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Continuous measurements of soil radon under regular field conditions (*)

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Summary. — Continuous soil radon measurements were performed in the frame of an EU-radon network using the Clipperton II detector. It has been found that in some periods, soil radon levels obtained with one Clipperton II probe are very different from those obtained with another probe placed at the same depth but a short distance apart. Sudden fluctuations of soil radon levels in a given site have been observed as well. To determine whether this behaviour corresponds to the nature of radon gas in the soil or to the detection technique, various experiments have been performed. It has been observed that when different detectors are exposed at the same regular field conditions, their discrepancy is lower than 11%. When the soil radon concentration is approximately constant, the statistical fluctuations of the Clipperton probes are lower than 15%. The application of the Fourier-filtering algorithm to the rough data, removing all frequency components smaller than $1/24\ h^{-1}$, has led to a complete correlation between different Clipperton II probes. The time response of the probes has been investigated in a specific experiment at the laboratory. It has been found that the response of the probes to a sudden change of radon concentration is controlled by the diffusion process along the bottom tube of the probe. Therefore, this study shows that the experimental data can be attributed to the natural behaviour of soil radon.

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1. – Introduction

In 1994, the research project on radon "Criteria for indoor radon concentration — An experimental study considering especially the Leipzig-Hall brown coal area" was initiated within the European Union programme Human Capital and Mobility (ERB-CHRX-CT 930422). The project intends to improve the understanding of the specific behaviour of the radon gas and is being carried out by six research groups belonging to five European countries [1]. Due to the importance of soil as a radon source, soil radon levels at one-meter depth are measured continuously with a one-hour sampling period. The measurements are performed in the soil of six test houses using the Clipperton II probes developed by the University of Montpellier [2]. Preliminary soil data have already been published [3-5] and the Clipperton probes have been intercompared with nuclear track detectors [6]. A common characteristic of the time series data obtained in the soil radon measurements at the six experimental sites is that in some periods, soil radon levels obtained with one Clipperton II probe differ from those obtained with another probe placed at the same depth but a short distance apart (few centimetres). Sudden fluctuations of soil radon levels in a given site have been observed as well. This paper reports on various experiments with Clipperton II probes exposed under regular field conditions and an experiment at the laboratory to determine whether the behaviour of radon in the soil obtained corresponds to natural phenomena or is an instrumental artefact.

2. – Experimental method

Each of the six research groups participating in the project selected a typical house for its region as a "test house". Soil radon concentration has been measured continuously with a one-hour sampling period at a minimum of five points of each test house garden soil. In each point, a single Clipperton II probe has been installed at 1 m depth approximately inside a 10 cm diameter isolated and covered PVC tube placed in the soil. The Clipperton II probe is based on a solid-state detector without polarisation, which is protected by special layers against friction and moisture. A black carbon fibre composite diffusion tube is set at the lower part of the probe. Its main role is to avoid the detection of thoron and light photons. The data processing and storing is performed by a NSC810A microprocessor. The probe is operated by a Psion-organiser computer for initialisation and data transfer [2].

To evaluate the reliability of the data obtained with the Clipperton II probes, various studies under real field conditions at the different European areas have been carried out. In each site, a 30 cm diameter and 1 m depth hole was dug in which several Clipperton probes were exposed at the very same conditions.

Since in many cases one is more interested in relative variations of radon concentration than in absolute values, a specific experiment was carried out at the Montpellier laboratory to find out the time response of the Clipperton probe. A small radon chamber containing a probe was filled up with a radon-rich air mixture. The probe was left in the chamber until equilibrium was reached and the counting rate was found to be constant. Then a vessel, evacuated down to 1 Torr vacuum, was connected to the radon chamber. The radon-air mixture is thus pumped off the radon chamber and admitted into this vessel, while it is automatically and rapidly—in a matter of seconds—replaced by pure air by means of a plunger valve connected to the atmosphere. Accordingly the radon concentration is decreased by a factor equal to the volumes ratio (which happens to be 1.6). The set-up is left alone until the counting rate reaches the new equilibrium.

3. – Results

3˙1. *Typical survey data.* – Figure 1 shows a characteristic 15 day pattern of soil radon concentration behaviour obtained at the Barcelona test house site. The Clipperton probes F1 and F2 have been installed at one-meter depth, separated 10 cm from each other. A soil sample was collected in each measurement point. Both samples presented the same texture, which corresponds to "Yolo light clay" [5]. It can be seen in fig. 1 that in some periods both Clipperton probes describe the same dynamics, while in others they display very different values.

3˙2. *Comparison of different Clipperton II probes exposed at the same regular field conditions.* – Figures 2 and 3 show the radon concentration profiles obtained in the holes made at Barcelona (five probes) and Leipzig (four probes) areas, respectively. The curves of fig. 2 have been smoothed by averaging each value with the preceding four values and the following four values to better differentiate the curves, while in fig. 3 the rough data obtained in Leipzig are given. It can be observed in both figures that after an initial increase of radon concentration, a steady state is reached.

The short-term discrepancies observed between the different Clipperton probes from the instant when the steady state is reached are interpreted as statistical fluctuations of the probes, so that when radon concentration is approximately constant, the statistical fluctuations of the Clipperton probes are less than 15%.

The mean soil radon concentration obtained under steady-state conditions with each Clipperton II detector differs from the total average of all detectors in less than 11% in the case of fig. 2 data and in less than 6% in the case of fig. 3 data.

To point out any correlation between the different Clipperton II probes, the method of Fourier-filtering has been applied to the original Leipzig data set. This means that

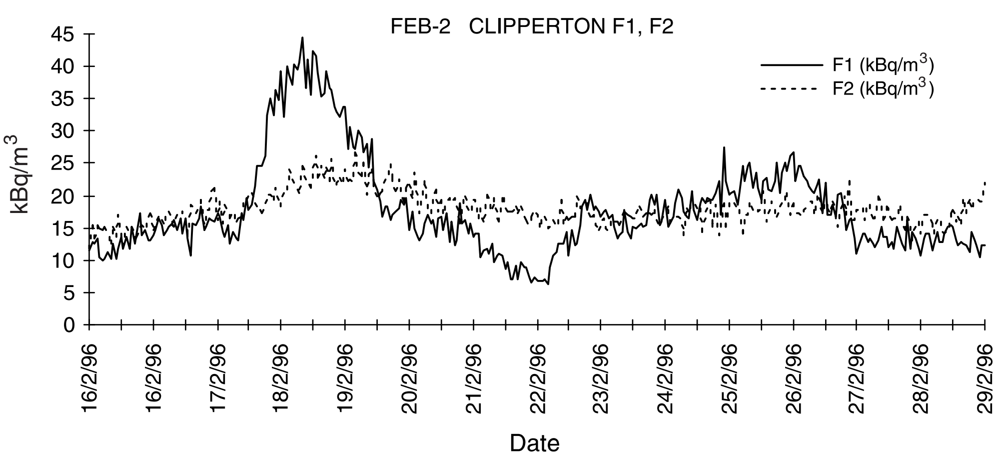

Fig. 1. – Typical 15 day pattern of soil radon concentration behaviour obtained at the Barcelona test house site.

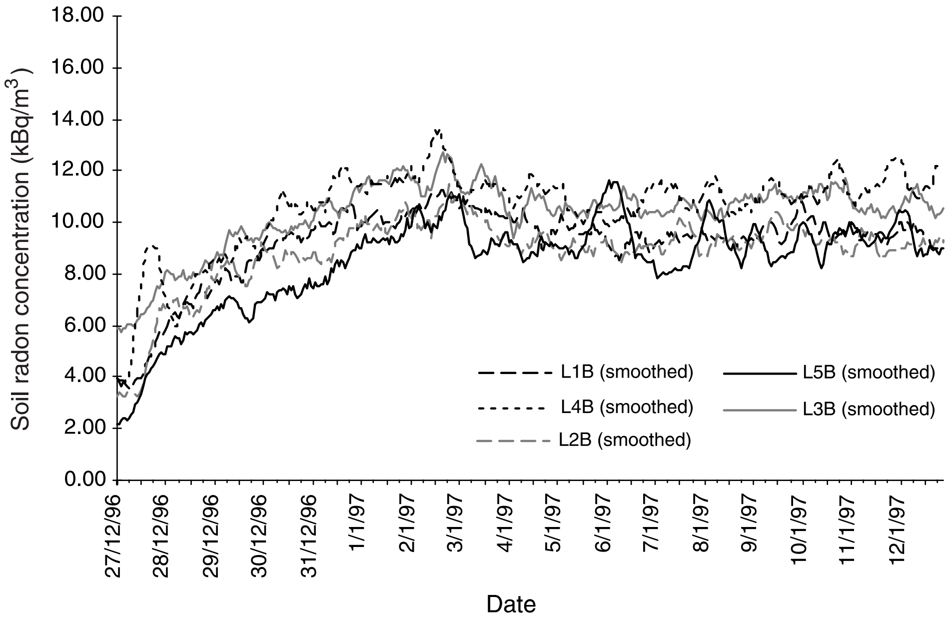

Fig. 2. – Comparison of 5 Clipperton probes exposed at the same conditions at the Barcelona experimental area.

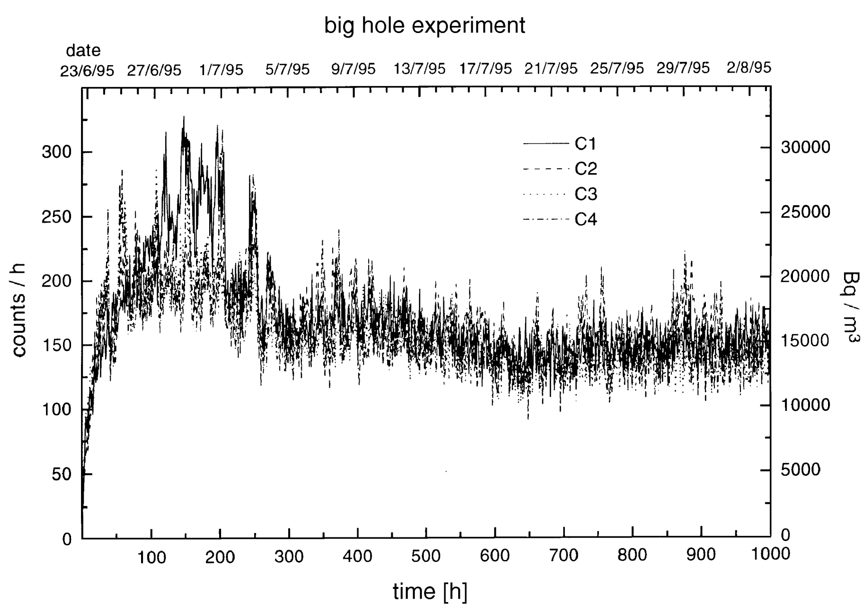

Fig. 3. – Comparison of 4 Clipperton probes exposed at the same conditions at the Leipzig experimental area.

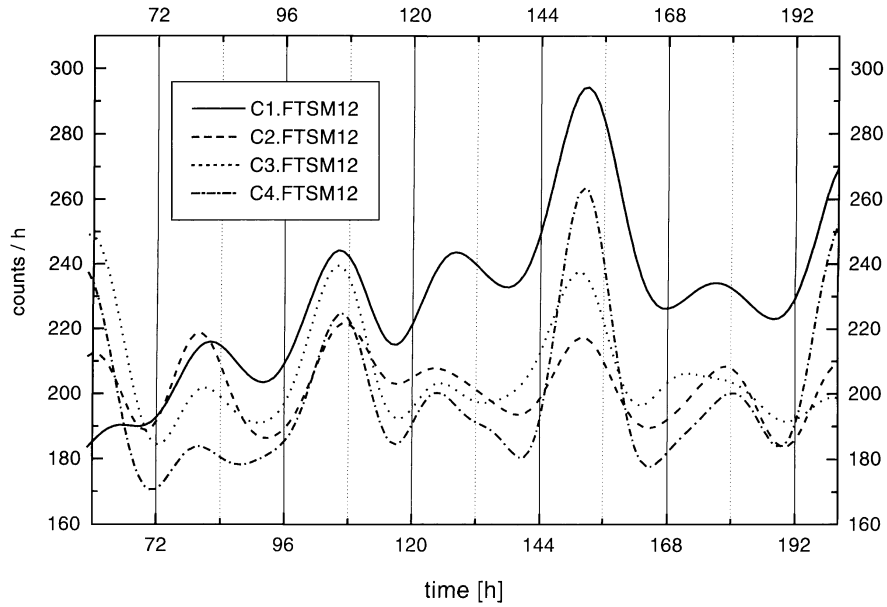

Fig. 4. – Comparison of 4 Clipperton probes exposed at the same conditions at the Leipzig experimental area after the Fourier-filtering, removing the frequency components higher than 24 hours.

after a Fourier-decomposition, all components with frequencies smaller than a given value are removed. Applying this procedure, removing all frequency components smaller than $1/24\ h^{-1}$, leads to a complete correlation, in which maximum and minimum of each detector correspond to one another, as can be seen in fig. 4. In this figure we have plotted the soil radon concentration behaviour obtained with each Clipperton II probe in the time interval from 60 to 200 h, because it is the period during which the rough data presented the highest scattering. For the other periods, the results are comparable or better.

3·3. *Time response.* – The results obtained at the Montpellier radon chamber are shown in fig. 5. The left part of the figure corresponds to the evacuation of radon-rich air, while the right part corresponds to the inverse process, in which an increase of the radon concentration is induced. The continuous line is the theoretical variation of concentration calculated in the following way. Once radon is admitted at the lower opening of the probe, it moves towards the detectors by diffusion only, whose describing equation is

(1) $$\frac{\partial C}{\partial t} = D \cdot \frac{\partial^2 C}{\partial z^2} - \lambda C ,$$

where C is the radon concentration at the distance z from the bottom opening of the

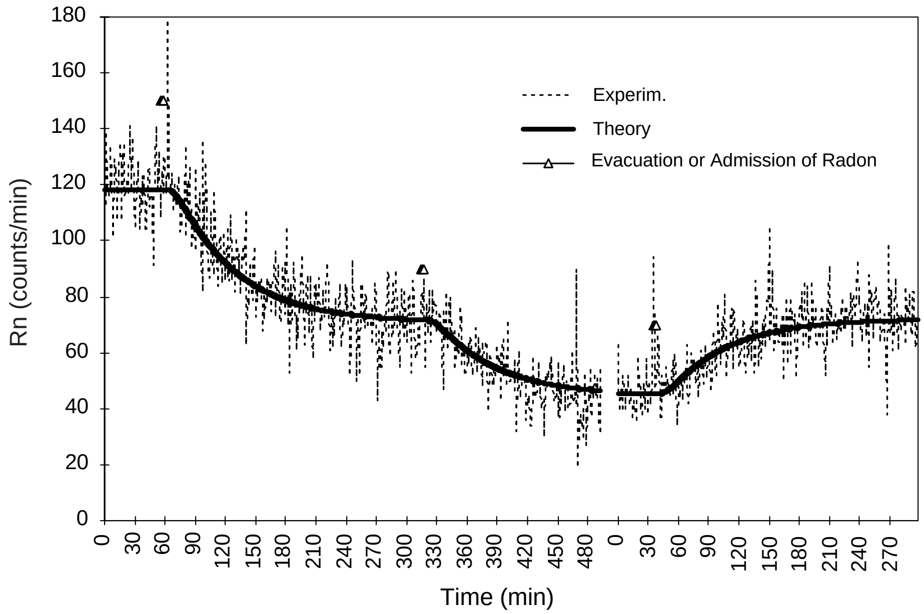

Fig. 5. – Study of the time-response of the Clipperton probe when radon-rich air is suddenly admitted or evacuated.

probe ($z = 0$), at time t, D is the diffusion constant of radon in air and λ the radioactive decay constant of radon. The boundary conditions are $C(z, t) = C_0$ (initial concentration) for $t = 0$ and $z = 0$ and $\partial C / \partial z = 0$ for $z = 30$ cm (*i.e.* at the level of the detector itself inside the diffusion tube). The above equation is solved by the method of finite differences.

As can be seen, the radon counting rate follows the theoretical curve quite closely. This experiment shows that the beginning of the response of the probe to a variation in the radon concentration occurs a few minutes after this variation is induced. However, it takes on average two hours before counting equilibrium is reached up to 80%. Shorter times could be used but would require the diffusion bottom tube to be shortened.

4. – Conclusions

The Clipperton II probes constitute a reliable instrument to continuously measure soil radon concentration. Taking into account the statistical fluctuations, agreement between different probes when exposed at the same regular field conditions has been found. The Fourier-filtering algorithm allows to obtain a good correlation between different probes. The time response of the probes to a sudden change of radon concentration is controlled by the diffusion process along the bottom tube of the probe. Thus, the data obtained in the survey carried out within the frame of the EU radon project is reliable and corresponds to the natural behaviour of radon in the soil.

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