Geofísica Internacional (2002), Vol. 41, Num. 3, pp. 265-270

Radon concentrations in karstic aquifers

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Received: September 5, 2001; accepted: April 13, 2002.

RESUMEN

Se midieron las variaciones temporales de la concentración del Rn en el agua del acuífero de Lamalou en Francia. Las mediciones se se realizaron al nivel de la fuente, así como en pozos asociados con el acuífero. Las variaciones de Rn registradas dentro del conducto principal y dentro de un pozo situado al lado del conducto principal han sido comparadas. Se encuentra que la respuesta a la lluvia depende fuertemente de la estación cuando ocurra la lluvia. En verano, después de un episodio de lluvia, se nota una respuesta del radón en el pozo; sin embargo, no se observa al nivel de la fuente. Además, el decaimiento del radón obedece a la ley de decaimiento radioactivo. Así pues, en verano el acuífero casi no se mueve horizontalmente. Todo lo contrario, en la estación de lluvia, cada precipitación produce una señal en el pozo, así como en la fuente, lo cual indica un tipo diferente de funcionamiento y un proceso de mezcla de las aguas en el conducto principal.

PALABRAS CLAVE: Radón, acuífero, respuesta a la lluvia.

ABSTRACT

Time variations of radon-222 concentrations in the water of the Lamalou, France, karst aquifer have been measured. The measurements have been performed at the spring outlet of the aquifer as well as in boreholes drilled from the surface. Radon concentrations variations recorded in the main outlet and in a well located next to it are compared. The response to rainfall depends strongly on the season when rainfall occurs. During summer, a rain episode is followed by a radon response in the well but not at the spring. Furthermore, the decay of the radon signal obeys strictly the radioactive decay law. Accordingly, during summer the water of the aquifer barely moves horizontaly. On the contrary, during the rainy season, every rainfall induces a signal both in the well and at the spring reflecting a different mechanism and a mixing process of the water in the main outlet.

KEY WORDS: Radon, aquifer, rainfall response.

INTRODUCTION

The study of radon concentration variations in the soil and in bore-holes provides an additional contribution to the evaluation of the physical characteristics of an aquifer (fracturation, permeability, porosity), on the water flow processes and possibly on the origin of the groundwaters (Andrews and Woods, 1972). In spite of its relatively short half-life (3.82 d), radon and the time variation of its water concentration may allow to assess the transit time of the percolating waters originating from the rainfalls or from the water flows near by the considered aquifer (Hoehn and Von Gunten, 1989).

However, the obtained data for aquifers of highly fractured bedrocks appear to be hardly interpreted. As a matter of fact, the concentration variability as a function of the sampling sites reflects the geological intricacy of the studied area and the petrophysic parameters multiformity (^{226}Ra average content, ^{222}Rn emanation rate of the bedrock, fracture surface in effective contact with the interstitial fluids; Torgensen *et al*., 1990)

A decade ago approximately, our research group has attempted to transfer its expertise in radon measurement in situ from the field of earthquake and volcanic eruption prediction to that of the study of aquifer functionning. The study was initiated on a fractured aquifer in a granitic environment and was followed by a work on several aquifers in a karstic environment within the frame of a European Union project (Monnin, 1998). A special attention has been paid to the rainfalls influence on the radon behaviour in the groundwater for trying to identify the hydrogeological phenomena governing the recharge of the aquifer, the water flows and eventually the watershed area of the studied aquifer. Preliminary results on a specific aquifer (Lamalou, Hérault, France) was published within the frame of the so-called COST65 action of the European Commission (Monnin *et al*., 1994; Pane, 1995; Pane *et al*., 1994). Approximately at the same time, quite interesting results were obtained in Switzerland, also on a karst system, (Surbeck and Eisenlohr, 1994; Eisenlohr and Surbeck, 1995) or in India in a granitic terrain (Reddy and Sukhia, 1996). Since then, several publications were released in the literature regarding precisely the role of radon as a tracer or as an indicator of the water flow (e.g. Cook *et al*., 1999; Hamada, 2000). However, these works are mostly related to fractured such as in granitic terrain and/or metasedimentary aquifers. In the case presented here one deals with a karstic aquifer. Aquifers of this type have a very distinct structure and functionning. Continuous recording of radon data in the specific aquifer of Lamalou was continued and it keeps going on by the time being. This paper intends to report selected findings gathered during this period of time.

EXPERIMENTAL SITE

The experimental site of Lamalou (Hérault, France) is located on the «causse de l'Hortus» plateau, 30 km north of Montpellier (43°50' N, 03°47' E). This karst aquifer is constituted by valangian limestones which present a very low porosity (1.8%) and permeability. Accordingly their contribution to the water circulation is negligible compared to the fracturation network. This 300 m thick formation is isolated from deeper aquifers by berriasian marls.

Two main structures provide the water transport (Durand, 1992): microfissured blocks with low permeability but highly capacitive on the one hand, and channels or drains with a high permeability but poorly capacitive. The surveyed area bears eight unsheathed bore-holes, ranging from 30 to 80 metres deep (measured from the surface). Two of these wells reach the main drain of the karstic aquifer, while others are located sideways from this main drain or channel. The channel is in the form of a gallery ended by a cave where stagnant water is present and which constitute a temporary outlet of the aquifer during the large floods of the underground river through the spring which is located somewhat farther down from the cave. On the contrary, during summer, the spring outlet shows only a rivulet flow, which even stops completely during particularly dry summers.

MEASUREMENTS

So far as this paper is concerned, ^{222}Rn measurements were continuously recorded at the spring and in the F5 well. These measurements were carried out using an automatic Clipperton radon probe devised and built in our laboratory at the University of Montpellier (Monnin and Seidel, 1998). The Clipperton probe is a field instrument designed for continuous long-term radon measurement. It is based on the detection of alpha-particle emissions using a solid-state electronic sensor. The probe is designed for the selective counting of radon decays with recorded count values over specified time intervals. The countings recorded during a space of time which can be selected at will among 1, 10, 20, 60, 120, 1440 and 2880 mn, are stored on RAM within the device. The RAM can store up to 3250 measurements and their identification labels. Both the alpha-particle sensor and the RAM are installed in a cylindrical stainless steel tube with an overall length of 50 cm, opened at one end in order to allow Rn to enter the probe, and a diameter of 5 cm. With this arrangement the probe responds within 12 mn to any change of the Rn concentration occurring at the level of its opened end. The Clipperton probe allows the measurement of radon activity levels in a range between 100 Bq m^{-3} and 1000 kBq m^{-3}, permitting an accuracy of about ±7.5%. Its sensitivity is: 1 count.h^{-1} = 90 Bq.m^{-3} . The probe is operated on 4 R20 DC batteries. The data extraction is carried out on the field with a lap top computer. Data can be stored on disk as ASCII files and further treated by data base and spread sheets such as Excel, QuattroPro or Lotus 1-2-3.

The rainfall intensity was continuouslty measured by the "rain gauge" classical technique.

RESULTS AND DISCUSSION

On Figure 1 and 2 are displayed the radon concentration variations in the F5 well and at the spring together with the rainfall recorded on the spot. Rn data were recorded every hour. However, they are exhibited after a "moving average" smoothering over 6 hours so as to lower the effect of spurious variations and to focus on genuine and significant variations. The shown data were recorded from January 1996 to December 1997.

Qualitatively speaking one can make the following remarks. The Rn response curve at the spring outlet of the aquifer is mostly flat (no response to rainfall) during the period of time preceded by a long period of draught, or when the rainfall episodes are separated by dry periods with much sunshine and heat, the duration of such episodes being of the order of one week at least. This can be observed in a well marked manner between mid-May to November 1996 and between mid-February and mid-October 1997. On the contrary, during the same periods of time, the Rn response curves recorded in the well are quite impressive. Rainfalls are followed by a steep increase in the Rn content, with a delay though of several days between the beginning of the rainfall event and the beginning of the Rn increase in the well. See for instance the response during summer 1996 (August to October), during spring 1997 (May and June) and during summer 1997 (August to mid-October). These facts can be interpreted in the following way. Regarding the "well" response first: during summer, the epikarst system is void of water. The very first quantity of water and an appreciable amount of what follows is absorbed in the soil cover and the "water demanding" plants (intense evapo-transpiration at this time of the year) which are growing on it. It is only after the saturation of this upper part of the system is achieved that water can travel further down. In the process it picks up the radon and takes it downward to the Rn probe level. This explains why, on the May-June 1997 event for instance, it takes 430 hours for the Rn concentration to increase after the first rainfall event, whereas, as we shall see later, it takes

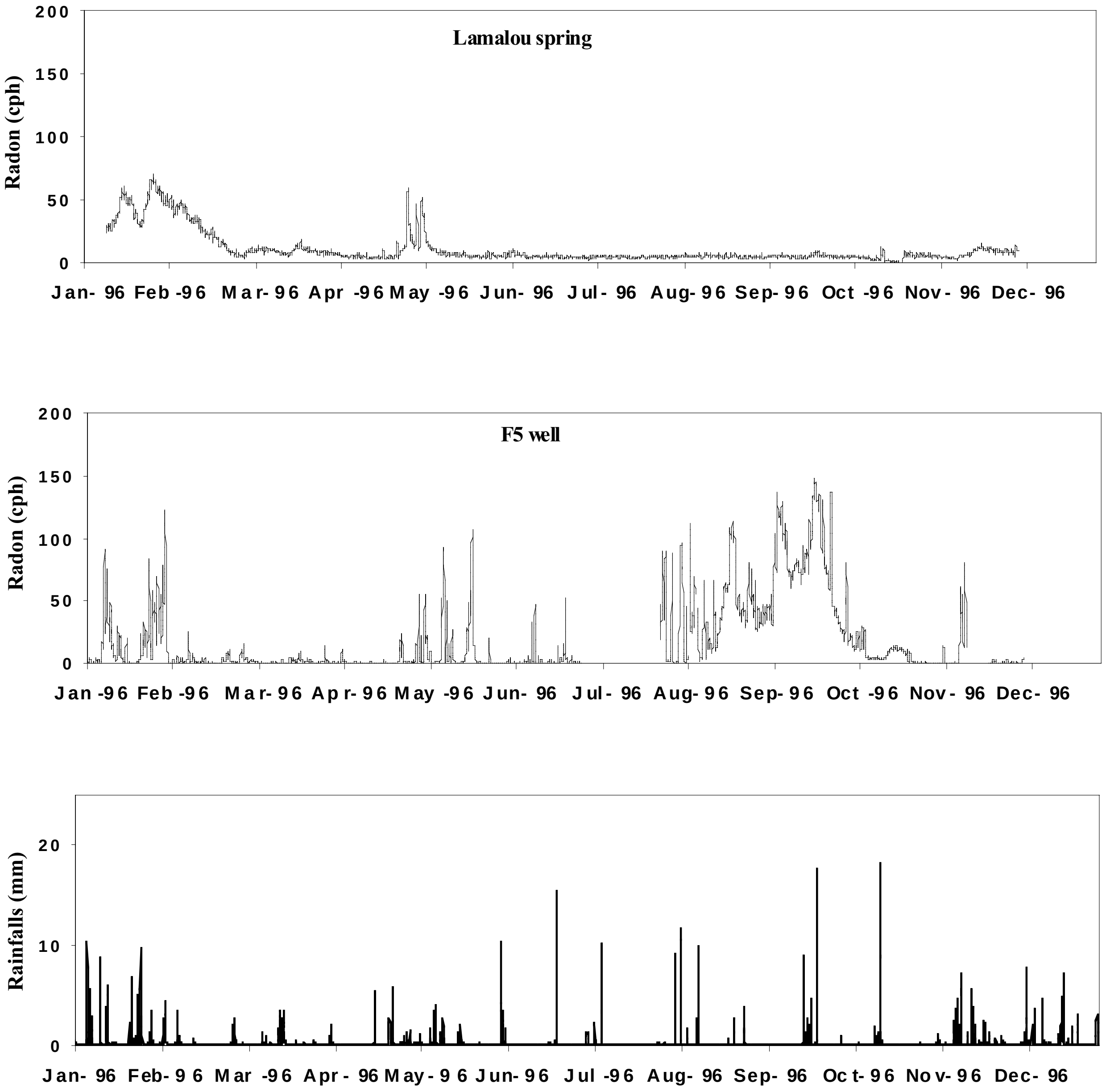

Fig. 1. Recordings from Jan. 96 - Dec. 96. Radon concentration variations; upper curve at the spring; middle curve in the F5 well. Rainfall: lower curve.

only a few hours to perform the same journey during the rainy season. Since the aquifer is located at 30 metres below the surface, this leads to an average vertical infiltration velocity of 0.07 m.h^{-1}. A similar value is obtained for the Rn peak which starts showing up in August 1997. This finding is contradictory to that of artifical and tracer experiments performed on the same spot under similar climatic conditions (Bakalowicz, 1995; Chevalier, 1988) and which yielded a mean velocity of 3 m.h^{-1} . If now one focuses on the curve of Rn variation after it has reached its maximum one finds that it decreases exactly as the radioactive decay law predicts (see Figure 3). In other words the water does not move sideways and has no reason to reach the main drain. Accordingly, no additional radon is introduced into the main water flows and this explains why, during the "dry" season, the Rn response at the spring level is nil.

If one now focuses attention on the "rainy" seasons, such as the period January to March 1996 and that from November to February 1997 the functionning is different. The soil and the epikarst are saturated. There is no delay and the response at the well level is much faster, typically of the

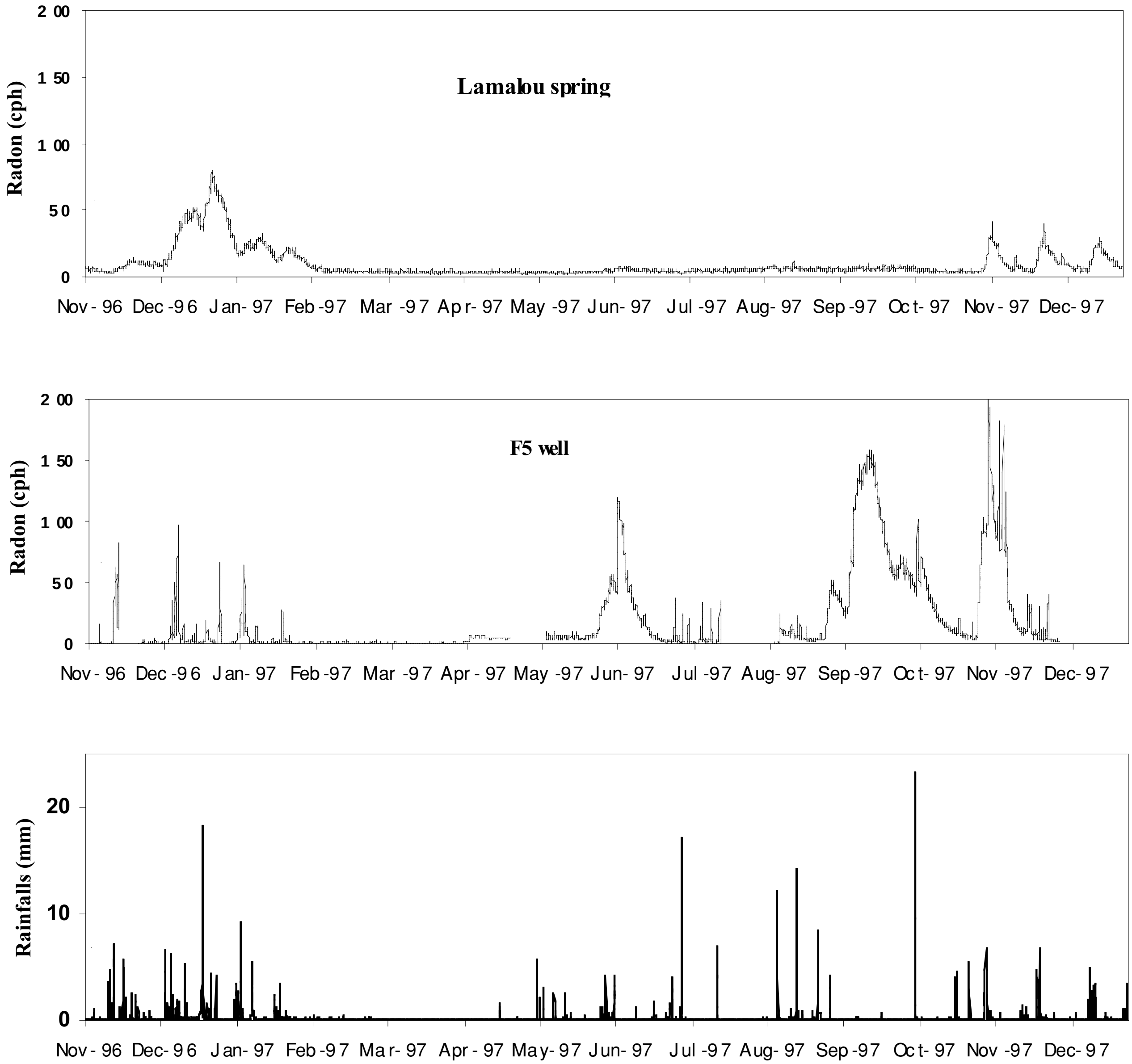

Fig. 2. Recordings from Nov. 96 - Dec. 97. Radon concentration variations; upper curve at the spring; middle curve in the F5 well. Rainfall: lower curve.

order of 3 hours. This time provides vertical velocities quite comparable to that found by Chevalier (1988): 1 m.h^{-1} on average. But more interesting is the fact that the decrease of the Rn concentration in the well does not follow, by far, the radioactive decay curve. It is much faster as can be seen in Figure 3 and this for all the events. In other words, the water table is moving in a direction more or less perpendicular to that of the well axis. This water, heavily concentrated in radon, will thus reach the main drain and provides for the radon response one can observe at the spring outlet. Hence, the variations in radon concentration observed at the spring outlet. These variations exhibit a broad mid-hight width, reflecting the fact that the water in the drain is a mixture of water from farther origin and that resulting from the local rain and which directly affects the radon concentration in the main channel. The water mixing is further demonstrated by the difference in radon concentration. In the well, these concentrations are systematically higher than in the main drain, by a factor of 2 to 4 approximately.

CONCLUSION

In a long term survey radon concentration variations onto a karstic site have been measured. The discussion of

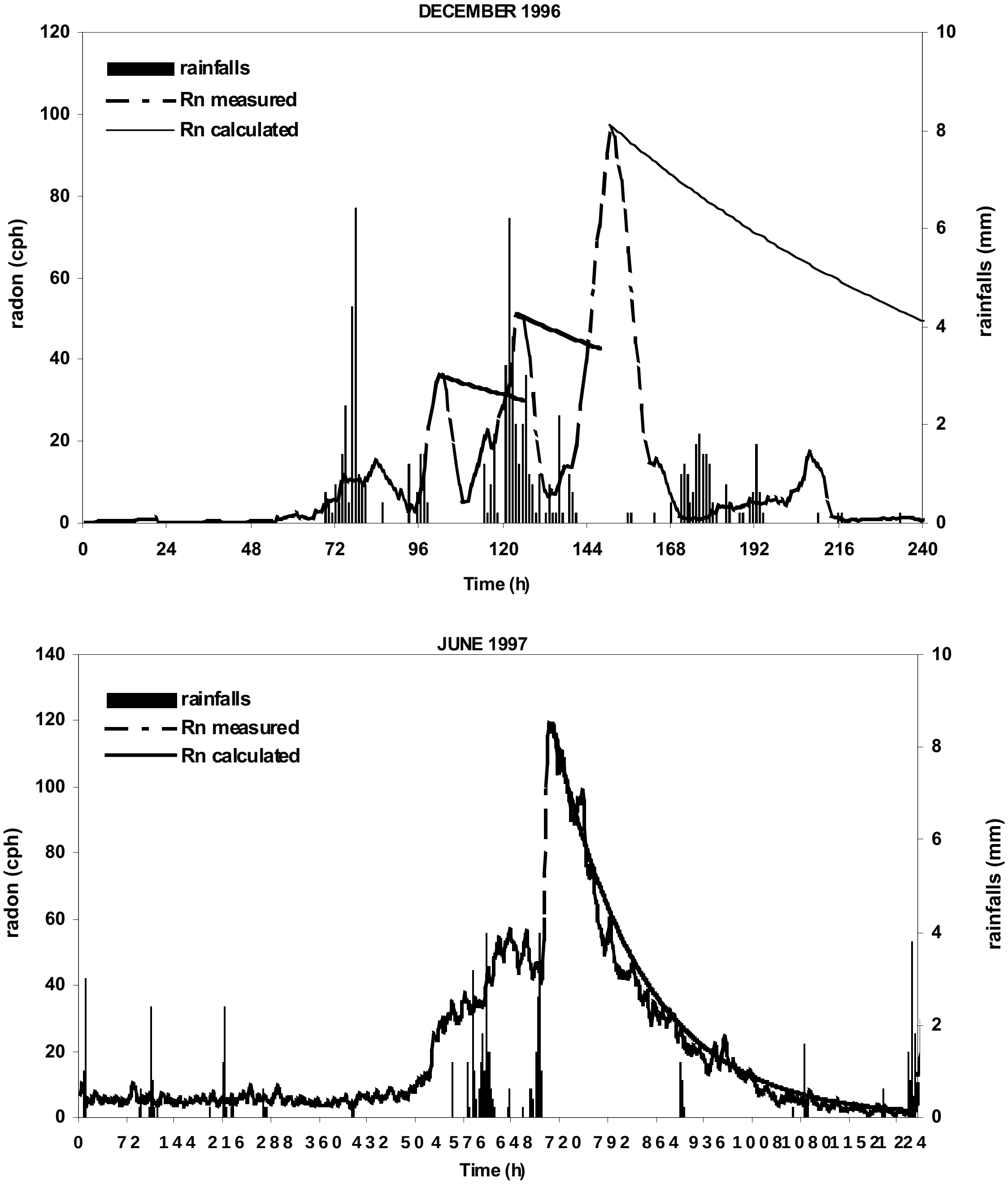

Fig. 3. Radon concentration decay: - upper curve, in the rain season - lower curve, in summer.

the results show that local radon measurement in the water can provide information regarding the functionning of the aquifer. Not only inflitration rate can be assessed but also the "horizontal" and lateral motion of the aquifer during the flood season.

ACKNOWLEDGEMENTS

The authors a grateful to Eric Gayrard for his valuable help during field measurements.

BIBLIOGRAPHY

ANDREWS, J. N. and D. F. WOODS, 1972. Mechanism of radon release in rock matrices and into groundwaters. *Trans. Inst. Min. Metall. Sec.*, B81, 198-209.

BAKALOWICZ, M., 1995. The infiltration zone of karst aquifers. *Hydrogeologie, 4,* 3-21

CHEVALIER, J., 1988. Hydrodynamique de la zone non saturée d'un aquifère karstique. Site du Lamalou. PhD Thesis, Université de Montpellier 2, 207p.

COOK, P. G., A. J. LOVE and J. C. DIGHTON, 1999. Inferring Ground Water Flow in Fractured Rock from Dissolved Radon. *Ground Water*, *37,* 4, 606-610.

DURAND, V., 1992. Etude des déformations du karst par mesures inclinométriques et extensiométriques: applications au site du Lamalou. PhD thesis, Université de Montpellier 2, 205p.

EISENLOHR, L. and H. SURBECK, 1995. Radon as a natural tracer to study transport processes in a karst system. An example in the Swiss Jura. *C.R. Acad. Sci. Paris*, *t.321, série II a,* 761-767.

HAMADA, H., 2000. Estimation of groundwater flow rate using the decay of ^{222}Rn in a well. *J. Environ. Radioactivity*, *47,* 1-13.

HOEHN, E. and H. R. VON GUNTEN, 1989. Radon in groundwater : a tool to assess infiltration from surface waters to aquifers. *Water Resour. Res.*, *25,* 8, 1795-1803.

MONNIN, M., J. P. MORIN, M. B. PANE and J. L. SEIDEL, 1994. Radon-222 measurements in a fractured karst aquifer. European Commission. DG XII-COST 65 Action-rept. p.80 -91

MONNIN, M. and J. L. SEIDEL, 1998. An automatic radon probe for earth science studies. *J. Appl. Geophys.*, *39,* 209-220.

MONNIN, M., 1998. A multidisciplinary global approach of groundwater flows in karstic areas and its consequences for water resources and environmental studies. Rept. ERB-CHRX-CT94-0567 European Commission DGXII - Brussels.

PANE, M. B., 1995. Le radon, traceur des circulations en milieu karstique. *C.R. Acad. Sci. Paris*, *340,* 4, 37-45.

PANE, M. B., J. L. SEIDEL, M. MONNIN and J. P. MORIN, 1994. Radon as a tracer of fluids motion in fractured aquifers. *Environ. Geochem. & Health*, *16,* suppl., 325-334.

REDDY, D. V. and B. S. SUKHIJA, 1996. Search for correlation between radon and high-yield borewells in garnitic terrain. *J. Appl. Geophys.*, *34,* 221-228.

SURBECK, H. and L. EISENLOHR, 1994. Radon as a tracer in hydrogeology : a case study. *Environ. Geochem. & Health*, *16,* suppl., 91-100.

TORGENSEN, T., J. BENOIT and D. MACKIE, 1990. Controls on groundwater Rn-222 concentrations in fractured rocks. *Geophys. Res. Lett.*, *17,* 6, 845-848

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