Mapping and prediction of geogenic radon potential in Germany (*)

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Summary. — Mapping and prediction of geogenic radon potential in Germany is based on the results of standardized field measurements, taking into account gas radon activity concentration, gas permeability and the geological situation as the major parameters for its classification and regionalisation. In a first approach, areas with metamorphic and silica-rich volcanic rocks as well as with distinct Paleozoic sedimentary rocks, characterized by enhanced radionuclide contents, were surveyed in regional scale. The sampling grid for these investigation areas was 5×5 km or denser, depending on the specific geological situation. For the major part of the total area of Germany which is covered by younger Mesozoic to Cenozoic rock units, the expected geogenic radon potential is medium-to-low. The sampling grid within these larger lithologically homogeneous areas was therefore more widely spaced. The regionalisation of the measured radon values was calculated on the basis of rasterized geological maps, taking into account the lithological boundaries as delimiting borders for the data interpolation. Such a GIS supported approach will allow further regional discrimination by including digital terrain models and soil maps. The obtained radon potential maps serve as a planning aid for government administration to direct further investigations and preventive measures. Finally, different techniques for regionalisation according to administrative boundaries are discussed.

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1. – Introduction

The migration of radon from its source in the subsurface into houses has been identified as the major factor contributing to indoor radon contamination (Nero and Nazaroff, 1984; Gunby *et al.*, 1993). The most important parameters controlling the

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geogenic radon potential are the characteristic radon emanation behaviour of different lithological units and the migration from the subsurface to the surface controlled by the gas permeability. If easy pathways exist from the ground into buildings, like fissures and cracks in floor and walls, enhanced indoor radon levels might occur. In summary, the main factors controlling radon level in houses are the geogenic radon potential, depending on geologic background, soil properties, and further the coupling of the buildings to the subsurface (Åkerblom, 1986; Gunderson *et al.*, 1988; Appleton and Ball, 1995; Barnet, 1991; Kies *et al.*, 1994).

National and international radiation protection agencies therefore recommend the identification of areas with high radon potential in the ground (ICRP, 1994). The presented geology-based approach allows the identification of such radon-prone areas by field measurements within representative geological units and interpolation of the obtained values within areas of similar lithological characteristics. This method has proven to be a useful tool for predicting radon-prone areas in Germany.

2. – Radon potential classification procedure

Mapping, classification and regionalisation of geogenic radon potential in Germany is based on the results of field measurements of soil gas radon activity concentration and gas permeability. This study is part of an ongoing research project of the German Federal Ministry for the Environment, Conservation and Reactor Safety. The standardized procedure for radon and permeability measurements and measuring systems are described in detail in Kemski, Klingel and Siehl (1994, 1996a, 1996b). The empirical ranking classification for assessment (fig. 1) results from the combination of radon activity and gas permeability data with the help of a matrix. In such a way six radon potential classes from 1 for low to 6 for high geogenic radon potential can be distinguished.

radon activity

<table>
<tr><th>permeability (m²) \ kBq/m³</th><th><10</th><th>10-29</th><th>30-99</th><th>100-500</th><th>>500</th></tr>
<tr><td>low <10⁻¹⁴</td><td rowspan="3">1</td><td>1</td><td>2</td><td>3</td><td rowspan="3">6</td></tr>
<tr><td>medium 10⁻¹⁴-10⁻¹²</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td>high >10⁻¹²</td><td>3</td><td>4</td><td>5</td></tr>
</table>

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Fig. 1. – Ranking matrix for the estimation of the geogenic radon potential classes.

3. – Selection of test areas

Field investigations were performed covering the whole area of Germany, giving first priority to representative test areas with suspected high geogenic radon potential. Especially areas with metamorphic and silica-rich igneous rocks (*e.g.*, Erzgebirge, Fichtelgebirge, Thüringer Wald, Schwarzwald) as well as pelitic Paleozoic sedimentary rocks (*e.g.*, Harz, Sauerland, Vogtland) commonly present enhanced radionuclide contents (Kreienbrock and Siehl, 1996). But also some areas of Mesozoic limestones, marls and sandstones were included in the investigation (*e.g.*, Thüringer Becken, Bitburg-Trier area). These local test areas cover altogether approximately 15% of the total area of Germany. For the remaining area, consisting mainly of flat-lying Mesozoic to Cenozoic sediments, the sampling density was reduced, considering that those extensive geological units with rather homogeneous lithologies normally have only medium-to-low radon potential.

4. – Classifying and mapping of geogenic radon potential at the example of the Schwarzwald area

The procedure of classifying and mapping the geogenic radon potential is discussed at the example of the crystalline basement of the Schwarzwald area in the SW of Germany (fig. 2). The boundaries of the Schwarzwald are the Oberrheintal Graben in the W and the Triassic cover in the E. The bedrock consists of ortho- and paragneisses, migmatites in the central part, and Lower-to-Upper Paleozoic granites, subdivided into northern, central and southern granites. At the boundary between the central and southern part of the Schwarzwald, metamorphic and clastic sediments of Paleozoic age occur within a E-W striking zone. Only small areas are covered by Pleistocene glacial deposits.

Radon activity concentration in soil gas and gas permeability of soils were measured at 154 locations. To obtain homogeneously distributed sampling points, the test area was first subdivided into squares of 5×5 km and then two sampling points were chosen within each of these squares taking into account the most prominent lithological units. For every sampling point, the radon potential was calculated using the ranking matrix of fig. 1. In a first approach, each sampled geological unit could be described by one radon class through the median value of all samples in this unit (fig. 2, lower part). For most of the geological units, the median radon potential class is 4. Only gneisses and Pleistocene glacial deposits have a lower value of 3. The Mesozoic cover in the E and the Tertiary and Quaternary sediments in the Oberrheintal Graben were ranked in classes 3 or 2. All granites have in average values around 4, the differences depending on radionuclide contents become visible looking at the percentile distribution, showing an increase in the radon potential from N to S.

Radon potential maps are planning aids for administration purposes, helping to estimate necessary further efforts and preventive measures. Therefore, the information about the predicted radon potential is required to be represented as a map, taking into account the spatial distribution and the variation of the values within a geological unit. For this reason a differentiated interpolation of data was performed, improving in such a way the spatial resolution of the map. This inter- and extrapolation procedure is confined by the boundaries of the geological units and considers only those data points lying within this area, assuring that the regionalisation refers strictly to distinct geological units.

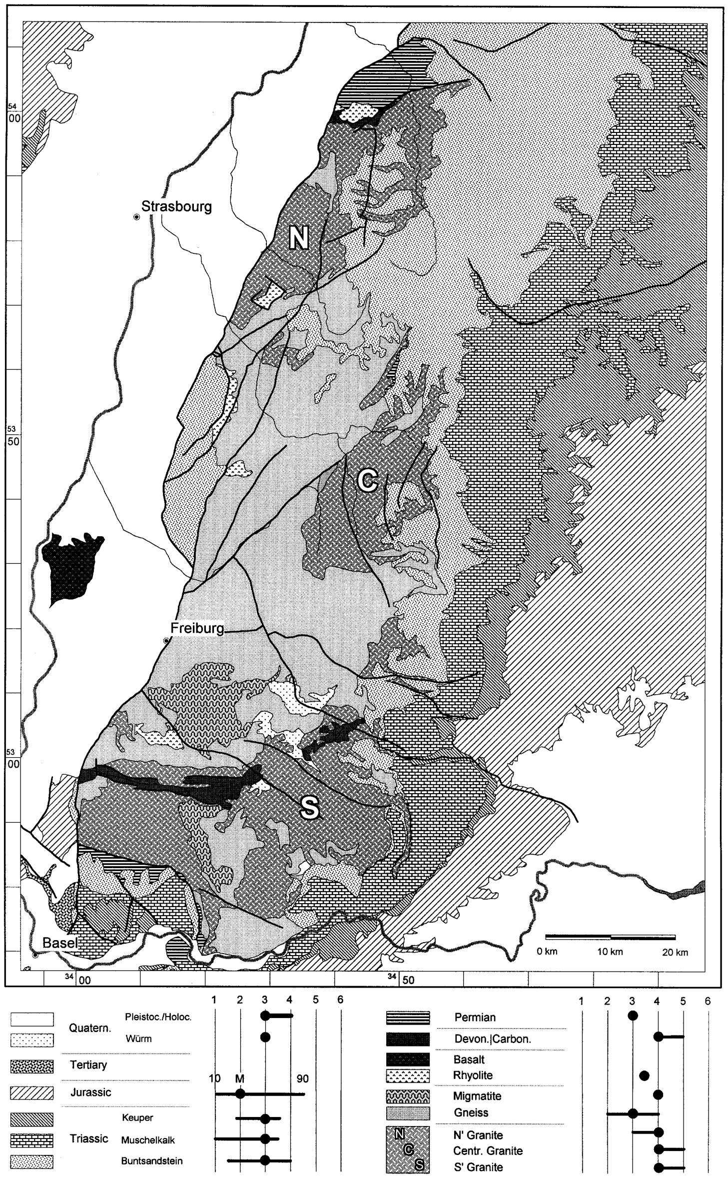

Fig. 2. – Geological map of the Schwarzwald region in SW Germany. The median values of the radon potential classes are shown with the corresponding percentiles for the main geological units.

For the Schwarzwald area the geological map was rasterized to a square element size of 1 × 1 km. For each raster element the radon potential class was calculated by distance-weighted interpolation of the next three sampling points within that same geological unit. The resulting map with the geological borders and data points shows clearly how the classification of radon potential is confined to geological units (fig. 3). The map shows further that the major part of the test area has medium-level radon

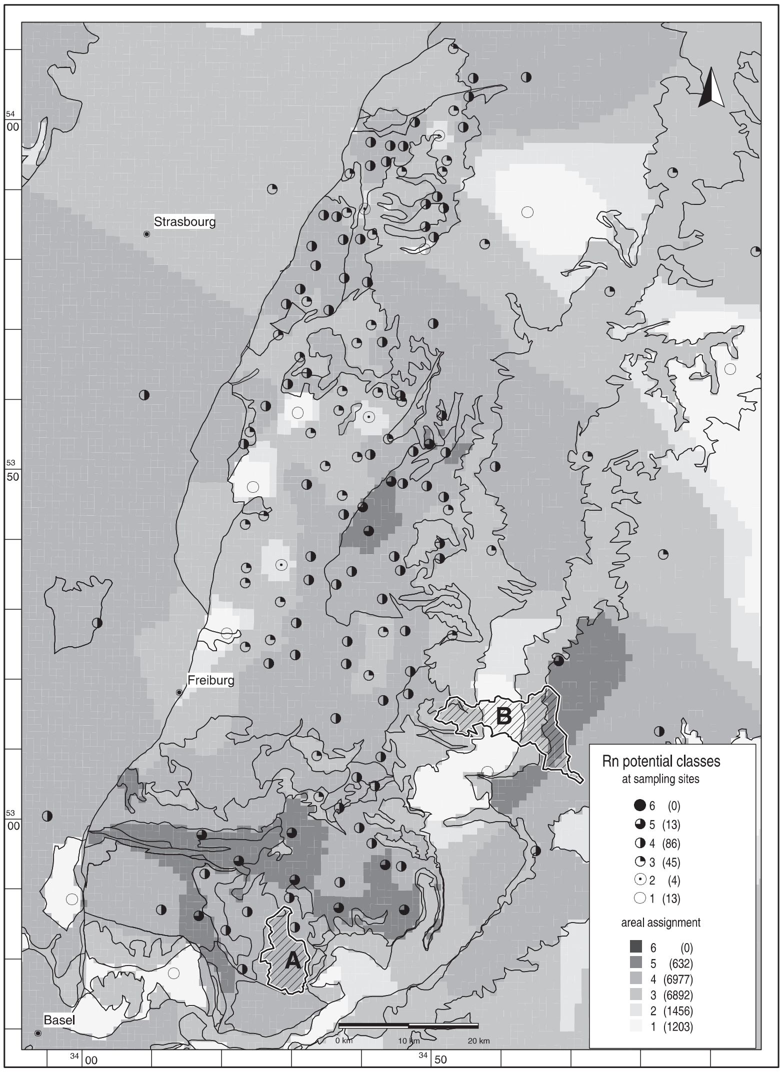

Fig. 3. – Rasterized map of the Schwarzwald area (see fig. 2) with a quadrangle size of 1 × 1 km showing the interpolated values of the radon potential classes and the corresponding data at the measuring sites, which were the basis for the interpolation. Additionally included are the boundaries of geological units in their function as interpolation boundaries and the borders of two municipalities (A and B) as examples of possible radon potential variations within administration units.

potential with values between 3 and 4. While the granites, especially in the south and partially in the central part, reach values up to 5, the northern granites remain at values of 4. The lowest values appear in the Mesozoic rocks surrounding the Schwarzwald. Here, especially the Muschelkalk of the Triassic as well as the Jurassic show values as low as 1.

5. – Conclusions

The radon potential maps presented here allow an evaluation of specific areas of interest in the sense of radon potential prediction as an aid to decide if additional measurements on smaller scale are required. The following step may consist in assigning radon potential classes to administrative units, which do not represent natural subdivisions of the area of investigation. Such a classification constrained by political boundaries is representative only in the case that within each administrative unit exits just one radon potential class (fig. 3: municipality A). But not even for small administrative units this might always be the case. When larger regional units have to be considered (fig. 3: municipality B), quite heterogeneous geological situations with different radon classes may occur. Simplifying approaches assigning automatically single average values to administrative units are therefore not fully satisfactory because of the loss of strongly localized information. The better alternative is to retain the interpolated data as presented here, enclosing indications to localize further detailed investigation if required.

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