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OUTDOOR RADIATION BACKGROUND SURVEY DESIGN

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Abstract. *Combined measurements of outdoor gamma background and radon in populated urban areas have not previously been conducted in Bulgaria. Such outdoor measurements can provide information on natural background concentrations, allowing the identification and quantification of anthropogenic contributions. In addition, local outdoor radon levels influence indoor radon concentrations; therefore, these data could supplement other parameters used to identify radon priority areas. Guided by these goals, an outdoor radiation background survey is planned under project КП-06-Н87/3 of the National Science Fund, Bulgaria. The purpose of this paper is to present the prepared research design. The preparatory activities include: (1) identification of the target population; (2) selection of a representative sample using an appropriate sampling method; and (3) determination of the types of detectors and the integrated system for combined measurements. The article presents the results of the statistical analyses performed for the sampling design using the Complex Samples procedures in IBM SPSS. The target population consists of all urban sites in Bulgaria (218 in total). Simple Random Sampling without replacement was applied, with each unit selected with equal probability. Population size was used for stratifying the urban sites into non-overlapping subgroups. The subgroups are defined as follows: fewer than 5,000 people, 5,001–30,000 people, and more than 30,000 people. The randomly selected sample consists of 96 towns (excluding Sofia city), each of which will be investigated using more than one detector. An integral system will be installed at each selected location, comprising passive radon detectors and TLD dosimeters for gamma background measurement, encased in a protective enclosure.*

Keywords: *gamma background, outdoor radon, detector, urban areas, sampling design*

1. INTRODUCTION

People are exposed to background radiation, and radionuclides are present in the air, soil, rock, water, and building materials. These radionuclides fall into three general categories: terrestrial (Earth's radionuclides), cosmogenic (formed as a consequence of cosmic-ray interactions), and human-produced (resulting from human activities) [1]. Cosmogenic radiation originates in outer space and varies slightly with latitude, but increases markedly with altitude. The main terrestrial radionuclides are those from the ^{238}U and ^{232}Th decay series, as well as ^{40}K. Their concentrations in soil depend on geographic location and on human activities such as mining, milling, and other industrial processes. These radionuclides contribute to both external and internal human exposure and generally determine the natural radiation background of a given area. The level of background radiation from these natural sources may be influenced by human-origin sources, including nuclear activities, accidents, and other human actions [2]. Depending on the behavior of radionuclides in the environment – their mobility and chemical forms in different media – radiation levels can vary significantly [3]. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the global annual average effective dose from natural sources is about 3.0 mSv, with a range of 1-14 mSv. The major contribution (about 60%) comes from inhalation of radon, thoron, and their decay products, amounting to approximately 1.8 mSv [4]. Assessing the natural radiation background is essential for analyzing population exposure and for establishing baseline measurements across different geographical regions. Background radiation has been widely studied for many decades [5]. However, combined measurements of gamma background and outdoor radon in populated urban areas have not been systematically carried out in Bulgaria. Such outdoor measurements provide information on the natural radiation background and help identify and quantify anthropogenic contributions. Urban environments are complex, as terrestrial background radiation depends not only on radionuclides in the soil and bedrock but also on radionuclides present in building materials used for constructing buildings, roads, and pavements [6]. Furthermore, the data obtained in this survey may complement other parameters used to identify radon priority areas. Guided by these objectives, the outdoor radiation background survey is planned to be conducted under project КП-06-Н87/3 of the National Science Fund, Bulgaria.

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To obtain representative data, a survey design was developed. This paper presents the research design, which includes: (1) identification of the target population—urban areas; (2) selection of a representative sample using an appropriate sampling method; and (3) a description of the integral system, including the detector types used for combined gamma radiation and radon measurements.

2. Materials and Methods

Conducting a qualitative national survey requires the application of key methodological principles, including an appropriate sample design that minimizes inferential bias and ensures representativeness. Sampling design provides the framework within which sampling occurs and includes the number and types of sampling schemes as well as the total sample size [7]. For this national survey, the sample size depends on how the general population was structured into strata. To determine the population of urban areas and stratify it by relevant characteristics, statistical data for Bulgaria were used [8].

The first characteristic used for stratifying Bulgarian urban areas was population size. The subgroups were defined as follows: towns with fewer than 5,000 inhabitants; towns with 5,001–30,000 inhabitants; and towns with more than 30,000 inhabitants. The second characteristic used for grouping urban areas was their classification into tectonic units. Bulgaria has a complex geological structure [9]. For stratification by tectonic units, the same grouping applied in a previous study on indoor radon was used, where significantly different radon concentrations were found between units [10]. The tectonic subgroups include towns located on the Moesian Platform, the Balkan Zone, the Srednogorie Zone, and the Morava–Rhodope Zone. Bulgaria lies within two major geological structures—the Moesian Platform and the Alpine Thrust Belt. The Moesian Platform consists mainly of terrigenous and carbonate rocks of various ages and occupies much of northern Bulgaria. The Balkan, Srednogorie, and Morava–Rhodope zones are subdivisions of the Balkan orogenic system.

The Balkan Zone contains diverse terrigenous, terrigenous–carbonate, and coal-bearing sediments, with widespread flysch, flysch-like, and molasse successions, as well as localized subvolcanic and volcano-sedimentary rocks and variably metamorphosed formations. The Srednogorie Zone is characterized by thick volcano-sedimentary sequences and numerous intrusive bodies. The Morava–Rhodope Zone includes widely exposed high-grade metamorphic basement complexes and intrusive bodies of different sizes. Sediments from Tertiary intra-orogenic continental and shallow marine basins cover large parts of both the Srednogorie and Morava–Rhodope zones [11,12]. In our previous investigation, indoor radon concentrations were highest in the Srednogorie Zone and lowest in the Balkan Zone [10].

The Complex Samples analysis procedures in IBM SPSS were used to develop the sampling design. This option allows samples to be selected according to a complex design and incorporates the sampling specifications into subsequent analyses, ensuring valid results [13]. In SPSS, stratified sampling involves selecting samples independently from non-overlapping subgroups, or strata. A Simple Random Sampling method without replacement was applied, with equal probability of selection for all units within each stratum.

The survey design also includes an evaluation of the measurement technique and the sampling (measurement) period required to obtain reliable results. Radiation background levels are not constant over time at a given location; they fluctuate considerably due to factors such as the removal of radon progeny by rainfall, soil moisture, and snow cover [2]. Based on this and to obtain annual average background levels in urban areas, passive detectors were chosen for the measurements. An integrated system consisting of passive radon detectors and TLD dosimeters for gamma background measurement, encased in a protective enclosure, was tested.

3. Results and Discussion

To generalize the results obtained to the overall group of urban areas, a sampling scheme was developed based on current statistical data for Bulgaria from the National Statistical Institute. The data were grouped into strata, and a statistical model for sample selection was applied.

3.1. Target population

The Republic of Bulgaria is administratively divided into 28 districts and 265 municipalities. Each municipality has an administrative center, typically a town. However, 46 municipalities have villages as their administrative centers. These villages were excluded from the total number of surveyed urban areas. The capital, Sofia, will be surveyed separately and in greater detail, as it has the largest population and the largest territorial area. As a result, the total number of urban areas of interest is 218.

One of the primary objectives of the radiation background study is to assess population exposure to outdoor radiation. For this reason, one of the characteristics used to group towns was their population size. Based on data from the National Statistical Institute, three population groups were defined. The proportions of towns with fewer than 5,000 inhabitants and those with 5,001 to 30,000 inhabitants are approximately equal, while towns with more than 30,000 inhabitants constitute only about 25% of all urban areas [8].

It is well established that natural environmental radioactivity and associated external exposure depend on geological and geographical conditions [14,15]. To assess the influence of geology on the radiation background, the towns were grouped into four strata according to their tectonic units. The proportion of towns located on the Moesian Platform (34%) and the Srednogorie Zone (32%) are approximately the same. In contrast, the proportions of towns located in the Balkan Zone (16%) and the Morava–Rhodope Zone (18%) are lower. This distribution is expected, as both the Balkan and Morava–Rhodope zones contain mountainous regions that are more sparsely populated.

3.2. Sampling scheme

The set of urban areas, distinct strata according to the two characteristics, can be considered a complex sample. The units within each stratum are as homogeneous as possible, with respect to population characteristics and geological conditions. Stratified sampling involves selecting samples independently from non-overlapping subgroups of the population. Separate samples are obtained for each stratum to improve the precision of the estimates [16].

The Simple Random Sampling (SRS) method in IBM SPSS Complex Samples is one of the fundamental sample-selection techniques and is based on the principle of equal probability selection. This means that each element in the population has an equal probability of inclusion in the sample [13]. Combining the two grouping characteristics resulted in a total of 12 strata. A fixed sample size of nine units was selected from each stratum to ensure equal representation across groups, thereby facilitating valid statistical comparisons.

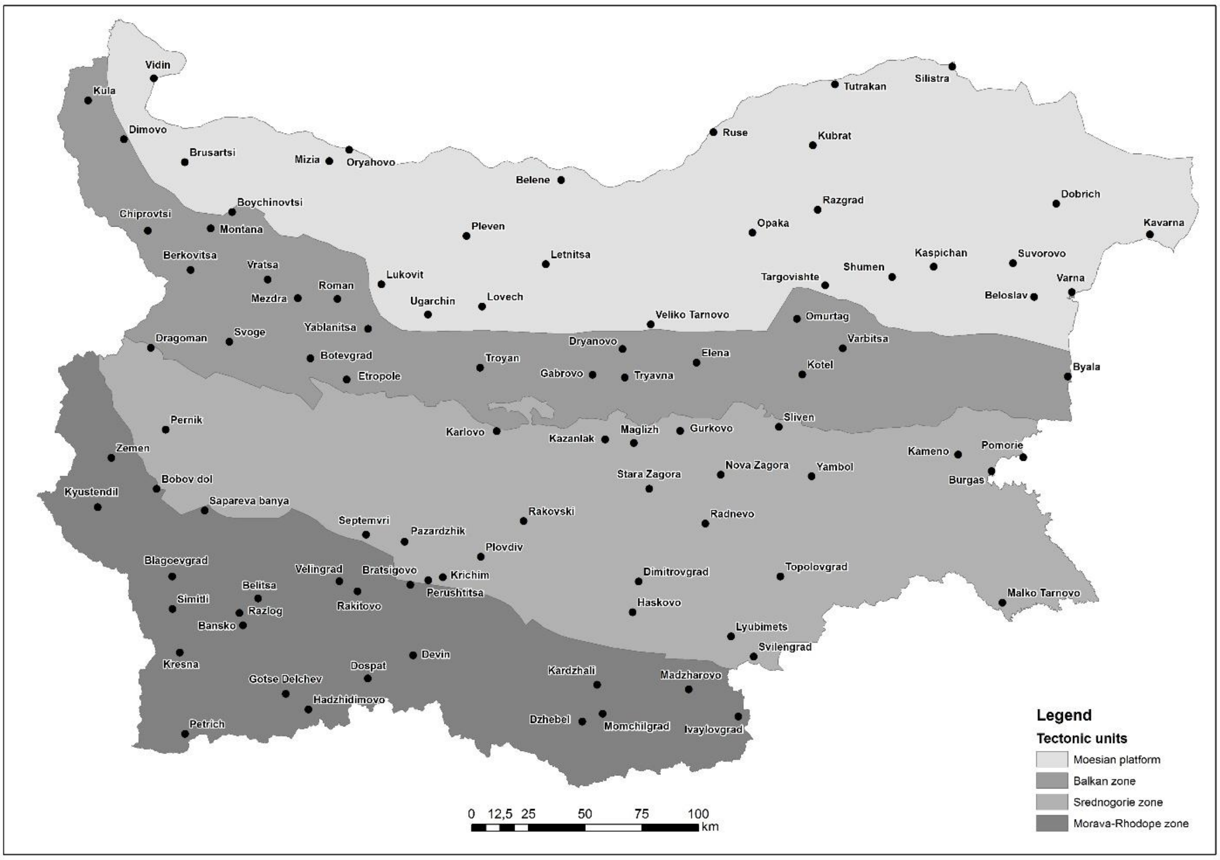


Figure 1. Map of Bulgaria with Tectonic units and chosen towns for measurement

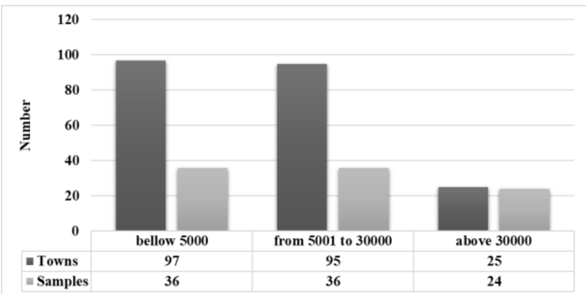


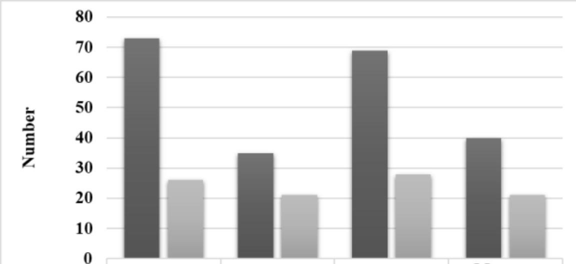
Figure 2. Number of target groups and samples according to the residents in towns.

Sample weights and joint probabilities were calculated for the selected sample. A sample weight is a value assigned to each unit in the dataset to adjust for potential bias and to ensure that the sample accurately represents the population from which it was drawn. This information is useful if a selected unit needs to be replaced because measurements cannot be conducted there. Two of the combined strata contained only three elements, and one contained eight. Therefore, all units in these strata were included directly. Additionally, one of the large cities not selected from the final stratum was included to increase the number of urban areas with larger populations in the study. The final sample size is 96 towns, and their spatial distribution within Bulgaria is shown in Fig. 1. Routes for optimizing detector placement at each site will be developed separately.

Figure 2 presents the distribution of towns in the general population and in the sample within each stratum, categorized by number of residents. The sample selection based on town population size does not exactly match the proportional distribution of the target population. This discrepancy arises because greater weight was given to towns with larger populations, as the primary goal is to estimate population exposure to the natural radiation background.

Figure 3 presents the distribution of towns in the general population and in the sample within each stratum, categorized by tectonic unit. Although the total number of towns in each geological unit is not equal, the sample size for each stratum was chosen to be equal in order to facilitate statistical analyses of the influence of geology.

The percentage of towns in each stratum relative to the selected target population closely matches the percentage of samples, indicating that the sampled towns is representative.



	Moesian platform	Balkan zone	Srednogorie zone	Morava-Rhodope zone
Towns	73	35	69	40
Samples	26	21	28	21

Figure 3. Number of target groups and samples according to the location of the towns on the Tectonic units

3.3. Integrated system for measuring

Direct measurements conducted throughout Bulgaria are an essential component of population protection, as they provide key information about the country's radiation background. The planned methodology for assessing doses from the radiation background in urban areas involves integrated, passive measurements.

A thermoluminescent dosimetry (TLD) system was chosen to estimate the average gamma background. The thermoluminescent dosimetric system for ambient dose measurement includes the TLD system RADOS-2000-A, which consists of the thermoluminescent reader RE-2000-A and MCP-N–type thermoluminescent dosimeters. The Dosimeter for Indoor and Outdoor Surveys (DORIS) is a plastic cylindrical case based on standard RADOS TLD cards containing two or four detectors in a slide.

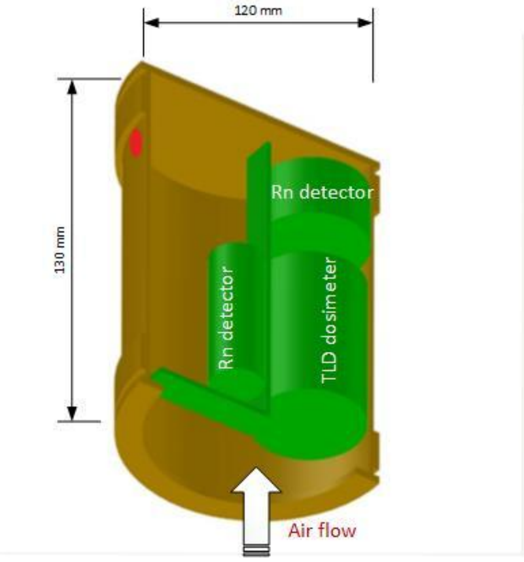


Figure 4. Scheme of the cross-section of the integrated system with detectors and a dosimeter situation

For the assessment of the ambient dose equivalent for environmental dosimetry, the Radiation Protection Instrumentation standard will be applied for the low dose range 0.01 mSv and in wide energy ranges [17].

The concentration of radon in open spaces is influenced by atmospheric conditions, both diurnally and seasonally [18]. Guided by the survey goals, which include estimating the average outdoor radon concentration, passive solid-state track-etch detectors with CP-39 chips will be used. It is well known that passive detectors are suited for obtaining long-term mean radon concentrations in air [19]. Nevertheless, calibration and additional investigation for low-exposure radon concentrations will be performed. A measurement protocol that includes an over-etching process will be implemented [20]. Two detectors will be used to reduce measurement uncertainty—one will remain in place throughout the year, and the other will be replaced to assess concentrations during the cold and warm seasons.

To protect the detectors from prolonged exposure to atmospheric conditions, a protective box integrating both types of detectors was designed and manufactured, as shown in Fig. 4.

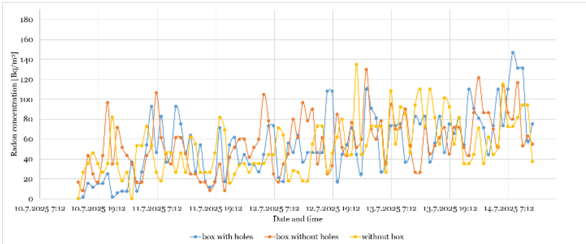


Figure 5. Measurement results of radon detectors placed in a box with holes, without holes, and a detector without a box

The box is not expected to influence the gamma background measurements obtained with the TL dosimeters. However, to assess its potential effect on radon concentration results, an indoor measurement was carried out. Three detectors were placed in the same room for over four days: one without a box, one in a box with holes, and one in a box without holes. The tested hypothesis was that the box would affect the radon concentration and would produce a measurable difference in the results. The data from the three detectors are presented in Figure 5. The results were similar, and no statistically significant differences were observed. Therefore, it can be concluded that the box does not affect the radon concentration results.

To improve air circulation inside the box, additional holes were added.

4. Conclusion

The preparation of the survey design based on its goals and objectives, is a crucial part of the study. To ensure representativeness and quality, data collection, analysis, and preliminary testing were conducted. The main outcomes can be summarized as follows:

- Two characteristics were used to stratify the urban areas in Bulgaria: the number of inhabitants in each town and the corresponding tectonic unit.

- A total of 96 towns were randomly selected within each stratum using a computer model for complex sampling. The capital, Sofia, being the largest city, will be studied with more than one detector and was therefore excluded from the general population.

- Measurements will be performed with passive radon detectors and TL dosimeters throughout the year, with replacements after six months to assess seasonal variations (summer/winter).

- Various protective boxes were tested to allow sufficient air circulation while protecting the detectors, and the most appropriate design was subsequently selected and manufactured.

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References

1. D. Shahbazi-Gahrouei, M. Gholami, S. Setayandeh, "A review on natural background radiation," *Adv. Biomed. Res.*, vol. 2, no. 1, pp. 65 – 71, Jul. – Sep. 2013.
   DOI: 10.4103/2277-9175.115821
   PMid: 24223380
   PMCid: PMC3814895
2. *Sources and Effects of Ionizing Radiation*, vol. 1, Annex B, UNSCEAR Report (A/55/46), UNSCEAR, New York (NY), USA, 2000, pp. 109 – 111.
   Retrieved from:
   https://www.unscear.org/unscear/uploads/documents/publications/UNSCEAR_2000_Annex-B.pdf
   Retrieved on: May 20, 2025
3. S. K. Jha, A. C. Patra, G. P. Verma, I. S. Iyer, D. K. Aswal, "Natural radiation and environment," in *Handbook on Radiation Environment*, vol. 1, D. K. Aswal, Eds., 1st ed., Singapore: Springer, 2024, pp. 27 – 72.
   DOI: 10.1007/978-981-97-2795-7_2
4. *Sources and Effects of Ionizing Radiation*, vol. 1, UNSCEAR Report (A/79/46), UNSCEAR, New York (NY), USA, 2024, pp. 10 – 13.
   Retrieved from:
   https://www.unscear.org/unscear/uploads/documents/unscear-reports/UNSCEAR_2024_Report_Vol.I.pdf
   Retrieved on: May 20, 2025
5. A. Khawlany, A. Hamoud, A. R. Khan, J. M. Pathan, "Review on studies in natural background radiation," *Radiat. Prot. Environ.*, vol. 41, no. 4, pp 215 – 222, Oct. – Dec. 2018.
   DOI: 10.4103/rpe.RPE_55_18
6. K. Nowak, A. Solecki, "Factors affecting background gamma radiation in the urban space," *J. Elem.*, vol. 20, no. 3, pp. 653 – 665, 2015.
   DOI: 10.5601/jelem.2014.19.4.755
7. A. J. Onwuegbuzie, N. L. Leech, "Sampling Designs in Qualitative Research: Making the Sampling Process More Public," *Qual. Rep.*, vol. 12, no. 2, pp. 238 – 254, Jun. 2007.
   DOI: 10.46743/2160-3715/2007.1636
8. *Regions, districts and municipalities in the Republic of Bulgaria*, NSI, Sofia, Bulgaria, 2023.
   Retrieved from:
   https://www.nsi.bg/publications/raionite-oblastite-i-obshtinite-v-republika-balgariya-2023-8322
   Retrieved on: May 15, 2025
9. Й. Йовчев, *Тектонски строеж на България*, София, България: Техника, 1971.
   (Y. Yovchev, *Tectonic structure of Bulgaria*, Sofia, Bulgaria: Technika, 1971.)
10. K. Ivanova et al., "Analysis of the spatial variation of indoor radon concentrations (national survey in Bulgaria)," *Environ. Sci. Pollut. Res.*, vol. 26, no. 7, pp. 6971 – 6979, Mar. 2019.
    DOI: 10.1007/s11356-019-04163-9
    PMid: 30645746
11. C. Dabovski et al., "Structure and Alpine evolution of Bulgaria," *Geol. Balc.*, vol. 32, no. 2 – 4, pp. 9 – 15, Dec. 2002.
    DOI: 10.52321/GeolBalc.32.2-4.9
12. I. Zagorchev, "Geomorphological zonation of Bulgaria. Principles and state of the art," *Proc. Bulg. Acad. Sci.*, vol. 62, no. 8, pp. 981 – 982, Jan. 2009.
    Retrieved from:
    https://www.researchgate.net/publication/271190963_Geomorphological_zonation_of_Bulgaria_Principles_and_state_of_the_art
    Retrieved on: May 20, 2025
13. *IBM SPSS Complex Samples 28*, IBM Corporation, Armonk (NY), USA, 2012.
    Retrieved from:
    https://www.ibm.com/docs/en/SSLVMB_28.0.0/pdf/IBM_SPSS_Complex_Samples.pdf
    Retrieved on: May 20, 2025
14. M. Tzortzis, E. Svoukis, H. Tsertos, "A comprehensive study of natural gamma radioactivity levels and associated dose rates from surface soils in Cyprus," *Radiat. Prot. Dosimetry*, vol. 109, no. 3, pp. 217 – 224, Jul. 2004.
    DOI: 10.1093/rpd/nch300
    PMid: 15254326
15. E. Kam, A. Bozkurt, "Environmental radioactivity measurements in Kastamonu region of northern Turkey," *Appl. Radiat. Isot.*, vol. 65, no. 4, pp. 440 – 444, Apr. 2007.
    DOI: 10.1016/j.apradiso.2006.11.005
    PMid: 17207627
16. I. Etikan, K. Bala, "Sampling and sampling methods," *Biom. Biostat. Int. J.*, vol. 5, no. 6, pp. 215 – 217, May 2017.
    DOI: 10.15406/bbij.2017.05.00149
17. *Radiation protection equipment. Built-in passive dosimetry systems for monitoring the environment and individuals with regard to photon emission and beta radiation*, БДС EN 62387:2016, Aug. 16, 2016.
    Retrieved from:
    https://bds-bg.org/en/project/show/bds:proj:93261
    Retrieved on: May 8, 2025
18. A. Podstawczyńska, K. Kozak, W. Pawlak, J. Mazur, "Seasonal and diurnal variation of outdoor radon (^{222}Rn) concentrations in urban and rural area with reference to meteorological conditions," *Nukleonika*, vol. 55, no. 4, pp. 543 – 547, Jan. 2010.
    Retrieved from:
    http://www.nukleonika.pl/www/back/full/vol55_2010/v55n4p543f.pdf
    Retrieved on: May 8, 2025
19. R. D. Hopper, F. Steinhäusler, M. Ronca-Battista, "IAEA/EPA international climatic test program for integrating radon detectors," *Health Phys.*, vol. 77, no. 3, pp. 303 – 308, Sep. 1999.
    DOI: 10.1097/00004032-199909000-00009
    PMid: 10456502
20. G. A. Gunning, D. Pollard, E. C. Finch, "An outdoor radon survey and minimizing the uncertainties in low level measurements using CR-39 detectors," *J. Radiol. Prot.*, vol. 34, no. 2, pp. 457 – 467, Jun. 2014.
    DOI: 10.1088/0952-4746/34/2/457
    PMid: 24894188