

# **The Gas-Migration-Simulator (GAMS) - A new device for the simulation of soil gas migration processes**

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## **RESUMEN**

La investigación de procesos de migración de gases a través de suelos normalmente presenta dificultades debido principalmente a la naturaleza no homogénea del suelo; esto limita la capacidad de modelar los procesos apropiadamente tanto para describirlos como para predecirlos. El Simulador de Migración de Gases en Suelos (GAMS) se desarrolló para resolver este problema. El GAMS consta de un recipiente cilíndrico, el cual puede llenarse homogéneamente con un volumen conocido de suelo. El diseño del GAMS permite una entrada difusiva de cierta fase gaseosa en la base de la columna de suelo, lo que al mismo tiempo permite investigar la velocidad de exhalación del gas. El diseño permite además efectuar una irrigación cuantitativa de la superficie del suelo y simular niveles hidrostáticos ajustables. Para registrar series de tiempo de los parámetros más relevantes, el GAMS está equipado con seis capas de monitores intercambiables a diferente profundidad. Las investigaciones más recientes empleando el GAMS se enfocan a la migración de radón a través del suelo y su dependencia con la temperatura y contenido de humedad del suelo utilizando monitores "Clipperton".

**PALABRAS CLAVE:** Migración de gas en suelos, simulación, columna de suelo, radón.

## **ABSTRACT**

Since natural soil conditions are hardly ever homogeneous, soil gas migration processes are difficult to investigate. The power of model calculations for describing or predicting soil gas migration processes is often limited. The Gas-Migration-Simulator (GAMS) has been developed to cope with this problem. The GAMS takes the form of a cylindrical box which can be homogeneously filled with a soil volume of 1.7 m<sup>3</sup>. The design allows a solely diffusive input of a gas phase into the base of the soil column. At the same time it allows determination of the gas exhalation rate. By providing a gas-tight crawling space immediately above the soil column and by adjusting a certain air pressure in this space the GAMS also permits the simulation of atmospheric high or low pressure fields, enabling the investigation of their influence on soil gas exhalation rate and soil gas migration. Quantitative irrigation of the soil surface and simulation of an adjustable groundwater table are also possible. To record time series of the relevant parameters, the GAMS is equipped with six layers of exchangeable probes at different depths. Recent research focuses on the migration of radon through the ground and its dependence on meteorological parameters. Special "Clipperton" probes have been used to record continuous time series of radon concentration of soil gas together with the temperature and the soil moisture content.

**KEY WORDS:** Soil gas migration, simulation, soil column, radon.

## **INTRODUCTION**

Improving insights into the diverse aspects of soil gas migration is of vital importance for many applications in geosciences. For instance, quantitative understanding of soil gas migration processes is essential for assessing the effectiveness of landfill coverings in general and of coverings over U-mine tailings in particular, or for estimating the health risk caused by radon migration from the soil into the basement of dwellings. However, since soil conditions are hardly ever uniform soil gas migration processes are complex. Thus the predictive power of theoretical models for describing on-site situations is usually limited.

To allow a close investigation of soil gas migration processes under defined conditions and thereby to tackle the problems arising with theoretical migration modeling the "Gas-Migration-Simulator" (GAMS, patent pending) has been developed. To a certain extent the GAMS, which has been designed and built at the UFZ-Umweltforschungszentrum Leipzig/Halle GmbH (Centre for Environmental Research in Leipzig/Germany), is comparable to the "radon vessel" used at the Kernfysisch Versneller Institute in Groningen/The Netherlands (van der Spoel *et al.*, 1997, 1998, 1999). The aim of this paper is to introduce the GAMS and to present some results of recent related investigations.

**METHODS**

Made entirely of polyethylene, the GAMS takes the form of a 2,2 m<sup>3</sup> cylindrical box with a surface area of 1 m<sup>2</sup> (Fig. 1). Its main body has to be filled with the soil to be investigated (1,7 m<sup>3</sup>). To enable the solely diffusive input of a certain gas into the base of the soil column, a 0.2 m high “gas generation box” is installed at the base of the GAMS where the gas can either be generated or quantitatively injected. This box is separated from the actual soil column above by a highly permeable but still very compact water resistant multi-layer sheet made of Poly Ethylene. Besides the gas diffusion processes additional upward convective soil gas migration can also be activated thanks to the presence of a heating device in the gas generation box.

To allow also investigation of the soil gas exhalation at the soil/atmosphere interface, the GAMS can be covered with a gas-tight lid. This creates a 0.3 m high closed crawl space right above the soil column in which the concentration of the exhaling soil gas can build up. By precisely adjusting the air pressure with an automatic air pump in this “exhaling chamber” one allows the simulation of atmospheric high or low pressure fields. Furthermore, the immediate sealing of the ground without any crawl space can be simulated by directly covering the soil column itself with

an internal gas-tight lid. The quantitative irrigation of the soil column and the simulation of an adjustable aquifer at its base are also possible.

To record all the relevant parameters the GAMS has been equipped with six layers of exchangeable probes. The probe layers have been placed successively in the gas generation box at the base (PL6: 180 cm from the top), in the exhaling chamber at the top (PL1: 0 cm), and in the soil column itself, at the depths of 5, 30, 70, and 140 cm (PL2 to PL5). Besides the concentration of the soil gas component of interest, relevant parameters to be measured include the soil temperature, the soil moisture content and the pressure of the soil gas.

A set of four GAMSs has been installed at an outdoor test site run by the UFZ in 1999. To enable a genuine temperature profile in the soil columns, the GAMSs were buried in the ground up to their upper rims. All the probes and soil gas sampling ports can be operated from a manhole that sits in the centre of the structure (Figure 2).

A recent investigation involving the GAMS focuses on the migration of radon through the ground. The main body of the GAMS has been filled with a homogenous mixture of quartz sand and uranium tailings. As a supplementary radon source, additional uranium tailings have been placed into the gas generation box. A special “Clipperton” radon probe developed at the University of Montpellier (Monnin and Seidel, 1998) was used to record continuous time series of the radon concentration in the probe layers. 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 count-

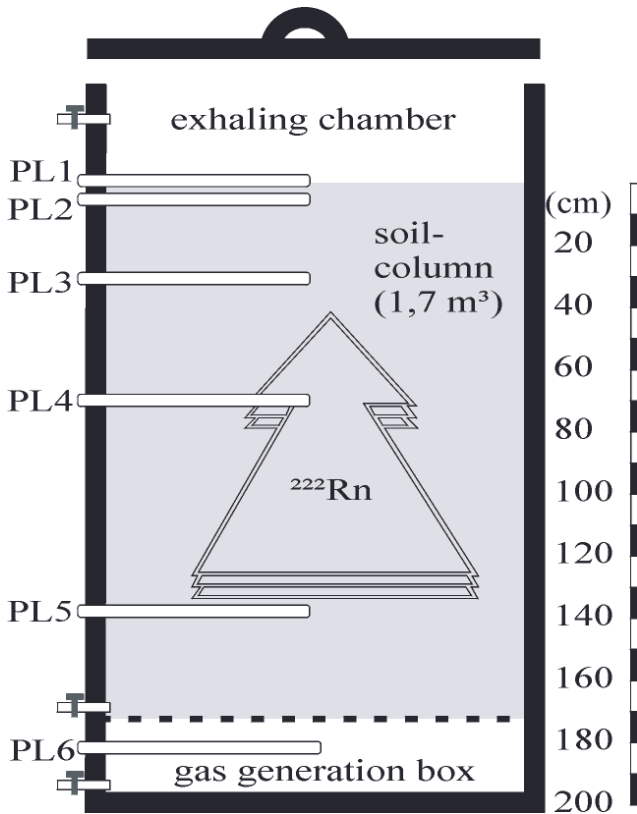


Fig. 1. Sketch of the GAMS.

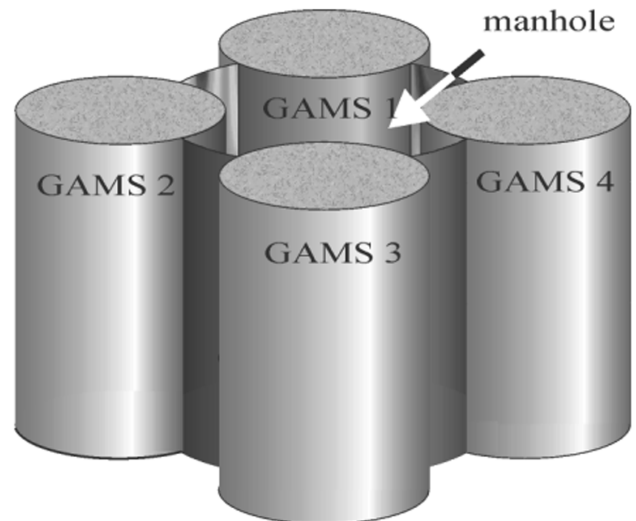


Fig. 2. Sketch of a set of four GAMSs.

ing of radon decays with recorded count values over specified time intervals. The countings recorded during a certain stretch of time which can be selected at will among 1, 10, 20, 60, 120, 1440 and 2880 minutes, 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 minutes to any change of the Rn concentration occurring at its opened end. The Clipperton probe allows the measurement of radon activity levels in a range between  $100 \text{ Bq m}^{-3}$  and  $1000 \text{ kBq m}^{-3}$ , permitting an accuracy of about  $\pm 7.5\%$ .

## RESULTS AND DISCUSSION

The aim of the recent investigation was to examine the dependence of the soil gas radon concentration at several depths on the temperature gradient in the ground and on the wind speed. Distinct diurnal variations of the radon concentrations could be observed down to a depth of 5 cm (PL2). The Clipperton probes installed at depths of 30, 70 and 140 cm did not show any significant diurnal changes of the soil gas radon concentration.

It could be shown that the diurnal pattern of the radon concentration observed at shallow depths (PL2, 5 cm) is closely correlated to the diurnally changing temperature gradient in the top soil. The temperature gradient either enforces or reduces the convective upward gas migration and thus increases or decreases the radon concentration in the uppermost soil layer.

The radon concentration measured at the soil/air interface (PL1, 0 cm) also showed typical diurnal variations which, besides its dependence on the diffusive and convective transport processes, are modulated by the diurnal variation of the wind speed. Results of this investigation are published elsewhere more closely (Schubert and Schulz, 2002).

Another aim of the GAMS experiments is to investigate the reaction of the soil gas radon concentration on heavy rain fall. As it has been noted by many authors (e.g. Schery *et al.*, 1984, Lindmark and Rosen, 1985) rainwater seals the ground temporarily and thereby reduces the radon exhalation from the ground which again gives rise to a significant increase of the soil gas radon concentration in shallow depths. To verify this hypothesis one of the GAMS has been used to simulate a heavy rain fall (30 mm in 10 minutes) on a homogeneous soil column consisting of mid grained sand. The radon concentrations that have been registered during the experiment are illustrated in

Figure 3. As expected the diagram shows a temporary rise of the radon concentrations in all examined soil layers following the precipitation. After about 12 hours the top soil, represented by the 5 cm probe, became cut off from the radon supply at depth due to the gravitative downward shift of the water saturated zone. While moving down the water not only blocks the upwardbound radon migration but also dissolves radon (Garcia, 1999). Thus the percolating water caused a temporary decrease of the soil gas radon concentration in the uppermost soil layer. In the mean time one notices an obvious correlated increase of the soil gas radon concentration at further depth due to the effect of the water moving downwards. It can also be observed that these local Rn variations start immediately after artificial raining started, within the time response limit of the probes as indicated above. The discussed results confirm the thesis mentioned above and suggest to avoid radon measurements at shallow depths shortly after heavy rain showers in the case one studies gas motion in general, or to take the phenomenon into account or even better to carry out experiments at further depth in the case one looks for precursors of earthquakes or of volcanic eruptions.

## CONCLUSIONS

The GAMS was developed in order to narrow the gap between on-site experiments and laboratory research in the field of soil gas migration research. The advantages of the GAMS are a) the use of a sufficiently large, defined soil column to simulate on-site conditions, and b) the continuous recording of gas concentrations and other relevant parameters at various depths under defined conditions. Since the GAMS allows all these parameters to be recorded

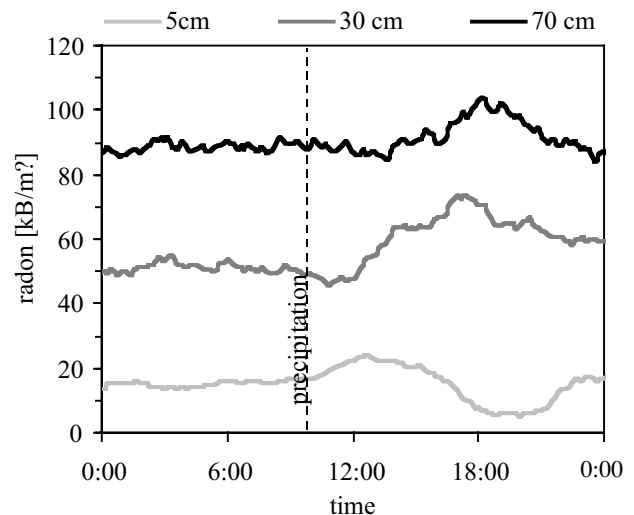


Fig. 3. The behavior of the radon concentration at three depth following heavy rain shower.

as time series with high sampling frequencies, the dependence of the soil gas migration on influences such as the meteorological conditions or physical properties of the soil can be studied very precisely.

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