Some observations of variations of the natural background radiation

By THOMAS THOMPSON, *The Swedish Meteorological and Hydrological Institute, Stockholm*, and PER ÅKE WIBERG, *Institute of Radiophysics, Stockholm.*

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ABSTRACT

Since the middle of 1960 the ionizing radiation at some 25 places in Sweden has been recorded by high pressure ionization chambers. Diagrams show how the ionization varied during October 1960. The variations (between 5 and 20% increase during 6 hours or more) are correlated to precipitation. Various factors influencing the natural radioactivity (Ra-226-series) of precipitation are discussed. From the measured additional dose contributions the average specific activity is calculated to $1.5\text{–}3 \cdot 10^{-11}$ curie per gram of precipitation.

Introduction

As part of a system for measuring the environmental radioactivity in Sweden there are 25 stations at which the ionizing radiation is automatically recorded (SIEVERT, 1959, 1963). During 1960 and the first part of 1961 only very small amounts of radioactivity were released into the atmosphere, and the fallout from previous nuclear bomb tests had decreased to low values. The circumstances were therefore favourable for a study of the long term stability and other characteristics of the apparatus during normal operation. The variations observed during the first period including July–October 1960 have been related to simple meteorological factors. Similar variations, together with an unusually great increase of the cosmic radiation, have been observed and reported earlier (SIEVERT, 1956).

Examples of records

To exemplify the observations of the variations of the ionizing radiation, some diagrams are shown. In figure 1 the records for all stations during October 1960 have been put together.[1] It is evident that the daily exposure dose on several occasions (8, 10, 25, and 26 October) exceeded the local average value by 5–15 %, and these peaks occurred in many cases simultaneously at neighbouring places. Figures 2 and 3 give by values averaged over 6 hourperiods more detailed information about the course of such peaks as well as records of precipitation and snow layer. In figure 2 are shown the dose contributions on 3 occasions. The close connection to corresponding rain periods is easily demonstrated. The dose contributions are sometimes accompanied by a momentary decrease below the average level as for instance on the 15 and the 16 October. Above that the dry periods show no significant variations of the dose rate. Figure 3 illustrates the complications which are expected during a snow fall. The initial dose contribution may still be observed but is weakened by the absorption of the increasing snow layer. Similarly the average level is suppressed by the snow layer.

The degree of possible resolution is demonstrated by figures 4 and 5, where the dose rate is calculated at 2-hourly intervals. In figure 4 the measured quantities of precipitation

[1] The *average* exposure dose rate varies with the location of the stations between 5.5 and 13 μr/hr (50–110 mr/year). The difference from place to place can to some extent be connected to the cosmic ray intensity at different heights above sea level. However, variations of the ground contents of radioactive elements are of greater importance.

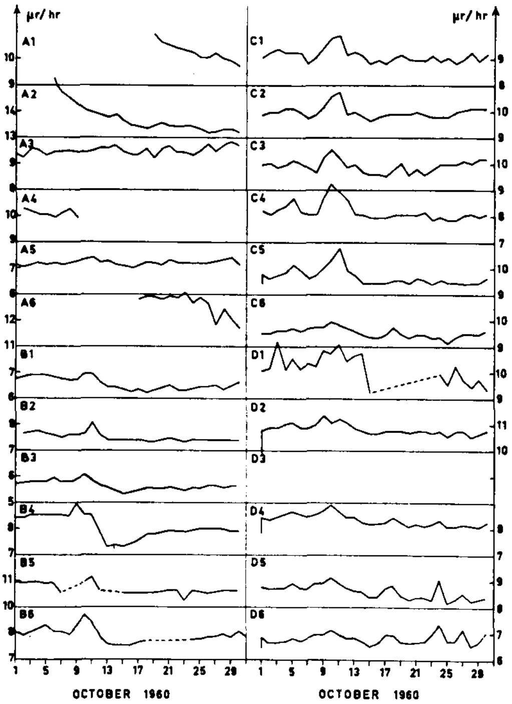

FIG. 1. Diurnal values of the dose rate at the 24 stations during October 1960.

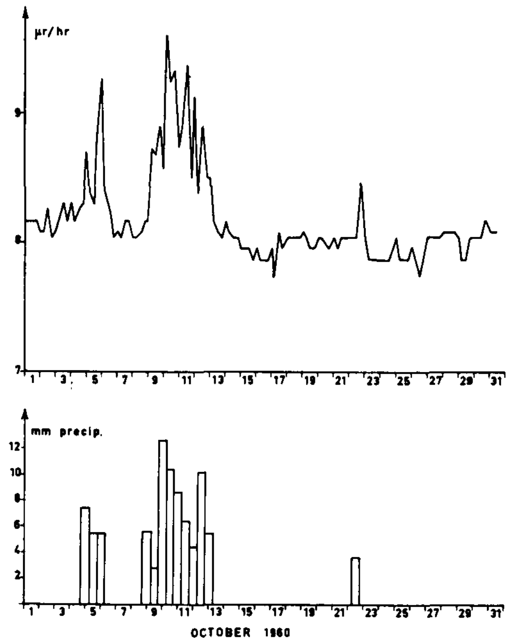

FIG. 2. 6-hourly values of the dose rate and precipitation at C 4 during October 1960.

has been complemented by aid of visual estimations of rain intensity for each 3rd hour. There is a remarkable correspondence between the two curves. In this figure and in figure 5 the dose contributions shown are unusually great as was the case at several other places during a period of August when a rain area moved over great parts of Sweden. The rain area and the approximate position of the increase and maximum of dose rate at 3 instances are shown in figure 6.

Discussion

a) ADDITIONAL DOSES

Figure 7 shows the additional doses of magnitude 3 μr or more for all stations for the period July–October 1960 as a function of the precipitation in millimetres. When the additional doses and precipitation amounts are small the dots are very scattered. For the months July–September the observations representing larger amounts of precipitation and larger additional doses have a regression line

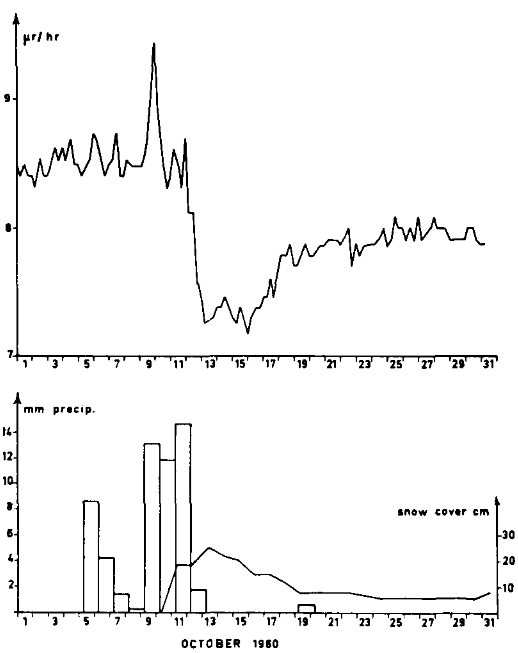

FIG. 3. 6-hourly values of the dose rate and precipitation and the thickness of the snow layer at B 4 during October 1960.

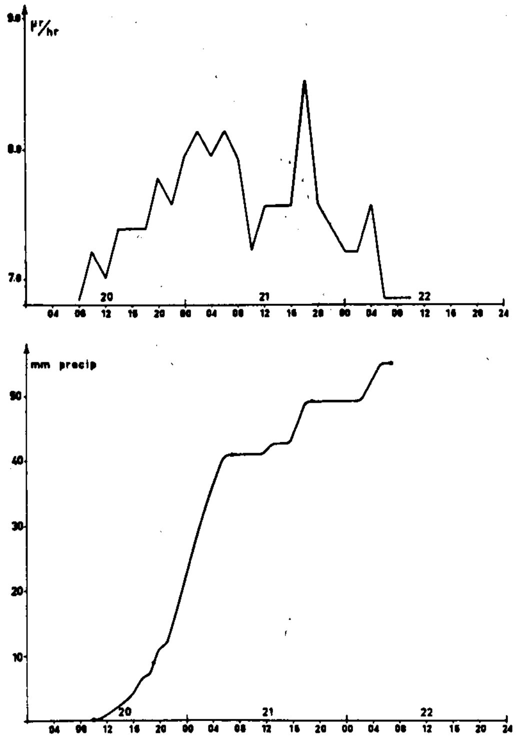

FIG. 4. 2-hourly values of the dose rate and the precipitation at A 5 during 20–22 August 1960.

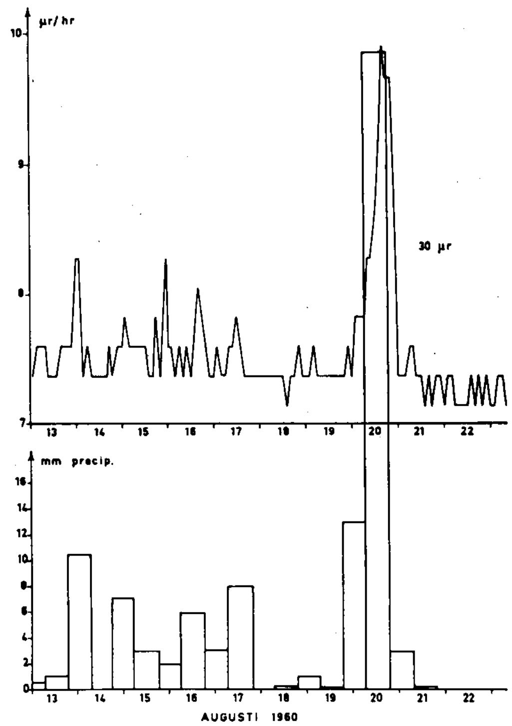

FIG. 5. 2-hourly values of the dose rate and the precipitation at B 2 during 13–22 August 1960.

with the slope of 0.5 μr/mm precipitation, while for October the corresponding slope is 1.0 μr/mm precipitation.

In table 1 a total number of 1786 days of observations has been listed with regard to the occurrence or nonoccurrence of precipitation and additional doses respectively. From this information a correlation coefficient of 0.90 may be calculated.

The additional doses which accompany the precipitation may to some extent be explained by the increase in cosmic radiation due to falling air pressure usually accompanying the precipitation areas. This variation in the cosmic radiation, however, is of a much slower kind than the radiation peaks treated in this investigation.

From the shape of the radiation peaks and the correlation shown above it can be concluded that they are caused by a short-lived ($T_{\frac{1}{2}} \approx 1$ hr) γ-radiating element which is associated with the precipitation. The natural radioactivity in the precipitation[1] consists mainly of decay-products of radon, and the specific activity lies within the range 10^{-12}–10^{-10} c/g. The specific activity is a decreasing function of the precipitation rate (g.cm^{-2}sec^{-1})

TABLE 1. *Demonstration of the correlation between precipitation and additional doses during the period July–October 1960.*

	Number of days with precipitation	Number of days without precipitation	Σ
Number of days with additional doses	300	19	319
Number of days without additional doses	28	1439	1467
Σ	328	1458	1786

[1] For a survey of observations and results, and discussion of various theories see DAMON and KURODA, 1954, and SOLODIKHINA, 1959. For a general treatment of the wash out process see FACY, 1962.

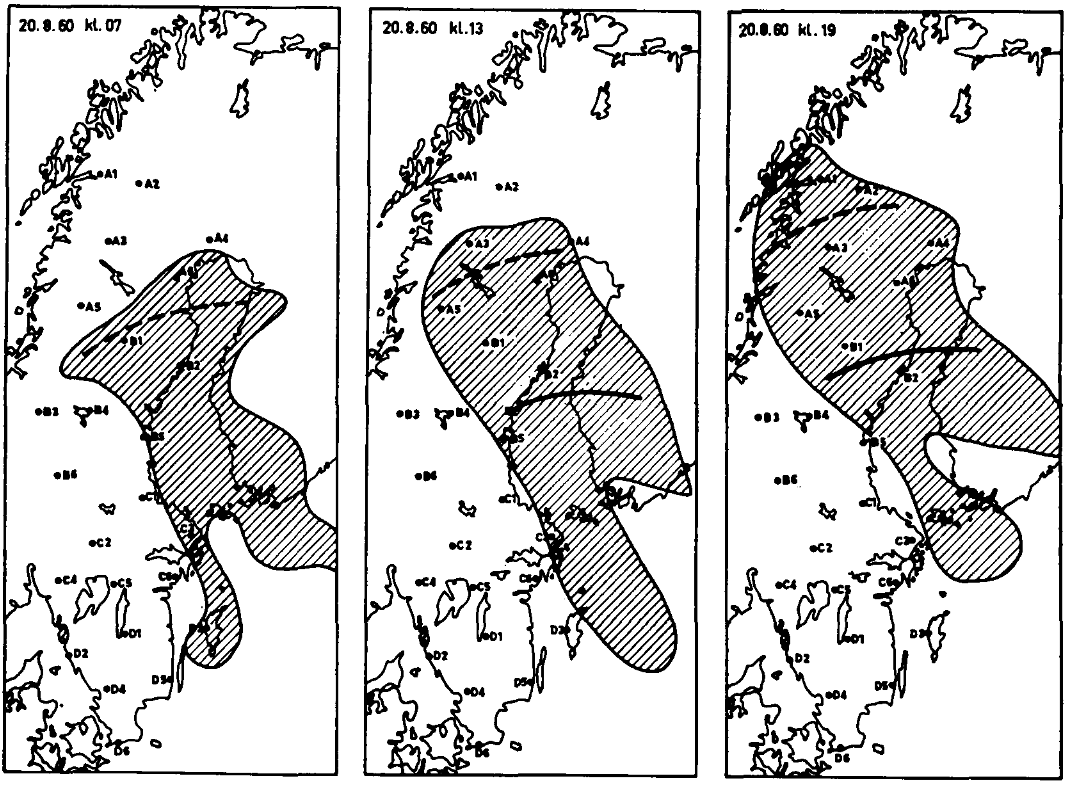

FIG. 6. The movement of a rain area and the position of the radiation peaks at three instants on 20 August 1960. (---- rise; —— maximum.)

and observations by SOLODIKHINA (1959) indicate that it also depends upon the type of precipitation (steady rain, rainshowers, granular snow etc.).

The theories for the acquisition of radioactivity by the precipitation differ, but through the investigations of Solodikhina on precipitation from the same cloud system, collected at different heights, it is evident that at least some part of the radioactivity is due to the washing out of radioactive particles in the atmosphere.

According to table 1 the period July–October 1960 contains 28 occasions with precipitation without additional doses, and 19 occasions with additional doses without precipitation. A more detailed study of the weather situation at the 19 occasions with additional doses but without precipitation shows that in one case a light pre-frontal rain was reported by neighbouring meteorological stations, which may indicate that the report "no precipitation" at this station may be wrong. On three occasions the stations were situated within rainshower or thunderstorm areas. In the remaining 15 of the 19 occasions the weather was calm and stable with a surface inversion. This inversion, which is mainly due to the temperature radiation during the night, has an average height of 100 metres and acts as a barrier against the upward (acting) turbulent diffusion. Most of the supply of radon from the earth's surface is consequently accumulated within this layer, and at the same time a certain concentration occurs of the shortlived products of radon (see GALE and PEAPLE 1959, JACOBI, SCHRAUB, AURAND and MUTH 1959). This results in an increase in the γ-radiation. When the inversion is destroyed due to heating during the day and/or increasing wind the radioactivity at the station decreases.

In order to clarify the circumstances which caused the 28 cases with precipitation without additional doses the topographical and meteorological conditions were analysed. On about

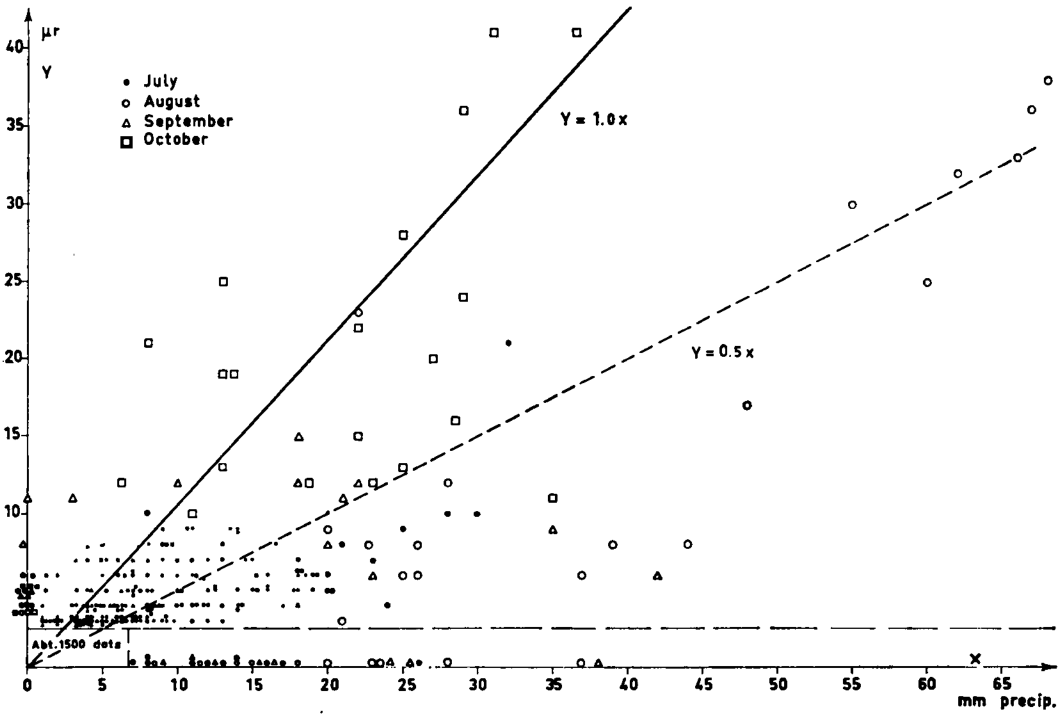

FIG. 7. The distribution of additional doses on amounts of precipitation based upon observations from all stations in function July–October 1960.

10 occasions at the coastal stations the wind was blowing from the sea in over land. Since the natural radioactivity in the atmosphere is considerably lower over the ocean than over land, one can expect less activity in such cases. To reach a definitive conclusion a detailed study would be necessary of the trajectories for several days preceding the observed cases. The air-masses must have stayed over the sea for a rather long time as compared to the half life of radon ($T_{\frac{1}{2}} = 3.8$ days).

On the other hand an unstable weather situation has been observed in each of the 28 cases with precipitation without additional doses. The precipitation has taken the form of showers, often in connection with thunder, which implies large drops and a large precipitation rate.

b) ATTENUATION OF THE AVERAGE DOSE RATE LEVEL

The attenuation of a snow cover has been calculated by SIEVERT and HULTQVIST (1952) for various densities as a function of thickness. For example, 25 centimetres of snow absorbs, depending on density, between 30 and 70 % of the radiation from ground. To the freshly fallen snow in figure 3 corresponds the lower value with which the radiation from the earth is estimated to 3.7 μr/hr and the ionizing component of the cosmic radiation to 4.7 μr/hr.

Heavy rains are sometimes accompanied by a short decrease of the average level. This seems to be caused by a disturbance of the diffusion of gases in the ground, which causes variations of the concentration of radon. Similar deviations appear in connection with frost in the ground, but observations are often complicated by snow cover.

Calculation of the specific activity of the precipitation

On the assumption that the measured additional dose contributions are obtained from the disintegration of Ra B and Ra C and that the ratio of the two elements is known, the specific

TABLE 2.

Period	Station	Figure	a (curie/gram)
Oct 9–13	C4	2	$3.5\ 10^{-11}$
Oct 24	D6		5.0
Oct 27	D6		9.0
Jul–Sept		7	1.5
Oct		7	3.0

activity of the corresponding amount of precipitation may be estimated.

The following formula is derived for the integrated dose 3 meters above an infinite plane covered by a thin layer of Ra B + Ra C.

$$D = 3.4\ 10^5\ p\, a$$

In this formula p (g cm^{-2}) stands for the amount of precipitation that has brought down the radioactivity, a (curie per gram) is the specific Ra C—activity of the precipitation. It has been assumed that equal amounts of Ra B and Ra C are present, and a dose build-up factor of 2. (For a discussion see HULTQVIST, 1956 and LINDELL, 1960.)

By use of this formula the specific activity has been calculated in some cases. The results have been collected in table 2. Similar specific activities have been reported by DAMON and KURODA and by SOLODIKHINA.

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