

## The influence of geology on elevated radon concentrations in Slovenian schools and kindergartens

### Vpliv geološke podlage na povišanje koncentracije radona v slovenskih šolah in vrtcih

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#### Abstract

76 instantaneous indoor radon concentrations above the Slovenian action level of 400 Bqm<sup>-3</sup> were selected from the database of 1600 radon concentrations in kindergartens and schools, assembled during the Slovenian National Radon Programme. A relationship was found between indoor radon concentrations, and geology of rocks under the foundations (uranium content, permeability, porosity, tectonic fractures) and the quality of building construction.

#### Kratka vsebina

Iz podatkovne baze 1600 koncentracij radona v slovenskih vrtcih in šolah, ki smo jo dobili v okviru Slovenskega nacionalnega radonskega programa, smo izbrali 76 trenutnih koncentracij radona iz tistih vrtcev in šol, v katerih je bila presežena dopustna koncentracija 400 Bqm<sup>-3</sup>. Našli smo povezavo med koncentracijo radona v igralnicah oziroma učilnicah in geološko zgradbo kamnin pod temelji zgradb (vsebnost urana, prepustnost, poroznost, tektonski prelomi) ter kakovostjo temeljne plošče.

#### Introduction

Rocks and soil contain varying concentrations of radionuclides of the uranium decay series (<sup>238</sup>U, <sup>226</sup>Ra). <sup>222</sup>Rn, a noble and radioactive gas, is a decay product of <sup>226</sup>Ra. Its half-life of 3.8 days is long enough to permit emanation and diffusion through rocks and soils into buildings.

Radon and its short-lived decay products in the atmosphere are the most important contributors to human exposure from natural sources. Radiation exposure of the lungs is mostly due to the alpha particles emitted

by several of these radionuclides, although some beta particles and gamma radiation are also emitted. The absorption by lung tissue of alpha, beta and gamma energy damages the tissue and thus increases the risk of lung cancer (UNSCEAR, 2000).

The National Radon Programme in Slovenia started in 1990. Instantaneous indoor radon concentrations in 730 kindergartens and 890 schools in Slovenia were measured between 1990 and 1994 using alpha scintillation cells. Overall geometric means of 58 Bqm<sup>-3</sup> in kindergartens and 82 Bqm<sup>-3</sup> in schools were obtained (Vaupotič et al.,

1994, Vaupotič et al., 2000). These radon concentrations were distributed log-normally. In 47 (6.4 %) kindergartens and in 77 (8.7 %) schools, radon concentrations exceeded  $400 \text{ Bqm}^{-3}$ , which is the action level in Slovenia (Uradni list RS, 2002).

From the database obtained during the National Radon Programme, 330 buildings with measured instantaneous radon concentrations were selected in such a manner that each area of Slovenia was represented uniformly. A relationship between indoor radon concentrations, rock type, tectonic faults and age of buildings was found. Indoor radon concentrations were elevated in buildings that were older than 50 years and in those with a fault under the foundations. If these buildings were not included, elevated indoor radon levels were found only in buildings built on limestone. Building material did not correlate significantly with indoor radon concentrations (Popit & Vaupotič, 2002).

For the present study, 76 schools and kindergartens with instantaneous indoor radon concentrations above the Slovenian action level of  $400 \text{ Bqm}^{-3}$  were selected from the database obtained during the National Radon Programme. The purpose of our study was to investigate the influence of lithology and associated uranium mineralization, geological structure, quality of building construction and building material on elevated indoor radon levels.

## Experimental

Instantaneous indoor radon concentrations were measured by the alpha scintillation technique (Vaupotič et al., 1992).

The survey was carried out during 1990 to 1994. The influence of seasonal variations on indoor radon concentrations was minimized by measuring instantaneous radon concentrations only during the winter-time. In each building, air was sampled in one selected room, usually on the ground floor. In order to achieve the same conditions in all buildings, rooms were closed for one night and radon measurements were performed early the next morning, before children arrived (Vaupotič et al., 2000).

In 124 (7.7 %) buildings radon concentrations exceeded the Slovenian action level of  $400 \text{ Bqm}^{-3}$ . In 48 places the kindergarten

and the school were located close together. In these cases only the building with the higher radon concentration was taken into consideration, not both. Thus, 76 buildings were selected from the data base (Fig. 1).

## Results and discussion

Litho-stratigraphical units and tectonic fractures under the foundations or in the vicinity of each building were determined from geological maps of Slovenia on the scale of 1:25000 by using national grid coordinates. In order to estimate the influence of a particular stratigraphical or lithological unit on indoor radon levels, other factors were considered – the age of a building (structures older than 50 years), the building material (bricks or prefabricated material) and materials used to stabilize the foundation floor. Where the buildings were constructed on a geological formation with superficial Holocene alluvium deposits, radon data were attributed to the older formation underneath.

Of the 76 schools and kindergartens, instantaneous radon concentrations were between 400 and  $600 \text{ Bqm}^{-3}$  in 23 (30 %), between 600 and  $1000 \text{ Bqm}^{-3}$  in 25 (33 %) and above  $1000 \text{ Bqm}^{-3}$  in 28 (37 %).

Foundation floors in three kindergartens and three schools were stabilized with material that was abundant in radionuclides of the uranium series, especially  $^{226}\text{Ra}$ , the parent of  $^{222}\text{Rn}$  (Tab. 1). Foundations of two schools (30, 67) and two kindergartens (74, 75) in Figure 1 and Table 1 were stabilized by fly ash, resulting in indoor radon levels up to  $5600 \text{ Bqm}^{-3}$ . The foundation floor of school 76 (Fig. 1, Tab. 1) was stabilized with material from the nearby steel plant, and that of kindergarten 65 was stabilized with tailings from the nearby mercury ore mine. In the last two cases instantaneous indoor radon concentrations were above  $1000 \text{ Bqm}^{-3}$  as well. These buildings were not considered in our study of the influence of geological factors on indoor radon concentrations.

### *Lithological units and elevated indoor radon concentrations*

Rocks were grouped into eight lithological units (Fig. 2a). In glacial sediments higher indoor radon levels were expected, so they

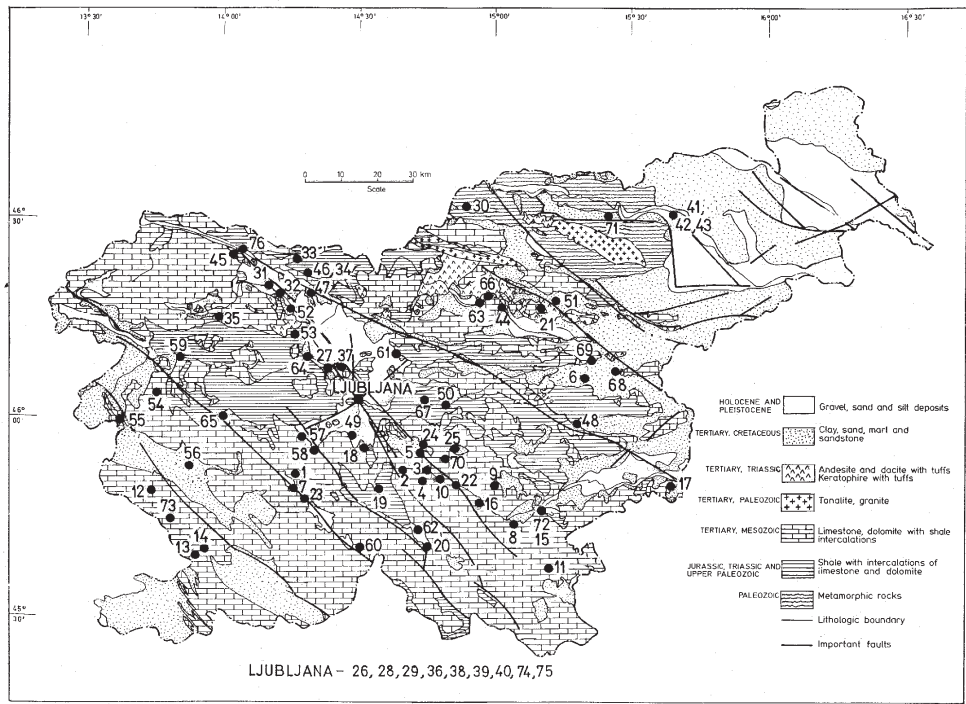


Figure 1: Geological map of Slovenia (provided by the Geological Survey of Slovenia) with locations of 76 buildings with instantaneous indoor radon concentrations above the Slovenian proposed action level of 400 Bqm<sup>-3</sup>.

Table 1. Foundation floor of schools and kindergartens stabilised with material abundant in radionuclides of the uranium series

Code numbers of schools and kindergartens and the year of construction	Indoor radon concentration (Bqm <sup>-3</sup> )	Building material	Material used to stabilise foundation floor	Litho-stratigraphical units under the buildings
Primary school 67, 1988	2980	Bricks	Fly ash	Permocarboniferous quartz sandstones
Primary school 30, 1963	735	Bricks	Fly ash	Pleistocene glacial sediments
Primary school 76, 1946	1060	Bricks	Material from the steel plant / scoria	Triassic claystone, sandstone, marl and conglomerate
Kindergarten 65, 1976	1540	Bricks	Tailings from the mercury ore mine	Cretaceous limestones
Kindergarten 74, 1963	5600	Bricks	Fly ash	Pleistocene glacial sediments
Kindergarten 75, 1972	650	Bricks	Fly ash	Pleistocene glacial sediments

are presented separately. Very large quantities of Pleistocene gravel and sand were brought away from glaciated regions by the rivers. These sediments consist mainly of carbonate rocks, except near Pohorje in the north – eastern part of Slovenia, where Qua-

ternary sediments were brought from mountains composed of Oligocene tonalite and Precambrian quartz – sericite phyllite, phyllite schist, gneiss, amphibolite, chlorite, biotite – chlorite schist and marble. Some of the Quaternary sediments in the Ljubljana

region were brought from regions composed of Permocarboneiferous clastic rocks (quartz sandstone, shale) with higher contents of radionuclides of the uranium series.

Other lithological units are quartz sandstones, marl, flysch sediments, claystone with intermediary layers of andesite tuffs. Where it was impossible to determine precisely which kind of clastic rock (marl, shale, sandstone, claystone, etc) was under a particular building, rocks were grouped simply to clastic rocks. Limestone and dolomite are presented separately (Fig. 2a).

Geometric mean indoor radon concentrations between 400 and 600 Bqm<sup>-3</sup> were found in buildings constructed on quartz sandstones, flysch (marl, sandstone, breccia, conglomerate, limestone, shale) and on claystone with intermediary layers of andesite tuffs

(Fig. 2a). Geometric mean indoor radon concentrations between 600 and 1000 Bqm<sup>-3</sup> were observed in buildings constructed on glacial sediments (moraines and glacial river terraces), marl and on various clastic rocks (sandstone, claystone, conglomerate, shale, breccia). Only in buildings built on carbonates did geometric mean radon levels exceed 1000 Bqm<sup>-3</sup>. In all 25 cases limestone was karstic. High radon levels can be explained by the high permeability of karstic rocks, together with poor building construction, which facilitated the transfer of radon from the rocks into classrooms or playrooms.

*Influence of building material, age of the building and presence of tectonic fractures under building foundations on elevated indoor radon concentrations.*

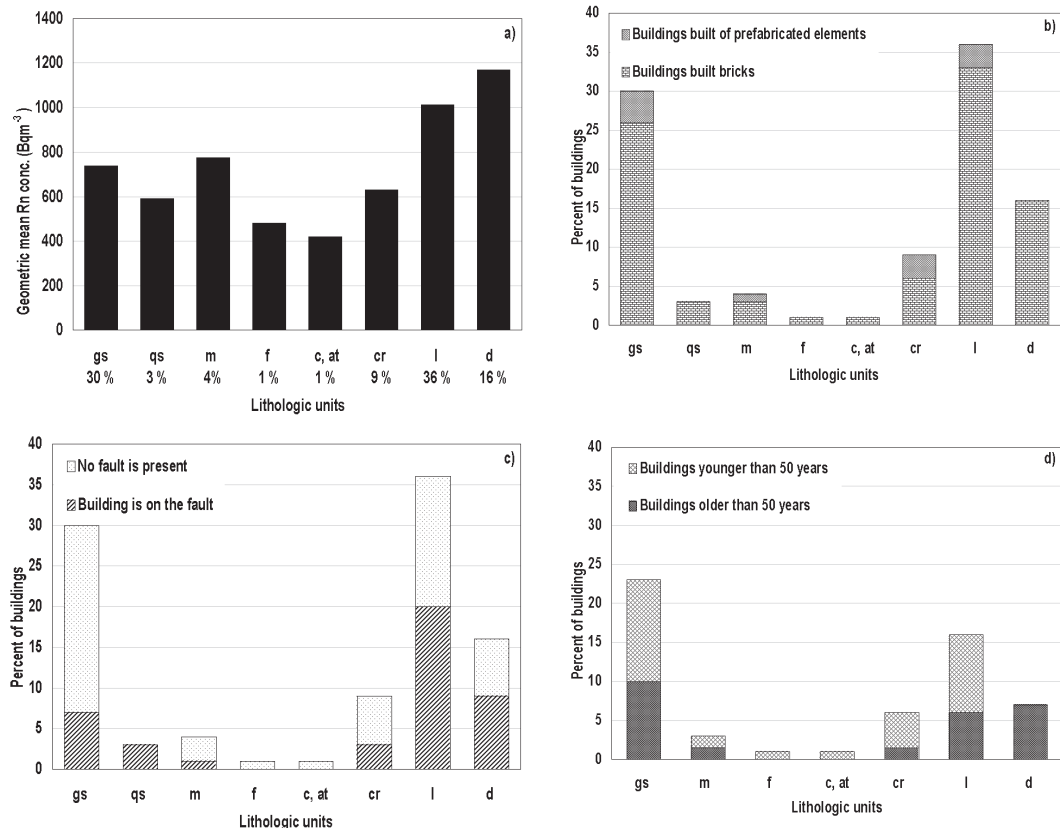


Figure 2: a) Geometric mean radon concentration on each lithologic unit; b) percent of buildings on each lithologic unit, constructed of bricks or prefabricated elements; c) percent of buildings on each lithologic unit, located on faulted rocks; d) percent of buildings on each lithologic unit, older or younger than 50 years (gs – glacial sediments; qs – quartz sandstones; m – marl; f – flysch sediments; c, at – claystone with intermediary layers of andesite tuffs; cr – various clastic rocks (marl, shale, sandstone, claystone, etc.); l – limestone; d – dolomite).

The majority of buildings (89 %) were constructed of clay bricks. Only a few percent were built of prefabricated material (Fig. 2b).

The maximum concentration of  $^{226}\text{Ra}$  activity for building material, as suggested in OECD countries, is  $370 \text{ Bq kg}^{-1}$  (OECD, 1979). Activity concentrations of  $^{226}\text{Ra}$  in clay bricks of some schools and kindergartens in Slovenia were measured. In two representative schools, the activity concentration of  $^{226}\text{Ra}$  measured in clay bricks of school 76 (with indoor radon concentration of  $1060 \text{ Bq m}^{-3}$ ) was  $21 \text{ Bq kg}^{-1}$ , and in school 20 (with indoor radon concentration of  $3600 \text{ Bq m}^{-3}$ ) it was  $57 \text{ Bq kg}^{-1}$ . They were thus far below the limit suggested by the OECD.

In order to estimate the influence of a particular lithology on indoor radon levels, the percentage of buildings with a tectonic fault under the foundations (Fig. 2c) and the age of buildings were considered (Fig. 2d).

Indoor radon concentrations in buildings 36, 39, 43, 45 and 46 (Fig. 1) built on glacial sediments, buildings 50 and 61 built on quartz sandstones, building 69 built on marl, buildings 51 and 53 built on various clastic rocks (sandstone, claystone, conglomerate, shale, breccia), buildings 1, 5 – 9, 11, 13, 15 – 17, 49, 62 and 73 built on limestone and buildings 20, 22 – 25 and 54 constructed on dolomites were affected by faulted rocks (Fig. 1, Fig. 2c). The grain size of uranium bearing minerals in crushed rocks along fault zones is reduced, thus increasing in radon emanation. Cracks in building foundations and very porous faulted rocks provided paths for migration of radon from rocks into rooms. Thus, elevated radon levels in buildings constructed on tectonic faults are explained by high rock permeability and porosity together with poor building construction.

In a study of soil-gas, radon anomalies along faults in North Jordan were 3 to 10 times higher than the background values reported (Al-Tamimi & Abumurad, 2001).

For those buildings with elevated indoor radon levels that were not located on a fault (Fig. 2c), the age of the building was considered (Fig. 2d). The probability of presence of cracks and fissures in the foundation floor is higher with increasing age of buildings. Thus, elevated radon levels, measured in buildings older than 50 years: i.e. in seven buildings on glacial sediments, a building

on marl, a building on various clastic rocks (sandstone, claystone, conglomerate, shale, breccia), four buildings on limestone and in all five buildings on dolomite, could be explained by the poor building construction.

Elevated indoor radon levels in buildings that were not situated on faulted rocks and that were younger than 50 years (Fig. 2d) were correlated with lithological units under the foundations. Elevated indoor radon concentrations on glacial sediments, ranging from 400 to  $1500 \text{ Bq m}^{-3}$  were found in two buildings in the Pohorje region (41 and 42, Fig. 1), where Quaternary sediments consist of igneous and metamorphic rocks with lesser carbonates, and in seven buildings in the Ljubljana region (26, 28, 29, 31, 38, 40 and 47, Fig. 1), where Quaternary sediments are composed of Permocarboneiferous quartz sandstones and shale. The higher content of radionuclides of the uranium series in glacial deposits from both regions, and the higher permeability were the main reasons for elevated indoor radon levels. Instantaneous indoor radon concentrations in seven schools and kindergartens (3, 12, 14, 58, 59, 70 and 72, Fig. 1) built on limestone ranged from 500 to  $1200 \text{ Bq m}^{-3}$ . The limestone in all seven cases is karstic, accounting for its high porosity and permeability, and thus facilitating radon transfer from rocks into buildings. In buildings built on marl (71, Fig. 1), flysch (56), claystone with andesite tuffs (66) and on other various clastic rocks (48, 63 and 64) (sandstone, claystone, conglomerate, shale, breccia) with no uranium mineralization, instantaneous indoor radon concentrations ranged from 400 to  $1300 \text{ Bq m}^{-3}$ . Although they are not located on the tectonic fault and are younger than 50 years, they exhibited elevated radon levels. The buildings were constructed about 17 to 41 years ago. Foundation floors might crack during the consolidation of clastic rocks and sediments under the burden of the building. Thus, poor building construction might be the reason for elevated indoor radon levels in the last six cases.

In a similar study in Finland it was found that in areas of moderately homogenous uranium content of the soil, the main reasons for high indoor radon concentrations are high permeability of the soil and subsurface types that allow radon leaks into dwellings (Mäkeläinen et al., 2001).



A clear relationship between the measured soil-gas radon concentrations and the underlying geological features (uranium content and permeability of rock and soil) was demonstrated in England. High concentrations were measured in areas dominated by granite intrusions, whereas the maximum level was measured over faulted area, where it passes through granite (Varley and Flowers, 1992).

A radon survey in a comparable study in schools in north-eastern Italy also showed the importance of rock permeability for indoor radon levels. Radon prone areas were found where the cover consists of highly permeable gravelly deposits, whereas low emissions of radon were found in the Quaternary cover of silt and clay with low permeability (Giovani et al., 2001).

### Conclusion

The most important factor causing elevated indoor radon levels was the uranium content of rocks, as in the case of buildings built on glacial sediments that were brought from regions with a higher content of radionuclides of the uranium series. However, elevated indoor radon levels were also found in schools and kindergartens that were built on sedimentary rocks with low uranium content, i.e. on karstic limestone with high permeability and porosity and on fractured rocks. The second important factor was therefore the structure of the area.

Building material in the 76 cases studied did not enhance indoor radon concentrations, whereas the quality of building construction, estimated by the age of the building, was important in 18 (24 %) of cases. The probability of presence of cracks and fissures in the foundation floor is higher with increasing age of the building; which explains elevated indoor radon levels.

We recommend that the authorities responsible for building construction regulations should consider radon risk. In the area where a building will be constructed, the geology should be carefully studied, and soil gas radon monitoring should be carried out. The type of construction and the choice of the building material should also be considered to prevent elevated indoor radon levels.

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