NUKLEONIKA 2010;55(4):471–475

ORIGINAL PAPER

Practical usefulness of radon risk maps and detailed *in-situ* classification of radon risk

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Abstract. The presentation answers the frequent question about the practical usefulness, advantages and disadvantages of radon risk maps and detailed *in-situ* classification of radon risk. Czech Radon Programme derives the benefit from radon maps on various scales – 1:500 000, 1:200 000 and 1:50 000, as well as from the uniform method for direct detailed classification of radon risk. The reliability assessment of the practical usefulness is based on the direct comparison between the results obtained from detailed *in-situ* classification of radon risk of building sites and the corresponding reading from the radon risk map. Altogether almost one thousand of detailed radon risk assessments, i.e. tens of thousands of soil-gas radon concentration measurements, were compared with the expected radon risk categories in five radon risk map sheets on the scale 1:50 000. The new results more specify and correspond to the previous results from comparisons performed in 1992, 1995 and 2002. We can prepare quite consistent maps, which can be successfully used to direct the search of existing houses with higher indoor radon values. On the other hand, the risk of underestimation or overestimation in the case of deriving the radon risk classification of a specific building site from the map seems to be too high to use the maps for direct assessment of specific sites. For new buildings, it is recommended to use detailed *in-situ* measurements and classification.

Key words: radon • risk • mapping • reliability of map

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Received: 29 June 2009
Accepted: 30 December 2009

Introduction

The radon programmes differ in various states due to various factors (geological potential, meteorological conditions, type of buildings, building structures, building foundations, ventilation practice, way of life). Different methods of radon mapping are used as well. Some of them are based on the probabilistic treatment of indoor radon data like in Austria [5]. Finding a primary source of indoor radon in geological bedrock is reflected in Hungarian [8] and German [6] approaches as well as in Estonia and Scandinavian countries, where a special attention is given to Quaternary till sediments [13]. The radon mapping in the United Kingdom is supported by using the airborne gamma-spectrometric measurements [7, 14].

In the Czech Republic, radon risk (radon index) maps are used mainly to direct the search of existing (old) houses with elevated radon levels, not to design preventive protective measures in new buildings. For the purposes of new buildings, since 1991 the soil characteristics are measured *in-situ* and protective measures are designed with respect to the measured properties of the soil and to the dwelling design. This approach is obligatory, i.e. the detailed assessment and classification of radon risk (index) of the building site is an integral part of building permission. As the uniform method for radon index classification as well as the radon maps are in almost perpetual progress, it is important to control the reliability of maps with respect to the purposes of their use.

Maps of radon index in the scale 1:50 000

In 1999, the Czech Geological Survey (CGS), Prague, started a detailed radon risk mapping programme, based on the geological maps on the scale 1:50 000. These maps are based on the vectorized polygons of geological units, which were generalized for the radon mapping purpose. For each map sheet, at least 20 test sites were measured for the main lithological units, or the soil gas radon data granted by Association Radon Risk were appended from the Radon database, administered by the CGS. Together, about 9000 soil gas radon data from test sites (15 probes each) enabled to characterize the statistically prevailing radon index in four categories – low, intermediate, medium and high in particular lithological units (Fig. 1). The computer processing of georeferenced data was based on Bentley Microstation, ArcGIS 8.3. and ArcGIS 9.2. programs. The additive layers comprised also the vectorized polylines of tectonic features and raster topography (data of the Czech Office for Surveying, Mapping and Cadastre).

The sequence of radon index mapping followed the priorities set by Radon Programme of the Czech Republic and previous radon mapping campaignes [1, 2]. The attention was concentrated on areas of the most radioactive rock types within the Bohemian Massif. The other rock types with expected lower radon index followed in later stages of the mapping programme.

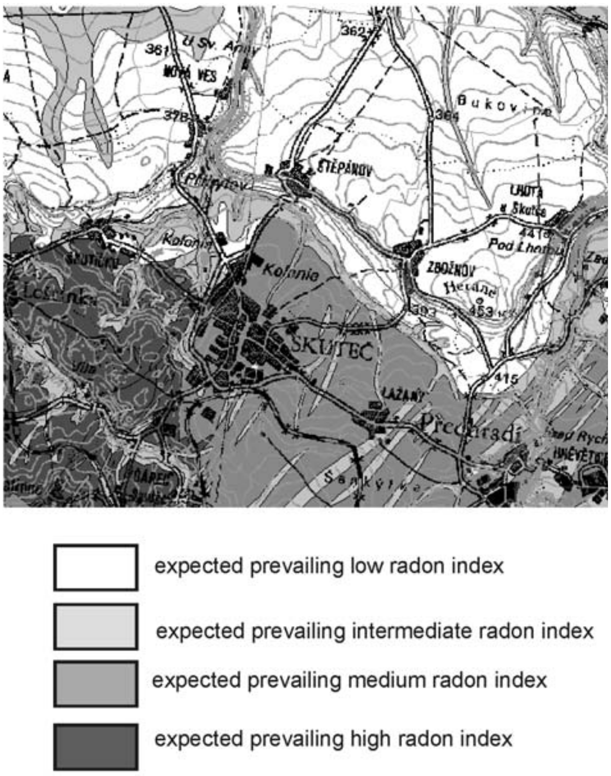

Fig. 1. Section of the radon index map on a scale 1:50 000 (coloured original).

The whole mapping programme has covered the state territory of 78 800 km^2 area by 214 map sheets on a scale 1:50 000 within the period of 1999–2005.

For each map sheet it is emphasized that the "Maps of radon index of geological bedrock" do not serve for building site assessment at particular building sites. The main benefit of these maps is found when setting the priorities of indoor measurements' distribution within the whole state territory, which, in fact, was the main target of the geologically based radon index mapping programme.

All soil gas Rn – indoor Rn comparisons performed in regional and wide-country scales [3, 4] confirm a good relationship between both the above-mentioned parameters and emphasize the importance of radon-geological knowledge for targeted indoor radon surveys.

Uniform method for assessment of radon index

The last modification of the uniform method used for the detailed assessment of radon index in the Czech Republic has been valid since 2004 [10]. Simple, low--cost sampling and measuring techniques are used for detailed radon survey. In brief, the determination of radon index of a building site is based on measurement of soil-gas radon concentration and *in-situ* measurement of soil permeability, or expert evaluation of soil permeability (description of vertical soil profile).

Uniform sampling and measuring depths at 0.8 m below the surface are used. When a building site of one family house is evaluated, it is required to realize at least 15 soil-gas sample measurements. If the building area is larger than 800 m^2, measurements are made at a scale 10 × 10 m. The decisive value is the third quartile (= the 75% percentile) of the data set (values of soil-gas radon concentration smaller than 1 kBq·m^{-3} are excluded from the evaluation because of possible sampling error). If the results of both soil gas radon concentration measurements and *in-situ* permeability measurements are available for all measuring points, a radon potential (RP) model can be used for determining the radon index (RI). For numerical values of soil gas radon concentration and the expert evaluation of soil permeability (given as low, medium, or high), the assessment procedure is based on a classification table. Both ways result in the determination of the radon index of a building site, i.e. index indicating the level of risk of radon release from the bedrock, surface material, and/or soil. The categories are low, medium, and high.

History of comparisons between radon risk maps and results of detailed measurements

When we have prepared any kind of a radon map, except the scale 1:1, we have to think about the reliability of that map and preferably to check it. Three comparisons were made in 1992, 1995 and 2002.

The first two comparisons were based on the assessment of differences between regional radon risk maps on the scale 1:200 000 and results of detailed radon surveys. They concerned 630 and 968 building sites, respectively.

The comparisons showed [9, 11, 12], that the large-scale maps are generally reliable. The satisfactory reliability of radon risk maps was observed in a large number of areas (62.9%, 56.7% resp.). When the bedrock is formed by Cretaceous sediments or by granites or granodiorites, and/or the cover formed by loess and loess loams – a satisfactory coincidence between the results of building site characterization and the radon risk map prediction (about or more than 70% of cases) was observed. Significant differences were found in areas with larger variability of soil environment (river terraces, or layers influenced by anthropogenic activity). In areas with the Quarternary cover formed by river terraces; or with some special rock types – chlorite-sericite phylite – detailed radon surveys did not confirmed the expected risk in more than 70 or 80% of sites (Fig. 2).

Observed differences confirmed the usefulness of a direct building site characterization. The comparison found and demonstrated another disadvantage of the radon maps as well. The lowest reliability, even lower than 40%, was found in expected high risk areas, i.e. in areas of the main interest (the search of existing houses with higher indoor values). Therefore, the CGS has been publishing the above-mentioned new radon risk (index) maps on the scale 1:50 000 since 1999.

The third comparison was focused on the reliability analysis of the new radon index maps on the scale 1:50 000. The reliability evaluation of maps 1:50 000 is more complicated, because the maps include the fourth category, called intermediate, which is not defined for detailed building site characterization and has in fact no corresponding counterpart.

In 2002, the reliability of radon index prediction maps was analysed by comparing data from detailed radon surveys with data from chosen four radon map sheets. We concentrated on the map sheets with expected variable radon index categories, or with predicted low and intermediate categories. The reliability was similar – about 62.2%. But the differences between the indications from the map and the data from the survey were again substantial. The spatial distribution of radon indices was induced mainly by variations in geological conditions, which can only be characterized by a thorough geological survey. A geological map of 1:50 000 scale, as the basis for radon risk map, cannot register such details.

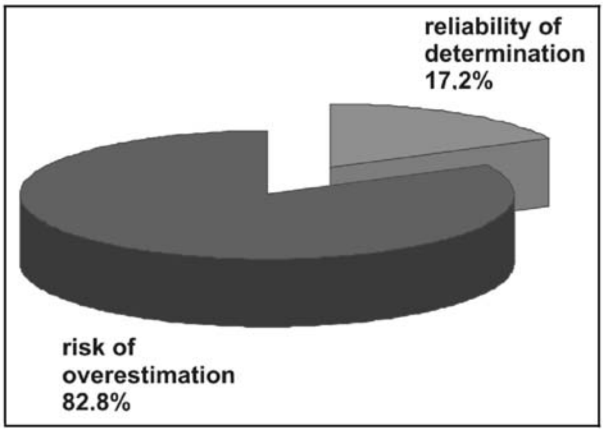

Fig. 2. Reliability of determination – expected high radon risk, regional radon maps 1:200 000, river terraces.

Comparison 2007

Finally, the comparison in 2007, when the whole teritory of the Czech Republic had been covered by the radon maps, had to answer the question: Is there a possibility to use the radon index maps on the scale 1:50 000 for the determination of radon index at a specific site and for preventive measures in new buildings without detailed *in-situ* investigation?

To avoid any interference, we used two independent and casual data sets from detailed radon surveys, which were processed separately: more than 600 classifications of radon index from RADON v.o.s. archives and about 240 assessments performed by the CGS. This second set served itself as the basis for the formation of radon index maps. Altogether almost one thousand of detailed radon index assessments (i.e. tens of thousands of soil-gas radon concentration measurements) were compared with expected radon index categories in five map sheets.

The choice of map sheets has been done with the goal to cover all basic situations. In the map sheet Mimon, the whole territory is classified as the low or intermediate radon index category. The medium radon index category is typical for the map sheet Semily and the high index one for the map of Liberec. The map sheet Ricany includes all four categories (low, intermediate, medium and high) in approximately the same extent. Finally, the fifth map sheet (Stara Boleslav–Brandys nad Labem) represents an example of a large city with its stream territory, laying in the area of expected low and medium radon index.

Two main approaches of testing the radon index maps reliability are discussed. The first one corresponds to the main purpose of maps, i.e. searching for existing houses with elevated radon levels. It minimizes the influence of the intermediate category. In this case, the intermediate category in the map is evaluated as corresponding to both low and medium radon index determined by detailed measurements (the agreement in higher risks is the most important). The reliability results (R_1) are summarized in Table 1. As can be seen, the reliability has varied from 63.0 to 67.1%.

In the second comparison, the doubtful intermediate category has been excluded. We have focused on the reliability of determination of each specific category. As can be seen in Fig. 3, in areas marked as low radon index areas in the maps, the reliability has been 37.1%. In almost 2/3 of cases we have found a higher category during the detailed survey (medium or even high radon index). As for the medium radon index, the expected medium radon index due to the map has been confirmed by detailed measurements only in about 3/5 of cases (the

Table 1. The reliability of radon index maps – first approach

Map sheet	Reliability (R_1) RADON data	Reliability (R_1) CGS data
Mimon	70.1	77.5
Semily	58.9	65.5
Liberec	72.4	72.5
Ricany	55.4	58.2
Stara Boleslav/Brandys	77.0	
5 Map sheets altogether	63.0	67.1

reliability has been 58.5%), the high radon index has been specified in 27.3% cases and the low one in 14.2% cases. And, finally, the expected high radon index due to the reading from the map has been confirmed in less than 3/5 of cases. The corresponding risk of overestimation has been 43.6%.

Conclusions and recommendations

The reliability of radon index prediction maps (1:50 000) were analysed by comparing data from detailed radon surveys with data from radon maps. The analysis was focused on the possibility to prepare predictive maps, the reliability of which would be high enough to define areas where radon index determination would not be necessary (i.e. where the radon index could be derived from the map).

It is known, that the soil-gas radon concentration may vary, often very significantly, in the distance of meters. In the region of some villages it is possible to specify by detailed surveys all radon index categories, although the regional geology can be invariable. The comparison results have confirmed very substantial variations between local and regional geological structure, and variations of particular lithological units throughout the entire Czech Republic. The reliability of predictive maps is, therefore, too low to achieve a satisfactory agreement with the results of *in-situ* surveys. The method of constructing radon index maps is based on the generalization of data acquired within the Czech Republic. Due to the map scale constraints, these maps cannot include detailed descriptions of the geological structure, and thus cannot be used for a direct prediction of the radon index at a given building site. We would need more and more measurements to prepare more detailed radon maps (on the scale 1:25 000, or even more accurate). But with respect to heterogeneity of soil and rock environment, we cannot be sure that we would receive a much better reliability, appropriate to the amount of money spent on creation such maps.

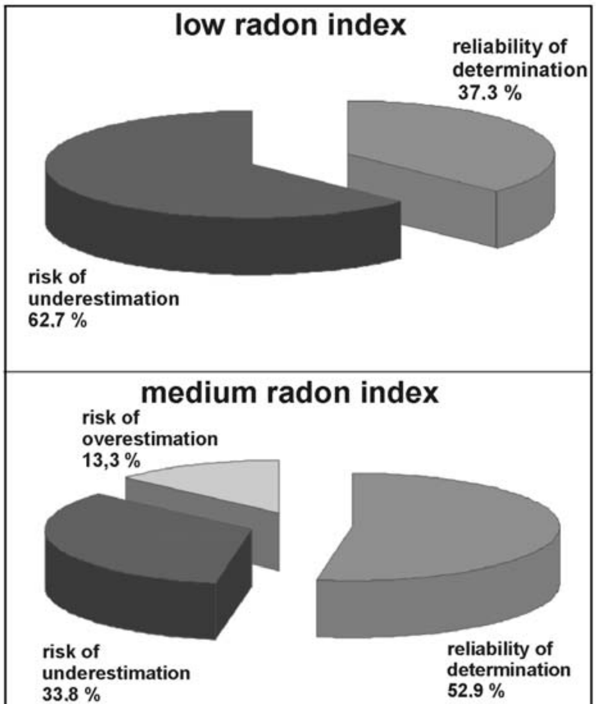

Fig. 3. Reliability of determination of low, medium and high radon index, radon maps 1:50 000.

On the other hand, the comparison confirmed the usefulness of new radon index maps on the scale 1:50 000 for other purposes. The reliability, especially in the expected high radon index areas, has markedly increased in comparison with the maps on the scale 1:200 000.

The answer of the above-mentioned question was relatively easy.

No, the radon risk maps cannot be recommended to be used for the determination of radon index of building sites for new buildings.

But the new maps have improved the effectiveness of searching the old houses with elevated indoor radon levels.

Acknowledgment. The survey was supported by the State Office for Nuclear Safety, Prague.

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