

SUMMARY OF THE THESIS

Nuclear measurement techniques for analysis of radioactive gases

Premises

The main source of indoor radon is the soil. The activity concentration of the radon coming from the soil can reach higher and higher values due to the better and better insulation technique of dwellings. Present epidemiological researches show the relative risk of lung cancer is 1.33 above 200 Bq m^{-3} (Pavia et al., 2003), and the relative risk increases by 0.15 – 0.2 per 100 Bq m^{-3} (Lagarde et al., 1997).

The indoor radon surveys started in the 1970ies all over the world. One of the most important aims was to find parameters that can predict higher than average radon activity concentrations in an area. Within the given area another aim was to find particular dwellings with high radon levels. Beyond these some truly random and representative sampling were done in a few countries.

There were some thoron surveys in the last years. In some dwellings the radon activity concentrations were commensurable with thoron activity concentrations (if the dwelling was built upon thorium rich soil, or if the wall paint contains thorium). That is why the thoron surveys come to the front in these days.

In Hungary Árpád Tóth carried out the first wider indoor radon surveys. (Tóth, 1972; Tóth, 1978) Later the INR^a and NRIRR^b performed indoor radon surveys covering the whole country (Somogyi et al., 1989; Nikl, 1996). These large research institutes working on radon problem (INR, Eötvös University, NRIRR, University of Veszprém) did not carry out nation wide indoor radon surveys in the last 10 years. Their main fields on radon were rather on measurements in caves (Hakl et al., 1997a; Kávási et al., 2003), determining of radon concentrations in drinking waters, spring waters, and thermal waters (Hakl et al., 1996; Hakl et al., 1997b; Vásárhelyi et al., 1997; Baradács et al., 2002a; Szerbin és Köteles, 1999; Kasztovszky et al., 2000; Kovács et al., 2003), detailed mapping and interpretation of local anomaly of indoor radon in some settlements (Somlai et al., 1997; Németh et al., 2000; Somlai et al., 2005; Gorjánác et al., 2006), and developing radon measurement technique (Csige, 1997; Csige és Csegzi, 2001; Hunyadi et al., 1999; Baradács et al., 2002b).

The RAD Labor (founded in 1992) measured the radon activity concentrations in almost all the homes in Mátraderecske between 1992-1994. The nation wide radon survey by the RAD Labor was started in 1994, and the works continue these days. The RAD Labor has measured the annual mean of radon activity concentrations, i.e. radon levels in more than 15000 Hungarian homes between 1994 and 2004 (Hámori et al., 2004; Hámori et al., 2006a).

I am working at RAD Labor from 1997. In the first year my tasks were the distribution, collection, etching, and counting of tracks of the detectors. Then I took part in the organizations of the public relation of the RAD Labor, I gave lectures with demonstrations in the settlements before the detector distributions, and I prepared and directed the students for labor works. The analysis of the 15000 radon levels measured between 1994 and 2004 started in Summer 2004. The present PhD dissertation introduces the methods, the results, and the discussion of this work.

On the base of international recommendations (ICRP 65) there is a statutory rule on workplace radon, namely action should be done above 1000 Bq m^{-3} as annual mean (regulation by the Hungarian Health Department, 2000). There is no statement on the indoor radon and on the radon in drinking water in the Hungarian regulation till these days.

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Aims

Decision makers have to know the national radon level distribution, i.e. how many homes can be expected above given radon levels when they determine the action level in a cost effective way. If they choose a too low action level then too many homes have to be mitigated. On the other hand: too high action level can leave too many people at high risk of lung cancer (Kanyár et al, 2004).

Health authorities have to know the regions of higher indoor radon levels of the country to urge measurements, to inform the population, and to help in mitigation in the region.

During the measurements and the analysis of the Hungarian indoor radon levels my work in the RAD Labor had the following aims:

1. To determine indoor radon levels in Hungary as many as it was possible. There was an intention to cover the whole country by the survey.
2. To find regions of Hungary where the proportion of homes above a given (high) radon level is larger than average.
3. Analyzing the applicability of mathematical statistical methods and the confidence of the gained results, which led to the national cumulative distribution.
4. To determine the national cumulative distribution from which one can read directly the proportion or the number of homes above any given radon level.

Further aims above these indoor radon surveys and interpretations:

5. Experimental study of thoron behavior.
6. Starting with indoor thoron survey.

Methods

Measurement: The indoor radon activity concentrations were measured by closed CR-39 track detectors, the detector container being a plastic cylinder with a threaded cap (diameter 4 cm, height 6 cm). In a given room, the radon activity concentration was measured three times, each measurement lasting about 3 months (autumn, winter, and spring). The radon level was calculated from the three measured radon activity concentrations. (Due to the too large error we did not determine radon levels in dwellings from where we had only one seasonal data.)

Sample taking: The rooms sampled were based on volunteers, where teachers facilitated the distribution of samplers.

Methods of stratification: If the set of dwellings were homogenous from the point of view of geology, of the house structure, and of the life style of inhabitants, then the distribution of dwellings on the radon levels can be approximated by lognormal distribution (Nero et al., 1986; White et al., 1992; Miles, 1998a; Miles 1998b). We were able to estimate the proportion of dwellings above any given radon levels, when we were able to create a set of homogenous dwellings. The points of view of grouping were somewhat physical reasons, as geology or as parameters of house structure. Dwellings of higher level than first floor were analyzed in one set, because the density of radon is 7.5 times larger than it is of air reducing its availability from first floors and upwards. The first floor dwellings were separated into sets based upon the population sizes of settlements. This separation reflects the differences of house structures between the houses of cities and villages. The third point of view was the geography and geology. At the beginning larger area of the country were chosen. When the

hypothesis tests rejected the application of the lognormal distribution at a given region, then the region was divided into smaller region. This grouping was improved until the distribution of radon levels in set of dwellings became lognormal according to the hypothesis test at a level of significance $\alpha = 0.05$ (Figure 1).

Statistics: Assuming that the measured data follow a lognormal distribution, the parameters m and σ of the normal distribution of the logarithm of the measured data were estimated by the maximum likelihood method (Figure 1). The hypothesis that the data set followed the lognormal distribution was tested by the χ^2 -probe at a level of significance $\alpha = 0.05$. The lognormal model was used only in those groups where the hypothesis test did not reject it. These sets of dwellings were called *stratum*.

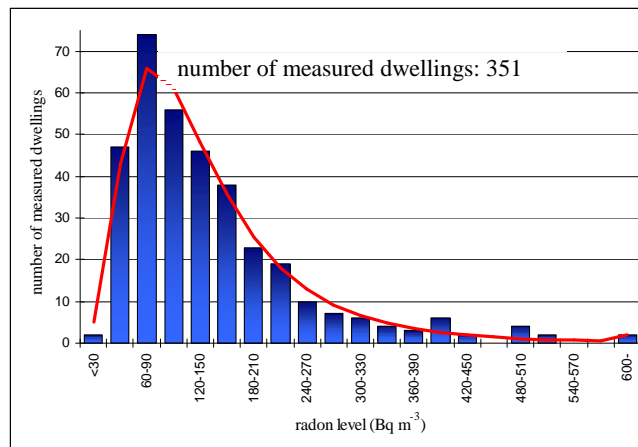


Figure 1 Dwellings distribution on measured radon levels in settlements of population sizes less than 10000 people in the Mountains Bükk. Columns show the number of measured dwellings, red line shows the best fit lognormal distribution. The lognormal model was not rejected by the χ^2 -test at a level of significance $\alpha = 0.05$.

Distribution of regions and the national distribution: The number of dwellings above the given radon levels can be estimated in each stratum using parameters m and σ of the best fit lognormal distribution. The national empirical cumulative distribution was determined by summing the estimated numbers of dwellings above the given radon levels in each stratum.

Thoron experiments: Investigations on electrostatic collection of thoron decay products as a function of field strength in a special source-electrode arrangement have been performed. Yields of the decay products vs. field strength were measured by solid state silicon and also by CR-39 track-etched detectors.

Indoor thoron: Indoor thoron measurements were performed by Raduet radon and thoron detector-pairs made by Radosys, Hungary. The two CR-39 plastic detectors were placed in two different containers. One of the containers is closed enough not to let entering thoron of short half life time, while the other allows to enter both radon isotopes. Raduet were placed into rooms for one season, where previous radon measurements indicated a possible thoron enhancement.

Results

The results of my scientific work can be summarized as follows:

1. Radon levels in about 8000 Hungarian homes were determined between 1997 and 2004. During this time interval 25 000 detectors were distributed and analyzed.
2. Indoor radon levels measured by the RAD Labor between 1994 and 2004 were apportionable into strata based upon geology and house structure. (Note: One can speak stratum if and only if the distribution of dwellings of the stratum on radon levels follows lognormal distribution.)
3. The number of dwellings above the given radon levels were estimated in each stratum using parameters m and σ of the best fit lognormal distribution. The proportions of dwellings above 200, 400, and 600 Bq m^{-3} in each region are given in this dissertation.
4. Our analyzes show those regions of Hungary where the proportion of dwellings of radon levels above 200 Bq m^{-3} can be predicted for more than 30% of dwellings. These regions are the Mountains of Mátra, and Börzsöny-Cserhát (Figure 2.), in addition three settlements: Kővágószőlős and two villages asking for anonymity.

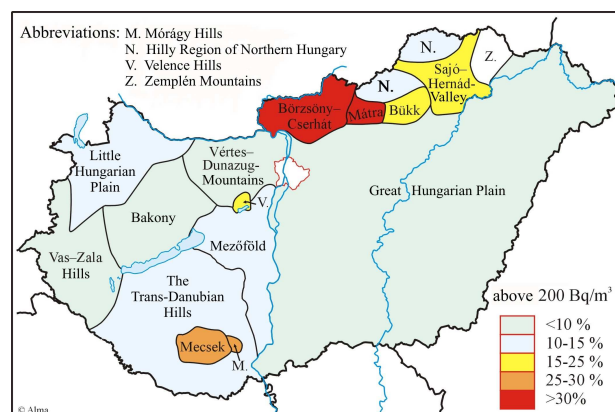


Figure 2 Proportion of dwellings above 200 Bq m^{-3} in regions of Hungary in settlements of population sizes less than 10000 people.

5. National empirical cumulative distribution was determined corresponding to 95 % of Hungarian dwellings.
6. Dependence of the activity of Th(B+C) emanation on the collecting voltage was determined in our experimental arrangement. The activity of the sample grows along with collection field strength at the beginning. At further growth of the voltage the activity of the sample decreases. Then an equilibrium enrolls: the activity of the sample is more or less constant over the field strength. The phenomenon was interpreted by the space charge effect in the activation cell.
7. It was proved that airing in the activation cell influences the sample activity significantly. Airing decreases the thoron concentration in the cell resulting in lower activity of the sample as compared to that obtained by no airing arrangement.

8. It was also proved that the activity of the sample can be reproduced only in the case of no airing. The standard deviations of activity of the samples activated at the same voltage are much larger than the statistical error in the case of airing.

9. Radon detectors were applied in measurements of indoor radon and thoron activity concentrations. In some dwellings the activity concentrations of the two gases were in the same order, so the continuation of thoron survey seems to be important.

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