THESIS OF DOCTORAL (PHD) DISSERTATION

RADIOHYGIENE EXAMINATION OF BUILDINGS

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Introduction

People spent most of their time in confined spaces. Inside the buildings, we are exposed to ionising radiation, receiving external and internal doses. The main sources of these doses are inhalation of radon gas and external gamma radiation. Their contribution to our total natural exposure is the highest; they are responsible for about three-quarters of the total of our annual dose. These doses are higher by some order of magnitude compared to the dose from artificial radionuclides occurring in our environment. For this reason, radiological examination performed in buildings has high importance.

The main source of indoor radon is the radon in soil gas beneath the building. The actual level of indoor radon is determined by several external and internal factors, and it also depends on how the building is used. The building materials have the highest contribution to indoor gamma radiation. The intensity of the gamma radiation is proportional to the radioactivity of building materials. In Hungary, bottom ash was frequently used as building material from the end of XIX century until the beginning of the 1990s. The bottom ash originated mainly from the operation of heating power plants, smelters, and furnaces, and frequently showed elevated radioactivity, which caused unjustified exposure to the inhabitants. There are no regulations, guidance, or accepted protocols for the evaluation of indoor radiation. Reference level exists only for the yearly average value of indoor radon concentration.

Aim of the work

This work aimed to evaluate the temporal and spatial variation of the indoor gamma radiation and radon concentration. An additional aim was the determination of the usual level of the indoor gamma radiation in buildings affected by bottom ash and without bottom ash; the examination of the level of gamma dose rate on the surface of different kinds of building materials; identification of the type of building materials and construction methods causing elevated, unjustified gamma doses; and derivation of a reference level for the indoor gamma radiation.

Furthermore, the changing tendency of the radon level was evaluated to determine the offered minimal time of the indoor radon measurement and to develop a method for the assessment of indoor radon potential based on the results of the evaluation.

Materials and methods

During my work, I performed indoor radon and gamma dose rate measurements using active and passive equipment on the whole territory of Hungary. The results were statistically analysed using simple methods.

I performed detailed gamma dose rate surveys in buildings using active scintillation probes. I studied the relationship between the measured values and the construction method of the buildings, and the types of building materials, respectively. Generally, the dose rate meters display the measured value in one of the operational dose quantities. But the dose limits given in regulations are expressed in effective dose. Thus, it was necessary to determine the relationship between them. Additionally, I derived a reference value for the indoor gamma dose rate, adopting the concept of the regulation applied to limit the radioactivity of building materials.

The indoor radon concentration was measured using active radon monitors in mainly non-ventilated rooms. Usually, the sampling time was only a few days. The time series of the measured values was analysed. During the analysis, I observed some typical tendencies, which were analysed, and indicator parameters were extracted from them regarding the magnitude of indoor radon potential.

CR-39 track attached detectors were used during the new national indoor radon surveys. The total sampling time was 1 year, but the detectors were changed quarterly. The results of the survey were statistically analysed to study the spatial and temporal variation of indoor radon concentrations.

I had reassessed the dose of the Hungarian population to natural sources. To do this, it was necessary to collect all the former and newer data related to the sources of exposure. The received data were compared to the former results and to the internationally accepted reference values.

Results

From the results of indoor gamma radiation surveys, I concluded that generally, the dose rate level in buildings where bottom ash was not built-in, exceeded only slightly the outdoor background radiation level (100 nSv/h). The average dose rate in these buildings was only 120 nSv/h, and the maximal measured value did not exceed 200 nSv/h. The distribution of the dose rate values did not show any specific tendency. The dose rate measured on the surface of different kinds of building materials fell into a typical dose rate range between 70 and 180 nSv/h, and these values were proportional to the radioactivity of the building materials. For this reason, these values can be used as an indicator during the radiation survey of the buildings.

At the same time, the dose rate values measured in buildings where bottom ash was built in spread over a wide range. The dose rate values showed high dependency on the place, the amount, and the radioactivity of the bottom ash, and the construction method, respectively. In these kinds of buildings, it was usual that the measured values exceeded the outdoor level several times. But in 92% of these buildings, the calculated average value did not exceed 250 nSv/h, and in 63% of them, the maximal value did not exceed this level. It means that in the majority of the buildings affected by bottom ash, only moderately elevated gamma radiation levels could be detected. As it was expected, a much lower radiation level was detected when the bottom ash in the floor space was covered by a concrete layer, or it was over the ceiling, compared to those cases when it was directly under the parquet. 2.6, 1.7, and 14% were the fractions of those places where the average values exceeded 350 nSv/h according to the place of bottom ash.

According to my calculation, the 1 mSv effective dose equals 250 nSv/h environmental dose equivalent rate. Consequently, I obtained 350 nSv/h for the reference level of indoor gamma radiation. The average dose rate was over this value in 3% of the buildings affected by bottom ash.

I demonstrated that the time series of indoor radon concentrations measured in non-ventilated rooms generally showed typical tendencies. Many times, I had observed stagnant or increasing radon levels in previously ventilated confined spaces where the increment stopped at a certain quasi-equilibrium level within 1 or 2 days. Thus, I found that we can get important information from the analysis of the time series, which can be used to characterise the indoor radon potential numerically. One of these is the radon level growth speed and the duration.

I showed that the radon growth periods can be grouped by the growth speeds and the duration of the growing periods. If the growth speeds were less than 8 $Bq/(m^3 \cdot h)$ and the durations were less than 48 hours, the average radon levels remained below 150 Bq/m^3. If the growth speeds were in the range of 8-17 $Bq/(m^3 \cdot h)$ and the durations were less than 24 hours, the average radon levels fell in the range of 150-300 Bq/m^3. If the growth speeds exceeded 17 $Bq/(m^3 \cdot h)$ or the durations exceeded 24 hours, it resulted in elevated radon levels.

Finally, I concluded that average and maximal radon concentration, and the radon level increment in the first 24 hours, can be used to calculate the indoor radon potential value (IRP). Additionally, the duration of the radon measurement should be at least 3 days to examine these parameters with enough confidentiality.

The long-term radon measurements using track detectors showed that elevated radon concentration (over 300 Bq/m^3) can be measured not only on the ground floor level, but at the first floor as well. Additionally, experiences from the short-term measurements showed that this can happen with a higher probability in that case, if bottom ash was used as floor space filling material at the construction of the buildings. On the second floor and above, the calculated long-term average values did not exceed 200 Bq/m^3.

According to my analysis, the seasonal quotient factor was 0.83, 0.56, 1.32, and 1.26 for spring, summer, autumn, and winter, respectively. These values are close to those which were published in the international literature. I also found that the values of the quotients did not depend on the floor levels and the yearly average value, if it was above 100 Bq/m^3. At the same time, the quotients were spread over a wide range in all seasons. This means that the application of their average values as a correction factor can cause high uncertainty in the assessed annual average radon concentration value.

According to my reassessment, the annual average value of the dose of the Hungarian population to natural exposures was 4.1 mSv compared to the former value, 4.4 mSv, and the 2.4 mSv global weighted average. The main reason for the difference from the former value was that the newer value of the weighted average of the indoor gamma exposure became higher than it was previously assessed. The main reason for the difference from the global average value came from the much higher average radon concentration. The weighted average value in Hungary was 112 Bq/m^3, compared to the 40 Bq/m^3 global average.

Thesis of doctoral (PhD) dissertation

1. According to my hypothesis, the building materials (BM) can be characterised by the gamma dose rate measured on their surface, and they can be separated into low, medium, and high radioactivity category groups. Additionally, mainly the bottom ash and the BM produced using bottom ash belong to the high-radioactivity group. To check this, I had examined the indoor gamma radiation in dwellings and workplaces on the entire territory of Hungary. I concluded that the gamma radiation in buildings which does not contain bottom ash varied in a narrow and low range (70-180 nSv/h). If the dose rate value measured on the floor or under the ceiling exceeds 200 nSv/h, it indicates the presence of bottom ash in the floor space with relatively higher radioactivity. I concluded that the BM can be characterised and separated into groups based on the gamma dose rate measured on their surface. The radioactivity of the generally used BM (like wood, concrete, brick, limestone) is low. Only 70-180 nSv/h can be measured on their surfaces. But elevated gamma dose rate can be detected usually on the surface of the bottom ash concrete blocks (160–290 nSv/h), and the dose rate can exceed 1 µSv/h. These findings are supported by the gamma-ray spectrometry measurement of the BM.

2. There is no reference level for the permitted level of indoor gamma dose rate in Hungary. According to my hypothesis, the legislation applied to control of the radioactivity of the BM is not applicable directly to the indoor gamma radiation. But the interest in its acceptable level is high among the general public, because radioactive bottom ash was built into the floor spaces in a large number of Hungarian buildings. Therefore, it was necessary to derive a reference level for the indoor gamma radiation. I adapted the legislation dealing with the radioactivity of BM and determined a value that can be used as a reference. I have used the model described in the European Commission Radiation Protection 112. I concluded that 250 nSv/h expressed in ambient equivalent dose rate [H*(10)] is equal to the 1 mSv annual effective excess dose defined by the 2/2022. (IV. 29.) HAEA Decree. According to my hypothesis, such high radiation levels can occur in buildings where radioactive bottom ash was used as

building material. The results of radiological surveys conducted in the buildings supported my hypothesis. Such high radiation, exceeding the calculated reference level, was measured only in those buildings where highly radioactive bottom ash was built into the floor spaces.

3. Generally, long-term measurement is needed to determine the exposure to radon and its daughter elements. According to my hypothesis, the required detection time can be significantly minimised. To ensure this assumption, I made a detailed statistical analysis of the results of short-term indoor radon measurements. During the radiological surveys of buildings, active radon detectors were placed in confined rooms for several days. In the majority of cases, the representation of the radon level could be observed. I had determined for each case the average radon accumulation speed, the accumulation time, and the increment of the radon level. By applying detailed statistical analysis, it could be established that the radon accumulation speeds can be grouped according to the contributing radon level increments. I observed that if the radon accumulation speed was less than 8 $Bq/(m^3 \cdot h)$, the contributing radon level increment did not exceed 150 Bq/m^3. If the radon accumulation speed was in the range of 8-17 $Bq/(m^3 \cdot h)$, the contributing radon level increment was in the range of 150–250 Bq/m^3. If the radon accumulation speed exceeds 17 $Bq/(m^3 \cdot h)$, the contributing radon level increment exceeded 300 Bq/m^3 with high probability. 300 Bq/m^3 is equal to the annual average reference radon level. Furthermore, I concluded that this type of information can be used to calculate the Indoor Radon Potential (IRP) index. The following data are used to calculate the IRP index: the radon level increment in the first 24 hours, the average, and the maximum of the radon concentration over the entire detection period.

4. I have recalculated the annual average level of our naturally occurring radiation exposure, taking into account the new results of the following examinations: indoor and outdoor gamma radiation, as well as the indoor radon concentration. During my calculations, I had used the methods described in the UNSCEAR Reports. I concluded that the new national value is 4.4 mSv/y compared to the previously calculated 4.1 mSv/y value, and instead of the 2.4 mSv/y value, which is referred to as the global average. The main reason behind the differences between the global and national average values comes from the differences between the representative values of the indoor radon concentrations. The worldwide average is 40 Bq/m^3, compared to the Hungarian 112 Bq/m^3. The biggest difference between the previous and the actual level of exposure sources was found regarding the indoor gamma radiation. Its earlier value was found to be 73 nGy/h, and its actual value is 101 nGy/h.

List of scientific publications

Scientific publication associated with the PhD work

Appearance in an international peer-reviewed journal

1. Zs. Homoki, G. Tóth, A. Csordás, E. Tóth-Bodrogi, M. Hegedűs, T. Kovács, Assessment of the residential radon concentrations in the Bakony Region, Hungary, Radiation Medicine and Protection 5 pp 243–247 (2024)
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5. Homoki Zs., Fülöp N., A hazai radon program aktualitásai, XLIV. Sugárvédelmi Továbbképző Tanfolyam: ELFT, Hajdúszoboszló, Magyarország (2019)
6. Zs. Homoki, National Radon Action Plan in Hungary, VII. Terrestrial Radioisotopes in Environment: International Conference on Environmental Protection, Veszprém, Hungary: Social Organisation for Radioecological Cleanliness (2020)
7. Zs. Homoki, Á. Szigeti, Gamma dose rate levels and radon concentrations in Hungarian homes, VII. Terrestrial Radioisotopes in Environment: International Conference on Environmental Protection, Veszprém, Hungary: Social Organisation for Radioecological Cleanliness (2020)

8. Zs. Homoki, Á. Szigeti, Methodology of Radiohygiene examination of buildings, XVI. Carpathian Basin Conference for Environmental Sciences, ELTE, Hungary (2021)
9. Homoki Zs., Szigeti Á., Az országos radon program előrehaladása, XLVI. Sugárvédelmi Továbbképző Tanfolyam: ELFT, Zalakaros, Magyarország (2021)
10. Zs. Homoki, Á. Szigeti, Gamma radiation and radon concentration in Hungarian dwellings, 10th. Jubilee Interdisciplinary Doctoral Conference, Pécsi Tudomány Egyetem (PTE), Hungary (2021)
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