Meteorological influences on the thoron (Rn^{220}) content of the atmosphere

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ABSTRACT

With a new equipment allowing the continuous recording of the atmospheric thoron content with a sensitivity of $0.5 \cdot 10^{-14}$ c/l and a resolution time of 220 sec, thoron was measured at different levels between 1–8 m for several months and related to meteorological variables. By studying the dependence on the wind direction and the increase with height of the thoron concentration we could verify the homogeneity of the thoron exhalation in the near surroundings of the measuring place at Mainflingen. By comparing the decrease of thoron with height with the theory we succeeded in determining the eddy diffusion coefficient K. It was found that, on an average, K increases linearly with height between 1 and 8 m, and that it is proportional to the mean wind velocity $\bar{u}$. The average eddy diffusion coefficients elaborated from the results of thoron measurements are compared with the corresponding diffusion coefficients of momentum having been calculated from the wind profile.

Introduction

In the last decade, natural radioactivity of the atmosphere has won a lot of interest as a tracer for meteorological investigations.

The behavior of radon (Rn^{222}), its daughters and of the thoron daughters in the atmosphere is researched thoroughly since some years ago at different places and discussed in connection with meteorological variables.

The atmospheric thoron (Rn^{220}) was excluded from these researches until recently, as it was impossible to lay hold of it, because of its short half-life time (54 sec) on one side and its small concentration rate on the other.

By development of an equipment measuring continuously the atmospherical thoron concentration with a sensitivity of $0.5 \cdot 10^{-14}$ c/l and a resolution time of 3 minutes, it became possible to close this gap.

With this method, which is described thoroughly by G. W. ISRAËL (1964, 1965) and H. ISRAËL & G. W. ISRAËL (1966), we registered the atmospheric thoron content for several months at different places.

First results of these measurements were published by the author (1965), which showed up the usefulness of thoron as a tracer for atmospheric researches.

This paper, which represents a continuation of our investigations on the behavior of atmospheric thoron and their application to meteorological problems, shows how it is possible to derive the eddy diffusion coefficient in the lowest atmosphere from thoron measurements and give a comparison between the diffusion coefficient calculated from thoron data and from the vertical wind profile. Furthermore a method is described allowing to test if there is a homogeneous surface source of thoron at the measuring place or not.

Theory

If we have a homogeneous surface source of thoron, i.e. no horizontal gradients in the exhalation rate from soil, the vertical decrease of the thoron concentration is governed by the atmospheric turbulence only. The vertical equilibrium profile of thoron may be described in this case in analogy to Fick's law by the differential equation (JACOBI & ANDRÉ, 1963).

$$\frac{\partial}{\partial z}\left(K \frac{\partial c}{\partial z}\right) - \lambda c = 0. \qquad (1)$$

z = height coordinate
c = thoron concentration
K = eddy diffusion coefficient
λ = decay constant of thoron

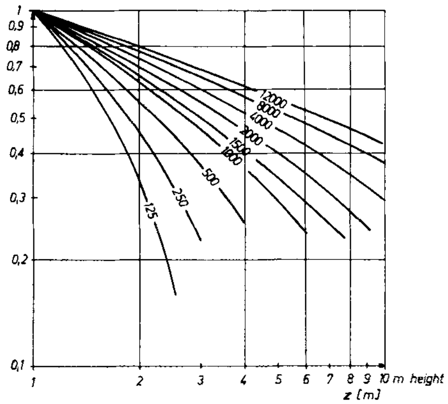

FIG. 1. Decrease of thoron concentration with height for different parameters K. The numerals give K in [cm^2/s] at $z = 1$ m.

To solve (1) we introduce as boundary conditions:

(a) $c(\infty) = 0$ as a consequence of radioactive decay. $c(0) = \text{const}$;

(b) $\int_0^\infty \lambda c dz = E$, where E is the exhalation rate of thoron.

This condition means that the total thoron activity in a vertical air column is equal to the exhalation rate of its ground surface area (stationarity condition).

Until now, there exist solutions for $K(z) = \text{const}$ or K as power function of z (SCHMIDT, 1926; PRIEBSCH, 1932; WILKENING, 1959; MALAKOV, 1959; PHILIP, 1959) only.

Generally, it is assumed that K increases linearly with the height z in the lowest decameters of the atmosphere (JACOBI, 1962).

With this assumption we get the following approximate formula for the vertical thoron profile:

$$\frac{c(z)}{c(z_1)} = \frac{\ln z}{\ln z_1} \exp\left[-\sqrt{\lambda}\left(\sum_{i=0}^{n-1}\sqrt{\frac{1}{K_i}}\right)\Delta z\right], \qquad (2)$$

where $c(z)$ is related to the concentration $c(z_1)$ at a height z_1 to eliminate the exhalation rate E. The interval (z_1, z) is subdivided into n intervals of width Δz. K_i means the K value at $z = z_1 + i \cdot \Delta z$ and is assumed to be constant in the interval $[z_1 + i \cdot \Delta z,\ z_1 + (i+1)\Delta z]$.

Fig. 1 shows the resulting vertical distribution of thoron with K as parameter. The concentration at the height z is referred to $z_1 = 1$ m.

By comparing these calculated curves with the measured vertical distribution of thoron, K can be determined by the thoron measurements as it is done below.

But this is only allowed if the assumption of a homogeneous surface source in the environs of the measuring place is fullfilled. A method to prove this assumption is described in the following:

The time a thoron atom needs to be transported by the vertical exchange from the soil to the measuring place at a height z is the greater, the higher above ground the measuring place is situated and the lower the vertical exchange is. In consequence of the horizontal transport of air by the wind, the distance between the exhalation place of the measured thoron and the measuring place is the greater the higher the measuring point is.

In the case of homogeneous exhalation, the decrease of the thoron content with height is described by equation (2). If there exist gradients in the exhalation, we may suppose that for a given wind direction the thoron at a measuring height z_2 or z_1 is exhaled from soil at a rate of $E(r_2(K))$ or $E(r_1(K))$, where r means the distance between exhalation point and measuring point. Then equation (2) may be extended to

$$c(z_2)/c(z_1) = \frac{E(r_2(K))}{E(r_1(K))} f(K, z_2, z_1), \qquad (3)$$

where $f(K, z_2, z_1)$ means the right hand side of equation (2).

If one determines $c(z_2)/c(z_1)$ by thoron measurements and calculates $f(K, z_2, z_1)$ from equation (2) if K is known, it is possible to compute the ratio $E(r_2(K))/E(r_1(K))$. In case it is found $E(r_2(K))/E(r_1(K)) = 1$ for any r, K and wind direction, one can conclude that no gradients of E exist, i.e. there is a homogeneous surface source of thoron.

Measurements

At Mainflingen (near Frankfurt) in a free, plane and uncultivated tract of land the thoron concentration was registrated with an ionization chamber from October till December, 1964. The thoron was measured at five levels between 1 and 8 m above ground one after the other with a change-over-time of about 15 minutes. Simultaneous measurements of the wind velocity at three levels between 1 and 8 m were realized.

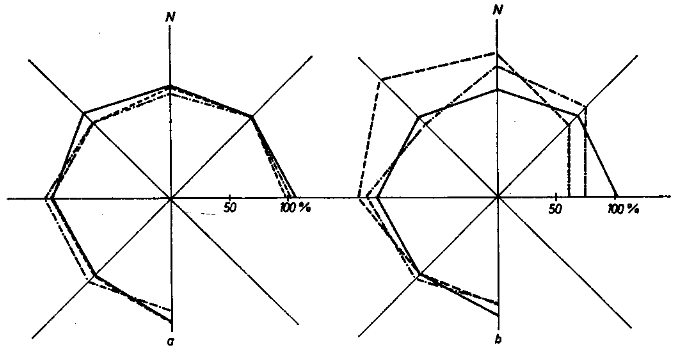

FIG. 2. Thoron concentration in percentage of the mean in dependence on wind direction. (*a*) Aspirating point: —— 1 m; --- 2 m; -·-· 3.5 m. (*b*) Aspirating point: —— mean from 1; 2; 3.5 m; --- 5.5 m; -·-· 8 m.

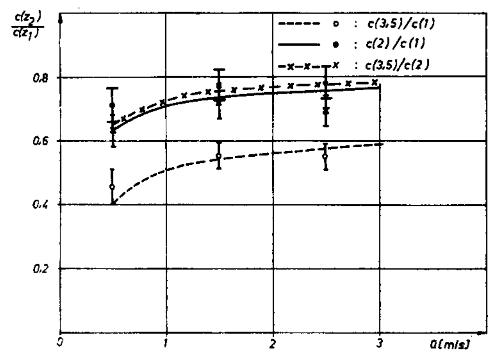

FIG. 3. Dependence of the ratio $c(z_2)/c(z_1)$ on the mean wind velocity $\bar{u}$; curves: calculated from equation (2) under the assumption of a homogeneous exhalation rate. Dots: measured ratios.

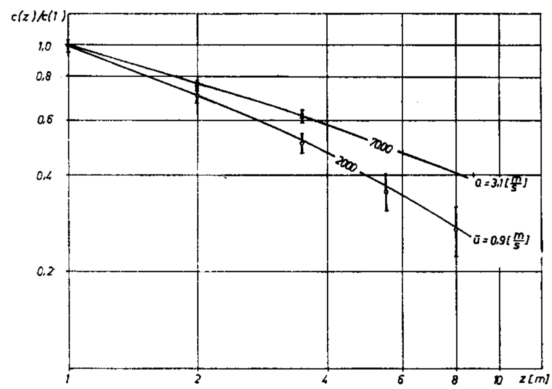

FIG. 4. Ratio of thoron concentration at height z to thoron content at $z = 1$ m. Full lines are calculated for linear increasing K. The numbers refer to K in [cm²/s] at $z = 1$ m. Dots are measured values.

Results

A. *Influence of the wind direction on the thoron concentration*

Fig. 2 shows the dependence of the thoron concentration on the wind direction at the different levels. At 1, 2 and 3.5 m (fig. 2*a*), we find, within the measuring accuracy, no dependence on wind direction, i.e. there is no azimutale change of the exhalation. The strong dependence at 5.5 and 8 m level from wind direction (fig. 2*b*) is caused by the influence of a gridded platform of a transmitting mast at 6 m height, where the aspirating points at these two levels are fixed. For that reason a part of these measurements must be excluded from the further investigations.

B. *Homogeneity of exhalation*

The windrose having shown the absence of azimutal dependences of the thoron exhalation, we shall have to verify now that no radial variations of the exhalation exist.

Measurements of the wind velocity between 1 and 8 m above ground gave a logarithmic wind profile as result. From this behavior we can conclude that, in the mean, we had an adiabatic layering of this region of the atmosphere. In this case the theory (see e.g. KLUG, 1963) requires proportionality between the eddy diffusion coefficient K and the mean wind velocity $\bar{u}$. By comparison of the K value calculated from the mean decrease of thoron with height with the mean wind velocity, we found between K and u at 2 m level the relation

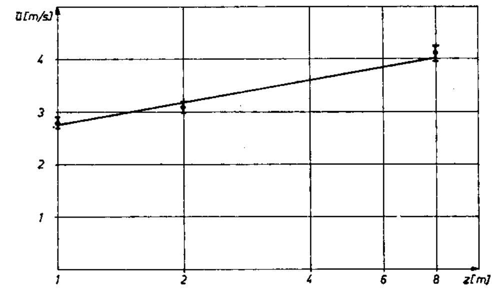

FIG. 5. Increase of the mean wind velocity $\bar{u}$ [m/s] with height z for windy and overcast days.

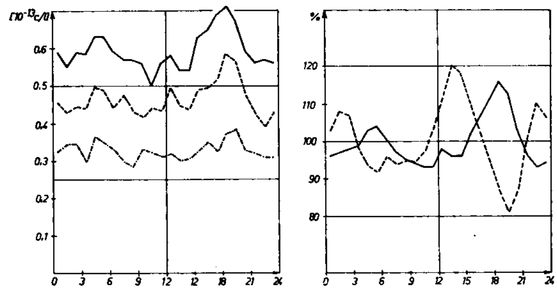

FIG. 6. (*a*) Mean diurnal variation of thoron concentration. —— 1 m; – – – 2 m; –·–· 3.5 m. (*b*) Diurnal variation of thoron concentration and wind velocity in percentage of the daily mean. —— Thoron concent.; – – – wind velocity.

$$K = 4400 \cdot \bar{u} \quad (4)$$

which defines the proportionality coefficient between K and $\bar{u}$. With this equation it becomes possible to calculate the term $f(K, z_2, z_1)$ of equation (3) in dependence of the mean wind velocity as done in Fig. 3.

Fig. 3 shows a good agreement within the error limits among the measured ratios of the thoron concentration and the under the presupposition of homogeneous exhalation calculated ratios for all heights and wind velocities. So we can conclude that no measurable radial gradients of thoron exhalation did exist at our station Mainflingen.

C. *Determination of K from thoron measurements*

Fig. 4 shows the measured mean decrease of thoron with height for two different wind velocities compared with the theoretical decrease calculated from equation (2). As seen in both cases, the measured decrease may be described very good by one of the theoretical curves. This behavior leads to the inductions:

(*a*) By comparison of the measured decrease of thoron with these theoretical curves, K may be determined with good accuracy from thoron measurements.

(*b*) In the region between 1 and 8 m above ground, in the mean, K increases linearly with height.

(*c*) There is found proportionality between K and the mean wind velocity, in good agreement with theory, as mentioned above.

To get a possibility of comparison between the thoron measurements and the meteorological exchange measurements, we calculated the eddy diffusion coefficient for very windy and overcast days from thoron measurements and from the wind profile, presupposing an adiabatic layering of the atmosphere.

Fig. 5 shows the mean wind velocity plotted against $\log z$. Within the variation range, the measured values lie upon a straight line, this implying that, as an average, an adiabatic lamination of the atmosphere can be assumed. Following this theory, K is appointed by the wind profile by:

$$K_m = \frac{k^2 \cdot \bar{u} \cdot z}{\log (z/z_0)}; \quad (5)$$

z_0 = "roughness length" = 1 cm
k = Karman-constant = 0.4
z = height above ground
$\bar{u}$ = mean wind velocity

Starting from the wind profile of Fig. 5, the equation yields:

$$K_m = 990 \text{ cm}^2/\text{s} \quad \text{for} \quad z = 1 \text{ m}$$

for the exchange of momentum, while the thoron measurements fix a $K = 7000$ cm²/s being approximatively the sevenfold of K_m. An explanation of this discrepancy is still outstanding.

D. *Daily variation of the thoron concentration*

In Fig. 6, on the left-hand side, the average daily variations of the thoron concentration at 1 m; 2 m; 3.5 m above the ground at Mainflingen are plotted. The daily variations of the thoron concentration being an intrinsic consequence of the atmospherical exchange, there should be a correlation among these daily variations of the thoron concentration and the wind velocity, while there is, as above mentioned,

$$K = f(u).$$

On the right-hand part of the figure, there are drawn the percentual daily variations of the thoron concentration (full line) and of the wind velocity (dashed line). There apparently exists an evident antiparallelity among the two parameters, as theoretically expected. According to the calculations of JACOBI (1962) for a $K = 10^3$–10^4 cm²/s the thoron concentration in the tested range should decrease with increasing exchange, i.e. growing wind velocity.

The investigations are continued.

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ВЛИЯНИЕ МЕТЕОРОЛОГИЧЕСКИХ ЭЛЕМЕНТОВ НА РАДОН (Rn^{220}), СОДЕРЖАЩИЙСЯ В АТМОСФЕРЕ

Содержание Rn^{220} на разных уравнях между 1–8 м и в различные месяцы было измерено с использованием нового оборудования, позволяющего непрерывно записывать количество радона с чуствительностью $0,5 \cdot 10^{-14}$ c/l и разрешающем временем в 220 сек. Полученные данные связывались с метеорологическими величинами. Изучив зависимость между направлением ветра и увеличением с высотой концентраций Rn^{220}, авторы подтвердили однородность выделения Rn^{220} в окрестности места наблюдения (Mainflingen). Из сопоставления уменьшения Rn^{220} с высотой с теорией был определен коэффициент турбулентной диффузии K. Установлено, что, в среднем, K линейно увеличивается с высотой между 1 и 8 м и пропорционален средней скорости ветра U. Средние коэффициенты турбулентной диффузии, полученные из результатов измерения Rn^{220}, сравниваются с соответствующими диффузионными коэффициентами количества движения вычисленными по профилю ветра.