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The sealing of soils and its effect on soil-gas migration (*)

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Summary. — The influence of a sealed soil on soil-gas migration is described by using ^{222}Rn as a natural tracer. It is shown that ^{222}Rn is focused to the rims of anthropogenic sealing, like asphalt or concrete. At a test site, the sealing effect was investigated in detail by using a radon-tight foil. A model to understand the soil-gas migration in dependence on the degree of sealing is developed. This study enhance the knowledge about the migration of hazardous gases in the soil, like methane or the carcinogenic ^{222}Rn itself. Additionally, the sealing effect can be used to increase the efficiency of soil venting systems.

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1. – Introduction

It is well known that impermeable layers within the soil or sealing the soil surface have a marked influence on the migration of percolation water. Such layers are usually natural impermeable beds, like fine-grained sediments, or they are of antrophogenic origin, like asphalt or concrete in connection with road and building constructions. In the same way the flow of percolating water is influenced, an upward directed flux of soil-gases is controlled by such sealing, *i.e.* the direction of migration is changed. This study tries to describe the influence of soil sealing on ^{222}Rn migration qualitatively and semi-quantitatively. Due to the short half-life of ^{222}Rn (3.8 days) the migration distance is limited. Therefore, it is not possible to transfer the results direct to other soil-gases.

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2. – Methods

Soil-gas samples are taken from the depths of 0.3, 0.5 and 0.8 m, in order to measure the ^{222}Rn concentration of soil-gas. The soil-gas samples are taken by using a gas-tight syringe. The samples are transferred into evacuated Lucas cells and measured scintillometrically [1]. The exhalation rate is measured with the accumulator method by using stainless steel cylinders with a diameter of 25 cm and a height of 14.4 cm. The cylinders are pressed approximately 2 cm deep into the soil to avoid the escape of exhaled soil-gas. After waiting a minimum of 20 minutes the soil-gas is sampled through a valve with a syringe and treated like mentioned above [2].

The soil moisture content is determined gravimetrically by taking soil samples. The gradient of atmospheric pressure was calculated by following subtraction: (air pressure of time of measurement) – (air pressure 24 h before measurement, or last minimum/maximum).

A test site was established in an abandoned sand pit NW of the city of Dorsten (Germany) [3]. The soil above the Upper Cretaceous sands was removed, and a 35 m^2, 1 mm thick, radon-tight PEHD-foil (high-density Polyethylene) was embedded 10 cm deep into the sands to ensure a good connection between the foil and the sand. Seventeen measuring points were situated in the direct vicinity of the V-shaped foil to obtain different degrees of sealing for each measuring point. The degree of sealing was determined by calculating the percental fraction of the area, which is covered by the foil in a radius of 1.5 m around each measuring point. 1.5 m were chosen because this should be the range of a sealing effect on radon migration within the permeable sand [4]. So one must keep in mind that the values of the percental degree of sealing, which will be discussed in the next sections, should not be considered as absolute values; *i.e.* a change of the "1.5 m radius" will change the values as well.

3. – Results

Measurements of the ^{222}Rn concentration in soil-gas, which were conducted in the vicinity of bifurcating roads and parking lots in the cities of Bottrop and Essen (Germany), showed a good correlation between ^{222}Rn concentration and the degree of sealing (fig. 1): The ^{222}Rn concentrations increase with a higher degree of sealing. Such measurements were repeated at other sites with similar results [5, 6]. The average ratios of ^{222}Rn concentrations between the different sealing conditions: "no sealing (>3 m off the sealing)/50% sealing (rim of the sealing)/90° corner (270° sealed)/approximately 45° corner (315° sealed)" are like "1/1.8/1.8/3.2" [5, 6].

The ratios between 90° corner and 45° corner show no differences, which could be explained by the fact that the 90° corner is not angular but rounded within an area of 2-3 m, which should be the maximum range of the sealing effect [4].

It seems that bifurcating roads are good test sites for evaluating the influence of soil-sealing on soil-gas migration. But the problem exists, to recognise or quantify the influence of an inhomogeneous backfill within the area of bifurcating roads, *e.g.*, the composition of the backfill beneath the asphalt. Therefore, a test site with a V-shaped foil was established (see sect. 2, fig. 2), and measurements were made before, during and after the foil was placed into the sand. Figure 3 shows the ^{222}Rn concentrations in soil-gas (0.3, 0.5 and 0.8 m depth) and the ^{222}Rn exhalation rate before the foil was embedded. The measuring points (D-1–D-11) are ranked after the future percental

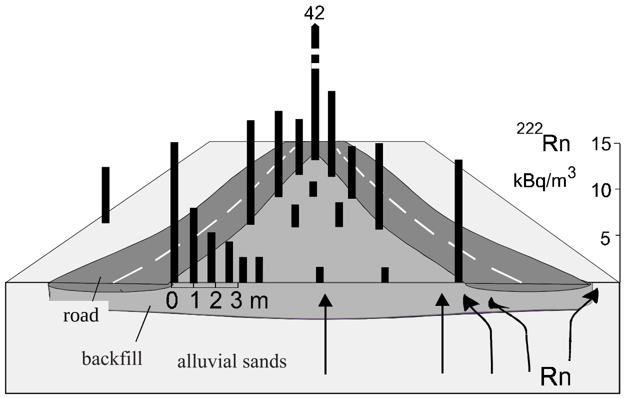

Fig. 1. – ^{222}Rn concentrations in soil-gas (0.5 m depth) in the area of a bifurcating road in the city of Bottrop. The ^{222}Rn concentrations are mean values of 3 measuring campaigns (1 in September 1995, 2 in February 1996).

degree of sealing (when the foil will be in place). Both the ^{222}Rn concentrations in soil-gas and the exhalation rates are distributed randomly. As expected, the ^{222}Rn concentrations within the sand are generally increasing with increasing depth.

Thirty-eight days after the foil was embedded into the sand, a second measuring campaign was conducted (fig. 4). Now, the ^{222}Rn concentrations in the soil-gas are increased at the 2 measuring points showing the highest degree of sealing (D-1, D-11). This increase can be seen in all 3 depths. In the same way, the exhalation rate is increased significantly at the measuring points D-2, D-7, D-1 and D-11.

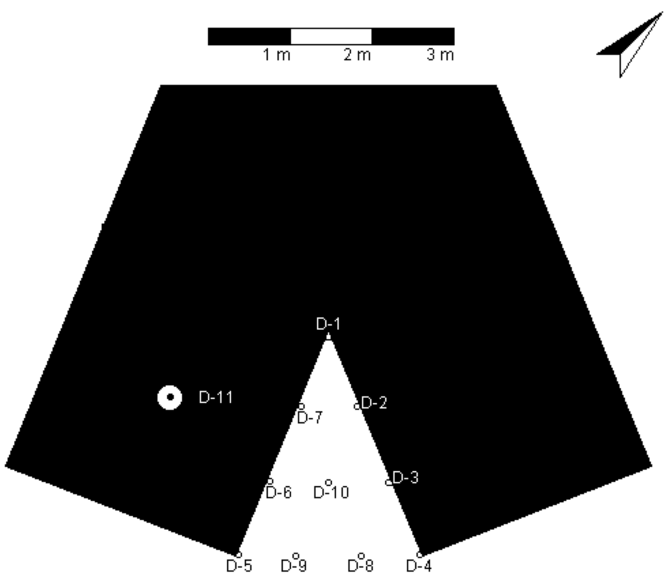

Fig. 2. – Shape and dimension of the foil placed in the test area, and position of measuring points.

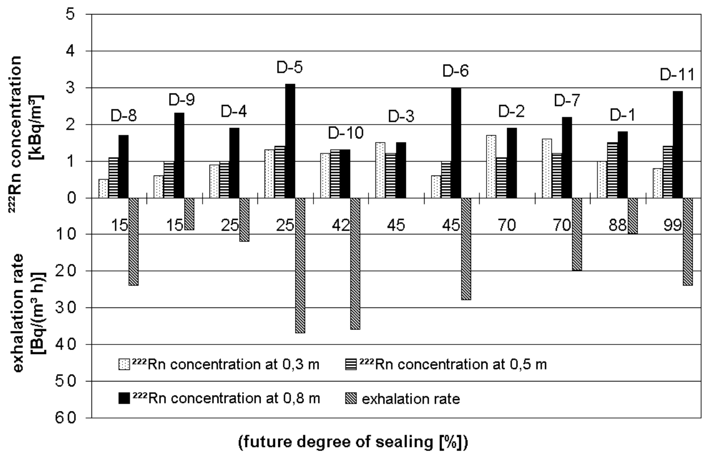

Fig. 3. – ^{222}Rn concentrations in soil-gas and ^{222}Rn exhalation rate in the area of the V-shaped opening of the foil at the test site. The measurements were done *before* the foil was embedded (12.07.1996).

Totally, 6 measuring campaigns were conducted at this site: 3 times under sealed and 3 times under unsealed conditions. In fig. 5 we have tried to compile and quantify the results of the investigation. Two results are observable: Firstly, at the depth of 0.5 and 0.8 m a ^{222}Rn increase due to the sealing starts at about 50% degree of sealing. For the depth of 0.3 m such an increase can be seen from 70 or 80% on. And secondly, at the highest degree of sealing (D-11, 99%), the factor of ^{222}Rn increase reaches its maximum in the depth of 0.3 m (factor = 3.1), followed by the depth of 0.5 m (factor = 2.9), and finally the lowest increase is observed at the depth of 0.8 m (factor = 1.8).

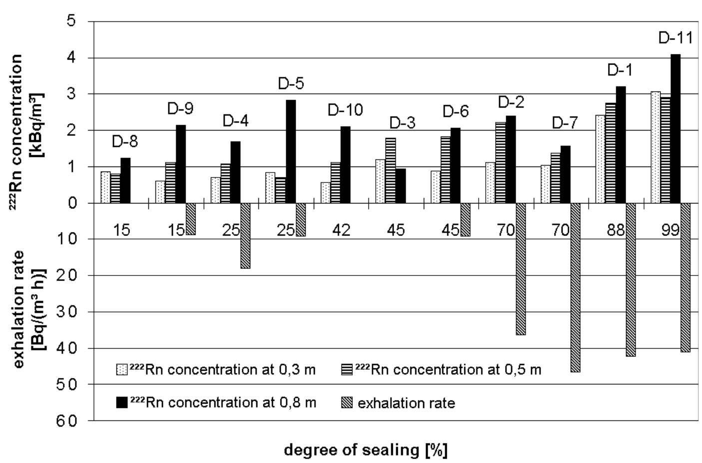

Fig. 4. – ^{222}Rn concentrations in soil-gas and ^{222}Rn exhalation rate in the area of the V-shaped opening of the foil at the test site. The measurements were done *while* the foil was in place (08.09.1996).

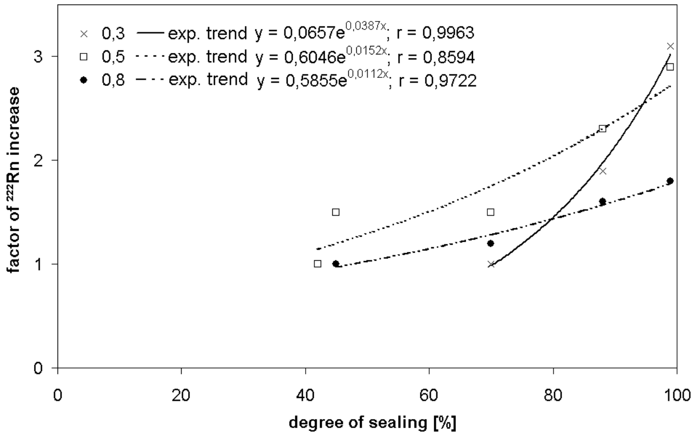

Fig. 5. – The factor of ^{222}Rn increase in different depths due to the degree of sealing.

4. – Interferences at test site

The influence of soil moisture on the ^{222}Rn emanation rate is well known: A higher content of soil moisture results in a higher emanation rate [2, 6-8]. Because the foil at the test site is focusing not only ^{222}Rn to the rims of the sealing but rain and percolating water as well, soil moisture can interfere with the sealing effect. Figure 6 shows the correlation of the moisture content of the sand and the degree of sealing at the test site. The moisture content, which was determined in a depth of 0.8 m, shows no correlation with the degree of sealing, either the foil was in place or not. If the moisture content is compared with the ^{222}Rn concentration directly, a slight positive correlation during sealed conditions is observed [3]. But this correlation is too weak to explain the ^{222}Rn increase during sealed conditions. On the other hand, shortly after

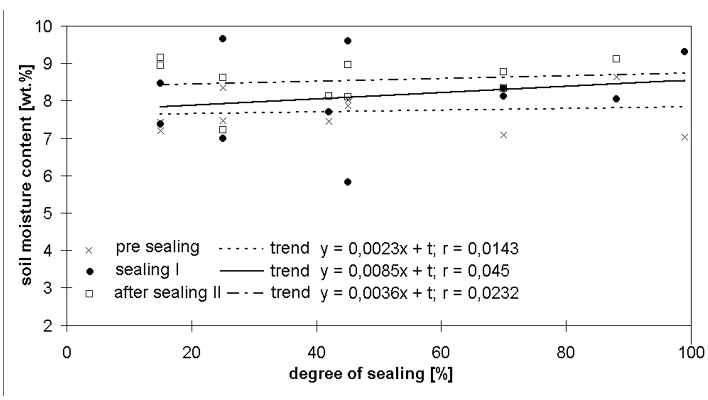

Fig. 6. – The correlation of the moisture content of the sand with the degree of sealing at the test site. The moisture content is determined 3 times in a depth of 0.8 m before, during and after the foil was in place.

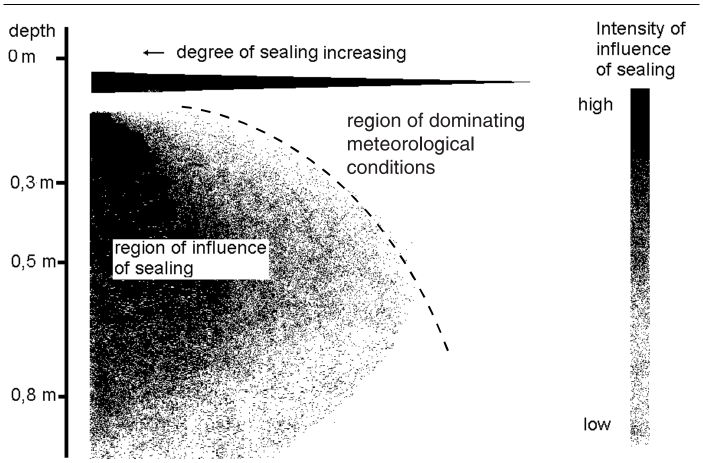

Fig. 7. – The model for the intensity and range of the influence of soil sealing on soil-gas migration in dependence on the degree of sealing.

a heavy rainfall the exhalation rate was lowered significantly due to a sealing effect of the water-filled pores close to the surface [3].

Beside the soil moisture, the influence of atmospheric pressure was investigated [3]. The gradient of the atmospheric pressure has a strong negative correlation with the exhalation rate, and a slight negative correlation with the ^{222}Rn concentration in the sand (all 3 depths). Looking at each measuring point separately, the exhalation rate is increased more at points with a higher degree of sealing.

5. – Model

On the base of the findings from measuring campaigns at bifurcating roads, parking lots and especially from the test site in the sand pit, a model for the influence of soil sealing on soil-gas migration is developed. Figure 7 shows the intensity and range of the soil-sealing effect on soil-gas migration in dependence on the degree of sealing. As can be seen within the cloud (region of influence of sealing) the increase of ^{222}Rn concentration at a high degree of sealing is higher in lower depths than in greater depths, and secondly, the ^{222}Rn increase is higher with an increasing degree of sealing. At a lower degree of sealing one would expect to see an influence of sealing (if there is any) firstly and mainly at the shallow depths. But under a low degree of sealing the meteorological conditions seem to dominate and exceed the influence of the sealing. Therefore, in a depth of about 0.5 m we have the intersection of the influence of the meteorological conditions with the increase of the region of the influence of sealing.

6. – Application of the soil-sealing effect

This study is not only a contribution to understand soil-gas migration with the help of ^{222}Rn as a natural tracer. The influence of sealing the soil can be important in the sense of health and radiation protection, if we consider upward migrating soil-gases like methane or the carcinogenic ^{222}Rn. Especially in urban areas we observe a high degree of soil sealing, which can result in a focusing of such gases to houses. Therefore, houses surrounded by impermeable layers may act like a chimney. Additionally, the sealing effect may be used for soil venting measures. A combination of sealing the soil with foils and an installation of ventilators in holes of the foil should enhance the efficiency of soil venting systems.

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