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THE EXPOSURE OF ROMANIA'S POPULATION TO RADON AND ITS EFFECT ON PUBLIC HEALTH

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Radon, a naturally occurring carcinogen, is a radioactive gas present in indoor air and poses considerable health risks in Romania. It is produced from the decay of uranium in rocks and is continuously released from the ground, making it ubiquitous in the atmosphere. This gas has emerged as a significant public health concern because it can penetrate enclosed spaces in buildings, leading to elevated concentrations that may threaten human health.

The paper discusses the health risks associated with radon and outlines legislative measures aimed at protecting the Romanian population from exposure in residential, occupational, and public environments, in accordance with European Directive 2013/59/EURATOM.

According to the latest radon map for indoor environments in Romania, 18% of surveyed buildings exceed the legal risk limit of 300 Bq/m³. There is an urgent need to implement radon measurement policies, especially in buildings, and to adopt effective mitigation strategies to protect children and staff. These actions are vital to ensure compliance with international safety standards and to safeguard public health.

The article concludes with key recommendations that support the execution of Romania's national radon program. These efforts will help reduce the population's exposure to radon and enhance the resilience of public health systems in the country.

Keywords: radon, public health, population protection, environmental factors, radon map.

INTRODUCTION

Radon (^{222}Rn) is a naturally occurring radioactive gas that is chemically inert, odorless, colorless, and tasteless. It is generated from the decay of radium (^{226}Ra), which is itself a byproduct of uranium (^{238}U) decomposition found in soil and rocks[1,2]. This gas can infiltrate enclosed spaces within buildings, such as homes and workplaces, where individuals may spend up to 90% of their time. Its accumulation in indoor air can lead to hazardous levels that pose risks to human health. Radon is the primary indoor air pollutant and is the leading cause of lung cancer among non-smokers, as well as the second leading cause among smokers. Extended exposure to elevated radon levels can severely damage lung tissue, increasing cancer risk. The International Agency for Research on Cancer (IARC) has classified radon as the most significant environmental carcinogen affecting populations[3].

Globally, radon is recognized as the second leading cause of lung cancer, according to the World Health Organization[4] (2009). Meta-analyses from Europe, the United States, and China, based on case-control studies and research involving mining cohorts, reinforce this link[2,5–11]. Research indicates that for every 100 Bq/m³ of radon exposure, non-smokers face a 16% increased risk of developing lung cancer[9].

Lung cancer remains the leading cause of cancer-related deaths globally, accounting for 1.59 million deaths in 2012, which is 19% of the total cancer mortality. In Europe, it contributes to 20% of cancer deaths, with 354,000 fatalities reported in 2012[11]. In Romania, residential exposure to radon is linked to 7–25% of lung cancer cases, translating to approximately 1,800 cases each year until present, according to various studies[12,13].

Indoor radon levels vary significantly, mainly influenced by the soil beneath the building and the construction materials used. Radon enters through cracks, gaps, or openings at the interface with the soil and through spaces around utilities. Factors such as local geology, construction materials, ventilation, building tightness, and usage patterns all impact its concentration. Due to the complexity of these factors, radon concentrations cannot be accurately estimated, and direct measurement remains the only reliable detection method[2], assumed by MDLPA, 2022.

The study aims to raise public awareness about the risks associated with exposure to the radioactive gas radon, emphasizing the importance of protecting the health of Romania's population in compliance with the requirements of European Directive 2013/59/EURATOM, which has already been integrated into national legislation. The document highlights the relevance and urgency of this issue from the perspective of public health and mandatory regulations, focusing on radon exposure in homes, workplaces, and public spaces.

The article's conclusions provide recommendations for the implementation of a national radon program in Romania, supporting public health protection by reducing radon exposure and strengthening the resilience of public health systems.

Implementing appropriate measures, actions, and public policies to reduce population exposure to radon in indoor air in Romania is crucial for safeguarding public health and ensuring the safety of citizens at risk from radon. Effective management of this issue primarily focuses on protecting public health by minimizing radon exposure, while also enhancing the resilience of the public health system and developing a suitable implementation framework aligned with the principles of sustainable development.

MATERIALS AND METHODS

Current Legislation on Radon at European and National Levels

The issue of radon, especially its risks to public health as outlined in relevant studies and scientific research, was first addressed in Europe through Council Directive 2013/59/EURATOM, adopted on December 5, 2013. This directive establishes essential safety standards for protection against the dangers of exposure to ionizing radiation and replaces previous directives, including 89/618/EURATOM, 90/641/EURATOM, 96/29/EURATOM, 97/43/EURATOM, and 2003/122/EURATOM[14].

The EU Directive 2013/59/Euratom mandates measures to prevent radon from entering new buildings (Article 103.2) and regulates radon exposure in workplaces (Articles 54, 35.2) and homes (Article 74). A reference level of 300 Bq/m^3 is established for both workplaces and homes, with any occupational exposure exceeding this level requiring reporting and specific management. The annual limit for planned occupational exposure is set at 20 mSv/year, while the World Health Organization (WHO) recommends a maximum level of 100 Bq/m^3 for public health protection. The National Radon Action Plan (NRAP) must comply with the requirements of Directive 2013/59/EURATOM, but it should also be tailored to the specific conditions and socio-economic context of each country.

Romania adopted the EU Directive 2013/59/EURATOM starting in 2018, establishing basic safety standards for protection against risks associated with exposure to ionizing radiation. This directive was transposed into national legislation through Government Decision No. 526/25.07.2018[15], which approved the National Radon Action Plan (NRAP), and through the Order of the CNCAN President No. 185/22.07.2019[16], later supplemented and repealed in 2023 by the CNCAN President's Order No. 153/27.07.2023, published in the Official Gazette No. 729/08.08.2023. The 2023 Order regulates the methodology for determining radon concentrations in indoor air in buildings and workplaces. Additional details can be consulted at: (http://www.cncan.ro/assets/Radon/2023/Ordin-153-din-2023-Metodologie-radon.pdf)[17].

Through this legislation, Romania has aligned its national regulations with European recommendations, setting a reference value of 300 Bq/m^3 for all types of buildings – residential, public, and workplaces. Radon detection measurements (determination/screening) using the passive method are mandatory across Romania, regardless of region or priority zone, and this requirement applies to all public buildings.

The legislation also mandates remediation measures to reduce radon concentrations in buildings where the reference level of 300 Bq/m^3 is exceeded, based on measurement results. These regulations are designed to reduce the risk of lung cancer linked to radon exposure, considering the cumulative effects of radon on both smokers and non-smokers. This ambitious goal can be achieved through mandatory measures for monitoring, controlling, and mitigating radon exposure in residential buildings and workplaces.

To implement the radon-related provisions at the national level, the National Commission for the Control of Nuclear Activities (CNCAN) is the primary responsible authority, collaborating with other organizations to enforce the National Radon Action Plan (NRAP). Institutions involved in ensuring the application and compliance with these regulations include the Ministry of Health, the Ministry of Development, Public Works, and Administration, the Ministry of Research, Innovation, and Digitization, the Ministry of Environment, Waters, and Forests, the Ministry of Education, as well as various professional associations in the field. Detection measurements for indoor radon concentrations are mandatory and must be conducted by laboratories in Romania designated by CNCAN[18].

Radon exposure mitigation can be achieved at minimal cost through efficient measures integrated into building renovation programs. These practical solutions not only lower radon levels but also enhance indoor air quality by controlling and reducing harmful pollutants such as formaldehyde, volatile organic compounds, inhalable particles, and particulate matter. The European Commission's strategy, adopted on October 14, 2020, as part of the Renovation Wave initiative to improve the energy performance of buildings for 2030–2050, mandates protection against radon and the optimization of indoor air quality. This strategy aligns with stringent health and environmental requirements[19] (EC 2020).

The development of an effective national radon program, in line with the National Radon Action Plan (NRAP), Government Decision No. 526/2018[15], and CNCAN Order No. 185/2019[16], aims to establish a comprehensive framework for implementing radon regulations in buildings across Romania. This program integrates public policies with harmonized European methods, positioning it as a crucial initiative for reducing radon exposure risks and safeguarding public health.

Updating The European and Romanian Indoor Radon Map in 2024

The project to complete the radon map for indoor air in residential buildings in Romania is based on an international scientific initiative, following the protocol developed by the Joint Research Centre (JRC) of the European Commission.

The European Indoor Radon Map reports the arithmetic means (AM) of annual indoor radon concentrations in ground-floor rooms, calculated over 10 km × 10 km grid cells. This grid, defined by the JRC, uses a GISCO-Lambert azimuthal equal area projection. The input data are provided by national competent authorities (in Romania, this is "Babeş-Bolyai" University), which aggregate their original data into the grid and calculate a set of statistics for each cell: the AM, standard deviation (SD), AM and SD of the ln-transformed data, as well as the minimum, median, and maximum values, along with the number of measurements per cell. This procedure ensures data protection, as the original data and their precise locations remain at the national level. The map is updated at irregular intervals as new indoor radon data are received by the JRC from participating countries. The radon map for Romania was developed based on scientific results obtained by "Babeş-Bolyai" University through systematic experimental measurements conducted between 2008 and 2024. These efforts were part of research projects carried out by the Radon Testing Laboratory "Constantin Cosma" (LiRaCC) within "Babeș-Bolyai" University (UBB)[20–25], in compliance with international standards set by the Joint Research Centre of the European Commission (JRC)[26] (Joint Research Centre JRC).

The methodology used complies with the requirements, procedures, protocols, and regulations established since 2012 under the BSS Euratom standards and the national standards of EU member states. For the period 2006–2012, prior to the adoption of European legislation, protocols developed by the Health Protection Agency (HPA), the National Radiological Protection Board (NRPB), and the Environmental Protection Agency (EPA) were followed[27].

The radon map has been developed for 45% of Romania's territory and has been officially recognized by CNCAN (National Commission for Nuclear Activities Control).

A sample of approximately 11,000 buildings was included in the radon measurements for indoor air, using the passive detection method. These buildings served various purposes, including energy-efficient or thermally insulated residences, as well as institutions such as schools, kindergartens, daycare centers, municipal offices, hospitals, and other types of workplaces[21,23,28–32].

The measurements were primarily conducted in the counties of Transylvania and the northwestern region of Romania. The analyzed building sample for determining radon levels includes over 300 schools, kindergartens, and daycare centers, as well as more than 8,000 residential buildings.

RESULTS

Distribution of Radon Levels in Romania

According to European assessments, Romania is one of the leading countries in Europe in terms of average indoor radon concentrations, highlighting a significant risk associated with radon exposure in indoor environments[27], as reveals by Cinelli *et al.*, 2019.

The analysis of the radon map for residential buildings in Romania shows that 18% of the investigated buildings exceed the risk threshold of 300 Bq/m³, as set by legislation. Furthermore, 75% of the buildings have radon concentrations above 100 Bq/m³, the level recommended by the World Health Organization (WHO). Additionally, in 24% of educational buildings, radon concentrations surpass the legal threshold of 300 Bq/m³.

High radon concentrations are primarily caused by poor ventilation, inadequate sealing, foundation cracks, elevated radon levels in the soil, and the increased risk of radon transfer and accumulation in indoor air[33].

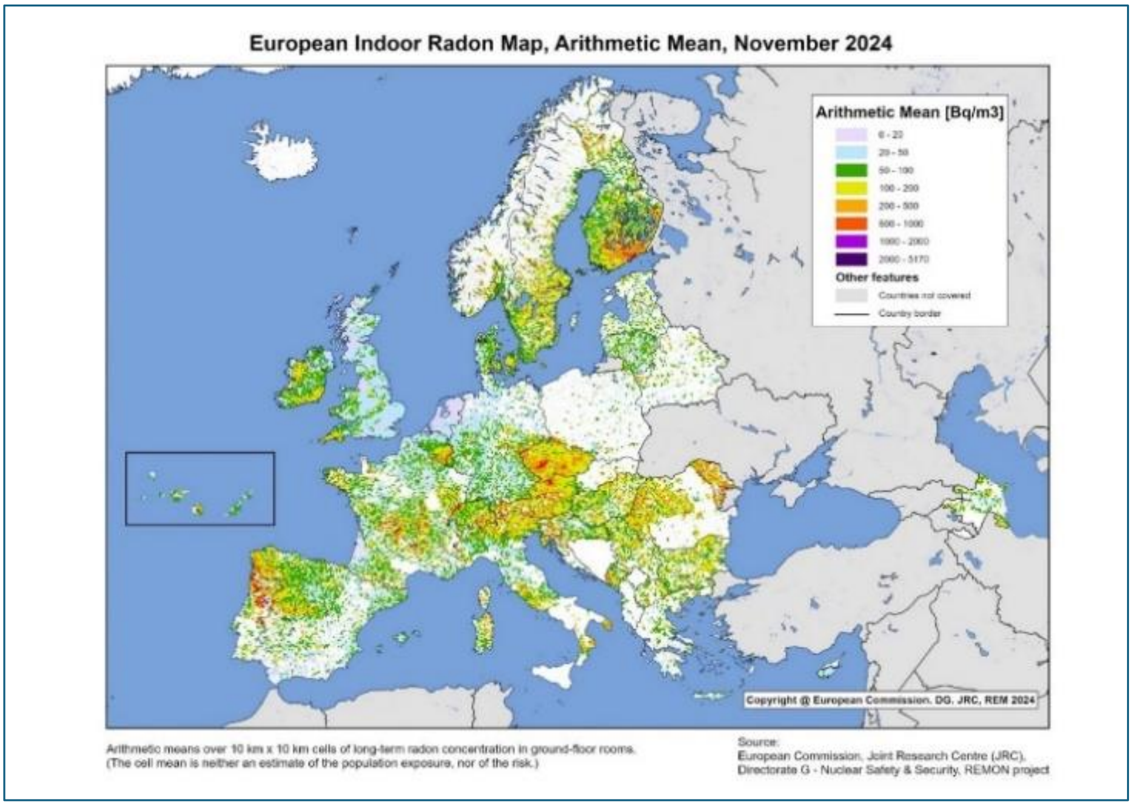

Figure 1. The European Radon Map, version December 2024, integrating the Radon Map for Indoor Air in Residential Buildings in Romania, developed by LiRaCC-UBB, as referenced in the legend provided by the JRC-EC (Joint Research Centre of the European Commission).

Source: Comisia Europeană, Centrul Comun de Cercetare (JRC), Direcția G-Securitate și Securitate Nucleară, proiectul REM/ Joint Research Centre (JRC), Directorate G-Nuclear Safety & Security, REM project. (Retrieved from the European Commission website, November2024) (https://remon.jrc.ec.europa.eu/About/Atlas-of-Natural-Radiation/Digital-Atlas/Indoor-radon-AM/Indoor-radon-concentration).

Analysis of Results and Comparison Between Radon Levels in Public (Educational) Buildings and Residential Buildings

The main findings of the previously published paper reveal that the investigated territory in Romania exhibits a significant level of radon exposure, based on the results obtained from integrated measurements. Approximately 18% of the investigated dwellings in this region exceeded the reference level of 300 Bq/m³, as highlighted by the study by Dicu, Cucos *et al.*, STOTEN 2023[34].

A recent study revealed significant differences in radon concentrations, which can be attributed to the architectural characteristics and usage patterns of each building. The study examined 948 rooms in 198 schools and 492 rooms in 266 houses in Cluj-Napoca, Romania, analyzing the concentrations of indoor radon activity (IRAC). The results showed that 13% of the houses measured had IRAC values exceeding the reference levels (RL). In contrast, 24% of school buildings surpassed the reference level, which is particularly concerning as it represents the highest percentage reported in studies of educational buildings[35].

In educational buildings, older structures exhibited indoor radon activity (IRAC) levels 50% higher than newer ones, with the absence of a basement increasing levels by 75%. Laboratories, typically located in basements or ground floors with low occupancy, had the highest IRAC. The lack of a concrete slab under the floor contributed to a 75% increase in IRAC, while tarkett flooring offered better sealing, effectively reducing radon infiltration.

In residential buildings, air conditioning systems reduced IRAC by 25%, while wooden ceilings and floors resulted in a 2.3 times increase in IRAC. Educational institutions had IRAC levels 1.4 times higher than residential buildings, indicating distinct risk patterns. Spatial analysis revealed no significant correlation between radon levels in residential and educational buildings, suggesting that radon maps based solely on residential data are insufficient for assessing other building types.

Given the key findings from previous studies, it is crucial and urgent to properly implement existing public policies related to radon measurements in public buildings, particularly in educational institutions. Additionally, the most effective mitigation measures must be applied to reduce the risk of radon exposure for both children and staff in these institutions. These actions are urgent and necessary to comply with international radon safety standards and to safeguard the health of the exposed population.

CONCLUSIONS

The radon map for Romania, developed by Babeș-Bolyai University, represents a significant step forward in assessing indoor radon risks. Based on international standards and extensive measurements from over 11,000 buildings, the map covers 45% of the country and has been officially recognized by CNCAN. While providing valuable insights for public health and mitigation strategies, the project emphasizes the need for nationwide coverage to ensure comprehensive risk management.

Romania faces substantial radon exposure risks, with 18% of homes and 24% of educational buildings exceeding the legal limit of 300 Bq/m³, and 75% of all buildings surpassing the WHO's recommended level of 100 Bq/m³. Poor ventilation, structural deficiencies, and high radon concentrations in the soil are significant contributors, underscoring the urgent need for mitigation efforts.

Previous studies have revealed notable radon exposure in Romania, with 18% of dwellings and 24% of school buildings exceeding the 300 Bq/m³ reference level. Older educational buildings and those lacking basements or concrete slabs showed particularly high radon levels, while air conditioning was found to reduce exposure in residential buildings. The findings highlight distinct risk patterns between residential and educational structures, emphasizing that radon maps based solely on residential data are insufficient. Immediate implementation of public policies, particularly in schools, and the application of effective mitigation measures are critical to protecting vulnerable populations and ensuring compliance with international radon safety standards.

In compliance with the requirements of Directive 2013/59/Euratom, Romania established its legislative framework on radon in 2018 through Government Decision No. 526/2018 (Government Decision No. 526/2018).

As of 2024, the main objectives of the National Radon Action Plan (PNAR) include:

1. **Raising Awareness**: Launching information campaigns to educate the public on the risks of radon exposure.
2. **Radon Mapping**: Expanding the radon map with new data to identify priority areas and high-risk workplaces.
3. **Building Prioritization**: Prioritizing buildings for remediation based on identified risks.
4. **Implementation of Technical Standards**: Applying the technical norms and implementation framework for remediation measures developed by the Ministry of Development, Public Works, and Administration (MDLPA).
5. **Integration in Renovation Programs**: Incorporating radon mitigation requirements into building renovation programs.
6. **Legislative Alignment and Policy Coherence**: Harmonizing legislation with technical construction standards to effectively enforce radon reduction measures.

The main conclusions regarding protection against radon exposure in Romania, based on current legislation (MDLPA, 2022), include:

1. **Mandatory Measurements**: Radon levels must be measured in public buildings and workplaces, with remediation measures applied if levels exceed the reference threshold value.
2. **Urgent Remediation**: High radon concentrations require immediate remediation to safeguard the health of occupants.
3. **Reduction in Existing Buildings**: It is crucial to lower radon concentrations below the reference level in existing structures.
4. **Preventive Measures in New Buildings**: New buildings must incorporate methods to prevent radon infiltration and ensure effective elimination when necessary.

To effectively implement radon regulations in Romania, it is essential to complete the radon map for buildings across the country. This will allow for the precise identification of high-risk areas, enabling the prioritization of monitoring, control, remediation, and prevention programs for both existing and new buildings.

The National Radon Action Plan (PNAR) outlines key objectives, including conducting indoor radon measurements and completing the national radon map. Delays in achieving these goals have left Romania vulnerable to infringement proceedings by the European Commission for inadequate enforcement of radon regulations. Addressing these challenges is vital to protecting public health and ensuring the safety of workers exposed to radon in buildings.

The following immediate actions are required to efficiently review radon policies implementation in Romania:

1. **Policy Coherence**: Align and simplify regulations with European norms in accordance with Directive 2013/59/Euratom.
2. **Completion of the National Radon Map**: Finalize the map and use it to prioritize measures in high-risk areas.
3. **Training for Specialists**: Provide training for administrative specialists to ensure the practical application of radon regulations.
4. **Awareness Campaigns**: Conduct information and awareness campaigns targeting administrators, decision-makers, and the public about the risks of radon exposure and the necessary prevention and remediation measures.

The proposed recommendations will greatly enhance indoor air quality and overall living conditions in Romania, contributing positively to both economic and social progress. Implementing these actions is crucial for developing effective radon exposure management policies, prioritizing interventions, and addressing the challenges posed by population exposure to this gas in buildings.

Efficient implementation of public policies on radon can have a profound impact on the national economy, public health, the environment, and civil society, considering the importance and seriousness of this issue.

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