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Indoor radon and NORM in building materials: Critical analysis of the current European regulation and road map for the next decade

Konstantin Kovler [a,*], Andrey Tsapalov [b], Robert Bobkier [c], Rob Wiegers [d], Wouter Schroeyers [e], Tibor Kovács [f], Edit Toth-Bodrogi [f], Omar El Bounagui [g], Arkadiusz Babczuk [h]

[a] Faculty of Civil and Environmental Engineering, Technion - Israel Institute of Technology, Haifa, Israel
[b] National Building Research Institute, Technion - Israel Institute of Technology, Haifa, Israel
[c] Abraham & Ben Hadar Law and Audit, Jelenia Góra, Poland
[d] IBV Consult VB, Haelen, the Netherlands
[e] Hasselt University, CMK, Research Group NuTeC, Diepenbeek, Belgium
[f] University of Pannonia, Veszprém, Hungary
[g] Mohammed V University, Rabat, Morocco
[h] Institute of Economic and Financial Expertise, Łódź, Poland

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ABSTRACT

This position paper deals with the critical analysis of the existing European regulation of indoor radon and NORM in building materials. It represents an opinion of the initiative group of experts created during the Workshop of European NORM Association (ENA) held in Rome, 15–17 May 2024. The main conclusions and propositions of the experts have been also discussed at the round table during the IX Terrestrial Radioisotopes in Environment International Conference on Environmental Protection, 19–22 November 2024, Vonyarcvashegy, Hungary.

The current paper lists and discusses several missing points and challenges within the European regulatory system in the field of NORM in building materials and indoor radon, consisting of three interconnecting functional levels: Legislative, Normative, and Methodological. It also serves as a Road Map for the regulatory development in the next decade.

Our analysis identifies areas for improvement. While the normative guidance (mid-tier of the hierarchical regulatory pyramid) is robust, the legislative framework has gaps, and methodological support remains underdeveloped with several serious deficiencies. These issues significantly hinder the global implementation of GRPs. To address these gaps, new harmonized standards and guidelines are necessary. It is concluded that enhancing radon and NORM regulations can be achieved by developing and globally implementing several relevant European (international) standards and guidelines within rational ISO/IEC concepts. From a legal-philosophical perspective, these findings are intended as an invitation to dialogue, not merely a critique.

1. Introduction

The primary factors of radiation risk are homes and workplaces, as people spend 80–90% of their time indoors. Inside buildings, internal exposure to radon, which is a known carcinogen, accounts for about half of the global average dose from all natural and man-made radiation sources (UNSCEAR, 2008), and in addition external exposure to gamma radiation emitted by building materials, are usually both higher (and sometimes significantly higher) than outdoors. This risk can be regulated and should be reduced by following fundamental guidelines issued by authoritative international organizations such as the IAEA, ICRP, WHO, and the Euratom, or the European Atomic Energy Community,

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* Corresponding author.
E-mail addresses: cvrkost@technion.ac.il (K. Kovler), ants9962@gmail.com (A. Tsapalov), contact@abrahambenhadar.com (R. Bobkier), r.wiegers@ibrconsult.nl (R. Wiegers), wouter.schroeyers@uhasselt.be (W. Schroeyers), kovacs.tibor@mk.uni-pannon.hu (T. Kovács), toth-bodrogi.edit@mk.uni-pannon.hu (E. Toth-Bodrogi), o.elbounagui@um5r.ac.ma (O. El Bounagui), arkadiusz.babczuk@ieef.lodz.pl (A. Babczuk).

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which includes all the member states of the European Union (EU).

This position paper deals with the critical analysis of the existing European regulation of indoor radon and NORM in building materials. It represents an opinion of the initiative group of experts created during the Workshop of European NORM Association (ENA) held in Rome, 15–17 May 2024. The main conclusions and propositions of the experts were also discussed at the round table during the IX Terrestrial Radioisotopes in Environment International Conference on Environmental Protection and considers, 19–22 November 2024, Vonyarcvashegy, Hungary.

The regulatory system in general consists of three interconnecting functional levels: Legislative, Normative, and Methodological. The paper discusses several missing points and challenges within the European regulatory system in the field of NORM in building materials and indoor radon,. Let us first define these three hierarchical functional levels of the regulatory pyramid of radiation risk due to radon and NORM, which is shown in Fig. 1.

Legislative Level: Refers to laws enacted by a legislative body, such as a parliament or congress. Examples include Basic Safety Standards (EU-BSS, 2014) at the Euratom Community level and generally applicable laws at the Member State level, such as national radiation protection laws and internal legal acts like national Radon Action Plans. These laws are based on rules and guidelines developed by international organizations, government agencies, and local administrations to implement and enforce the legislation.

Normative Level: Includes documents issued by IAEA, WHO, and ICRP, which establish normative values to protect workers and the public from ionizing radiation, referred to as "Reference Levels" (RLs). The EU-BSS belongs to both Legislative and Normative Levels as it also establishes RLs.

Methodological Level: The lower level at the base of the regulatory pyramid of radiation risk due to radon and NORM, covering recommendations and guidelines as well as measurement standards to assess compliance with specific radiation safety requirements within the Normative Level.

In the group of expert analysis, we consider the regulatory system as consisting of three interconnecting functional levels (Legislative, Normative and Methodological), and the results of our analysis are discussed in detail below following this structure.

2. Legislative and Normative Levels

The highest level of the system for regulating radiation risk shown in Fig. 1, called the *Legislative Level*, refers to laws enacted by a legislative body, such as parliament or congress.

We can list the following legislative documents in the EU member states:

- Basic Safety Standards (EU-BSS, 2014) at the EU level;
- Generally applicable law at the Member State level - including in particular national radiation protection laws;
- Internal legal acts, including national Radon Action Plans (RAPs).

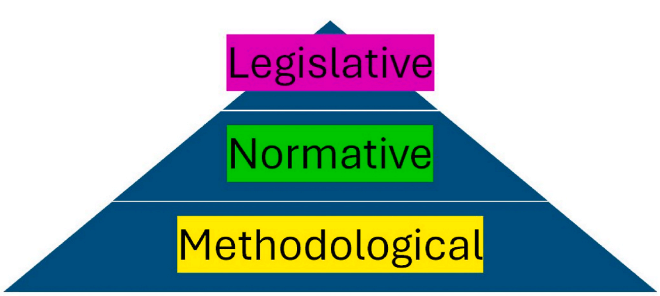

Fig. 1. Regulatory system consisting of three interconnecting functional levels.

These laws refer to detailed rules and guidelines developed by international organizations, as well as government agencies and local administrations to implement and enforce the laws created by legislation.

For example, EU-BSS (EU-BSS, 2014) provides the following Reference and Control Levels:

Article 54(1): *Member States shall establish national reference levels for* ***indoor radon concentrations in workplaces****. The reference level for* ***the annual average activity concentration in air shall not be higher than 300 Bq/m³****, unless it is warranted by national prevailing circumstances.*

Article 74(1): *Member States shall establish national reference levels for* ***indoor radon concentrations****. The reference levels for* ***the annual average activity concentration in air shall not be higher than 300 Bq/m³.***

Article 75(1) and Annex VIII: *The reference level applying to* ***indoor external exposure to gamma radiation emitted by building materials, in addition to outdoor external exposure, shall be*** **1 mSv** ***per year****, while the calculation of dose needs to take into account other factors such as density, thickness of the material as well as factors relating to the type of building and the intended use of the material (bulk or superficial).*

Article 75(2) and Annex VIII: ***Activity Concentration Index (ACI), which limits the activity concentration of NORM in building materials, is set as a Control Level,*** which *can be used as a conservative screening tool for identifying materials that may cause the reference level laid down in Article 75(1) to be exceeded. The activity concentration index I is given by the following formula:*

$$I = C_{Ra226}/300\ \mathrm{Bq/kg} + C_{Th232}/200\ \mathrm{Bq/kg} + C_{K40}/3000\mathrm{Bq/kg}$$

where C_{Ra226}, C_{Th232} and C_{K40} are the activity concentrations in Bq/kg of the corresponding radionuclides in the building material.

Thus, the target parameters to be controlled for assessing the compliance of buildings (residential, office, industrial, etc.) with radiation safety requirements are clearly defined in the modern system of regulating internal (indoor radon) and external (NORM in building materials) exposures by natural sources of ionizing radiation. This level in the hierarchical system of regulating radiation risk is proposed to be defined as the *Normative Level*. This level is situated in the middle of the regulatory pyramid, between the *Legislative Level* (top of the pyramid) and the *Methodological Level* (base of the pyramid), which will be discussed further.

Normative Level represents so-called "soft law/techno science regulations". It includes the documents issued by IAEA, WHO, ICRP, which establish the normative values to protect workers and public from ionizing radiation, which these fundamental documents call "Reference Levels" (RLs). EU-BSS in this sense belongs to both Legislation and Normative Levels, because also establish RLs. Reference levels (in contrast to directives) are allowing to adjust to the national situation and (social) demands. The first Normative Level regulations came from the 1940s in Germany and concerned the permissible concentration of radon in mines (Bobkier et al., 2025a), while it was only in the ICRP 65 recommendations (ICRP, 1993) that protection frameworks were extended to the general public, including residents of homes (Bobkier et al., 2025b).

Normative documents of this level can be either binding (in the form of a regulation, directive or delegated act), such as EU-BSS, or not binding (in the form of guidance), such as those issued by IAEA, WHO and ICRP. Even in the case of a directive, a room for national implementation is generally given to enable members states to adjust the directive to their situation through the introduction of national Reference levels.

Within the Legislative and Normative levels, it is advisable to highlight examples of Good Regulatory Practices regarding the control of radon and Naturally Occurring Radioactive Materials (NORM), which represent clear benefits of the regulation, and address some drawbacks and missing issues. Let us discuss several Good Regulatory Practices (GRP) first.

2.1. Good Regulatory Practices

GRP 1: In accordance with IAEA GSR Part 3 Article 5.21a (IAEA, 2014), and EU-BSS Article 103 (EU-BSS, 2014), it is important to note the implementation of national Radon Action Plans for controlling public exposure due to radon indoors in EU countries (Petko et al., 2023). This allows for consideration of both the existing exposure situation and the social and economic circumstances in each country (implementation). Practically every EU member state has accumulated data which are integrated into the Radon Atlas of Europe (https://remon.jrc.ec.europa.eu/About/Atlas-of-Natural-Radiation/Digital-Atlas/Indoor-radon-AM/Indoor-radon-concentration) supporting the implementation of EU-BSS for identifying areas with elevated radon concentrations. Available data allows for a general assessment of the existing exposure situation; therefore, every Member State has already established its own national Reference level for indoor radon concentration equal to or below 300 Bq/m^3.

GRP 2: Considering the challenge of organizing large scale radon control surveys in tens or even hundreds of millions of buildings, European countries are gradually incorporating the provision of IAEA GSR Part 3 (Article 5.21b) into their legislation: "*The government shall assign responsibility for determining the circumstances under which actions are to be mandatory or are to be voluntary, with account taken of legal requirements and of the prevailing social and economic circumstances.*" In this context, the following definition of responsibility looks preferable for regulators:

- In residential (non-commercial) buildings, testing and mitigation are conducted voluntarily at the expense of the residents (owners) or management companies.
- In commercial (industrial, office, hotel, retail, store, etc.) buildings, testing and mitigation are mandatory at the expense of the landlords, with appropriate fines in place.
- In buildings of children's and municipal administrative institutions (which are relatively few), testing and mitigation are mandatory at the expense of federal or regional budgets (the activity of federal or regional authorities in this direction serves as a good example and motivation for both voluntary and mandatory testing of buildings).

GRP 3: The practice of radon regulation in the US shows that placing the responsibility for the radiation safety of a dwelling (room, apartment or entire building) on the new owner upon transfer of ownership strongly motivates voluntary testing of radiation situation in both new and existing buildings among realtors, future property owners, and developers (renovators), who benefit from ensuring the radiation quality of future buildings at the design stage. It should be noted that there is a precedent in this regard within the EU. Specifically, the Directive on the energy performance of buildings (Directive, 2010/31/EU) explicitly requires Member States: "when buildings or building units are constructed, sold or rented out, the energy performance certificate or a copy thereof is shown to the prospective new tenant or buyer and handed over to the buyer or new tenant" (Article 12.2). This provision has been implemented into the national legislation of the Member States.

GRP 4: The new EU rules on the safety and sustainability of construction products have been published recently (CPR, 2024) making the EU regulatory system together with its link to the Construction Product Regulation is very important. These new regulations mark a new step for the construction sector's competitiveness and strengthen focusing on the need to monitor and control the radiation safety of building materials, according to EU-BSS Article 75(2,3).

GRP 5: According to EU-BSS, Article 103(2): *Member States shall ensure that appropriate measures are in place to prevent radon ingress into new buildings. These measures may include specific requirements in national building codes.*

GRP 6: Significant evolution in the approach to monitoring indoor radon. Initially, it was believed that conducting measurements (and mitigation) exclusively in radon priority areas (RPA) was the most effective approach to radon regulation, according to ICRP Publication 65 (1993). However, the results of recent computational studies conducted in Germany (Petermann et al., 2022) and international practical experience gained in the US (ANSI/AARST MA-MFLB, 2023; EPA, 2024) and Sweden (Tryggve, 2021) have shown that buildings in all areas, not just RPAs, should be tested. Finally, the survey of any area is also promoted in ICRP Publication 126 (2014).

GRP 7: It is important to note the relevance of the practical implementation of the recommendation from ICRP Publication 126 (2014), par. (n), page 17: "*It is the responsibility of the appropriate national authorities, as with other radiation sources, to establish their own national reference levels of dose and derived reference level of concentration, and to apply the process of optimisation of protection within their country. The objective is both to reduce the overall risk to the general population and, for the sake of equity, the individual risk to the most exposed individuals.* ***In both cases, the process is implemented mainly through the management of buildings rather than individual exposures,*** *and should result in radon concentrations in ambient indoor air that are as low as reasonably achievable below the national reference level.*"

2.2. Drawbacks

Drawback 1: Unfortunately, ICRP Publication 126 (mentioned in GRP 6) was published later than EU-BSS Directive, so in Articles 54(2a), 103(3), and Annex XVIII, there is still excessive attention to the issue of RPAs, following outdated and some already irrelevant recommendations of ICRP Publication 65 (also mentioned in GRP 6). That's why following EU-BSS, Article 103, and specifically Article 103(3) and Annex XVIII, European national regulators initially focused their attention and main efforts on identifying RPAs instead of organizing mass (large-scale) indoor radon measurements and implementing mitigation measures. Meanwhile, Article 74(2) states: "*Member States shall promote action to identify dwellings with radon concentrations (as an annual average) exceeding the reference level and encourage, where appropriate by technical or other means, radon concentration-reducing measures in these dwellings.*"

The regulatory experience in the US within GRP 6 shows that large-scale indoor radon measurements (across the entire country, not just in RPAs) using short-term tests allow for the creation of a more accurate (detailed) radon map of the US compared to the Radon Atlas of Europe (mentioned in GRP 1). It should be noted that different approaches are traditionally used to create the Radon Atlas of Europe, mainly involving relatively few results from long-term indoor radon measurements, as well as extensive collection and analysis of geological and other data. While EU-BSS, Article 103(3) clearly expresses the method of assessing RPAs (based on direct measurements of indoor radon concentration): "*Member States shall identify areas where the radon concentration (as an annual average) in a significant number of buildings is expected to exceed the relevant national reference level.*"

Despite the very effective regulation of indoor radon in the US under GRP 6, some national regulators in Europe, instead of regularly updating national Radon Action Plans as required by Article 103(1), continue to focus their main efforts on identifying RPAs using alternative methods (Rey et al., 2024). This is to the detriment of organizing mass indoor radon measurements and implementing mitigation measures. This outdated approach with a focus on RPA lacks rational justification, especially since RPAs have already been identified with satisfactory accuracy in almost every EU country. In this context, the goal of further increasing the accuracy of RPA identification using alternative methods is unclear, especially considering GRP 2, where the burden of regulation costs is mainly shifted to the population (property owners and landlords). It is obvious that neither federal nor regional (municipal) budgets will ever be sufficient to finance measurements and mitigation in tens of millions of buildings (Tsapalov et al., 2025).

Drawback 2: The absence of focus on the importance of large-scale instrumental control of external exposure to gamma radiation (including search for orphan sources as per EU-BSS Articles 92–95) and the standardization of corresponding measurements to assess compliance with radiation safety requirements, as clearly defined in EU-BSS Article 75(1), is concerning. According to this article the Normative Level applying to indoor external exposure to gamma radiation emitted by building materials, in addition to outdoor external exposure, shall be 1 mSv/a. However, the recently published document IAEA-TECDOC-1951, “Protection Against Exposure due to Radon Indoors and Gamma Radiation from Construction Materials — Methods of Prevention and Mitigation” (IAEA, 2021) addresses in situ dose rate measurement of gamma radiation indoors only, rather than the difference between gamma dose rates indoors and outdoors. The IAEA document also provides other recommendations for radon concentration and dose rate measurement, which, however, require justification and clarification at the level of measurement standardization.

Drawback 3: It is well known that the costs of radon mitigation systems are significantly lower in newly constructed buildings compared to existing ones. To select the most effective radiation protection measures in new buildings (if needed) the geogenic radon potential of the construction site and the gamma dose rate outdoors (including the search for orphan sources as per EU-BSS Articles 92–95) should be characterized before the design phase begins.

Unfortunately, the legislation does not emphasize the importance of determining and selecting the best practices for assessing the radiation and geological parameters of sites intended for the construction or reconstruction of new buildings. Consequently, the question remains unresolved: which target radiation and geological parameters of sites are most relevant for the design and construction of radiation-safe buildings at minimal cost?

Drawback 4: There is a lack of legislative support for European industry in mitigating existing buildings with elevated radon concentration (exceeding the Reference Level). Additionally, there is very little discussion on this important issue, despite the rich experience in mitigation in several countries, such as the US, Sweden and the UK.

Drawback 5: IAEA Safety Guides (IAEA, 2013; IAEA, 2015; IAEA, 2019; IAEA, 2021; IAEA, 2024) recommend using long-term indoor measurements for radon (and thoron EEC) simply because it “seems more reliable.” However, scientific justification for such a recommendation is still absent. We are convinced that conformity assessment which aims to demonstrate whether the measurement results meet the relevant requirements, such as Reference Levels, should be based on a defined quantitative relationship between the measurement duration and the reliability (or uncertainty) of a practical decision. This should be included in any official document related to indoor radon regulation at the international or national levels (Tsapalov et al., 2025).

Drawback 6: There are no principles and clear quantitative criteria for evaluating the effectiveness of radon and NORM regulation systems. Until such criteria are formulated, it is impossible to clearly define either short-term or long-term regulatory tasks, the output of which could be measured for comparison with the initial plan. Apparently, for this reason, the national action plans in many countries are not updated on a regular basis, which does not comply with EU-BSS, Article 103(1), as mentioned above.

Drawback 7: There is no clear definition in Legislative Level of who is responsible for radiation protection of buildings. The approaches of national regulators can differ.

For example, control of radioactivity of building materials in some countries is often under responsibility of construction industry. However, some national regulators oblige independent commercial laboratories and inspectors to conduct testing in buildings and building contractors – to ensure that the radiation protection meets the requirements of the regulator.

Regarding the testing and mitigation of indoor radon, we can distinguish between several different categories of buildings, each requiring different approaches to appoint responsible parties as outlined in GRP 2.

Drawback 8: Unlike the established regulatory framework for energy performance certificates (Directive, 2010/31/EU), the European legal framework lacks a comparable, explicit obligation requiring the disclosure of radon concentration levels in buildings during property transactions.

This regulatory gap creates several key issues: regulatory inconsistency (if the energy efficiency must be disclosed, the same principle should apply to radon exposure risks, given their direct health implications), insufficient consumer protection (buyers and tenants remain unaware of potential radon exposure risks, leading to health hazards, particularly in high-radon areas), lack of market incentives (unlike in the U.S., where disclosure practices have encouraged voluntary radon testing and mitigation by realtors, property owners, and developers, the absence of a disclosure requirement in the EU discourages proactive radon mitigation efforts).

To ensure a cohesive and effective approach to indoor air quality and public health protection, European legislation should introduce a requirement analogous to the energy performance disclosure rule, explicitly mandating radon concentration reporting during property transactions. This could be incorporated into revisions of the EU-BSS or a dedicated regulation on indoor environmental health. The current legal solutions in some EU member states (e.g., Poland), where the seller or landlord provides information on the annual average concentration of radioactive radon only “upon the request of the buyer or tenant,” must be considered highly inadequate. This is because the entitled parties are typically unaware of their right to request such information. Moreover, competence does not imply an obligation for the actant to exercise it.

Drawback 9: A certain weakness of the current European regulatory framework is the inconsistent allocation of responsibility for the development and implementation of Radon Action Plans (RAPs) across Member States. The EU-BSS delegate this obligation to national authorities but do not specify a standardized institutional structure for its execution. As a result, the responsibility for RAPs has been assigned to vastly different bodies, including Nuclear Safety Regulators (e.g., Belgium, France, Czech Republic, Greece), Ministries of Health (e.g., Spain, Slovakia, Poland, Italy, Hungary), and, in some cases, even central government administrations (e.g., Luxembourg, Bulgaria). In Lithuania, a hybrid approach is applied, combining the Ministry of Health with a Radiation Protection Centre (Perko et al., 2024).

This fragmented approach leads to substantial discrepancies in the emphasis and effectiveness of RAPs. Ministries of Health, by their very nature, prioritize public health and epidemiological aspects, often neglecting the technical and engineering-based mitigation strategies that are crucial for effective radon risk reduction. In contrast, nuclear regulatory authorities tend to focus on radiation safety and technical compliance but may lack expertise in large-scale public health interventions. The consequences of this divergence are evident in the varying depth and scope of national RAPs across the EU.

A comparative perspective highlights a critical shortcoming: unlike the European approach, the United States incorporates construction and housing authorities into their radon regulatory framework (EPA, 2011; EPA, 2019; American Lung Association, 2022). This ensures a more technical and infrastructure-oriented mitigation strategy, which is largely absent in Europe. Without a harmonized regulatory model that integrates both radiation safety and construction engineering, European RAPs risk being skewed towards public awareness campaigns rather than actionable, technically sound mitigation measures.

To enhance the effectiveness of RAPs, the EU regulatory framework should introduce minimum structural requirements for the competent authorities responsible for their implementation, ensuring that both health and engineering expertise are systematically included in the development of national plans.

3. Methodological Level

The lower level at the base of the regulatory pyramid of radiation risk due to radon and NORM, called the *Methodological Level*, covers the development and implementation of recommendations and guidelines, as well as measurement standards to assess compliance with specific radiation safety requirements within the Normative Level, considering best practices within the Legislative Level.

Unfortunately, no good practices can be identified within the Methodological Level, so below is a list of drawbacks (i.e. problems requiring solutions):

Drawback 10: For indoor radon testing at the international level and, in particular, in Europe, the ISO 11665-8 standard was developed in 2012, which later was updated without significant improvements in 2019 (ISO 11665-8, 2019). In the US (with the most developed radon regulation industry), ANSI/AARST standards are used, such as MAH-2023 for homes (ANSI/AARST, 2023) or MA-MFLB-2023 for shared structures (ANSI/AARST MA-MFLB, 2023). The US and ISO standards differ significantly (for example, in the duration of indoor testing) and have the following common drawbacks:

a) The principle of measurements and conformity assessment is not provided.

b) The quantitative impact of temporal (key) uncertainty in indoor radon measurements on the reliability of decision-making is still not adequately considered.

c) While these standards focus on the accuracy of measuring the indoor radon activity concentration, the main objective of indoor radon testing is not to measure radon concentrations with a controlled accuracy or to monitor radon dynamics in a tested room. The primary goal is to assess the conformity of a room or building with safety requirement, expressed as Reference Level limiting the **annual average** activity concentration, according to documents from authoritative international organizations such as IAEA, ICRP, WHO, and the European Directive EU-BSS (see above).

d) Metrological support (QA/QC) for indoor radon measurements does not comply with rational ISO/IEC concepts such as “measurement uncertainty” and “conformity assessment”. Although these concepts were established 10–20 years ago and were adopted in measurement standardization globally with the support of the Joint Committee for Guides in Metrology, the recommendations of such authoritative bodies have yet to be integrated into the practice of radon and NORM measurements (Tsapalov et al., 2025).

e) Innovative proposals for harmonizing and improving the standardization of indoor radon measurements based on rational ISO/IEC concepts do not find wide discussion among national regulators and the radon measurement community (Tsapalov et al., 2025).

Drawback 11: The absence of a European and international measurement standard for conformity assessment of indoor external exposure to gamma radiation with radiation safety requirements, which are clearly defined in EU-BSS, Article 75(1).

Drawback 12: The existing international standard EN ISO 19581:2020 specifies a screening test method to quantify rapidly the activity concentration of gamma-emitting radionuclides, such as ^{131}I, ^{132}Te, ^{134}Cs and ^{137}Cs, in solid or liquid test samples using gamma-ray spectrometry with lower resolution scintillation detectors (EN ISO 19581, 2020). However, this standard does not address NORM in building materials. Consequently, it does not mention their Activity Concentration Index.

On the other hand, the new European standard (prEN 17216, 2023), which regulates the measurement of activity concentrations of NORM in construction products using semiconductor gamma-ray spectrometry, is under preparation and is going to be published soon. While not diminishing the importance of this standard for the control of building materials, it cannot be used for conducting screening measurements by means of gamma-ray spectrometry with scintillation detectors. It is not practical to use a cooled (to liquid nitrogen temperature) semiconductor spectrometer. The improved efficiency, for the same size detector, and the lower cost of scintillators can be traded-off against the better resolution of semiconductor detector (Kovler et al., 2013). To conclude, the use of this standard for mass control of radioactive contaminants in building materials is not possible. In addition, it should be noted that this standard also overlooks the method for assessing compliance with the normative value of ACI.

In view of this, the lack of a European and international standard for screening (quick, simpler, cost-effective) and laboratory (more accurate but time-consuming, more expensive and requiring specialized equipment and trained personnel) measurements for conformity assessment of Activity Concentration Index (ACI) in building materials with radiation safety requirements, which are clearly defined in EU-BSS Article 75 (2) and Annex VIII, is concerning.

Drawback 13: An additional drawback is the lack of European and international guidelines for assessing the radiation and geological parameters of sites for the design and construction of radiation-safe buildings. This process, known as site characterization, remains a topic of debate within the radiation protection community, with no consensus on its necessity.

Fig. 2 schematically presents various alternatives for conducting site-specific characterization. In most countries, this is not required, and the decision to install a radiation protection system is made after testing. In some countries, basic radiation protection for all buildings (or buildings in specific regions defined by national regulatory authorities) is mandatory. If post-construction testing reveals non-compliance with normative values, the responsible party must mitigate radiation levels by upgrading the existing protection. In other countries, site-specific characterization is required. This raises questions about which parameters should be measured and what guidelines are needed. Should it be the gamma-dose rate outdoors, soil permeability and radium concentration, or radon flux from the soil surface, as studied in the ‘traceRadon’ project? Building norms in some countries include recommendations for radiation safety that directly relate to the radiation and geological characteristics of the construction site. Has regulatory harmony in this field been achieved? Please see also Drawbacks 2 and 3.

Drawback 14: The lack of an internationally agreed-upon guideline with clear principles and criteria for evaluating the effectiveness of national radon and NORM regulation systems.

Drawback 15: Over the past decade, the practice of measuring thoron (^{220}Rn) in buildings in Europe, Canada, Africa and Southeast Asia has been rapidly developing (Kim et al., 2007; McLaughlin et al., 2011; Chen et al., 2011; Tokonami et al., 2022). It is important to clarify that the source of internal exposure is the Equilibrium Equivalent Concentration (EEC) of thoron progeny, not the concentration of thoron gas, as there is no definite correlation between these parameters unlike the correlation between radon gas and radon EEC (UNSCEAR, 2006). Nevertheless, in many cases, thoron gas concentration is still measured. In other cases, attempts are made to measure thoron EEC using the passive deposition of thoron progeny by SSNTD method. However, the passive method of measuring thoron EEC lacks metrological support even in controlled laboratory conditions. Therefore, it cannot be standardized for measurements in buildings (Tsapalov et al., 2025). Nevertheless, the results of indoor thoron EEC measurements in Europe and Southeast Asia by the non-standardized passive method were used to justify a sharp increase in the global dose estimate (up to 0.3 mSv) due to internal exposure to thoron (UNSCEAR, 2025). Initially, the estimated global dose due to internal exposure to thoron, equal to 0.1 mSv (UNSCEAR, 2000), had not changed for more than 20 years. However, European and international standard for measuring EEC of thoron progeny based on a reliable forced deposition method is still missing. Additionally, although thoron is not limited in the EU-BSS, the issue of standardizing direct thoron EEC measurements is evident and relevant, because the results of such measurements are used to assess collective doses in different countries, as well as globally by UNSCEAR.

Drawback 16: At the level of countries and national institutions in Europe, hundreds of studies on radon and NORM are being conducted, judging by the large number of published articles, especially over the past decade. Additionally, there are well-known large international (mainly European) projects such as COST Action NORM4BUILDING

(2014–2018, Tu1301), MetroRADON (Metrology for radon monitoring, 2017–2020), traceRadon (Radon metrology for use in climate change observation and radiation protection at the environmental level, 2020–2023), and the ongoing RadoNORM (Towards effective radiation protection based on improved scientific evidence and social considerations – focus on Radon and NORM, Euratom H2020 project No 900009, 2020–2025), which were coordinated by metrological institutes and universities. However, despite such grand expenditures (tens of millions of EUR) and research efforts in the field of radon and NORM, as well as special attention from metrological institutes, the most relevant high-level standards (guidelines) are still lacking or do not meet modern metrology requirements, considering Drawbacks 10–15. At the same time, there are too many lower-level standards. For example, the ISO 11665 series includes more than ten parts related to radon measurements. That is why there is a serious concern about the observed misalignment in priorities within the scientific community and regulators in terms of the research into, and standardization of, radon and NORM measurements (Tsapalov et al., 2025).

4. Proposals for improving radon and NORM regulation

- An analysis of the hierarchical pyramid (system) of radiation risk regulation due to radon and NORM shows a satisfactory state at the Normative Level (middle level of the pyramid). However, the Legislative Level, despite the noted Good Regulatory Practices (GRP 1–7), has several certain drawbacks (1–9) that need to be addressed.
- The Methodological Level, which forms the foundation of the regulatory pyramid, remains underdeveloped (compared to the Legislative and Normative Levels), with a whole list of identified drawbacks (10–16). It is important to note that the global implementation of GRPs at the Legislative Level is significantly hindered by the extremely weak development of the Methodological Level. The drawbacks at these levels are closely related, so addressing them at the Methodological Level will also contribute to improvements at the Legislative Level.
- There is serious concern about the observed deep conservatism and lack of critical analysis, which has led to a shift in priorities within the scientific and regulatory community regarding the research and regulation of radon and NORM. Therefore, it is necessary to refocus the community's attention on the current challenges and actual needs in developing and implementing harmonized international standards for radon and NORM measurements.
- Considering the above conclusions, the improvement of radon and NORM regulation can be achieved by developing and globally implementing the following relevant European (international) standards and guidelines within rational ISO/IEC concepts (in order of decreasing priority):
  - i) A measurement standard for conformity assessment of both the annual average concentration of radon and external exposure to gamma radiation with the radiation safety requirements of buildings, as clearly defined in EU-BSS, Articles 54(1), 74(1), and 75(1).
  - ii) A standard for screening and laboratory (more accurate) measurements for conformity assessment of ACI in building materials with radiation safety requirements, as clearly defined in EU-BSS, Article 75(2) and Annex VIII.
  - iii) A guideline for assessing the radiation and geological parameters of sites for the design and construction of radiation-safe buildings.
  - iv) A guideline with clear principles and criteria for evaluating the effectiveness of national radon and NORM regulation systems.
  - v) A standard for reliable direct measuring thoron EEC.
  - vi) An update of the European regulatory documents is needed to cancel the excessive focus on RPAs.
  - vii) Although the current paper focuses on the European regulatory system, the authors also recommend a revision of international documents, such as IAEA-TECDOC-1951 "Protection Against Exposure due to Radon Indoors and Gamma Radiation from Construction Materials — Methods of Prevention and Mitigation" (2021), and especially IAEA safety reports series no. 98 "Design and conduct of indoor radon surveys" (2019).

5. Conclusions

The current position paper suggests a road map toward a global reduction of radiation risk and an improvement in the long-term health expectation for populations worldwide.

Despite recent scientific advancements that have enabled the incorporation of several Good Regulatory Practices (GRPs) in national radiation control, the international regulatory system still has gaps and

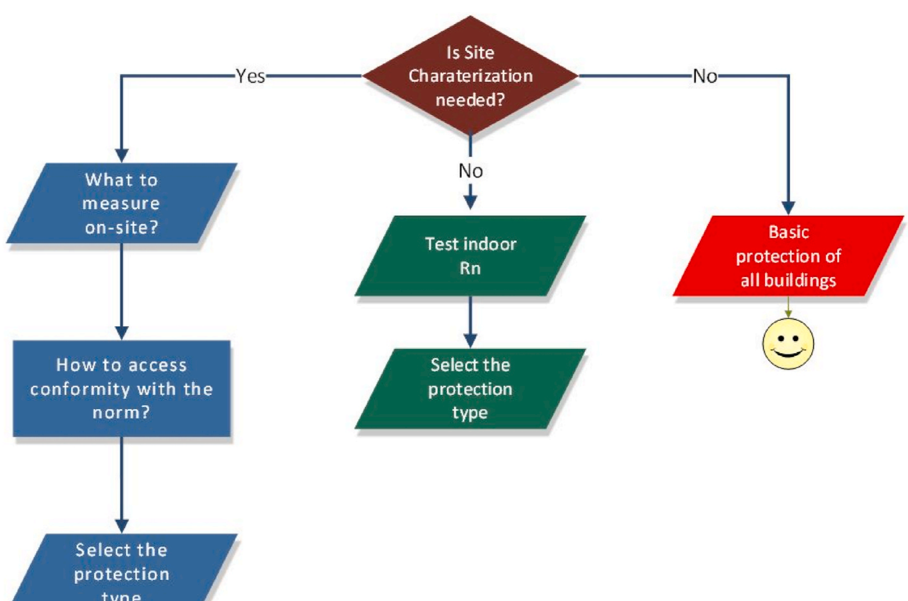

Fig. 2. Different alternatives regarding conducting site-specific characterization.

inconsistencies that need improvement.

Our analysis indicates that the Normative Level (mid-tier of the hierarchical regulatory pyramid) is satisfactory. However, the Legislative Level, despite incorporating seven GRPs, has nine significant drawbacks that need to be addressed. The Methodological Level is underdeveloped, with seven serious deficiencies. This weak development greatly hinders the global implementation of GRPs.

It is concluded that enhancing radon and NORM regulations can be achieved by developing and globally implementing several pertinent European (international) standards and guidelines within rational ISO/IEC concepts in the Methodological Level.

As NORM and indoor radon issues are only part of the social issues in any country, it is essential to evaluate their relevance to set priorities. If this evaluation determines that the NORM and indoor radon issues described in this paper are significant, it is crucial to take appropriate action. This includes further research and development in these areas and securing the necessary budgets for these R&D activities. Additionally, it is crucial to involve relevant experts to identify gaps, including the necessary R&D and other activities, and to transform the outcomes of these R&D activities into the development of best practices. These practices can then be efficiently utilized to address all the issues mentioned in this paper, providing relevant and cost-effective tools to improve the indoor radiation situation.

The EU-BSS framework provides common safety benchmarks for radon and NORM while allowing Member States to tailor implementation to – different – local exposure conditions, in line with subsidiarity. Our analysis identifies areas for improvement. While the normative guidance (mid-tier of the hierarchical regulatory pyramid) is robust, the legislative framework has gaps, and methodological support remains underdeveloped with several serious deficiencies. These issues significantly hinder the global implementation of GRPs. To address these gaps, new harmonized standards and guidelines are necessary.

It is concluded that enhancing radon and NORM regulation can be achieved by developing and globally implementing several relevant European (international) standards and guidelines within rational ISO/IEC concepts. From a legal-philosophical perspective, these findings are intended as an invitation to dialogue, not merely a critique. This approach encourages constructive regulatory debate, supports Euratom's broader mission of continually improving radiation protection, and acknowledges that radon and NORM science is well-established but translating scientific insight into effective policy requires collaboration. In practice, national authorities should gauge the priority of these issues and invest in targeted research and expert engagement where needed; leveraging subsidiarity in this way can foster a more coherent European radiation protection regime.

CRediT authorship contribution statement

Konstantin Kovler: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Andrey Tsapalov:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Robert Bobkier:** Methodology, Writing – review & editing. **Rob Wiegers:** Writing – review & editing. **Wouter Schroeyers:** Methodology, Writing – review & editing. **Tibor Kovács:** Writing – review & editing. **Edit Toth-Bodrogi:** Writing – review & editing. **Omar El Bounagui:** Writing – review & editing. **Arkadiusz Babczuk:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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