Indoor radon levels in relation to geology in southern Belgium (*)(**)

H.-C. ZHU ([1]), J. M. CHARLET ([1]) and F. TONDEUR ([2])

([1]) *Faculté, Polytechnique de Mons, Service GEFA - 9 Rue de Houdain, 7000 Mons, Belgium*
([2]) *Institut Supérieur Industriel de Bruxelles - 150 Rue Royale, B1000 Brussels, Belgium*

(ricevuto il 9 Giugno 1998; approvato il 18 Novembre 1998)

Summary. — A statistical study of an indoor radon data set of about 1700 short-term measurements shows a striking relationship between indoor radon concentration and the geological factors, such as stratigraphic unit and rock type.

PACS 91.25.Ey – Interactions between exterior sources and interior properties.
PACS 91.65.Dt – Isotopic composition/chemistry.
PACS 92.60.Sz – Air quality and air pollution.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

A potential radon risk was found in the Walloon region in previous studies (Vanmarcke *et al.*, 1988). More detailed radon maps for the Walloon region have confirmed the significant radon risk in large parts of the region (Poffijn *et al.*, 1992; Tondeur *et al.*, 1994, 1995; Zhu *et al.*, 1994, 1996).

As no particular radon problem associated to building materials has been noticed till now in Belgium, we expect the subsoil to be the main source of radon in the study region. If this is true, the geological environment, which includes the radon source and migration pathway, should largely determine the radon potential. Comparisons of indoor Rn measurements and geological information could be used to identify areas which have a high probability of generating elevated indoor radon levels. In this work, we use an indoor radon data set of about 1700 short-term measurements to study the statistical relationship between indoor radon and the geological environment. On the basis of our results, it will be possible to use geological information to identify areas with an expected high radon potential.

(*) Paper presented at the "Fourth International Conference on Rare Gas Geochemistry", Rome, October 8-10, 1997.
(**) The authors of this paper have agreed to not receive the proofs for correction.

2. – The data

The data set used in this study was collected by the Institut Supérieur Industriel de Bruxelles (ISIB) in 1680 homes of southern Belgium from June 1988 to February 1995 (Tondeur *et al.*, 1994, 1995), of which 1339 short-term (3 to 4 days) measurements were carried out on the ground floors. The measured result was entered into the database along with the geographic coordinates and geological information such as rock types, geologic formations and metamorphism. The geological information which is obtained mainly from geological maps on a scale of 1/40 000 is coded for the reason of data processing.

Stratigraphy is divided into 43 stages from Cambrian to Oligocene (cf. fig. 2). Superficial formations are grouped into 3 categories, Quaternary sediments (q1, q2, q3), alluviums (ale) of slopes and modern alluvion (alm) of valleys. Lithologies are classed with 16 rock types (cf. fig. 3).

The geological structure of the area under study is characterized by a folded Paleozoic basement and a Mesocenozoic subhorizontal cover modified by brittle structures. The Paleozoic basement includes the folded lower Paleozoic, characterized by phyllites and quartzites, and the Upper Paleozoic characterized by pelitic formation and limestones.

In analysing the data, two options are considered for the superficial covers. In the first approach, superficial formations are not considered. That is, if a house is constructed on a geological formation with one or more superficial formations, Rn data is attributed to the older formation underneath. In the second approach, superficial formations are considered as a distinct stratigraphic unit, namely q1-q3, ale and alm, respectively (fig. 2). This implies that the other stages then only include the houses without superficial formations.

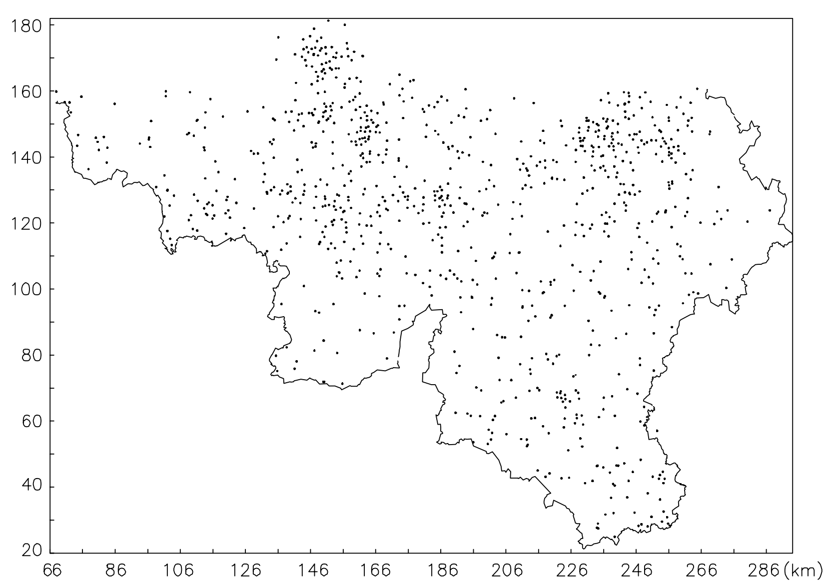

Fig. 1. – Location of declustered houses.

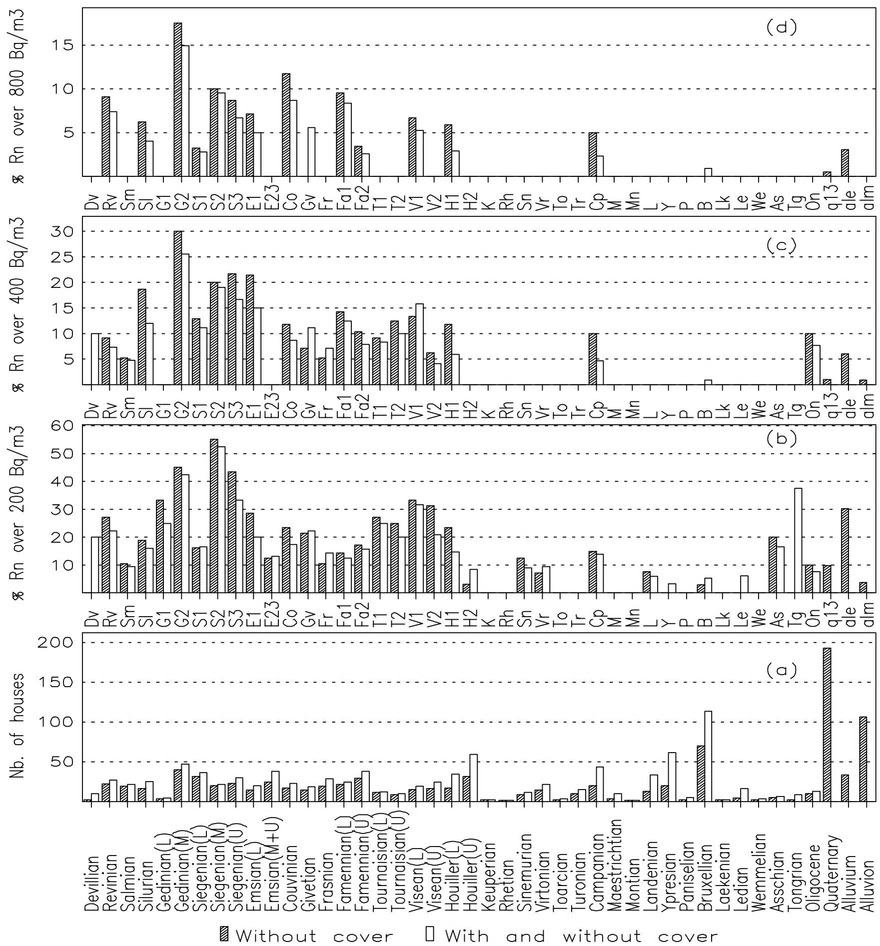

Fig. 2. – Distribution of homes over different Rn levels in relation with geological stages.

3. – Declustering of the data

Because the sampling was voluntary, a higher density of observations appears in populated areas and in the areas where a radon problem was known previously. Over-sampled areas are therefore present in low-concentration areas (for example, the city of Brussels), and in elevated Rn areas such as the Dyle valley and several communes in the Ardenne massif. If we make use of this clustered data set for calculations of statistical correlations between indoor Rn concentration and the geological environment of homes, such as geological stage or series, lithologic type and metamorphism etc., there will be a risk of biasing the results. To reduce the effect of over-representation in the over-sampled areas, a data selection has to be performed using a declustering technique. The idea is simply to superimpose a regular grid on the study area and to pick up within each 1.5×1.5 km grid cell a single sample closest to the centre of the cell. About 30% of sample values are removed in this way. The new data set (fig. 1) has almost the same statistical distribution as the original one.

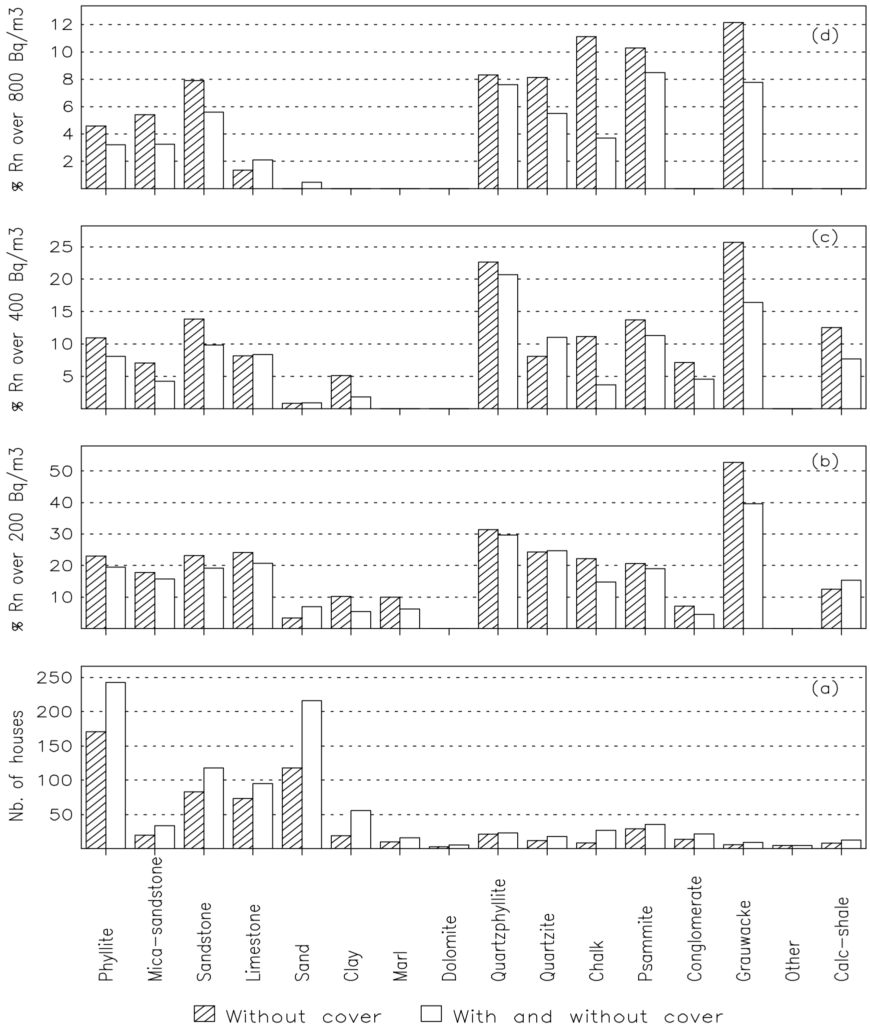

Fig. 3. – Distribution of homes over different Rn levels in relation with lithologic types.

4. – Results

4·1. *Geological formations and indoor radon.* – From this section onwards, we shall only refer to declustered data for ground floors (949 houses).

As stated before, we expect that the geological environment should largely determine the radon potential in the region where we study.

The relation between indoor radon concentrations and geology will be discussed in terms of the percentage of homes observed to be above certain given levels: 200, 400 and 800 Bq m^{-3}.

The proportion of dwellings with a Rn concentration above the chosen reference levels and in relation with each individual geological stage is calculated. As indicated before, the calculation has first been done without considering the superficial cover as a distinct unit. The results are shown in fig. 2 as white bars. Figure 2a indicates the total number of houses for each of the stages, while fig. 2b, 2c and 2d show the percentage of homes in relation with geological stages. Figures 2b and 2c show a similar pattern with two peaks. One peak is present between the Gedinian and Siegenian (G2 to S3), the other in the lower Visean (V1). For Rn levels of 800 Bq m^{-3} or more, the percentage of homes reaches the highest value in G2, with a general decrease from G2 to the younger formations (fig. 2d).

G1 is a special case. It seems that no home has more than 400 Bq m^{-3}, but it is expected to have a higher proportion of homes over the higher Rn levels based on our knowledge of groundwater radon levels for the same region (Zhu *et al.*, 1995; Charlet and Zhu, 1997). The reason here is that observations are extremely rare for the stage G1 (fig. 2a). In general, however, areas where the stages from G1 to E1 are present have high radon potential.

From Co to H1, only Co, Gv, Fa1, Fa2, V1 and H1 have houses above 800 Bq m^{-3}. Thus, the stages from Co to H1, mainly characterized by carbonates and shales, have at least moderate potential, of which Co, Gv, Fa1 and V1 are likely to have high Rn potential.

Dv has moderate potential, while Rv and Sl have high potential.

Stages of the post-Carboniferous (including H2) have low to very low indoor Rn potential although Cp is likely to pose a radon risk, while B and On have sporadic moderate Rn potential.

In the second approach, superficial formations are considered as distinct stages, namely q1-q3, ale and alm. Similar calculations are performed. The results are shown as hatched bars in fig. 2. Comparing the results of the two approaches in fig. 2b, 2c and 2d, it can be seen that houses constructed on a given stage without superficial deposits have usually higher Rn concentrations than those on the same stage with superficial sediments. So this proves again that superficial deposits can significantly decrease indoor Rn concentrations.

Among the three types of superficial formations (q1-3, ale and alm), alluvions (alm) have the strongest effect on indoor Rn decreases. Sediments of q1-3 also effectively decrease indoor Rn concentrations, but the decrease is not significant for the houses where alluviums (ale) are present.

4·2. *Lithology and indoor radon.* – Regional lithology is also an important factor in the control of indoor Rn concentrations. Similar methods used for geological formations are also applied to lithology. Figure 3 shows the results of the two approaches. It is noted that rock types of quartz-phyllite and grauwacke have dominantly the highest percentages of homes over the given Rn levels (fig. 3b, 3c and 3d). So these rock types are thought to be related to high radon potential. Quartzite, psammite and chalk are also very important rock types in the control of indoor radon, while phyllite, mica-sandstone, sandstone, limestone, calc-shale and conglomerate are relatively important. These rocks can have high to moderate radon potential. Sand, clay, marl and others are likely to have low radon potential.

Comparing the results of the two approaches in fig. 3b, 3c and 3d, a significant radon decrease related to superficial formations is also observed, except on sand.

5. – Conclusions

The statistical analysis shows that the stages from G1 to E1 have the highest radon potential, while the stages Dv, Rv, and Co to H1 have moderate to high radon potential, of which Rv, Co, Gv, Fa1 and V1 are likely to have high radon potential. The stages from the Westphalian (H2) to the Oligocene (On) have low or very low indoor Rn potential. The results for lithology show that quartz-phyllite, grauwacke, quartzite, psammite and chalk are very important for radon accumulation, whereas calc-shale, phyllite, sandstone and limestone are important, but to a lesser degree.

REFERENCES

CHARLET J. M. and ZHU H.-C., *Radon in the underground waters, relation with geological risks and environmental pollution, the case of Belgium* (*northwest Europe*), in *Rare Gas Geochemistry, Applications in Earth & Environmental Sciences*, edited by H. S. VIRK (Guru Nanak Dev University, Amritsar, India) 1997, pp. 270-282.

POFFIJN A., UYTTENHOVE J., DROUGUET B. and TONDEUR F., *The radon problem in schools and public buildings in Belgium, Rad. Prot. Dos.*, **45** (Suppl.) (1992) 499-501.

TONDEUR F., GERARDY I., LICOUR C. and DUBOIS N., *Répartition géographique et géologique du risque "radon" en Belgique francophone, Ann. Associat. belge Radioprotect.*, **19** (1994) 205-226.

TONDEUR F. and GERARDY I., *Répartition géographique et géologique du risque "radon" en Belgique Francophone*, in *Gas Geochemistry*, edited by C. DUBOIS (Science Reviews, Northwood) 1995, pp. 467-479.

VANMARCKE H., POFFIJN A., RAES F., EGGERMONT G., UYTTENHOVE J., BERKVENS P., VANDINGENEN R., BOURGOIGNIE R. and JACOBS R., *Radon in het leefmilieu, Ann. Belgian Associat. Radiat. Protect.*, **13** (1988) 33-56.

ZHU H.-C. and CHARLET J. M., *Geostatistical analysis of radon data in groundwaters in Walloon Region, Ann. Associat. belge Radioprotect.*, **19** (1994) 161-174.

ZHU H.-C., CHARLET J. M., DOREMUS P., FLEMAL J. M. and HALLEZ S., *Some geological factors relative to concentration of radon in underground water in Walloon region*, in *Gas Geochemistry*, edited by C. DUBOIS (Science Reviews, Northwood, UK) 1995, pp. 119-134.

ZHU H.-C., CHARLET J. M. and TONDEUR F., *Mapping indoor radon using geostatistical approach*, in I. BARNET and M. NEZNAL (Editors), *Proceedings of the Radon Investigations in the Czech Republic VI and 3rd International Workshop on Geological Aspects of Radon Risk Mapping* (Czech Geological Survey, Prague) 1996, pp. 51-61.