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European radon abatement policy: state and ongoing discussion

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ABSTRACT

Radon is a hazardous air pollutant which can cause detriment to individuals and to the society. Thus, the natural consequence is avoiding it or in practice, limiting exposure. This has led to regulation on national and international level whose objective is reduction of radon exposure. In Europe, the Basic Safety Standards (BSS) issued in 2013, whose implementation is mandatory for EU Member States, caused a boost to efforts towards radon regulation as well as to radon research since a number of components of radon abatement policy appeared not resolved sufficiently reliable in the sense of quality assurance. In this contribution, we present the state of implementation of EURATOM Basic Safety Standards in Europe and in Germany, as a particular example. We also address a number of topics currently discussed.

Keywords: **Radon policy, Europe, exposure, hazard and risk, quality assurance.**

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1. INTRODUCTION

Radon (Rn) and its progeny are known as carcinogenic agents [1]. This motivated regulation with the objective of reducing exposure. Although of natural origin (as part of the decay chain of ubiquitous uranium), its indoor concentration is strongly controlled by anthropogenic factors such as building type and user behaviour. This is also where protection measures take up. For the European Union, the essential document is the EURATOM Basic Safety Standards [2] (EU-BSS), which is an EU Directive. This means that all Member States are obliged to transpose it into National legislation. The process gave rise to a large range of political, administrative and scientific activity. A number of problems were identified, some treated in European research projects such as MetroRadon, RadoNorm, Big Buildings, Life Respire, EU-RAP and TraceRadon [3]. Also, the European Atlas of Natural Radiation [4] is partly a product of the discussion about Rn.

In this contribution[1] we present the main features of the EU-BSS, address the state of its implementation and mention open problems, some of which emerged only in the legal process.

2. THE EUROPEAN BASIC SAFETY STANDARD DIRECTIVE

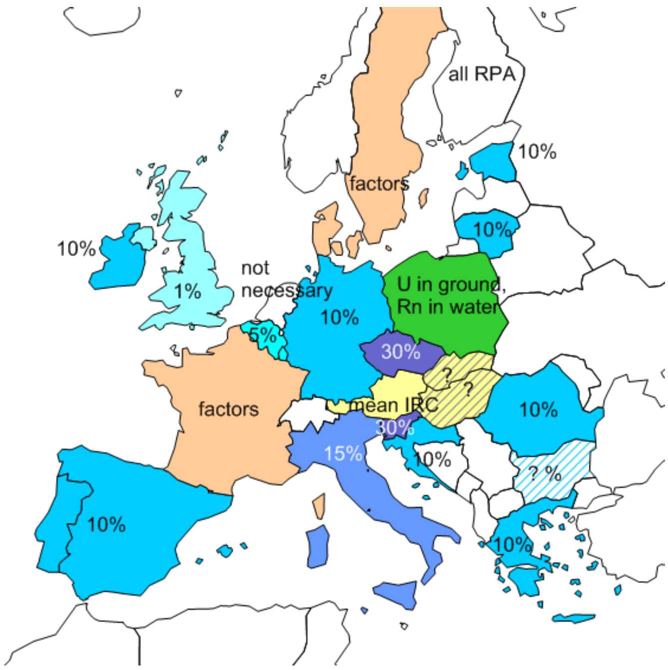
2.1. Essentials of the EU-BSS

The EU-BSS is similar to the IAEA-BSS [5], but stricter in details. It deals with all aspects of radiation protection, but here we limit the discussion to radon regulation. Important paragraphs regarding Rn are: An indoor concentration reference level (RL) must be defined, which is at most 300 Bq/m³ as a long-term (in practice annual, to average out periodicities) mean for dwellings and workplaces (incl. public buildings) alike. (Arts. 54/1, 74/1). In workplaces located in Radon priority areas (RPAs) (below), Rn surveys must be performed. Dwellings with Rn>RL shall be identified and remediation is "encouraged" for private owners and required by law for workplaces and in constructive measures for new buildings (Annex XVIII (8)).

[1] based on a presentation at the Intl. Conf. Radio 2022, 15-19 Aug 2022, Poços de Caldas, MG, Brazil. Book of abstracts, www.sbpr.org.br/site/media/arquivos/livro_de_resumos_radio_2022.pdf , p.263f.

A Rn Action plan must be established "addressing" long-term Rn risk (Art. 103/1). RPA must be defined (Art. 103/3), which are ones, "where the Rn concentration in a significant number of buildings is expected to exceed the relevant national RL"; details given in Annex XVIII. Conventionally, this is interpreted as the frequency or probability that in an area, Rn concentration is >RL. The formulation emerged from a complicated, heavily politicised decision process. It was clear from the beginning that delineation of RPAs is a hot issue between stakeholders, because its consequences are possibly expensive economically and politically. For residential buildings, most EU Member States chose 300 Bq/m³ as RL (Italy, Latvia and UK (not EU): 200; Netherlands, Denmark, Norway (not EU): 100) and probability threshold as 10% of the national RL (e.g. in Germany, RL=300 Bq/m³). For workplaces, all countries chose 300. A more complete global overview including maps can be found in [6]. The varieties of RPA definitions across Europe are shown in Figure 1. From the rather confusing picture it is evident that comparison of RPAs across borders is not easy. The problem of RPA harmonization has been addressed in the MetroRadon project and in [7], but no authoritative solution exists.

Figure 1: *Definitions of RPA in Europe: blue: based on exceedance probability (% prob > RL) in a geographical unit; but notice that RLs are different!; yellow: based on mean per unit; rose: based on factors such as geology; green: different; white: not known, entire country RPA (Finland) or considered not necessary due to overall low Rn (Netherlands).*
Based on data from [8], state early 2022.



2.2. Transposition in Germany

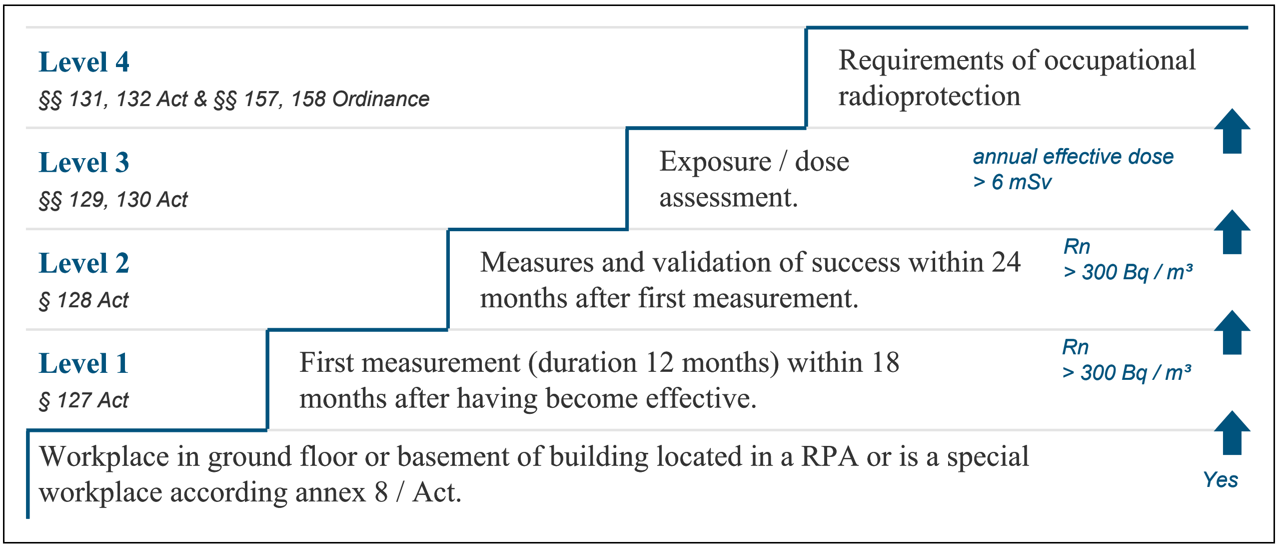
Germany has a federal structure and implementation of federal law is largely the competence of Federal States (FSs). Radioprotection legislation essentials are located in the Radioprotection Act [9], detailed in the Ordinance [10]. In Germany, the RL is defined by Act/§§ 124 and 126 as a means to evaluate the radon indoor situation (in common rooms and workplaces). Particularly in RPAs, where the RL is exceeded more often, the legislative authority stipulated additional and obligatory measures for the protection against Rn in new buildings and working places. By contrast, private owners of existing dwellings are not required to take further action, albeit it is recommended on a voluntary basis. In accordance with Ordinance/§154, private new buildings must incorporate a constructional Rn reduction method in addition to common protection methods against moisture from the subsurface to inhibit the infiltration of Rn to buildings to reduce its concentration. Furthermore, the Radiation Protection Act obliges the person responsible for a working place to certain measures to mitigate radon exposure and health risks of employees in RPAs. After a year-long measurement to determine the average annual Rn concentration, certain Acts and Ordinance come into action in case the RL is exceeded. Here, Act/§§127-132 serve as a step-by-step guideline to measure, remediate, remeasure, estimate the dose level, and if necessary (if Rn is still >300 Bq/m3), register and survey (Ordinance/§§ 157, 158) the working place to protect employees against elevated radiation levels due to Rn exposure. The procedure designed as "graduated plan" is shown in Figure 2.

To date, 6 out of 16 FSs have identified and specified RPAs in Germany. Regardless, the number of RPAs is likely to change in the future since Act/§121 par 1/3 requires that the specified RPAs are to be reviewed at least every 10 years. The debate about RPA definition was strongly disputed and led to results whose efficiency remains to be evaluated in the future, as foreseen by legislation. For a detailed discussion of the legal structure and the BSS implementation process until mid-2020, see [13].

3. ONGOING DISCUSSION AND OPEN QUESTIONS

In sections 3.1 to 3.3, we address topics which we believe are of particular interest in current discussion. This is, however, a personal impression of the authors. Further topics, probably equally relevant, are mentioned in section 3.4.

Figure 2: *German graduated plan to protect from Rn exposure on workplaces, adapted from [11,12]. "Act" denotes the German Radioprotection Act, see text.*



3.1. Uncertainty of decisions; RPA classification

Decisions about action are derived from scientific knowledge, observed data and stakeholder interests. As far as based on data, the chain from data to conclusions inferred from them should be quality assured in the metrological sense as well as regarding modelling, mapping and other evaluation steps (e.g., [14]); Stakeholder interests should be transparent. An example of a decision is whether an area (municipality, etc.) is classified RPA.

As estimated from data, a RPA is a "random object", naturally affected by uncertainty. For a classification problem, these are 1st and 2nd kind errors (1st kind: an area is labelled RPA although it is not; 2nd kind: it is not labelled RPA, although it is). Their origins are (a) data uncertainty, (b) deviation from surveying representativeness; (c) true variability of Rn.

(a) can be reduced by increasing sample density, (b) by careful survey design (and its verification). (c) cannot be reduced as it is a natural, not a data phenomenon. Therefore, one has to tolerate an irreducible classification error in models, which should, however, be quantified. To our knowledge, this has been attempted only in Germany so far.

The importance of the matter lies in the economic and legal (and hence political) cost that misclassification of RPAs can imply. Economic consequences of the RPA label of an area can be important (remediation cost, additional provisions for new buildings), as can be political ones (alleged deterrence of investors, decrease of real estate value, unease of citizens).

3.2. Hazard and risk

In conventional interpretation, RPAs are hazard, but not risk areas (hazard: potential risk, i.e. reflecting physical cause; risk: hazard × susceptibility × exposure, i.e., presence of people who can be harmed; susceptibility or vulnerability mean factors which control how the hazard translates into exposure, for example in the field of Rn: physical characteristics of a building or floor level). If the objective of regulation is reduction of the detriment to society, i.e., lung cancer fatality (EU-BSS Annex XVIII (13)), one should concentrate on risk in the first place, while focusing on hazard protects highly exposed individuals, of whom there may be few. Both objectives must be honoured by radioprotection legislation. Debate of this subject is currently ongoing [e.g.,15]. The consequences of defining "radon risk priority areas" as complement to "radon hazard priority areas" (the current dominant concept) whose patterns are clearly different, would be far-reaching and certainly bear potential of political conflict.

An unresolved issue is the significance of low Rn exposure, below corresponding to concentration, say, 100 Bq/m³. The linear-no-threshold (LNT) hypothesis of dose-risk-relationship is compatible with most epidemiological findings and widely accepted (probably not least because of its simplicity), see [1], but not proven. Indeed, some authors [16] claim a positive effect of low Rn exposure, called the hormesis hypothesis. The case seems currently dormant, so to speak, but not resolved.

3.3. Dealing with temporal variability

Environmental Rn concentrations (indoor, soil, outdoor, groundwater) are highly variable temporally, in most cases. Variability components of indoor Rn are typically periodic ones: seasonal, daily and weekly cycles, related to climatic patterns and usage. Aperiodic variability results from weather episodes and unusual usage. To estimate long-term means, long-term measurement is consequently recommended to average out the cycles; best 1-year measurements or during the "transition seasons" (spring and autumn) when most variability is assumed to be covered.

Therefore, one faces two distinct situations: (a) For reliable assessment of the Rn status of a building in comparison to the RL, one would prefer long-term measurement. The same applies to Rn mapping because local observation uncertainty induces noise in the map. (b) If a fast decision is necessary, for example in case of house transaction, one cannot afford month-long measurements, but usually measures for several days only. Also, for the evolving task of Rn measurement through Citizen Monitoring, long-term measurement is hardly an option.

(a) What is a long-term mean?

The RL refers to long-tem means. This entails two questions:

- Also, annual indoor Rn concentration means are not constant, but subject to variability of up to 15% between years, e.g. [17]. This implies that annual concentrations near, but below the RL can in fact be above, and v.v., hence causing another classification error. How to deal with this is currently strongly debated in the ISO norm committee.
- A long-term mean exists only if Rn concentration is a stationary process, that is, the mean is constant up to variability (see previous bullet). There seem to exist indications that this is not the case. As reasons have been proposed: climatic change (impact on migration of Rn in the ground), increasing prevalence of home office (change of user behaviour) and energetic retrofitting of buildings (reducing air exchange). Systematic investigation is missing.

(b) Short-term Rn measurements

Quite evidently, the shorter a measurement, the higher its uncertainty with respect to the target quantity, which is the long-term mean. (Note that here we do not speak about uncertainty of individual measurement, which is intrinsic to the physical measurement process.) This percolates to uncertainty of decisions, typically whether the Rn situation of a building complies with the RL and consequently, whether some remedial action is necessary. In [18,19], probabilistic procedures have been proposed to verify compliance with a target, usually the RL. In any case, we think that short-term Rn measurements, whether as indicative screening or decision supporting measurements, should be integrated in the QA regime which currently only considers long-term measurement. The discussion in the ISO committee is controversial and seems currently (late 2022) stalled.

A second aspect is the increasing importance of Citizen Monitoring [20]; for an example: [21, 22]. Its benefits lie in its ability to generate large datasets, its educative aspect and its potential to "democratize" science. Problems are found in QA matters, in particular lack of geographical representative sampling design (if used for regional evaluation and mapping), possibly in individual measurements not conforming to standard procedures, and lack of temporal representativeness, in case of short-term measurements. How to deal with these problems is a subject of current discussions.

3.4. Further topics

As additional topics, we mention only superficially the following, without giving references and discussing them, for the sake of brevity:

Radon maps

Maps are important tools to visualize the presence of ambient hazards and resulting risks, and thus are important as decision support and for information of stakeholders. This has motivated, among other, the European Atlas of Natural Radiation [4] which covers Rn among other agents that may represent environmental hazards. Global Rn mapping is in discussion since recently. Progress in mapping techniques is still ongoing, in particular regarding inclusion of multiple predictors and classification problems, typically delineation of RPAs.

Maps must be adapted to the target audience; Fellow scientists and professionals, media, the general public, administrations, politicians and decision makers likely have different expectations of a map and which information it conveys and how it does. This concerns the choice of quantities to be displayed, mapping style and degree of detail, among other.

The tectonic factor

Geogenic factors are known to influence local ambient Rn concentration. Increasingly, the influence of tectonic features such as fault lines and seismicity is acknowledged. Their inclusion as predictors for estimating Rn is studied intensely.

Thoron

Mostly, ^{220}Rn, called thoron (Tn) is considered a minor risk compared to Rn. Locally it can still be relevant, if building materials rich in Th or with high exhalation power are used. In Germany, clay as a building material is gaining importance again in the context of sustainable building practices due to its ecological and physical properties, which ensure a good indoor climate. Clay basically does not contain more U or Th than other building materials, but it has a greater surface because it is very finely grained. Due to the greater surface area, more Rn and Tn are released into indoor air than from fired clay bricks. In case unfired clay is used as a building material, as a precaution, care should, therefore, be taken to ventilate affected rooms regularly to reduce the radon and thoron concentrations. Passive Tn measurement is possible, but QA aspects remain to be worked on, in particular measurement protocols which assure comparability of results.

Radon and Thoron progeny

Risk originates not from Rn and Tn gases but from their progeny. Their long-term mean concentrations are more difficult to measure than the ones of their parents. Exposure is usually estimated applying default equilibrium factors between parents and progeny, which are, however, known to be variable in reality. Cheap passive techniques for progeny measurement have been developed, essentially based on bare track-etch detectors, but also in this case, QA issues remain.

Workplaces vs. dwellings

Radon policy is largely based on surveys of residential Rn, although the most rigid regulating paragraphs of the BSS apply to workplaces and public buildings. Since in general, these building types have different physical characteristics, it is questionable to apply results from the survey of one type to buildings of the other at the (hypothetically) same location. In particular, RPAs derived from residences may not be the same as if they were derived, e.g., from schools. Therefore, for some time, intensive surveys of buildings other than residential ones have been under way, but reliable general conclusions regarding comparability are not yet available. Discrepancies may impair credibility and acceptance of Rn policy by stakeholders and even lead to legal problems.

Public awareness and inclusion of stakeholders

In most of Europe, the general public is still little aware of Rn as an indoor air pollutant. Media releases and educational activity by Rn professionals and authorities had moderate success so far. Some think that strategies different from common top-down approaches, in particular Citizen Science may help increasing Rn awareness. In any case, the matter must be given continuing attention.

Closely related to this is more intense inclusion of stakeholders such as the health industry, construction industry, media and public administration on local level. One crucial question is, how to weigh conflicting stakeholder interests? Public discussion about it is nearly inexistent. Stakeholder interests may assert themselves through their political and economical power, which one may find little satisfying from a democratic perspective. One particular problem seems to be that very often Rn professionals are no communication experts and are themselves little aware of that they are indeed also stakeholders, and of the implication of this position regarding communication.

4. CONCLUSIONS

Implementation of Rn policy is well under way in most of Europe. However, fine-tuning remains, as does further development of conceptual issues, such as the hazard vs. risk debate or due implementation of short-term radon measurement. Progress has been made in establishing QA chains (e.g., [14]), which we understand as the chain from QAed radon metrology to the final products which constitute radon abatement policy, such as delineation of RPAs on a geographical and collective scale, or decision on whether a building must be remediated, on a local and individual base.

Limitations and shortcomings of current Rn regulation have been identified and suggestions for improvement made, e.g. [23]. It can be expected that these questions will keep the Rn debate well alive for some time. However, it must be kept in mind that one has to find compromises between scientific accuracy and administrative viability. Finally, although not discussed here, the inclusion of stakeholders and in particular of the general public is crucial for the success of any Rn abatement policy.

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