Thoron (Rn-220) measurements in the atmosphere and their application in meteorology

By GERHARD W. ISRAËL, *Institut für Geophysik und Meteorologie der Rheinisch-West-fälischen Technischen Hochschule Aachen*

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ABSTRACT

With new equipment which allows the continuous recording of the atmospheric thoron content down to $0.5 \cdot 10^{-14}$ C/l, the thoron content of the atmosphere, at different levels was measured at the Meteorologisches Observatorium des Deutschen Wetterdienstes in Aachen. The measurements were carried out from June until September 1964.

The results show a close relation between the thoron content and the meteorological variables. The thoron concentration and its decrease with height shows a remarkable diurnal variation with a maximum at noon and a minimum during the night. The thoron at this station is influenced by wind direction. Rain diminished the thoron content by 50 %; the recovery time to reach the initial concentration is about 10 hours.

It could be shown that the turbulent diffusion coefficient K increases linearly between 1 m and 4 m. A mean value of $K = 330 \pm 30$ cm²/s at 1 m level was found.

Introduction

The natural decay series have as an intermediate link an isotope of the noble gas with atomic number 86. These isotopes thoron ($_{86}Rn^{220}$, half-life 54 sec), radon ($_{86}Rn^{222}$, 3.8 d) and actinon ($_{86}Rn^{219}$, 3.9 s) seep out of the soil by diffusion into the atmosphere and are there distributed by eddy diffusion and wind. There have been numerous investigations concerning the concentration of radon, radon daughters and thoron daughters which show the usefulness of these radioactive substances as tracers for atmospheric research (BOLIN, 1962; H. ISRAËL, 1962; JACOBI & ANDRÉ, 1963). The atmospheric An concentration relative to radon and thoron is negligible.

The measurement of the atmospheric thoron content is very difficult in view of the low concentration as well as the short half-life time. Therefore until now, only few measurements are available (FONTAN & BLANC, 1962; FONTAN, 1964; JACOBI, 1963).

Because of its short life-time thoron is a very good tracer for determination of the eddy diffusion and other meteorological variables of the lowest levels of the atmosphere, which are difficult to explore by meteorological methods of observation. For that reason we have developed equipment to measure the atmospheric thoron content for the first time continuously with a resolution time of some minutes.

Equipment

The instrumentation used is an ionization chamber for registering the α-decay of thoron and radon in an air stream flowing through the chamber.

Through the ionization chamber IK, volume 300 l, a continuous air stream of about 10 l/s is drawn. Before entering the chamber the air is filtered (Dräger Micronfilter CH-620-2) to remove the aerosols and radioactive particles, i.e. only the noble gases thoron and radon enter the ionization chamber.

A fraction of thoron and radon decays in the chamber by emission of α-rays and creates an ionisation current. The voltage drop of this current at the resistance $Ra = 10^{12}\,\Omega$ is registered by a vibrating reed electrometer A. The insulating material is "Plexiglas". The voltage supply U_K compensates the background current caused by wall and environmental radiation. The condensor C_d diminishes the resolution time of the apparatus for smoothing.

To separate thoron and radon the air is

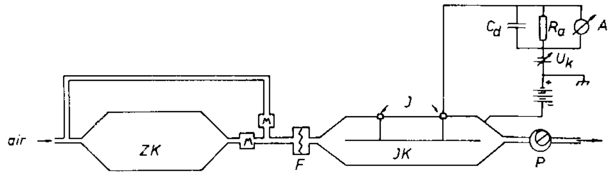

FIG. 1. Scheme of apparatus. M, Magnetic valve; F, filter; ZK, decay chamber; IK, ionization chamber; C_d, condensor; R_a, highohmic resistance; U_K, voltage supply; A, vibrating reed electrometer; P, pump.

aspirated alternately; once directly into the ionization chamber and once after passing a decay chamber ZK, where the air has a residence time of 3–4 half-life times of thoron. In the first case the ionization current is generated by radon plus thoron, in the other case only by radon. The difference yields the thoron content of the aspirated air.

The short-lived radon and thoron daughter products originated in the ionization chamber do not disturb the thoron measurement.

ThA (half-life 0.16 sec) decays simultaneously with thoron, whilst ThB (half-life 10.6 h) and its decay products effect an increasing of the background, only because of their long half-life period.

The short-lived Rn daughters generally are in radioactive equilibrium with the radon, as a change of the atmospherical Rn-concentration generally occurs slowly compared with the half-life periods of its decay.

The sensitivity of the apparatus is essentially governed by the atmospheric radon concentration and its variation. A radon content of 10^{-13} C/l, i.e. the expected mean value in the lower atmosphere together with the background causes short time variations of about $1.8 \cdot 10^{-15}$ A at a resolution time of $\tau = 220$ s. This corresponds to a thoron content of $0.5 \cdot 10^{-14}$ C/l which may be taken as detectable limit. The calibration was done with a Th-228 reference solution of $1.96 \cdot 10^{-8}$ Curie.

The instrument measures alternately in 15-minute intervals the radon and thoron concentration. In the future we intend to compensate the radon current to register immediately the thoron current.

Measurements and results

The first measurements with this device were carried out at the Meteorologisches Observatorium at Aachen from June through September 1964. The thoron was measured at three different levels, one after another, with a change-over time of 15 minutes.

During the first period (18 June – 13 July 1964) the thoron was measured at 0.5 m, 1 m, 2 m; during the second period (24 July – 2 September 1964) at 2 m, 2.8 m, 4 m altitude. The area 200–300 m around the test point consists of public gardens with lawn, trees and footpaths. Several tennis courts are situated in the South.

The thoron seeps out from the first 1–2 cm of the soil into the atmosphere. There it is distributed in horizontal and vertical direction by wind and atmospheric turbulence. The distance that a thoron atom may travel is limited by the radioactive decay. For that reason the thoron may reach in the horizontal only some hecto-meters, in the vertical only some decameters (JACOBI, 1963). Therefore the thoron content of a fixed point is influenced by the exhalation of a region of some hundred meters only. For that reason the exhalation of the soil and the transportation time of the air to reach the measuring place determine the thoron content of a given point, i.e. the thoron concentration is mainly influenced by turbulent transfer and sometimes by wind direction and wind speed. If no radial gradients exist the thoron decrease with height is only determined by vertical turbulence.

It is an essential advantage of thoron in relation to radon and other radioactive substances used as tracers for meteorological investigations that it is easily possible to find a homogeneous surface source. This would eliminate the difficulty in the discussion of results which appear if the horizontal distribution of the sources and the origin of the measured material is unknown.

The following shows up the results of the first continuous thoron measurements and the rela-

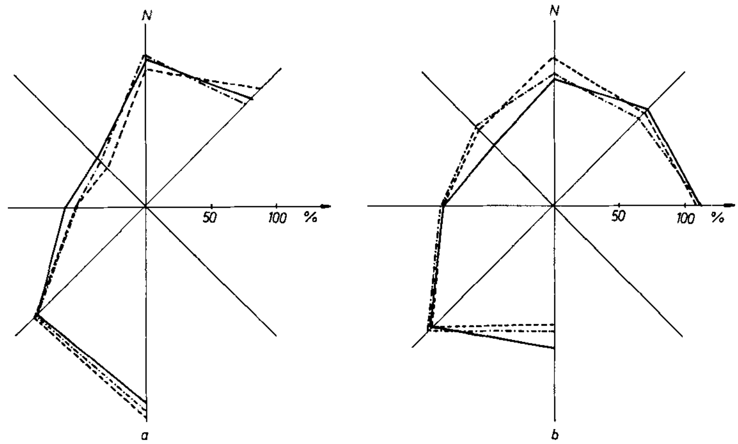

FIG. 2. Percentage of thoron content in relation to wind direction. (*a*) 18 June–13 July 1964; Aspirating level: —— 0.5 m; ---- 1 m; -·-·- 2 m. (*b*) 24 July–2 September 1964; Aspirating level: —— 2 m; ---- 2.8 m; -·-·- 4 m.

tion between the atmospheric thoron content and meteorological variables.

Fig. 2 shows the influence of wind direction on the thoron concentration for both measuring periods. For both intervals the windrose is, within the error limit, identical for the different levels, i.e. there exist no troublesome radial gradients of the thoron content.

Amongst a strong dependence on wind direction, the thoron content at South and West shows an evident change of the windrose from one period to the other. We guess this behaviour in the south to depend on the renewal of the foot paths and tennis courts at the beginnings of August. The change in the West may depend on gardening, too, which might change the exhalation.

Fig. 3 shows the influence of precipitation. On the left side the thoron content is given in per cent of the mean, from 2 hours before the beginning of rain until 7 hours after the end of rain. Only precipitation cases of more than 1 l/m² are considered. Hence, as expected, the concentration is greatly diminished by rain. The reaccumulation is exponential with a recovery time of about 10 hours.

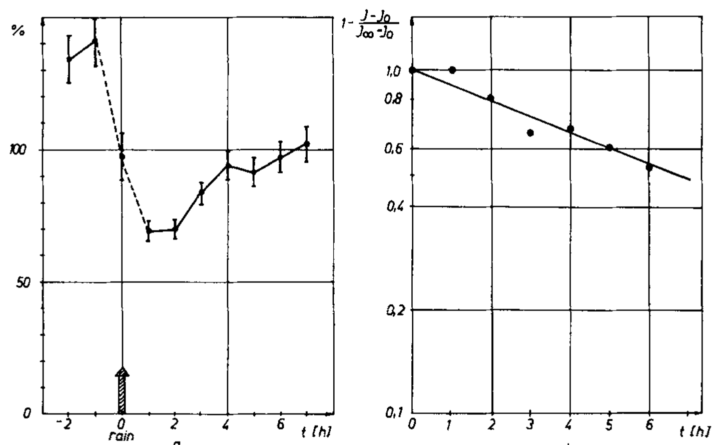

FIG. 3. Influence of precipitation on the thoron concentration. (*a*) Percentage of the mean Tn-concentration from 2 hr before the begin of rain until 7 hr after end of rain. (*b*) Recovery of the thoron concentration I = value at time t; $I_\infty = 138$; $I_0 = 69.5$.

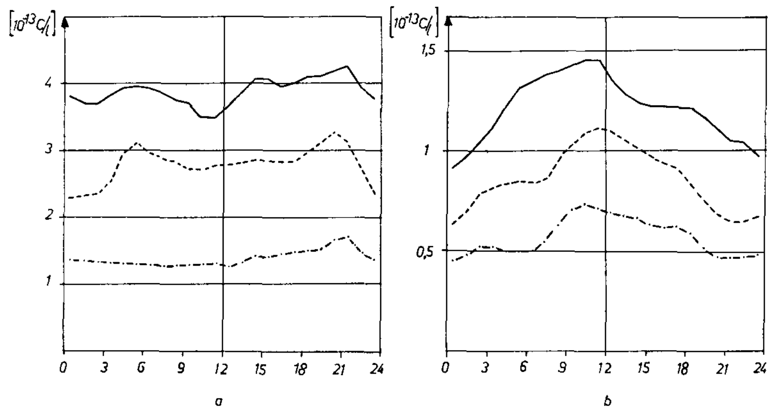

FIG. 4. Diurnal variation of the thoron content in different heights (smoothed). (*a*) 18 June–13 July 1964; Aspiration level: —— 0.5 m; ---- 1 m; -·-·- 2 m. (*b*) 24 July–2 September 1964; Aspiration level: ——2 m; ---- 2.8 m; -·-·- 4 m.

Fig. 4 shows the mean diurnal variation of thoron at the different levels. Both the measuring intervals show different diurnal variations. This depends probably to some extent on different diurnal variations of the atmospheric turbulence in the two intervals.

Fig. 5 confirms that the greater the diurnal variation of the turbulence, the greater is the diurnal variation of thoron. The figure shows a comparison for the second interval of observation—averaged for the three aspiration levels—between the cloudless days with strong temperature variation and the overcast days with little temperature variation. One expects a strong variation of eddy diffusivity for clear summer days with a maximum at noon initiated by convection and minimum at night caused by stability. This diurnal variation is less pronounced on overcast days with little temperature variations. Fig. 5 shows, as expected, the same behavior for the thoron content.

As indicated above the decrease of thoron with height depends only on the vertical exchange which can be described by the turbulent diffusion coefficient K. JACOBI (1963) has calculated the decrease of thoron with height for different values of K and the case of linear increase in z.

The ratio of the thoron content at a height z to the thoron content for $z = 1$ m is given in

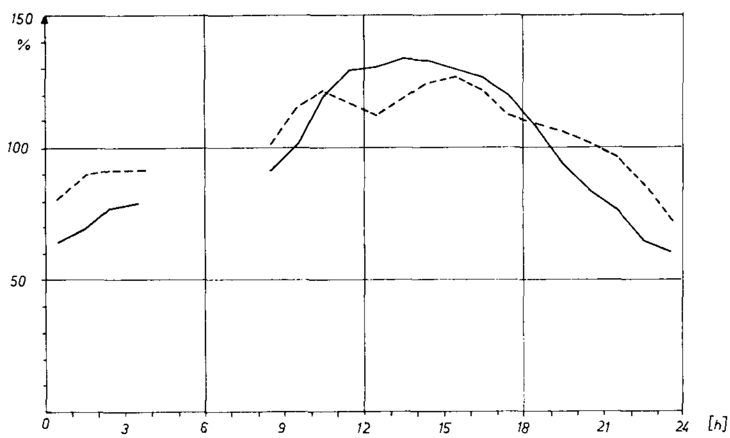

FIG. 5: Diurnal variation of thoron content between 2 m and 4 m in percentage of the daily mean (smoothed). —— Cloudless days with strong temperature variation. ---- Overcast days with little temperature variation.

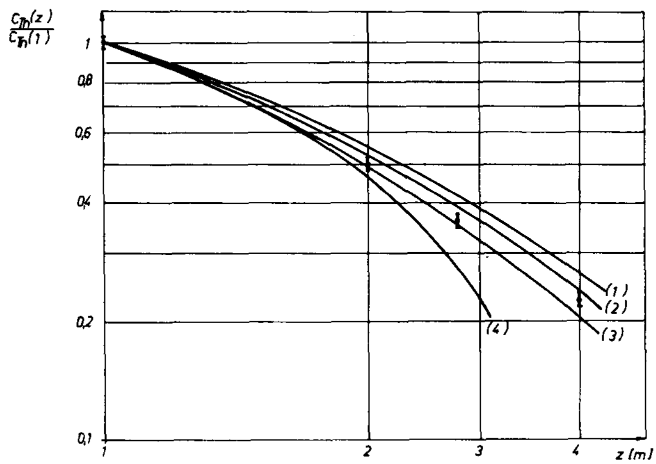

FIG. 6. Ratio of thoron content at height z to thoron content at $z = 1$ m. The full lines are calculated for linear increasing K.

(1) K (1 m) = 450 cm²/s; dK/dz = 500 cm²/s m.
(2) K (1 m) = 350 cm²/s; dK/dz = 380 cm²/s m.
(3) K (1 m) = 300 cm²/s; dK/dz = 320 cm²/s m.
(4) K (1 m) = 225 cm²/s; dK/dz = 250 cm²/s m.

Fig. 6. The full lines give the theoretical decrease of thoron for different K at 1 m level, linearly increasing with height. There is a good agreement between the measurements and the calculated curves. On an average the turbulent diffusion coefficient K between 1 m and 4 m increases with height. Therefore it is possible to determine K in the lowest meters of the atmosphere with high accuracy by thoron measurements.

During the whole measuring interval, the ThB content of the lowest atmosphere has also been measured. These measurements show, like those of FONTAN (1962), that there is no radioactive equilibrium between thoron and its daughters in accordance with the considerations of H. ISRAËL (1964).

Table 1 shows the ratio of Tn/ThB.

Table 1

Level [m]	0.5	1	2	2.8	4
$\frac{C_{Tn}}{C_{ThB}}\left[\frac{Curie}{Curie}\right]$	118	85	39	26	17

Summary and conclusions

The following summarizes our first continuous thoron measurements.

1. The thoron measurements provided information about the heterogeneity of the horizontal distribution of thoron within some hectometers and the change of exhalation in this region.
2. The data also reveal the fact that large changes of the thoron concentration occur with precipitation. The exponential reaccumulations take place with a recovery time of about 10 hours.
3. The thoron concentration shows a remarkable daily variation which is closely related to the eddy diffusion coefficient K. The greater the diurnal variation of K the greater is also the variation of the thoron content.
4. The decrease of the mean thoron concentration with height between 1 m and 4 m is in good agreement with the assumption that K increases linearly with height. A mean turbulent diffusion coefficient of 330 ± 30 cm²/s at 1 m could be determined by the thoron measurements.
5. It was found that, as expected no, radioactive equilibrium between thoron and its daughters exists.
6. No influence of pressure on the thoron content was detectable.

The relation between the thoron concentration and the other meteorological variables indicate that thoron is an excellent tracer for studying meteorological processes in the lowest decameters of the atmosphere. The thoron will be a particularly good tracer for studying the turbulent transfer at these levels, which are difficult to explore by meteorological methods.

For obtaining instantaneous values of K, we shall extablish several sets of instruments of the same type to measure the thoron simultaneously at different levels with high resolution.

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