drain the ground on which the accelerators are located and part of the ground under construction for the intersecting proton storage rings. Effluent 3 drains the rest of the latter ground.

Continuous radioactivity monitoring is carried out on the main effluent 1 since August 1969, on effluent 2 since August 1970, and will start on effluent 3 in 1971 together with the start of operation of the intersecting proton storage rings.

Automatic water monitors are installed in huts at the points where the effluents leave the Laboratory site. The water is received from a pump and applied with a feed rate of 240 cm^3/h to a continually moving paper tape. The tape speed is 3 cm/h. A motor driven tube distributes the droplets equally over a certain surface on the tape. The water is made to evaporate by an infrared heater underneath the tape. As the tape moves on it passes a GM counter for total beta activity measurements. The mean counter background is 110 cpm, the efficiency for energies above 1 MeV is 30%. The data are printed out and computer processed.

In addition to the total beta activity measurements of air, precipitation and drainage effluent water, isotope analyses and total gamma activity measurements are carried out gamma-spectroscopically. For this purpose the paper tapes of the air and water monitors are cut into weekly strips. NaI(Tl) detectors and a Ge(Li) detector are used together with a 400 and an 8000 channel analyser. The resolution of the 3x5" NaI(Tl) detector is 64 keV, of the Ge(Li) 2.4 keV at an energy of 0.66 MeV. The total efficiency of the NaI(Tl) is about double that of the Ge(Li) at the same energy. The spectroscopical data are computer processed.

3. MEASUREMENTS

The average yearly integrated dose due to stray radiation with background subtracted is indicated in Fig. 1. The dose-rates at the various locations depend greatly on the way in which the accelerators are used[1)]. It has been established that, in spite of increasing intensity of the accelerated beams, improvement in shielding layouts and better control of beam losses have largely compensated for the increase expected in stray radiation levels produced[2)]. The figure also clearly indicates that in the most populated part of the Laboratory a contribution to the environmental radiation is of the order of 20% of the natural background or less. This fraction increases rather rapidly as one approaches the accelerators. It should also be noted that the largest portion of the stray radiation is due to neutron radiation. In certain places, particularly along beam lines of extracted proton beams, muon beams have been observed and about half of the observed dose might then be caused by this radiation. The measurements show that stray radiation levels normally stay within 100 mrem/year at a distance exceeding 100 m from the accelerators or the experimental halls, which should be judged satisfactory from a radiation protection point of view.

Measurements of environmental radioactivity at CERN show three sources: radioactivity of natural, of nuclear bomb test, and of accelerator origin. Environmental radioactivity of accelerator origin shows isotopes produced by spallation, by thermal neutron capture, and by (n,gamma) reactions caused by high-energy particles travelling inside the accelerator buildings, inside the experimental halls, and in the soil of the earth shielding on top of the proton synchrotron. Due to the rapid decrease in intensity measured for environmental stray radiation away from the accelerators, its contribution as a radioactivity source is insignificant[3)].

Accelerator produced radioactivity detected in the environment comes from radioactive gases and aerosols which escape through openings in the accelerator buildings and experimental halls, as well as from radioactive soil and dust. The latter are washed out by precipitation and enter together with activated water into the drainage systems.

Induced airborne radioisotopes are basically produced in gaseous phase[4)]. A fraction converts into particulates either by direct materialization or by gas absorption in aerosols[5)].

Continuous radioactivity monitoring of particulates suspended in ground-level air of the CERN Laboratory site is used for assessment of total airborne radioactivity and to control the inhalation risk.

Figure 2 shows the results of continuous monitoring of the total beta activity of ground-level air at CERN between August 1969 and August 1970. The applied monitoring methods allow direct comparison of these data with those of the French and Belgian stations added to the plot[*)].

It can be seen that the CERN data fit well into the general trends and activity levels. The seasonal variation with winter minimum and spring maximum shows up at all stations. It is typical

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*) Dr. P. Pellerin and Dr. J.Grandjean are thanked for making these data regularly available.

for atmospheric fission product activity from nuclear bomb tests. Minor deviations such as the CERN December 1969 value present local variations of fission product activity but give no indication of an additional β- radioactivity from accelerator operation.

This result is confirmed by the gamma-ray analyses. Compared to the neighbouring months a slight increase of the isotope concentration of relatively short-lived fission products was noticed in December 1969, which might be attributed to the Chinese bomb tests of the winter.

The concentration of airborne, accelerator produced Be-7 in ground-level air of the CERN Laboratory site is on the average 0.5 pCi/m^3 during periods of normal accelerator operation. During December 1969 the Be-7 concentration in air was 0.04 pCi/m^3. This corresponds to about the natural concentration measured at other laboratories for this month. The drop of the Be-7 concentration to about the natural level is due to the stop of ejected beams and a long shut-down of the accelerators during this month.

Besides the Be-7, no other gamma-emitting isotopes from accelerator origin are detected in airborne environmental radioactivity. The pure beta emitters P-32, P-33 and S-35 of accelerator origin were identified from analyses of total beta activity decay curves. Their environmental concentration in air remains extremely small.

Radioactivity of precipitation is monitored to determine the wash-out ratios for air and for soil. The surface water from precipication makes on the average the highest contribution to drainage effluent water.

Figure 3 gives the monthly means of specific total beta activity of precipitation at CERN and at French and Belgian stations from December 1968 to May 1969. Good agreement among the data is noticed with regard to trends and to levels. The spring maximum is observed at all stations. Like the spring maximum of air activity it is a typical seasonal variation of fission product activity from nuclear bomb tests.

For the period no continuous measurements of air and drainage water activity have been made. The wash-out ratio calculated from air sampling experiments of about 3 weeks in January/February and April 1969 gives values comparable to those of other laboratories.

In Fig. 4 the monthly means of specific total beta activity of drainage effluent water at CERN has been plotted together with the monthly amounts of precipitation deposited on the ground drained between August 1969 and August 1970.

It can be noticed that peaks of specific drainage water radioactivity coincide with small amounts of surface water, and the reverse. This indicates that the precipitation washes activated dust deposited on the Laboratory site or activated soil into the drains. The low radioactivity of the effluent water indicates a rather high retention of the soil for radioactive products which are either induced in it by penetrating accelerator radiation, or intrude with precipitation. This model is confirmed by the daily data of drainage water radioactivity. These data show additionally, that the slower the precipitation penetrates into the soil layers, the better is the filtration by the soil. This result is in agreement with the studies of Na-22 and C-45 concentrations in soil samples from the accelerator earth shielding. Equilibrium distribution coefficients between water and soil of 1/100 for sodium and 1/1000 for calcium have been found[6]. Both isotopes are produced in soil by penetrating accelerator radiation. Gamma-ray analyses of soil samples show additionally the isotopes Be-7 and Mn-54 induced by accelerator radiation.

The quantity of radioactive substances dissolved by the intruding precipitation depends on soil and water quality, the chemical properties of the radioactive substances, and whether equilibrium between ions in liquid and solid phase is achieved. This latter is not the case for short, heavy rainfalls after a dry period. The daily data of drainage effluent activity show that short, heavy rainfalls are related to sudden radioactivity peaks and to relatively high concentrations of particles suspended in the water. This situation happened in particular during November 1969 and explains that during this month a relatively high surface water amount corresponds to a relatively high value of effluent water radioactivity.

The seasonal variation of precipitation activity corresponds in general to that of air activity. Due to soil retention it is expected that the amplitude of this seasonal variation is significantly quenched. Superimposed to this the influence of accelerator operation is observed in Fig. 5 from the variations of drainage water radioactivity. Since no precipitation radioactivity measurements have been carried out at CERN during this period of observation, it is referred to data from Mol. This is justified by the good general agreement in the data trends of both stations (see Fig. 3). The variation of the total monthly radioactivity discharge by effluent 1 shows the relation to the variation of accelerator intensities. The radioactivity peak of November 1969 coincides with a slightly higher precipitation radioactivity than that of the neighbouring months and with a pronounced peak of accelerator intensity. The relatively high amplitude of the peak confirms that the heavy and short rainfalls of this month led to a strong wash-out of radioactivity from the soil.

4. CONCLUSION

The environmental radiation and radioactivity caused by the operation of the accelerators at CERN have been measured and assessed and show that outside a distance of about 100 m from the accelerators or experimental halls, the stray radiation contributes less than an additional level equal to the natural environmental radiation. Air, dust and effluent water radioactivity originating from the accelerators and measured on the CERN site are barely detectable at a distance of about 350 m from the sources and represent a very small contribution to the environmental radioactivity of the Laboratory surroundings. Although soil radioactivity in the shielding materials near the accelerators shows in certain areas relatively high levels, the activity in the wash-out water from this soil is negligible.

ACKNOWLEDGEMENTS

We are grateful to Dr. A.H. Sullivan for many valuable discussions and for leading the performance of the routine radioactivity programme. We gratefully acknowledge the help of Mr. J. Dutrannois with writing the computer programmes.

We should like to thank the technicians whose assistance was of great help to us, in particular Mr. Marchal, Mr. Nielsen and Mr. Renaud, and the members of the Health Physics Group who contributed to the work.

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FIGURE CAPTIONS

Fig. 1. Locations of the various monitoring stations on the CERN site, the year when they were installed, and the average net annual dose recorded.

Fig. 2. Total β activity of air at CERN and some other European monitoring stations from August 1969 to August 1970.

Fig. 3. Total β activity of precipitation at CERN and some other European monitoring stations from December 1968 to May 1969.

Fig. 4. Total β activity of drainage water from the main CERN effluent 1 (pCi/l), and monthly amount of surface water (l) collected into this drain from August 1969 to August 1970.

Fig. 5. Monthly total β activity discharged by the drainage water of the main CERN effluent 1 (mCi); monthly amount of accelerated protons (p/a) at CERN and total β activity deposited; precipitation at Mol, Belgium (mCi/km^2) between August 1969 and August 1970.

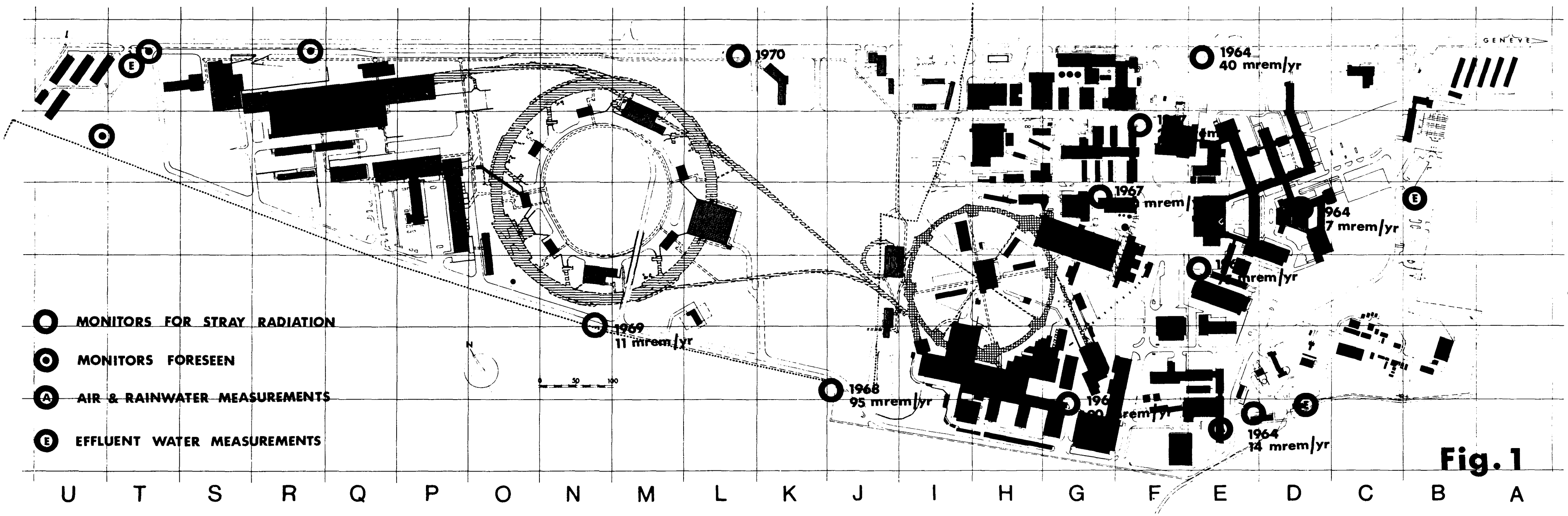

MONITORS FOR STRAY RADIATION
MONITORS FORESEEN
AIR & RAINWATER MEASUREMENTS
EFFLUENT WATER MEASUREMENTS
GENEVE
1970
1964
40 mrem/yr
1967
964
7 mrem/yr
1969
11 mrem/yr
1968
95 mrem/yr
1964
14 mrem/yr
U T S R Q P O N M L K J I H G F E D C B A
1 2 3 4 5 6

Fig. 1

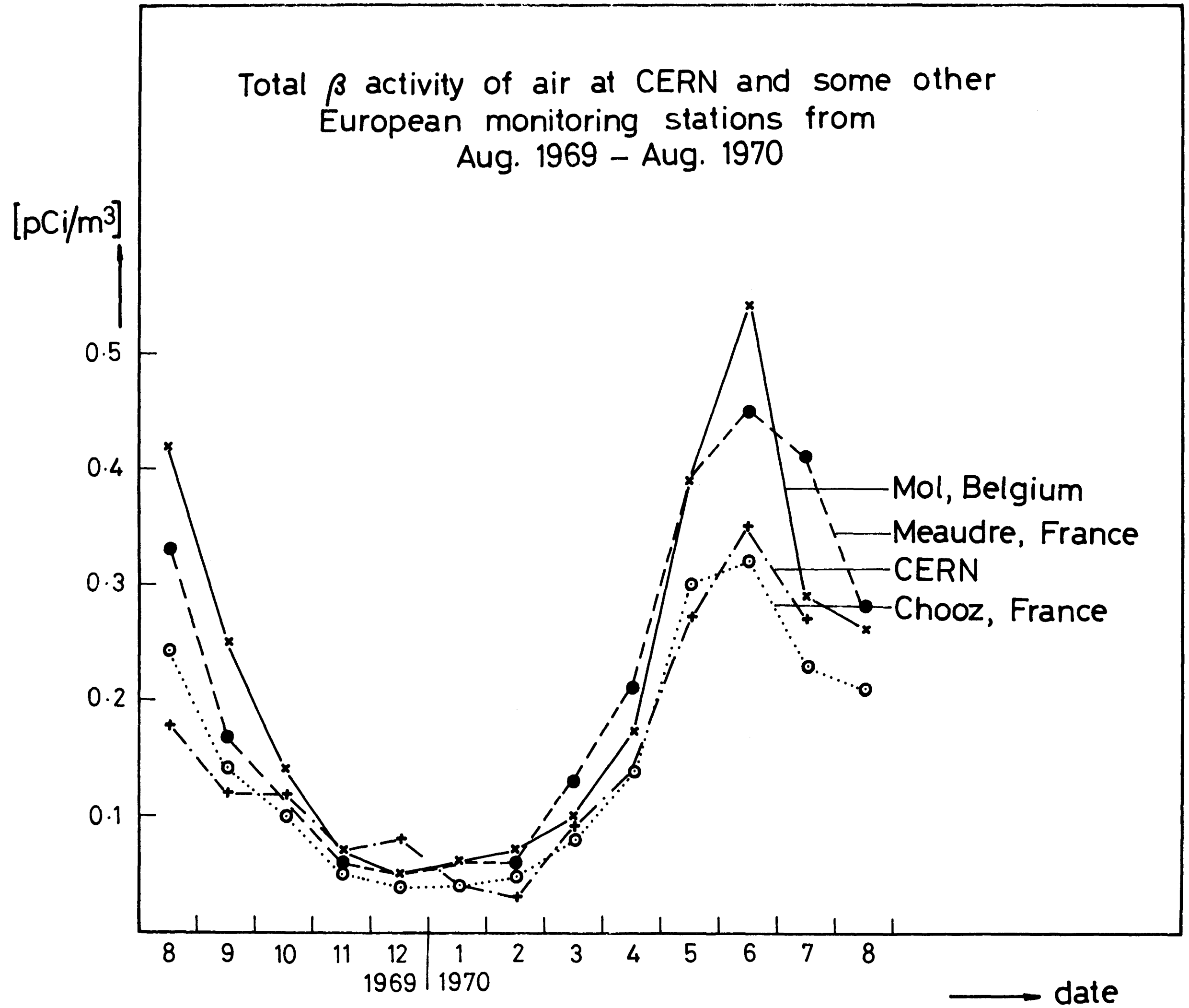

Total β activity of air at CERN and some other
European monitoring stations from
Aug. 1969 – Aug. 1970
[pCi/m3]
0·5
0·4
0·3
0·2
0·1
Mol, Belgium
Meaudre, France
CERN
Chooz, France
8
9
10
11
12
1
2
3
4
5
6
7
8
1969
1970
date

Fig. 2

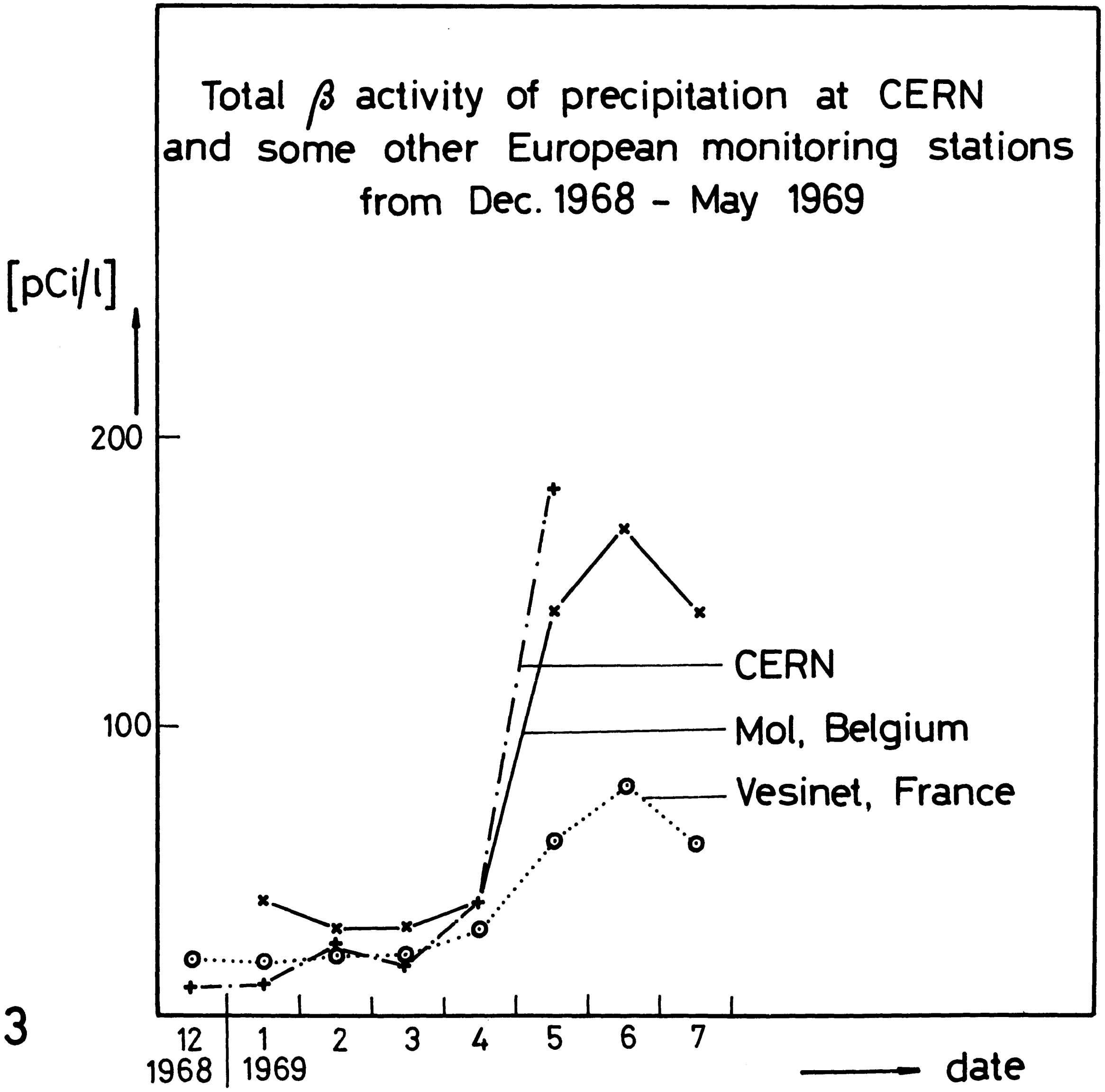

Total β activity of precipitation at CERN and some other European monitoring stations from Dec. 1968 - May 1969
[pCi/l]
200
100
CERN
Mol, Belgium
Vesinet, France
12
1968
1
1969
2
3
4
5
6
7
date

Fig. 3

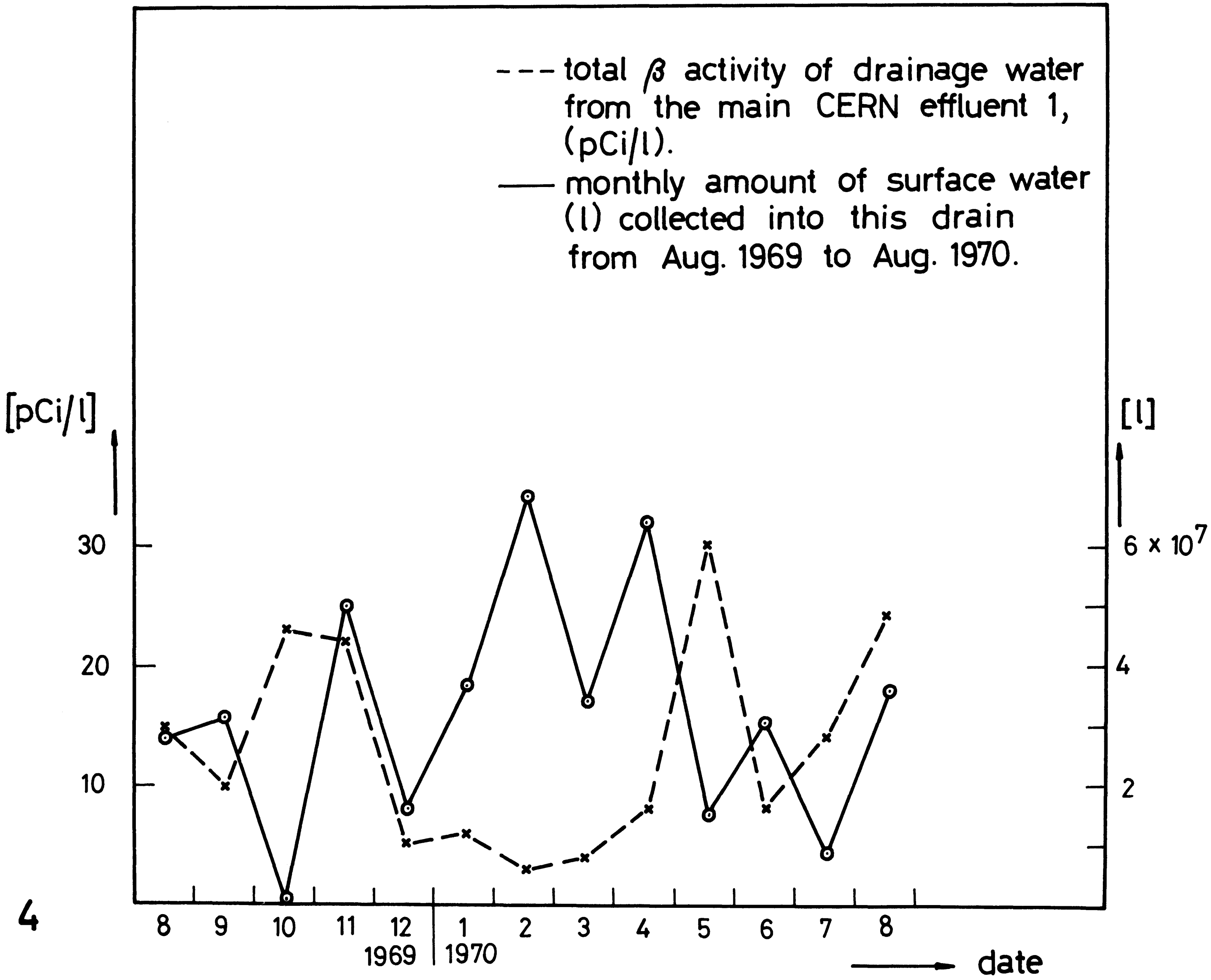
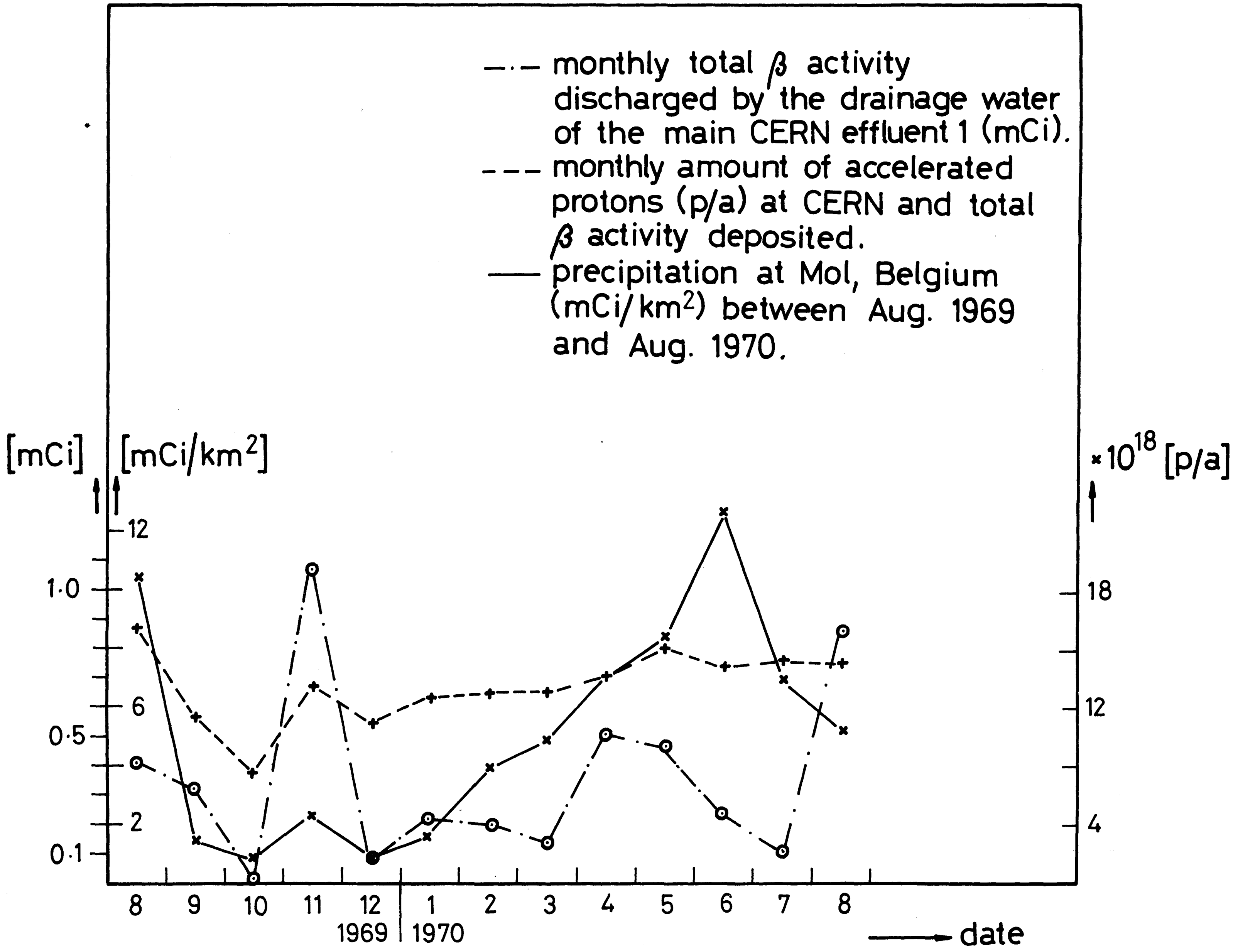

--- total β activity of drainage water from the main CERN effluent 1, (pCi/l).
—— monthly amount of surface water (l) collected into this drain from Aug. 1969 to Aug. 1970.
[pCi/l]
30
20
10
[l]
6 x 10^7
4
2
8
9
10
11
12
1969
1
1970
2
3
4
5
6
7
8
date

Fig. 4



—·— monthly total β activity discharged by the drainage water of the main CERN effluent 1 (mCi).
- - - monthly amount of accelerated protons (p/a) at CERN and total β activity deposited.
—— precipitation at Mol, Belgium (mCi/km²) between Aug. 1969 and Aug. 1970.
[mCi]
[mCi/km²]
×10¹⁸ [p/a]
12
6
2
1·0
0·5
0·1
18
12
4
8
9
10
11
12
1969
1
1970
2
3
4
5
6
7
8
date

Fig. 5

Paper : Environmental radiation and radioactivity from the CERN high-energy accelerators

MAUSHART: Welches sind Ihre Gründe dafür, keine passiven integrierenden Dosimeter zur Bestimmung der akkumulierten Dosis in der Umgebungsüberzeugung zu benützen?

BAARLI: I would think that the main reason for not yet using LiF dosimeters for dose-integration is that my group has at present not sufficient experience with this type of dosimeter. Another point in this connection is that after exposing LiF for hours in a high-energy neutron beam from our 600 MeV synchro-cyclotron we observed deviations from one measurement to the next which we could not explain.

TESCH: You showed a particular location where the dose is due to muons. With what instrument did you measure this dose-rate and how did you perform the calibration for muons?

BAARLI: With the monitor station which is located centrally on the site and in the direction of the ejected beam from the PS East Experimental Hall, we have observed on occasions a considerable increase in the level of charged particles or γ-rays. A more careful investigation of this showed the presence of a beam, the cross-sections of which we were able to measure. These measurements were made with a TPA ionization chamber (5 ℓ 20 atm Ar/air filling) which was calibrated by a ^{60}Co γ-source.

THOMAS: Dr Baarli, with your air sampling, have you assessed the radioactivity of both gaseous and particulate material? Did you also do any particle sizing for the radioactive dust case?

BAARLI: Yes, we have used filters and we have also investigated the gazes, mainly at the outlets of accelerators' tunnels.

GOLLON: Have you sampled the water which seeps into the ground for activity which may have leaked out of the radioactive soil near high-loss points like beam dumps? Such sampling would have to be done by wells, etc.

BAARLI: The rain-water on the CERN site is supposed to be collected into the main CERN drainage system and we make a continuous measurement of the radioactivity leaving the site from this system. There are two such points at CERN I, where the PS and SC are located and one place for the ISR.

NISHIWAKI: In some of your slides, you have compared the results from air monitoring of your laboratory with those of other institutes in Belgium and France. Are you co-ordinating the methods of sampling and measurement with those of the other institutes? Or, is it just the comparison of the data independently reported by each institute without any co-ordination and intercalibration of the methods of sampling and measurement? A considerably different result from air monitoring may be obtained sometimes, even on the same day at the same institute, depending on a number of factors, such as the pore size and grade of filters, flow rate and humidity of the air and the methods, location and time of sampling, etc. What methods of sampling and measurements are you employing for air monitoring at this institute?

BAARLI: In the slides I showed it is just intercomparison of measured results at the places over the same period. We have not co-ordinated our measurements by selecting the same methods in any way. I am aware of the many factors which influence the results, and in our case we used a moving filter tape of glass fibre material and sucked 12 m^3/h through the filter which was moving continuously at a speed of 4 mm/h. Two measurements are made with 100 hours intervals to allow the Ra and Th daughter activity decay.

GRANDE: Is there any co-operation between CERN Health Physics and the Swiss Radioprotection Authority?

BAARLI: Concerning radiation protection of the CERN site my group has worked out Rules for radiation protection (Section F of the CERN Safety Codes) and a Radiation Safety Manual indicating how these rules should be applied to specific situations. This Manual is subject to revision by my group as the development goes on within the laboratory. The collaboration on this matter with the Swiss authorities is assured by an agreement which CERN and the Swiss Federal authorities have signed. Among other matters, the agreement provides for regular meetings between my group and the Swiss authorities and that we supply the Swiss authorities with information regarding radiation protection measures within the laboratory.

VIALETTES: Dans les résultats concernant la radioactivité ambiante, vous ne faites état que de mesures β; ceci signifie que le ^{7}Be, qui se désintègre uniquement par capture électronique n'est pas compris dans ces résultats. Est-ce parce que ^{7}Be est négligeable ou bien parce que vous le mesurez séparément par ailleurs?

BAARLI: It is correct that I referred principally to the β-activity measurements, since these would represent those of greatest concern from a radiation protection point of view. In addition to these we are also measuring the γ-radioactivities; as stated in my paper ^{7}Be shows during accelerator operation a level which does not exceed 0.5 pCi/m^3.