Hydrogeologie und Umwelt	Heft 33	(1) 1-10	2 Abb.	3 Tab.	4 Anh.	Würzburg 2005

A semi quantitative method to evaluate the soil radon potential: The “10 point system“

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Abstract

This study gives a compilation and evaluation of important parameters on the soil radon potential. According to their importance, seven parameters were strung in a ranking system: made grounds – geology – relief – vegetation cover – tectonics – soil sealing – traffic vibrations. While the first four parameters control the soil radon potential on a more regional scale, the last three ones can modify it locally. This ranking system builds the base of the so called “10 point system”. The advantage of this system lies in the possibility to estimate the soil radon potential of any site on a local scale. Common classifications and rankings, based on never sufficient scaled maps, can be implanted into the proposed system. Furthermore, the “10 point system” was verified at 511 test sites throughout Germany. The predicted soil radon potential has a highly significant positive correlation with the actual measured radon concentration in the soil-gas (R^2 of mean values: 0.94).

1 The “10 point system”

The “10 point system” (in the following “10 PS”) was developed by the working group “environmental radioactivity” of the Essen University (WIEGAND 2001). Since then, the “10 PS” was checked and verified in the field throughout Germany (BLEILE & WIEGAND in press). This study summaries the state of the art, and can be used as a guideline for the application of the “10 PS”.

The “10 PS” is considering the soil radon potential, it does not include the influences of building characteristics, like GUNDERSEN & SCHUMANN (1996) did. WIEGAND (2001) recommends a separation of the two main parameters for indoor radon (soil and architecture), and an individual evaluation of these two parameters. The “10 PS” is different from the usual approach, where radon potential maps are produced in scales, which may be too small to be satisfying (BALL et al. 1992, SCHUMANN 1993, BARNET 1994, SHIRAV & VULKAN 1997, KEMSKI et al. 1999). The main problems of those maps are a lack of flexibility and the impossibility to consider sudden spatial changes of the local soil radon potential, like changes in lithology, relief or vegetation. SCHUMANN (1993) and FRIIS et al. (1999) prove a failure of geologically based radon risk maps. Therefore, APTE et al. (1999) started to insert other parameters than geology into the prediction of indoor radon concentrations.

This idea was followed by the development of the "10PS" (WIEGAND 2001). The base of the herewith presented system is a grouping of fundamental parameters on the soil radon potential, like concentration and distribution of Ra-226 in soils or grain size, moisture content and permeability of soils. Because it is not suitable to measure the fundamental parameters at each site, those were assigned to parameters, which are already mapped (geology, occurrence of made grounds or faults), or which are noticeable (relief, vegetation, soil sealing, traffic vibrations). Furthermore, if the geogenic radon potential of an area is already mapped (e.g. KEMSKI et al. 1999), that information could be considered within the proposed system.

Since it has been possible to provide answers on the importance of geogenic, biological and anthropogenic parameters on the soil radon potential, those factors could be used to establish a comprehensive ranking system (Fig. 1, Annex II). The soil radon potential is a semi quantitative estimation of the radon concentration in the soil-gas on the one hand, and of the radon availability (i.e. possibility for radon to migrate) on the other hand. While the former is mainly controlled by the radium concentrations of the bedrock and the soil, the latter depends strongly on the gas permeability of bedrock and soil.

The tool presented in this study enables the user to evaluate the soil radon potential by checking seven parameters of major importance in a simple exclusion / accepting - system. For its application, the seven items have to be treated one after another by assigning point marks, and the corresponding points are summed up. Scores range from 0-10, whereby 0-3 classifies a low, 4-6 a medium and 7-10 a high soil radon potential (Tab. 1). Only few sites have a soil radon potential ≥ 8.

Tab. 1: Classification of the soil radon potential:

	points
low soil radon potential	0 – 3
medium soil radon potential	4 – 6
high soil radon potential	7 - 10

The seven parameters are: (1) made ground, (2) geology, (3) relief, (4) vegetation cover, (5) tectonic elements (faults), (6) soil sealing and (7) strong traffic vibrations (Wiegand 2001). Influences of building characteristics are neglected – the "10 point system" is a tool of radon risk mapping and indicates where low, medium or high indoor radon concentrations are expected.

Parameter				P
1. Origin of soil		1) undisturbed soil (go to 2.1) 2) layer of backfill < 3 m (go to 2.1)		2
		backfill > 3 m (go to 2.2)		0
2. Geology	2.1 variety of rocks	sediment: magmatic rock: metamorphic rock:	black shale, phosphorite, bauxite - silicic rocks (e.g. granite, granodiorite, syenite, monzonite, rhyolite, dacite, pumice, pegmatite), - alkaline rocks (e.g. phonolite, nephelinite) orthogneiss, greisen	3
		sediment: magmatic rock: metamorphic rock:	gravel, clay, pelite, carbonate rock, loess intermediate rocks (e.g. diorite, andesite) clay schist, mica schist, paragneiss, granulite, marble	1
		sediment: magmatic rock: metamorphic rock:	sand, sandstone, conglomerate, evaporite - mafic rocks (e.g. gabbro, basalt, diabase), - ultramafic rocks (e.g. peridotite) quartzite, amphibolite, eclogite, serpentinite	0
	2.2 type of backfill	high ^{226}Ra conc.:	slags, ashes, sewage sludge, tailings (ore mining)	3
		low ^{226}Ra conc.:	sand, gravel, soil aggradation, rubble, tailings(coal mining)	0
3. Relief		upper part of hill		1
		lower part of hill		0
		plain		0
4. Vegetation		field, meadow or no vegetation		1
		forest		0
5. Local parameters		tectonic elements: fault, mining subsidence		1
		soil sealing > 50 %		1
		strong traffic vibration (trains or trucks) < 10 m distance		1

Fig. 1: The classic "10 point system" to estimate the soil radon potential. For the estimation of indoor radon or radon concentration in soil gas see Annex II and Annex III.

The first four items (made ground → vegetation) represent those factors that influence the soil radon potential in a more regional scale and characterise fundamental parameters like concentration and distribution of radium in the soil, grain size, moisture content and permeability of soils. The last three ones (tectonics → traffic vibrations) can modify the soil radon potential locally. The seven parameters are usually present on existing maps in the scale of 1 : 25,000 (parameter: 1, 2, 3, 4, 5) or observable in the field (parameter: 6, 7).

2 Application of the "10 PS"

The possible applications for the "10 PS" are manifold (Tab. 2). In principle, the "10 PS" was designed for an evaluation of the soil radon potential (Annex II). Nevertheless it can be adjusted easily, to estimate the radon concentrations in the soil-gas as well (Annex III).

In countries where radon prone areas are defined, the "10 PS" can be applied within such areas to estimate the local "radon risk". This is a crucial point, because the verification of the local soil radon potential within radon prone areas is a major task. Another important application is the use of the "10 PS" as a support for radon measurements, whether they are conducted indoor or within the soil. Considering the strong diurnal and seasonal variations of indoor and soil radon concentrations, it is recommended, to use a second evaluation method (i.e. the "10 PS"), which is independent from the first one. Last but not least, the “10 PS” can be used to estimate indoor radon concentrations as well. This would be possible for the cases, where the soil is the major radon source and not the building material - an assumption, which is generally accepted (at least for buildings with indoor radon > 50 Bq/m^3).

Tab. 2: Applications of the “10 point system”:

→ Estimation of the soil radon potential
→ Estimation of radon concentrations in soil-gas
→ Verification of local radon risk in radon prone areas
→ Support of measurements (indoor radon or soil-gas)
→ Estimation of indoor radon

3 Advantage of the “10 PS”

One of the main advantages of the “10 point system” lies in the possibility to estimate the soil radon potential at any site on a local scale (Tab. 3). The requirements to apply the “10 PS” are usually fulfilled:

- access to the sites where the “10 PS” should be used,
- availability of a geological map in a scale > 1 : 100 000 (the more detailed the better),
- seasonal changes in the climate of the sites; i.e. a warm season (summer) and a cold season (winter). The “10 PS” was designed for an application in temperate zones. An application in other climates has to be verified.

Another major advantage is the independence of a season or meteorological conditions. The “10 PS” can be applied throughout the year, a prerequisite, which is not fulfilled for e.g. measurements in the soil-gas. Furthermore, the seasonal variations of indoor radon or soil radon concentrations are not affecting the use of the “10 PS”.

The seven parameters of the soil radon potential were evaluated under standardized conditions. I.e. during the evaluation of each single parameter, all the others were not changed. That guarantied a semi quantitative estimation of the influence of each parameter.

Tab. 3: Advantage of the “10 point system”:

→ Applicable at any site on a local scale
→ Application is independent of season
→ Evaluation of parameters were done under standardised conditions
→ Based on existing maps (1:25000) and simple observations
→ (No need of further measurements)

The application of the “10 PS” is user friendly. It is based on a very detailed data base: Geological maps, which are available in Germany in a scale of 1 : 25 000. While the parameters “made ground”, “geology” and “tectonic elements (faults)” can be evaluated from geological maps, the information of the parameters “relief” and “vegetation cover” is available from topographical maps. Finally, the parameters “soil sealing” and “strong traffic vibrations” can be evaluated by simple observations in the field.

Like with all predictive tools, there is in principle no need of further measurements. Anyway, it is always recommended to do measurements to enhance the reliability of a classification.

4 Validation of the “10 PS”

The “10 PS” was checked at 511 test sites throughout Germany, covering Devonian to Quaternary sediments, intrusive, extrusive and metamorphic rocks as well as different types of backfill. At each test site, the soil radon potential was calculated and the radon concentration was measured. A significant correlation ($R^2 = 0.94$) between the arithmetic means of evaluated and actually measured radon concentrations demonstrates the power of the “10 point system” (Fig. 2). For all measuring points the soil radon potential was calculated using Annex III, and correlated with the actual measured radon concentration in the soil-gas. The figure shows the exponential increase of the arithmetic mean, the median, the 10 – 90 percentiles and the 25 - 75 quartiles. Because the two local parameters „soil sealing“ and „traffic vibration“ were not rated, a maximum of 8 points could be achieved.

In the future it should be tried to implant elements of existing radon risk maps or classifications into this system. The information of those maps can optimize the parameter “geology”, especially when the radon measurements for the maps were done standardized (e.g. in summer, on plane areas, on meadows) (Annex IV).

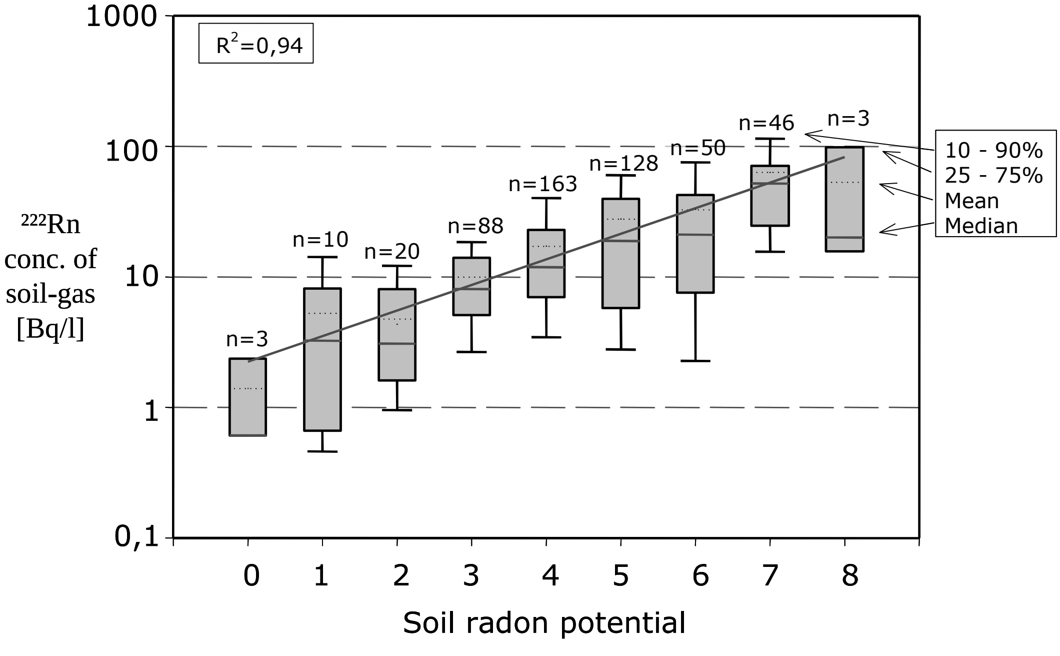

Fig. 2: Correlation of calculated soil radon potential and measured soil radon concentrations in a depth of 0.5 m (n = 511). The numbers placed above the 90 percentiles indicate the number of measurements.

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Annex I: General remarks for the use of the "10 PS"

- **Occurrence of made ground:** Made grounds (backfills) occur mainly in urban areas and are frequently used as building ground in cities. Geological maps show the distribution of backfills, but frequently they don't give information about the type of backfill (item 2.2 type of backfill). Usually the municipality can communicate such information. According to our studies, 98 % of the backfill in Germany consist out of material with low radium concentrations (mostly post war rubble). Therefore it is recommended to assign "0 points", if the type of backfill is unknown.

- **Interbedding of sediments:** Many clastic sediments show a small scaled interbedding of different sediments types (e.g. a change from sandstone to pelite and back to a sandstone within meters). If a predominance of one sediment type for a specific geological unit can be determined, this sediment type should be used to calculate the soil radon potential. If not, the assigned points of all occurring sediments are summed up and divided by the number of sediments (e.g. interbedding of sandstone and pelite: 0+1=1; 1:2=0.5 points).

- **Classification of the parameter "geology":** For the parameter "geology" 0, 1 and 3 points are assigned. Why are 2 points missing? Indeed, the "3 point rocks" consist out of "2 and 3 point rocks". The variability of radium concentrations of those rocks is too large, and therefore measurements are needed to decided, if such a rock is a "2 point rock" or a "3 point rock". E.g. not all granites have a high soil radon potential, some granites have low radium concentrations justifying an assignment of 2 points. To avoid an underestimation of the soil radon potential, 3 points are assigned, if no measurements are done.

- **Quaternary cover:** In cases of Quaternary covers with no lithological but generic names (e.g. solifluction soils, talus deposits, flood plain deposits) the lithological material of the cover is of relevance for the soil radon potential. E.g.: For a solifluction body, which is build up by redistributed loess, the soil radon potential should be calculated for loess; for a talus deposits build up by orthogneiss, the soil radon potential should be calculated for orthogneiss.

- **Exotic geology:** If the soil radon potential of a rock type should be calculated, which is not listed within the "10 PS", use uranium concentrations of the rock type (see table below) or choose a "geological reasonable" proxy beneath the listed rock types.

U conc. [ppm]	or	Ra conc. [Bq/kg]	given points
> 4.8		> 60	3
3.3-4.7		40-60	2
1.6-3.2		20-40	1
< 1.6		< 20	0

Annex II: The evaluation of the soil radon potential for indoor radon

Parameter				**P**
1. Origin of soil		1) undisturbed soil (go to 2.1) 2) layer of backfill < 3 m (go to 2.1)		2
		backfill > 3 m (go to 2.2)		0
2. Geology	2.1 variety of rocks	sediment: magmatic rock: metamorphic rock:	black shale, phosphorite, bauxite - silicic rocks (e.g. granite, granodiorite, syenite, monzonite, rhyolite, dacite, pumice, pegmatite), - alkaline rocks (e.g. phonolite, nephelinite) orthogneiss, greisen	3
		sediment: magmatic rock: metamorphic rock:	gravel, clay, pelite, carbonate rock, loess intermediate rocks (e.g. diorite, andesite) clay schist, mica schist, paragneiss, granulite, marble	1
		sediment: magmatic rock: metamorphic rock:	sand, sandstone, conglomerate, evaporite - mafic rocks (e.g. gabbro, basalt, diabase), - ultramafic rocks (e.g. peridotite) quartzite, amphibolite, eclogite, serpentinite	0
	2.2 type of backfill	high ^{226}Ra conc.:	slags, ashes, sewage sludge, tailings (ore mining)	3
		low ^{226}Ra conc.:	sand, gravel, soil aggradation, rubble, tailings(coal mining)	0
3. Relief		upper part of hill		1
		lower part of hill		0
		plain		0
4. Vegetation		field, meadow or no vegetation		
		forest		
5. Local parameters		tectonic elements: fault, mining subsidence		1
		soil sealing > 50 %		1
		strong traffic vibration (trains or trucks) < 10 m distance		1

Remarks

- Thickness of Quaternary covers and made grounds: Quaternary covers or made grounds with a thickness > 3 m will control the soil radon potential for many small buildings constructed with cellars (approx. foundation depth 2.5 – 3 m). For buildings without cellar, the relevant depth lies between 0 and 1 m. In the latter case use "item 1" as follows:

1. Origin of soil	undisturbed soil (go to 2.1)	2
	backfill (go to 2.2)	0

For calculating the soil radon potential for no specific building site it is recommended to consider only Quaternary covers and made grounds with a thickness > 3 m. For covers with a thickness < 3 m, the rock type below the cover should be used for calculating the soil radon potential.

- Vegetation cover: For the possible radon entry into dwellings the vegetation cover is of minor importance as long as trees are not in the direct vicinity of buildings (< 5 m). Since this is true for the most cases the type of vegetation cover should be not considered evaluating the soil radon potential for estimating indoor radon.

Annex III: The evaluation of the radon concentration in soil-gas

Parameter			P
1. Origin of soil		undisturbed soil (go to 2.1)	2
		backfill (go to 2.2)	0
2. Geology	2.1 variety of rocks	sediment: black shale, phosphorite, bauxite magmatic rock: - silicic rocks (e.g. granite, granodiorite, syenite, monzonite, rhyolite, dacite, pumice, pegmatite), - alkaline rocks (e.g. phonolite, nephelinite) metamorphic rock: orthogneiss, greisen	3
		sediment: gravel, clay, pelite, carbonate rock, loess magmatic rock: intermediate rocks (e.g. diorite, andesite) metamorphic rock: clay schist, mica schist, paragneiss, granulite, marble	1
		sediment: sand, sandstone, conglomerate, evaporite magmatic rock: - mafic rocks (e.g. gabbro, basalt, diabase), - ultramafic rocks (e.g. peridotite) metamorphic rock: quartzite, amphibolite, eclogite, serpentinite	0
	2.2 type of backfill	high ^{226}Ra conc.: slags, ashes, sewage sludge, tailings (ore mining)	3
		low ^{226}Ra conc.: sand, gravel, soil aggradation, rubble, tailings(coal mining)	0
3. Relief		upper part of hill	0
		lower part of hill	1
		plain	0
4. Vegetation		field, meadow or no vegetation	1
		forest	0
5. Local parameters		tectonic elements: fault, mining subsidence	1

Remarks

- **Parameter "relief":** The modifications are calculated for the summer season, when temperatures in the atmosphere are higher than in the soil-gas. Usually, these conditions can be assumed from May to October. If measurements are done during the winter season, use item 3 as follows (i.e. skip this parameter):

3. Relief	upper part of hill	0
	lower part of hill	0
	plain	0

- **Parameter "soil sealing" and "traffic vibrations":** Both parameters are difficult to measure *in situ* with spot measurements, and should be not considered estimating the radon concentrations in the soil-gas. The main difficult with the parameter "vibration" results from the randomly occurrence of vibrations on potential sites, and thus the "pump effect" due to the vibrations is observed only irregularly. Difficulties with the parameter "soil sealing" are based on the circumstance, that most measuring points with a degree of soil sealing > 50 % are placed direct at buildings or along roads and parking lots. In those cases the gravel bed beneath the sealing, consisting mainly of high permeable loose sediments, became apparent. Therefore, the effect of the parameter "soil sealing" is superposed by the effect of the backfill.

Annex IV: Recommendations for radon mapping based on soil-gas measurements

During the development of the “10 PS” the importance of the parameter “geology” for the soil radon potential becomes obvious. This dependence is used in the course of geology based radon mapping, where radon is measured in the soil-gas, and the geological boundaries define the boundaries of the radon map. Nevertheless, other major parameters, like “relief” and “vegetation” can modify the soil radon potential strongly (Fig. 1). Therefore, if the “10 PS” is not applied and radon mapping by soil-gas measurements is preferred, it is highly recommended to do the measurements under most standardized conditions: I.e. within a geological unit the measurements should be conducted in flat areas or flat parts of hilly regions and on meadows only. Furthermore, the measurements should be restricted to the summer season, i.e. from April to October.

→ Homogeneous areas of radon classes are defined by geological boundaries
→ Depth of measurements: approx. 1m
→ Measuring sites are placed in flat areas or flat parts of hilly regions
→ Measuring sites are placed on meadows
→ Measurements should be restricted to the summer season, i.e. April - October