16ENV10 MetroRADON

Activity 4.1.1/4.1.2

Review and Evaluation of the concepts of the definitions of radon priority areas

Lead organisation: BfS
Other involved organisations: AGES, INAIL, IRSN, JRC, UC, VINS

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Table of contents

1. Motivation 3

2. Introduction 3

3. Legal Background and concept 4

European Basic Safety Standards 4

Reference Level 5

Radon priority area 5

4. Review of RPA concepts and definitions 6

5. Role of stakeholders in the RPA selection and implementation process 8

Stakeholder definition 8

Types of Stakeholders regarding radon policy 9

Risk, risk perception, interests and values 9

Stakeholder interests: its origin and its expression 10

Communication to Stakeholders 13

Experiences and Case Studies 13

6. RPA derived from dwellings vs. workplaces 28

Motivation 28

Methodology 28

Results 29

7. Cross-usage of concepts 31

Cross-usage of concepts - workplaces vs. dwellings 32

Cross usage of concepts - different mapping methods and RPA definitions 33

8. Case Studies 35

Austria 35

Germany 37

France 38

Spain 40

Implementation on European level 41

9. Summary and Conclusion 46

10. References 48

1. Motivation

The purpose of the MetroRADON project, funded within the European Metrology Programme for Innovation and Research (EMPIR) is to develop reliable techniques and methodologies to enable SI traceable radon activity concentration measurements and calibrations at low radon concentrations. The need for this project has been largely motivated by the requirements of the implementation of the European Council Directive 2013/59/EURATOM (EU-BSS) (EC, 2013), one aim of which is to reduce the risk of lung cancer for European citizens due to high radon concentrations in indoor air. Furthermore, it is a goal of the project to enable uptake and exploitation of its results and experiences by all stakeholders concerned with radon, from regulators and policy makers, professionals in designing, performing, evaluating and interpreting radon surveys, radon instrument manufacturers to the end-users (e.g. companies providing radon measurement, construction industry) and the scientific community. More details about the MetroRADON project can be found at the project website (MetroRADON, 2020).

Article 103 of the EU–BSS requires that member states identify areas where the radon concentration in a significant number of buildings is expected to exceed the relevant national reference level – referred to as radon priority areas (RPAs) within the MetroRADON project and this report. The definition of RPAs will influence political and technical decisions, which in turn will have economic effects in these countries, such as mandatory radon measurements in workplaces in these areas according to Art. 54 EU-BSS, as well as mandatory preventive measures or priority of awareness programmes. As the definition of RPA in the EU-BSS allows a wide range of interpretation, different concepts and methodologies have been proposed and some already adopted.

Within the MetroRADON project a specific work package is included with the aim to analyse and develop methodologies for the identification of radon priority areas, to investigate the relationships between indoor radon concentrations and quantities including soil exhalation and to develop the concept of a “geogenic radon hazard index” (RHI) as a tool to help identify radon priority areas. One specific task within this workpackage is dedicated to collect information and compare the methods for radon mapping and delineation of RPA which are already being used in different countries or regions.

2. Introduction

Delineation of radon priority areas (RPAs) is generally considered an essential tool in the overall target of reducing the radon risk of the population. The definition of radon priority areas (RPA) in the European BSS allows a wide range of interpretation. In the past a number of different approaches has been brought forward, motivated by the availability of data for the predictor quantities (for various reasons different types of data sets are available in different countries) and by the purpose of RPAs which may also vary. In course of the European BSS process, concrete proposals have been made in some countries, and already implemented in a few cases. These will be reviewed and compared in detail in this Task. Given the possible political and economic consequences of RPAs, stakeholders are keen to promote their interests in the discussions on defining RPAs.

The tasks reviews and evaluates concepts and definitions of RPAs, which have been proposed or already implemented in the past and the role of stakeholders in the implementation process of RPA. It is evaluated what purpose these approaches can be used for (e.g. in workplaces, preventive measures, public radon exposure) and if and how certain methods, developed in one country for a specific purpose, could be used or adapted for other purposes or in other countries or regions.

Particular RPA concepts are considered in detail from some countries and available documents are evaluated and experiences discussed between the partners, most of whom play an active role in assessment of RPAs. All results of the activity are discussed and summarised in this report.

The text for the specific activities and the involved partners are listed here:

Activity number	Activity description	Partners (Lead in bold)
A4.1.1	BfS, BFKH, AGES, IRSN, JRC and UC will review and evaluate the concepts and definitions of RPA which have been proposed or already implemented in the past and the role of stakeholders in the implementation process of RPA. It will be evaluated what purpose these approaches can be used for (e.g. in workplaces, preventive measures, public radon exposure) and if and how certain methods, developed in one country for a specific purpose, could be used or adapted for other purposes or in other countries or regions Particular RPA concepts that will be considered in detail are the ones from Spain (based on ambient gamma dose rate and geology), Germany (geogenic Rn potential and geology), Austria (standardised indoor concentration) and France (a multivariate scoring system). Available documents will be evaluated and experiences discussed between the partners, most of whom play an active role in assessment of RPAs. The consequences for developing a flexible multivariate RPA definition (to be carried out in A4.3.4) will be discussed.	**BfS**, BFKH, AGES, IRSN, JRC, UC
A4.1.2	Based on the results of A4.1.1, BfS and AGES will write a report which will be published that summarises and discusses RPA concepts existing and under discussion that will feed into D5, including information obtained from the stakeholder interest groups formed in A6.1.7, A6.1.8 and A6.1.9.	**BfS**, AGES

The report starts with an introduction to the legal background and concept (Chapter 3), followed by a review about RPA concepts and definitions (Chapter 4). The role of stakeholders in the selection and implementation process of RPA is an interesting topic, which is discussed in chapter 5, taking into account all relevant stakeholders and summarises the practical experience in some countries (Austria, Germany, Serbia and Spain). In many cases RPA are delineated based on radon measurement data derived in dwellings, but the main implication of RPA are the mandatory radon measurements in workplaces in these areas according to Art. 54 EU-BSS (EC, 2013; EC, 2020). So, chapter 6 is dedicated to the comparability of RPA derived from dwellings vs. workplaces. As written in the description of the activity, it is interesting if and how certain methods, developed in one country for a specific purpose, could be used or adapted for other purposes or in other countries or regions. Chapter 7 focus on this cross-usage of concepts, taking into account results from chapter 6 and MetroRADON activity 4.4.2. In addition some case studies of RPA concepts and delineation of RPA are presented in chapter 8. Finally, the report ends with a brief summary and conclusion in chapter 9 and references are listed in chapter 10.

Parts of the text of this report have been taken from Bossew (2018 a-d) and a contribution of the same author to the European Atlas of Natural Radiation.

3. Legal Background and concept

European Basic Safety Standards

On the one hand, radon exposure is ubiquitous, and contributes to total dose dominantly, also in low-radon regions, but on the other hand, technical possibilities and logistic and financial capacities to reduce it are limited. Thus, quite logically, the idea emerged that caring about the radon problem should start where it is most urgent. This logic led to the priority concept, as laid down in the EURATOM Basic Safety Standards (EC, 2014) which among regulating other sources and pathways of radiation exposure (e.g. medical and industrial exposure), also deals with indoor radon. The overall goal of the BSS concerning radon is sustainable reduction of the risk (in terms of lung cancer incidence and fatality) posed by indoor radon. This leads to the priority concept, as implicit in the notions of Reference Level (RL) and RPA. It implies that radon exposure should be reduced everywhere, if possibly with lower priority (given usually limited resources); after all, Ann. XVIII (13) states as part of the radon action plan: [Establish] “long-term goals in terms of reducing lung cancer risk attributable to radon exposure”. Par. 6 of the same annex says, that a strategy for reducing radon exposure in dwellings should give priority to situations with potentially high radon exposure, which applies to the RPAs or other circumstances which may lead to high radon exposure.

As European law, the BSS have to be transposed into national law by EU Member States.

Reference Level

Main tools to this objective are concentration *reference levels* (RL) and *radon priority areas* (RPA). RL are set to maximum 300 Bq/m³ for dwellings and workplaces alike. However, a RL must not be confused with a limit or an action level.

BSS Art.4 (84) states,

> *"reference level" means in an emergency exposure situation or in an existing exposure situation, the level of effective dose or equivalent dose or activity concentration above which it is judged inappropriate to allow exposures to occur as a result of that exposure situation, even though it is not a limit that may not be exceeded.*

And Art.7 (1,2):

> *1. Member States shall ensure that reference levels are established for emergency and existing exposure situations. Optimisation of protection shall give priority to exposures above the reference level and shall continue to be implemented below the reference level. 2. The values chosen for reference levels shall depend upon the type of exposure situation. The choices of reference levels shall take into account both radiological protection requirements and societal criteria.*

Note that in par.1 the term *priority* appears. Put more colloquially, a RL could be understand as a guideline to assess the urgency of action or intervention. If exceeding a RL is deemed inevitable or reasonable, this has to be justified properly.

Radon priority area

The second tool is the *radon priority area*. This term does not occur in the BSS but has been coined later, about 2014, to underline the priority concept. Historically, the term *radon prone area* has been common. During discussions in the early 2010s that led to the BSS, this term has been rejected. In our opinion, although the forwarded arguments were without scientific rationale, this was still a good decision for conceptual reasons: the term radon prone area suggests that in areas which are not labelled so, radon exposure poses no risk, which is certainly incorrect. Instead, RPAs, how ever defined and estimated in practice, point to areas, in which prevention and remediation should be performed with priority; other areas are given lower priority with given resources, but certainly are NOT defined as “safe”. Unfortunately, RPAs are often understood by administrations and the public in exactly that wrong way, thus foiling the underlying concept. Discussions are ongoing and hopefully the correct notion will eventually be accepted and prevail.

I should be noted that according BSS (Recital 22), *"Recent epidemiological findings from residential studies demonstrate a statistically significant increase of lung cancer risk from prolonged exposure to indoor radon at levels of the order of 100 Bq m^{3}"*, hence, the RL and RPA rules cannot be misinterpreted for defining areas as "safe".

Some have concluded that graded approaches match the priority notion best; either by defining different RPA level classes requiring action of different severities or priorities, or by subsequent enlargement of RPAs according to completed tasks.

The philosophy of the priority concept has been well explained by Bochicchio et al. (2017).

The most serious consequences of an area labelled RPA concern workplaces and public buildings. According BSS Art. 54, in RPAs, workplaces in basements and ground floors have to be measured. No similarly strict rule has been foreseen for dwellings, except that in dwellings exceeding the RL, concentration-reducing measures shall be "encouraged" (Art. 74 (2)). Some countries, among them Germany, require that for new buildings, stricter construction norms apply for residential buildings (this mainly concerns insulation against the ground). As already quoted above, Ann. XVIII/6 says that in RPAs, strategies for reducing radon exposure should be developed as part of the National Radon Action Plan (required, Art. 103).

Since BSS implementation is still ongoing in many countries, no authoritative overview on radon regulation in detail (including technical specifications, mostly left to sub-legislation and ordinance) in European countries is available by mid 2020.

An important message is that there is no "natural" definition of RPA and consequently, no such thing as a "true RPA". Delineated RPAs always depend on their definition – resulting from political decisions, stakeholder interests, availability of resources and of databases – and to some degree also on estimation method. As results of statistical estimation, RPAs are uncertain objects (specific activity in MetroRADON, A 4.3.1, see deliverable D5). Communication of RPA uncertainty to the public and to decision makers is another challenge, not to be discussed here, but from experience known to be not easy.

4. Review of RPA concepts and definitions

Article 103 (3) of the BSS states,

> *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.*

The conceptual definition has to be transposed into an operational definition by the EU Member States. It is based on a radon measure, for example the mean over a geographical unit (grid cell, municipality etc.) or the probability that within the unit indoor radon exceeds a reference level.

Existing solutions are pragmatic in the sense that they have to rely on available data and on external "political" parameters such as reference levels, spatial units to which the term "area" refers and tolerable uncertainty.

RPA definitions differ by concept and by aspects of the practical implementability. While the target quantity is always - per BSS definition – the annual mean indoor radon concentration and its limiting value the RL, the meanings of "significant number", "area" and "exceed" are open to interpretation. Also "annual" is problematic, because it is known that annual radon concentrations in one room or building vary between years. The more appropriate term is therefore, “estimated long-term”.

(a) The simplest RPA definition may be, an area is called RPA if the mean radon concentration in buildings or rooms of certain type within an area (municipality, grid cell, etc.) exceeds the RL. Regarding room and building type, the definition can include the entire building stock, or filter for certain properties, such as dwellings only, ground floor rooms (frequent practice), buildings with basement, etc.

(b) Another definition may be based on exceedance probability: An area is labelled RPA, if the probability that a room or building has radon concentration above RL, exceeds a given probability threshold.

(c) Also, qualitative criteria may be used. A RPA is one, in which certain conditions are met, for example dominance of geology which is known for high GRP or prevalence of buildings without insulation against ground.

(d) Yet another definition, quite different from the above, and not applied by any European country so far, to our knowledge, could consist in calling RPA those geographical units (grid cells, municipalities) which represent an upper percentile of radon measures; for example, say, the 5% municipalities with the highest mean radon concentrations. Such strategy would also reflect the prioritization idea implicit in the BSS and limitation of resources: once radon problems have been largely tackled in the upper 5% of municipalities, one may start working the second highest 5%, and so on, as long as found reasonable and feasible.

(e) One can also argue that RPAs should not be defined based on radon concentration values in actual buildings, since these are subject to long-term variation. If an area has been labelled RPA, buildings will be remediated and new buildings better insulated against the ground, which results in lower radon concentration. After re-evaluation, the area could then be relabelled non-RPA, the radon protection rules removed and buildings return to higher radon concentration, which is obviously counter-intentional. Therefore, it has been proposed to base RPA definition on the non-remediated housing stock at a certain time (Belgian approach) or on geogenic quantities, which are not subject to change over geologic times, e.g. the GRP (German approach, Bossew 2015, 2018a). This is equivalent to arguing that not radon concentrations in actually existing buildings define RPAs, but concentrations that are expected to occur for geogenic reasons in a location, if a building of certain type was there, regardless of whether there is one (a concept analogous to the one of seismic vulnerability of a location).

(f) A different approach has been proposed by Elío et al. (2018). The authors argue that in order to reduce exposure, priority should be given to areas where most of *exposure* is located, opposed to the above approaches, which assign priority to areas where highest radon *concentration* occur. Indeed, highest concentrations may occur in little populated regions and thus do not contribute to total exposure, and hence to collective risk in terms of number of lung cancer cases. In most cases, approach (f) leads to assigning RPA status to densely populated areas such as cities, irrespective radon concentrations. In fact, one can argue that a small reduction of radon concentration in a densely populated area with low average radon concentration decreases exposure more than large reduction in an area with high concentration, but few buildings. Probably a radon strategy aimed towards statistically identifiable reduction of exposure will, at least to some degree, have to keep the Elío approach in its agenda.

(g) Yet another approach has been proposed recently, based on the frequency with which radon extremes occur in area, irrespective of the overall mean in that area. The idea is that anomalies (mainly of geological or tectonic nature) may occur also in otherwise “harmless” areas. The extremes may still not contribute significantly to the mean due to their small spatial extent. See Bossew (2018b) for initial considerations. The matter is illustrated in Figure 1, for an area in which the mean radon concentration equals 100 Bq/m³. The probabilities that 300 Bq/m³ are exceeded, depend on the dispersion, measured as GSD. High GSD is an indicator of the presence of anomalies.

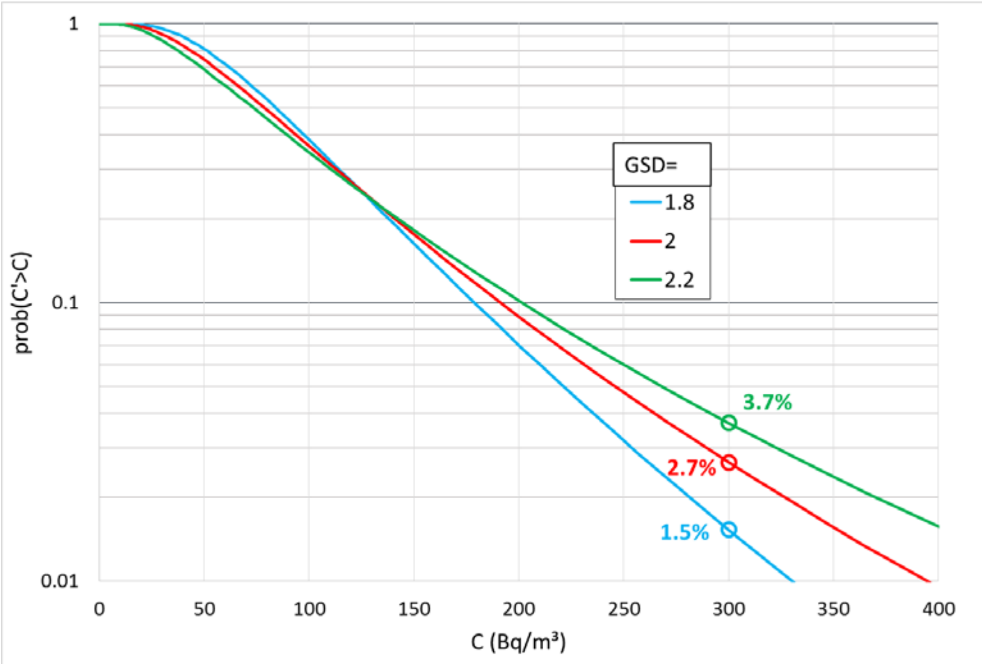

Figure 1: Probabilities that C Bq/m³ are exceeded in an area with arithmetic mean concentration AM(C)=100 Bq/m³, for different geometrical standard deviations GSD. For threshold C=300 the probability values are given.

The discussion is still ongoing. Radioprotection has two targets: minimizing overall risk, where reasonably feasible, and protecting individuals exposed to high dose, even if they contribute little to total exposure. Evidently, the approach (f) of Elío et al. concerns the first target while the more common approach based on reducing concentration, as well as the one based on extreme frequency, the second. Perhaps the solution is not to choose between approaches; but defining different preventive and remediation action in RPAs defined by different approaches.

To repeat, there is no "natural" definition of RPA! Therefore, there is also no "true" RPA. RPAs always depend on definition and to some extent, on estimation method. This is partly a political decision, partly a pragmatic one (i.e. availability of data).

One consequence is that RPAs delineated by individual countries may be inconsistent across borders, in general. This may create communication and credibility problems. This subject is evaluated further in MetroRADON task 4.4, "Harmonisation of radon priority areas across borders", results are summarised in Deliverable D5 of MetroRADON project.

5. Role of stakeholders in the RPA selection and implementation process

Stakeholder definition

A *project stakeholder* is "an individual, group, or organization, who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project", Wikipedia, 2020a; original sources there).

This definition appears most appropriate in our context, supposing the term *project* for radon policy. Original usage of the term seems to have been *corporate stakeholder* (Wikipedia, 2020b) which to some degree can be understood as a subset of the former, as persons of groups which have an interest in the activity or in certain decisions or outcomes resulting from the activity.

Types of Stakeholders regarding radon policy

Usually, *primary stakeholders* are called those that are directly involved materially and economically in an activity; in our context this would be tax payers, those who decide about radon policy (parliament), who administrate it (government, ministry, regional administration), who design it (scientific institute, ministry).

Secondary stakeholders are those who are affected by decision of a project or an action. These cover a possibly wide range from citizens affected by high radon levels to construction industry, health business, media and NGOs.

Evidently, a clear distinction between primary and secondary stakeholders is impossible. In the following list of stakeholders, no distinction will therefore be made.

Risk, risk perception, interests and values

Tackling risks naturally implies costs in one or the other way, and hence conflicts of interests between different stakeholders, depending on the degree of benefitting of risk reduction or having to bear its costs. Below we shall give a list of stakeholders and their respective interests in the case of radon policy. Before this, we address the question of how interests in a matter translate into perceptions about that matter; in particular, we ask, how do interests related to either benefits or costs of radon-reduction-policy control perception of radon risk.

Objective vs. perceived risk has been discussed by a number of authors. For example according to Renn (2004), normative focus on technology-based risk model is not sufficient to achieve communication about risk, preventive and remediation measures, because it does not consider that risk perceptions are based on subjective issues, as values, for example. This leads to the question: How do these subjective values constitute? Understanding this is important to develop risk communication strategies, because, obviously, the balance which each stakeholder attributes to costs and benefits of risk reduction, depends on his preferences and values which are in turn controlled by his interests. This argument essentially follows classical Marxist sociology and its concept of material base and cultural superstructure ("Überbau") (Marx 2010).

Subjective values are based on different initial knowledge, different interests, expectations and desires. Actual creation of values depends on the interdependency of base and superstructure. Base denotes the group or society to which one belongs, economical relationships and material interests. Superstructure refers to the constitution of the nature of cognition according to the economic and social relations derived from the social group to which one belongs, which means knowledge, believes, ideology, mentality, cultural imprint and attitudes. The actual process of superstructure formation as function of these conditions is a matter of social psychological research.

Compromises which are built in a situation of conflicting interests bear the imprint of values which define the weights that are given to the interests. Dominant values are the ones defined by dominant interests. They can only prevail if they dominate the societal discourse. Therefore, the actual shape of a compromise always reflects hegemony in a discourse about values.

The purpose of this excursion is to show that for successful risk management it is not sufficient to address "objective" risks and the benefits and costs of their reduction, but account for risk perception by stakeholders, which leads to possibly controversial attitudes and approaches in dealing with the risk.

Stakeholder interests: its origin and its expression

Different stakeholders have different interests. In the following, we attempt to give a list of stakeholders affected by the radon risk, and involved in dealing with it. We try to identify, in terminology given above, their material base, i.e. their position in society, and their attitude towards radon risk management, i.e. the manifestation in the superstructure domain.

Stakeholders 1: Radon professionals

The radon professionals are an important category of stakeholders. They provide services to the citizens and employers to protect the workers. The main services in which they are involved are: radon measurements and radon remediation. Being involved in radon measurements, they are interested to have the techniques and methodologies available to enable SI traceable radon activity concentration measurements and calibrations at low radon concentrations. They are essential stakeholders, as they are covering the demands of radon measurements and remediation actions providing complementary services to the ones of the national authorities and strictly collaborating with the latter. They are directly affected by the implementation of EU-BSS in the definition and delineation of RPA in the countries, as this defines the amount of mandatory or necessary measurements and remediation, which influences the business of radon professionals. A quality control system (certification, accreditation) should be set up in the countries and radon professionals should be motivated, informed and trained to follow these standards to ensure sound radon measurements and remediation for workplaces and dwellings.

Stakeholders 2: Health professionals

Medical doctors, pharmacies and social workers are usually considered trustworthy persons by the public. In many cases, unfortunately, they are little informed about radon and natural radiation and it should be improved. It seems that so far they have been involved only marginally, but the existing examples show that their impact can be very high. A relevant issue could be, that the radon problem can not be solved by the health professionals themselves. So, they need to be informed and motivated to be an essential part in the overall radon protection system and should be involved more strongly in the radon debate.

Stakeholders 3: Constructions Corporations and Industries

Effective radon protection is mainly a civil engineering and architect task, either by including radon prevention measures in new buildings or remediate existing buildings with high radon levels.

Radon prevention measures ("radon proof" buildings) and radon remediation could create additional profit for construction industry. On the other hand, regulation has legal implications: compliance with strict laws could be costly because construction standards regarding radon must be assured because of liability. This implies additional quality assurance, including measuring building and construction materials.

An important point is the conflict between energy saving and radon protection. Conventional measures to reduce energy consumption make windows more air tight, which reduces air exchange and hence may increase indoor radon levels. In energy saving remediation measures, the radon issue needs to be taken into account, even if it might be more expensive. Good information and communication with the responsible stakeholders will be necessary for that purpose.

Stakeholder 4: Employers and Companies

In designated radon priority areas, regulation may imply measuring and possibly remediation in workplaces and if applicable implement additional radon protection measures (information of the employees, dose assessment etc.). This will be a cost factor for the company and an additional responsibility for the employer to provide a safe workplace and ensure occupational safety of his/her workers. Additionally, as a rather psychological effect, being labelled radon priority area may deter investors and costumers.

Workplaces with radon concentrations above the reference level shall undergo appropriate remedial actions. If, despite all actions to optimise, the radon concentration in a workplace remains above the national reference level, this workplace needs to be notified to the competent authority (according to Article 25 (2)) and the relevant occupational radiation protection requirements may apply (see Article 35(2) of the new Directive (EC, 2013). In this context is it worth noting that Article 31 paragraph 3c clearly recognises the responsibility of the employer or the undertaking for the protection of workers who are exposed to radon at work, in the situation specified in Article 54(3).

Stakeholders 5: Population and House owners

In general, all radon measures, radon regulation and radon work is to protect the population from radon. So, the population is an important stakeholder. The population can have all nuances of emotion and knowledge about radon - well informed, interested, indifferent, afraid, ignorant, sceptical, etc. about radon, depending on their knowledge, education, health interest, risk perception, social circumstances, economic environment, etc. Therefore, it is difficult to summarise the interest and their attitude towards radon, and therefore it is important to have very different strategies to address the population as a stakeholder. The population might also act different in their role as an employee, as a parent, as an individual, as a house owner, as a tenant etc. An employee or a tenant expects to be protected in his/her work place or in his/her dwelling. A parent wants to have his/her children protected in school or kindergarten. But they might have a different perception if they are responsible about the protection themselves. For house owners, radon can be a cost factor. Given possible remediation costs and maybe also possible legal consequences, they could be sceptic against radon regulation. Additionally, elevated radon levels in a house, or being located in a radon priority area, can decrease property value. People with health interest, want to have their dwelling as a safe place for themselves and their families, so they will be more receptive about radon risk communication and measure and remediate radon levels in their dwellings. House owners, who do not live in their houses themselves (landlords, investors) might have less interest in measuring and remediation of the houses, but should be sensitised to their responsibility for their tenants.

Stakeholders 6: Media

Media are important tools for informing and engaging the population on the radon issue. Media includes newspapers, TV and radio, social media etc and allow to reach a wide audience. Media are mostly enterprises acting on the market, or are in competition about quotas with such ones. Therefore, interest of the media mostly consists in quota, which generates their profit. This leads to a tendency to simplify topics or create lurid headlines. If a subject does not serve quota, it might be ignored by the media. So far, radon has drown little attention by the media. However, an information campaign on radon cannot avoid the use of media and it is important to increase the dialogue between the journalists, communication experts and radon experts to provide correct and catchy (attractive) information.

Stakeholders 7: Associations, unions

In some countries, Consumers' Associations inform the members about the radon problems providing them some tips and suggestions on how to perform measurements and remediation also indicating an average price for some services. So, they are relevant stakeholders for radon protection, as they are trusted by the consumers. In addition civil protection associations can play an essential role for the radon information of the public, as they are not seen to have a commercial interest and therefore are trusted in risk communication topics. These trusted associations should be addressed as information multipliers in the field.

In addition, occupational associations and unions are important stakeholders, as they have access to and impact on either the employers or employees. Both groups are relevant in radon protection (see stakeholders above) for effective information campaigns and support for the employers/companies (e.g. providing information material) for occupational safety. Occupational associations and unions should serve as a trusted information and communication channel for radon protection at the workplace.

ERA (European Radon Association) is a large and growing community in Europe of professionals such as scientists, technologists, public health officials and decision makers working in the radon field. Their areas of interest range from epidemiology, radiation dosimetry, instrument development and measurement protocols, remediation and prevention construction technologies to control strategies and regulation. In recognition of this, the European Radon Association (ERA) has been formed aimed at serving the interests of the European radon community and to assist in reducing the health burden of Radon Exposure in Europe (ERA, 2020a).

Stakeholders 8: Government, Administration

In Europe, in 2014, the latest Basic Safety Standards Directive – Directive 2013/59/Euratom laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation has been published (EC, 2013). The scope of the Directive has been extended to apply now to all human activities including those, which involve the presence of natural radiation sources and lead to a significant increase in the exposure of workers or members of the public. Based on this, the Directive introduces, for the first time, legally binding requirements on protection from exposure to radon.

As major provision with regard to the radon protection strategy, the new BSS Directive requires in Article 103 that Member States establish a national radon action plan addressing long-term risks from radon in dwellings, buildings with public access and workplaces for any source of radon ingress, whether from soil, building materials or water. Finally, Article 103 requires Member States to 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. For the annual average activity concentration in air, the reference level shall not be higher than 300 Bq m^{-3}. Moreover, the Directive requires the establishment of a national reference level for indoor radon concentration in workplaces. The reference level for the annual average activity concentration in air shall not be higher than 300 Bq m^{-3}, unless it is warranted by national prevailing circumstances. Member States are free to establish different reference levels for workplaces and for buildings, as long as they are not higher than 300 Bq m^{-3}. For further details, see chapter 3 - Legal Background and concept.

The government/administration in the countries are the ones who are responsible to transpose the EU-BSS directive in their national legislation. The national legislation need to fulfil the requirements of EU-BSS, but will be adapted to the country specific situation regarding e.g. radon levels and economic situation. The government is responsible to establish a radon protection legislation to protect the population in the best way, following the ALARA principle. Consultancy with all relevant experts (radiation protection, health) is therefore necessary for best possible implementation.

Stakeholders 9: Authorities and regulators

Member States need to ensure that the population is informed on a national level and even more on a local level in radon-priority areas, about indoor-radon exposure, the associated health risks, and the importance of performing radon measurements, as well as on the technical means available for reducing existing radon concentrations. Member States are also requested to establish programmes to carry out radon measurements in workplaces within the areas identified under the national radon action plan (see also Article 103(3)), and in specific types of workplaces also identified in the national action plan (see point 3 of Annex XVIII).

The Radiation Protection Authorities and regulators are directly involved on the implementation process of the Directive after the transposition phase. This process involves the technical aspects, i.e. metrology, standard, as well as the social aspects (inform the population). Practical and harmonized solutions to important regulatory issues to be implemented at the national level are also discussed at European level thanks to platforms as for example HERCA (Heads of the European Radiological Protection Competent Authorities).

Radon protection may also be under the responsibility of other authorities, which are usually not directly concerned with radiation protection, e.g. health, occupational safety, building sector. It is important to inform and motivate those authorities and regulators about the importance of radon protection, as they are often the ones who need to implement, evaluate and control the radon protection measures. Sufficient resources, information and training should be assigned to them to fulfil this task.

Communication to Stakeholders

Communication must be customized to the expectations, preferences and values of the stakeholders, as determined by their interests, and prior to any compromise, valuing them on an equal level, without ideological premise. Radon communication to stakeholders is not the scope of this report and activity, but some examples of initiative for improving communication are reported below.

The SHARE platform (https://www.ssh-share.eu/background/) aims to help society in its interaction with radiation risk by bringing together researchers from all relevant platforms, associations and projects related to ionising radiation.

The “Potsdam radon communication manifesto” was published (Bouder et al., 2019) as result of an international expert workshop of BfS in Potsdam, October 2019. The paper is addressed to governments, authorities and other stakeholders responsible for providing information on radon health risks and intend to help improve radon communication. The paper can be downloaded at the ERA website (ERA, 2020b).

The project RadoNorm (stated in September 2020) proposes a multidisciplinary and inclusive research project targeting all relevant steps of the radiation risk management cycle for radon and NORM exposure situations. One point of RadoNorm is the dissemination of the project achievements through targeted actions to the public, stakeholders and regulators by linking dissemination efforts directly to knowledge achievements and new recommendations.

Experiences and Case Studies

In the framework of MetroRadon project a questionnaire for collecting information about indoor radon surveys has been prepared and addressed to all European institutions working in this field. The questionnaire forms have been collected between December 2017 and July 2018. A report on the results of the questionnaires is included in Annex 3 of Deliverable 3 of MetroRadon project.

The focus of the questionnaire was on three main topics: characteristics of indoor radon survey – design; measurements methods; data management, statistical treatment, aggregate and mapping. Moreover, in section 5 "Policy on Indoor Radon", some information have been collected about how EU Member States intend to transpose (or have transposed) the latest Basic Safety Standards Directive into national law and hence about RPA. This session was addressed only to national authorities.

Figure 2 reports the role in the organization of the respondents to the questionnaire, in which multiple answers where possible. The majority of respondents are specialists/expert and researcher, only two covering policy function, while seven regulators. Therefore, it seems that in radon field the technical roles (Specialist/expert, researches) are separate from the policy function-regulator roles.

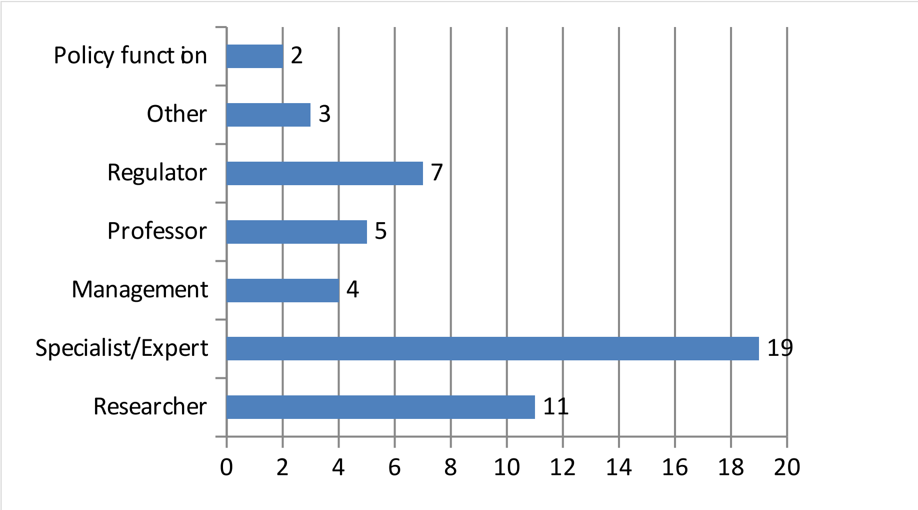

Figure 2: Role in the organization of the respondents to the MetroRadon questionnaire.

Austria

The requirements of the EU-BSS in the field of radon protection are transposed into Austrian legislation via a new radiation protection act (Republik Österreich, 2020) and a specific radon protection ordinance. The national authority responsible for radiation protection is the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK, Status August 2020), which is the leading organisation to implement the EU-BSS into Austrian national legislation. Austria has nine federal states with federal governments and administrations and important parts within the field of radon protection are under the responsibilities of the federal states (buildings legislation, protection of workers). Therefore, the authorities of the federal states are important stakeholders and were involved in working groups in the process of the implementation of the EU-BSS. Building legislation is under the responsibility of the federal states, but the Austrian Institute of Construction Engineering (OIB) issues guidelines to harmonise the construction engineering regulations in Austria. Those guidelines are adopted by the federal states into their construction laws. Thus, the OIB is an important stakeholder in radon protection, and they included recommendations regarding radon protection in their guidelines.

The delineation of RPA was done on a national level, based on the measurement campaign and methodology described in chapter 8. The measurement campaign was financed by BMK and carried out by AGES in close cooperation with the federal states governments and the voluntary fire brigades. The methodology for the campaign and the delineation of RPA was proposed by the radon experts of AGES in cooperation with the BMK, and then discussed and agreed with the stakeholders in a working group (federal states, OIB, other ministries). As described in chapter 8, in Austria so called radon protection areas are established for the mandatory radon measurement in general workplaces (see Figure 5). In addition, a graded approach is planned for preventive measures in buildings, based on the type of area. The municipalities which are classified as radon protection areas or radon prevention areas are listed in the radon protection ordinance. The draft of the ordinance was sent to all stakeholders (federal states, building/construction sector, occupational safety sector, radiation protection institutes, relevant unions etc.) for review and comments in spring 2020.

The concerns about the new radon regulations of the stakeholders from the economic sector (Austrian Economic Chambers, Unions) were, that companies/employers will have a lot of extra costs, with the need to measure radon and remediate, in addition to so many other obligations they need to fulfil and especially in hard economic times, after Covid-19. The importance for radon protection for the health of the employees and the low cost of passive radon measurements and the already existing and tested efficient remediation methods were good arguments in these discussions. But it needs a lot of communication to transport these messages to the relevant stakeholders. As a next step, it will be important to communicate the obligatory radon measurements and the importance of radon protection to all the affected employers/companies. With the new regulation, that all workplaces in ground floor and basement in delineated areas, need to take action for radon protection, a lot of employers will for the first time be faced with radiation protection - e.g. offices, shops, hair dressers, crafts enterprises. To communicate this understandably and effective, will be a challenge. The involvement of stakeholders like the economic chambers and specific unions, which are trusted representatives for these groups, will be necessary.

One major point of criticism from the building sector and OIB within the process of the delineation of radon preventive areas is that it will increase the costs for new buildings, both private dwellings and workplaces. The counter-arguments are that if new buildings are built to the state of the art, there are in most of the cases no additional radon preventive measures necessary and if so, it is normally below 0.5 % of the total building costs. On the other hand, radon remediation and radon preventive measures could also be an additional market for the building industry and therefore a good impact for the economy. To have experts within the building sector for radon remediation and radon prevention a special training course was established by BMK and AGES, in cooperation with OIB and federal states and will be repeated in the next months.

The federal state governmental offices are the responsible authority for the control of radon protection at workplaces. Their major concern was a lot of additional work with the notification process, controlling and evaluation of measures of the radon workplaces without additional resources (staff, budget). In cooperation with the BMK and the federal states governmental offices electronic systems are being developed to simplify the notification process. In addition, the radon measurements and dose assessments in Austria need to be done by accredited laboratories according to standard protocols, to have unobjectionable results and easy control and evaluation by the authorities. Also the training of building professionals will ensure sufficient approved experts available, who provide sound, efficient and sustainable radon remediation.

The delineation of radon protection areas and radon preventive areas also concerns the municipalities. Their concern is that because of higher costs for workplaces (radon measurements, radon remediation) and new private houses they are less attractive. If communication about relatively low costs for workplaces and new buildings is done effectively (see above), then there should not be a relevant disadvantage for those municipalities. It is also important to have the municipalities well informed about radon protection, as the municipalities are the authority to grant permissions for new buildings. Training and information events for representatives of building authorities (local, regional) were organised in the last years in all federal states in cooperation of BMK, federal states and AGES.

In general, the implementation of the EU-BSS in Austria affects a lot of stakeholders and therefore the interest was quite high. It was tried to inform and involve them in an open way, via workgroups, information events, training, meetings and personal communication by BMK and radon experts of AGES. Of course, within that topic, very different roles, interests and views are present and it is not easy to satisfy every stakeholder and take everything into account. In the end, of course, the way of implementation of the EU-BSS is a political decision and always needs compromises between economic interests and optimum health protection, but nevertheless needs to follow the ALARA principle.

France

A local radon action was led by the French Institute for Radiological Protection and Nuclear Safety, in cooperation with 15 municipalities and the “Lycée des Métiers du Bâtiment” in Felletin , a college specialized in building works. This campaign was carried out in an area characterized by a high geogenic radon potential. It started in winter 2015/2016 for two years and was based on a voluntary and individual initiative. Firstly, 729 free radon measurement kits were distributed (10% of homes). The indoor radon concentration was above 300 Bq.m^{-3} for around 70% of the measurements (main room), with 27% above 1000 Bq.m^{-3}. Then the participants were encouraged to find solutions and start mitigation actions to reduce the exposure to radon. Their initiatives were supported with small workshops and control measurements after mitigation were proposed. The final synthesis of this action provides a useful experience feedback for future similar actions in other territories.

Moreover, In the Region “Bourgogne-Franche-Comté” a regional pluralist project has been carried out since 2011, involving different local and national stakeholders (www.radon-qai-fcomte.fr/). The objectives of the project are to contribute to the information, training and support of different target audiences for the management of the radon risk: public, information relays such as doctors and teachers, health and building professionals as well as local decision makers. All the work of this program is carried out in a global perspective of "indoor air quality" and "energy saving" so that all the solutions proposed by the pluralist project are applicable and beneficial for the overall establishments open to the public and private housing. It is also part of public policies conducted at local, national and international level to benefit from synergies, resources and existing tools (example: Regional Health Environment Plan 3 Bourgogne - Franche-Comté, Local Health Contract of the Vosges Saônoises , Home energy renovation plan, etc.).

The different partners of this regional project continued to work together in the Interreg France-Switzerland project named JURAD-BAT (2016-2020) (www.jurad-bat.net). This European project aimed to improve the radon risk management in buildings in the Jura Mountains, at the border between France and Switzerland. The final objective was to develop a new online tool to provide information and propose courses/trainings on radon risk management for different targets audiences (public, building professionals/companies, experts, students, researchers etc.).

Serbia

The Article 106 of the EU-BSS says that “Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive by 6 February 2018”.

The responsibility to establish a Radon Action Plan (RAP) in Serbia is on Serbian Radiation and Nuclear Safety and Security Directorate (SRBATOM). The first step within the RAP was to determine the radiological exposure risk to radon in residential areas and the national reference level for radon. For that purpose, SRBATOM has formed a “radon working group” consisting of academic experts in radon field from all relevant Institutes that will help manage the RAP. The members of Group helped SRBATOM in design and conduction of the first national indoor radon survey. Radon Reference Level (RRL) and RAP are a part of Exposure Situation Management Strategy document. SRBATOM is currently in the process of drafting the Strategy. Taking into account the regular process in Serbia for the adoption of legal documents such as the strategy, it is estimated that RRL and RAP will be implemented by the end of 2021.

Therefore, at this stage of establishing the RAP the stakeholders that are involved in its design are beside competent authority (SRNSSD), different institutions with their academic radon experts.

For the time being, definition of RPA in Serbia does not exist and therefore neither Republic not local authorities are responsible for areas that are at least by radon experts identified as a RPA. Although local authorities, as well as residents in dwellings where high indoor radon concentrations is found, are informed, they do not make any mitigation actions to reduce risk due to exposure to radon.

Full implementation of RAP will be extremely difficult, especially in areas (municipalities) that be delineated as a RPA.

Two examples are given:

1. Distinguished international radon experts have offered a free remediation to residents in certain dwelling, having annual average radon concentration >1.000 Bq/m³, yet it was refused out of fear and not due to financial reasons.
2. One tourist region in Serbia is known for high indoor radon concentrations. Since that gave bad publicity to the region and decrease of number of tourists (at least by interpretation of local authorities) some members of the local authorities have even asked one of the experts to give an interview stating that their area is not an area with high radon concentration.

It is also interesting to mention that some insurance and real estate companies ask about the radon level in the dwelling of interest, although it is not regulated by any regulations. Therefore, once the EU-BSS is transposed into Serbian law, it will influence a wide range of stakeholder, not only policy makers but a lot of different industrial stakeholders.

Having in mind that transposing EU-BSS into Serbian’s law is in progress, Serbia and its stakeholders (from authority to public) will gain a lot from the dissemination of knowledge from MetroRadon project aiming among others to develop strategy to harmonise methodologies and data and to reduce inconsistencies that will help to implement EU-BSS.

Spain

As is the case in different neighbouring countries, the degree of involvement of the stakeholders related with the radon issue has been very uneven in Spain during the last few years. The beginning of the radon activities in Spain dates back more than 30 years, having as main drivers for its development groups of researchers from different universities, among which the University of Cantabria, the University of Barcelona, and the Polytechnic University of Cataluna or the University of Santiago de Compostela had important role. Through research projects funded by the Nuclear Safety Council (CSN) and by European calls, it was possible to establish the fundamental background of the National Radon Plan, such as the elaboration of an indoor radon map in dwellings and the creation of a metrological control system of radon measurements. Along these main lines, very diverse training and dissemination activities were carried out, intercomparison exercises of radon measurement techniques, and specific research projects on radon remedial techniques and exposure in different workplaces such as spas, galleries, tourist caves or tunnels, among others.

Practically until 2001, in which the 1996 EURATOM Directive was implemented in Spain, including exposure to radiation of natural origin in the general framework of radiation protection in Europe, the role of other stakeholders was residual or directly non-existent. Few industries lend themselves to assessing the risks for workers as there was no solid normative basis in this regard during this period. Rarely the media echoed the problem of exposure to radon, resulting in news that was sometimes anecdotal and even imprecise. Likewise, the interest of administrations and governments, both national and local, was scarce, and in the field of construction corporations the problem of radon was not taken into account.

Obviously, the publication in 2013 of the EURATOM Directive has attracted the attention and interest of different stakeholders until today. The explicit definition of the different items that must constitute a National Radon Plan in all member countries has established a clear roadmap for many agents who were not previously involved in the issue. The number of professionals dedicated to radon measurement and mitigation has been increasing gradually, with the incorporation of foreign companies into the market and the creation of new national companies. On the other hand, the recent publication of the latest version of the Technical Building Code, which includes measures to prevent the entry of radon for new or renovated buildings, means that both construction and geotechnical companies are specializing specific radon departments, and even show bigger interest in participating in technological development projects.

It is becoming increasingly common to find news and reports in local and national media about the radon problem. The impact of these broadcasts continues to be uncertain, causing indifference in some cases, or excessive alarm in others. This highlights the need for continued efforts to improve the way we communicate the risk to the general population, and even to the authorities, who normally have never heard about radon.

Finally, it is important to indicate that the maximum responsibility for coordinating the development of the National Radon plan in Spain has been given to the Ministry of Health, which traditionally has not had any competence or experience in this field. Most of the actions contained in the Radon National Plan are supported by the regulatory body, the Nuclear Safety Council (CSN), and by the Ministry of Development. This latter body approved on December 27, 2019 the latest version of the Technical Building Code that contains, for the first time, protection requirements against radon in newly constructed and rehabilitated buildings. For its part, the CSN also approved in December 2019 the entire set of actions that correspond to it within the National Radon Plan.

Germany

Disclaimer:

> *The following text does not represent the position of the BfS, but the experiences and the state of knowledge and its interpretation by the author. Since German radon policy is still evolving, so is its perception, and quite naturally there is no static final position about is viability. The text is intended as a contribution to the discussion which goes along with that evolution.*

Introduction

The German administration seminally engaged in shaping the EURATOM Basic Safety Standards (BSS) since its first drafts around 2010. After final publication (late 2013) and according obligation to transpose it into National Legislation, the new German Radioprotection Act was designed, including radon regulation, and issued 2017 [1]. Work on sub-legislation (ordinance level [2]) including radon Action Plan [3] was finished end

2018 (in compliance with the timeline specified by the EC), which was the point when the entire law came into force. Radon priority areas (RPA) shall be defined by the Federal States by end 2020.

Main stakeholders which actually engaged in the process were:

- Regulator, i.e. the German Federal Ministry of Environment, Nature Conservation, Building and Nuclear Safety;
- Its scientific office, the BfS
- Administrations that have to execute the radon Action Plan; i.e. mainly the Federal States (Bundesländer; FS), which by German constitution are the competent authorities in radioprotection that act on behalf of the State, Art 83-85 GG [4].
- Construction industry (to minor degree)

Stakeholders not really present were health industry (doctors, pharmacists), the radon measurement industry, radon science (universities etc.), media, NGOs and the public altogether, although participation was encouraged on different occasions. Some input came from experts about indoor air quality.

The entire process can be generalized by several phases: weakening initial proposals from the European Commission (about 2011-2013) to interpreting flexible and fuzzy regulations in a sense to render radon regulation as lean as possible (2014-2017): The BSS, which provides for minimum rules (preamble (5)) were mostly implemented in this minimum sense. However, finally a reverse tendency appeared to outweigh the former, which resulted in potentially efficient radon regulation and Radon Action Plan. During the legislative process, elements of the initial strict proposal re-entered. In particular, the Radon Action Plan appears promising from the perspective of radiation protection.

The federal structure of Germany

A key to understanding the complicated process is German federalism. It is deeply rooted in history (see e.g. Wikepedia, 2020c) and laid down in § 20/1 of the German constitution (Grundgesetz or Basic Law). § 30 says that legislative, executive and judiciary powers are with the FSs unless regulated otherwise by overruling State competences. (The relation is somewhat similar to the one between the EU and its Member States, which is characterized by primacy of European Law on the one hand, and subsidiarity on the other.)

Therefore, the representatives of the Länder have a strong say also in radon regulation. National laws and ordinances for radiation protection need the vote of the Bundesrat (the second chamber of the parliament with representatives from the Länder). The Bundesrat can enforce changes in the text or block the process for some time by calling the “conciliation committee” between the Bundesrat and the main parliament, the Bundestag. Regarding radon regulation, to avoid blockage, the Bundesländer were involved in a quite early stage of the political process. As a result of this early involvement, the German delegation at the Atomic Question Group meetings to transform the basic safety standards of the Article 31 Group of Experts (based on Arts. 30- 32 of the EURATOM Treaty, see references) to the draft council directive was required by the Bundesrat to avoid any binding regulation related to Radon at home and workplaces (Bundesrat 639/11, 25.11.2011). In the end, the German delegation was unable to impose this demand on its European partners. But it still succeeded in weakening the very strict first proposal by the European Commission, the be discussed in more detail in section in the next section.

The phase of BSS design, 2010 - 2013

The first proposal for the BSS was issued by the European Commission on 29 Sept 2011. Notable changes in the extant BSS (2013) are:

- Unification of Reference Levels (RL);
- removal of the term “radon prone area” (with the concept remaining, only without naming the areas);
- removal of the obligation to establish building codes for residential buildings in RPAs;
- removal of the obligation to notify the EC about RPAs.

The deletion of the term “radon prone areas” was first criticized by the radon community but then seen as a chance, and around 2012 the now common term “radon priority area” was coined to emphasize the priority concept that underlies these areas (Bochicchio et al. 2017). However, the new term did not enter the BSS text. Intense discussion between EU Member States (MSs) and EC dealt with RLs, their consequences, their relation to the 6 mSv rule, the concept and wording of then so called radon prone areas.

In a meeting between Ministry and FSs in September 2012, the participants agreed that the by then rejection of any radon Action Plans should be weakened since now the list of actions was indicative and not obligatory (and could be repudiated at all, as was added). The obligation to report delineated radon priority areas to the EC was rejected (still included in the BSS draft 15 May 2012, disappeared by 20 Dec 2012). Also, the obligation to define RPAs at all was rejected, including the term “Radon prone area” because of its inherent “stigmatization potential” (the term “particular concerned areas” was proposed instead). On the other hand, the usefulness of radon maps as tool to prioritize action was acknowledged at that point. It was found important that wording of the BSS was such that radon action would remain on a voluntary base. Obligation to remediate buildings in which the RL is exceeded, was rejected. It seems that these positions were fiercely defended in the non-public negotiations with the EC. According information from participants, the removal of the term “radon prone areas” in later versions of the BSS was indeed mainly owed to German pressure.

In the conference “Radon Fachgespräch” organized by BfS, 16 May 2013, the Ministry proudly boasted about its negotiation successes in the BSS preparatory group at the EC to avoid strict and obligatory rules in the articles concerning radon protection. (Although, according to our information, by March 2013 Germany already had withdrawn from some of her initially strict positions.) At the time, most concerned with radon on a technical expert level did not comprehend the rationale of the Ministry, while on its part, the Ministry appeared surprised of the by large sceptic reactions of the experts.

On the other hand, the German delegation reasonably proposed to modify article 103/3 about RPAs that action should be taken more generally in “situations with potentially high exposure to radon”, additionally to RPAs also if “other parameters” justify it (proposal 25 March 2013). This proposal has not been implemented in the final version of art. 103/3, but moved into annex XVIII (2).

As a summary, Germany (together with other MSs) succeeded to some extent to weaken the wording of the BSS, removing as much as possible any obligatory action. However finally, the content was largely saved, mainly owed to the linguistic skill of EC officials to rephrase paragraphs such as to please the advocates of weak regulation while preserving the substance. For example, the mandatory Radon Action Plan (art. 103) remained; the RPAs re-entered the article as par. 3 although removed in intermediary versions in 2012 (e.g. 11 Dec 2012), shifted to the indicative annex. This annex is now not any more labelled indicative, but its points “to be considered” (document 14 Feb 2013).

This tortuous process (mainly in 2013) may explain some awkward and overly diplomatic sounding formulation in the BSS. It seems that neither the process which led to the German positions nor the negotiations in the Article 31 group themselves included active consultation of and scrutiny by the public and stakeholders, although the formal possibility existed e.g. for NGOs, except federal and regional administration. The public was formally involved only in the legislative process, section 3. – Here is not the space for a detailed analysis of the history of the European BSS, which would however certainly be a rewarding endeavour. From today's perspective, some contributions had satirical potential.

National transposition and implementation phase 2014 - 2016

It seems that in the end the federal and regional administrations came to terms with the BSS although its radon regulations were stricter than deemed acceptable by them two years earlier. Energy now was shifted towards transposition into Law, and in particular, Radioprotection Ordinance, which contains the operable rules.

Suggestions of operable rules were prepared by the BfS and transmitted to the FSs by the Ministry. Main critical comments of the FSs were:

- RL=100 (BfS proposal) was rejected as too low, apparently mainly for economic reasons and because it was feared that regionally large fractions of buildings would be affected which would render implementation almost impossible;
- Proposed GRP and RPA maps were criticized because of unreliable or un-representative input data (regarding sampling design and methodology; the arguments are partly correct, but there was little choice but to work with factually available data);
- Methodology (geostatistics and cross-classification to link GRP to IRC) was met sceptically by some. Some doubted the suitability of the GRP as IRC predictor. Partly in response to the critique, partly following scientific progress in the field, methodology continues to be further developed by the BfS.
- Some doubted the practical value of radon maps, because they might led to misinterpretation; they would suggest false safety and not address scale issues. These are indeed serious issues, which deserve further discussion the future.

On the other hand, two FSs claimed underlining the priority aspect in defining RPAs, very much in line with the position of the BfS. This did not enter the next stage of discussion (see also below), but seems to have reappeared about 2018.

Many laid quite some effort onto interpreting the BSS in the weakest possible sense. Apart from usual populism – which is always at hand since EU bashing is a common diversion strategy; however unlikely in this case because the BSS never became a case of public dispute - as reasons one may see scepticism against rampant over-regulation (which is indeed a EU problem, or at least has been one in the past) and secondly, related to it, an attempt to fight the unpopular home-made "Regelungsflut", i.e. the perceived tsunami of norms for each and everything, by trying to abolish one regulation for every new one enacted.

The legislative process was public, as proposals were submitted to a public hearing. Unfortunately, the civil society did not recognize the relevance of the new radioprotection legislation and its bearing to future radon protection policy. (An exception was the "Bund für Umwelt und Naturschutz Deutschland (BUND; Friends of the Earth Germany), which called for an IRC maximum permissible value (instead of RL) of 50 Bq/m^3 which is clearly unrealistic; in fact also counterproductive because this way they practically disqualified in the discussions.)

In the perspective of 2020, German radon policy is certainly not to be called courageous or innovative, but certainly much better than what had to be feared in the earlier phase, as can be concluded from available documents about the decision-making process between administrations and authorities.

Implementation

Reference level

Given the constitutional power of the Federal States and political respects, the Federal Ministry was strongly driven by the interests of the FSs. In the absence of public pressure, the main interest of most FSs (with notable exceptions) consisted in avoiding any radon action to utmost degree. The BfS, on the other hand, tried to defend the interests of radiation protection, which led to frictions with the Ministry, whose subordinate the BfS is. For example, the BfS opted for a reference level (RL) 100 Bq/m² and still considers it scientifically sounder than the RL 300 Bq/m³, which was finally adopted in the radiation protection law ([1] §§ 124, 126) on pressure of administrations. 300 Bq/m³ is the highest allowable choice according to the European BSS (Art. 54/1, 74/1). It corresponds to up to some 15 mSv/a, depending on the dose conversion factor chosen. Indeed, also the very EU-BSS state (preamble (22)), that "a statistically significant increase of lung cancer risk from prolonged exposure to indoor radon at levels of the order of 100 Bq/m³" has been demonstrated. Recently, the BfS seems to adapt its position in reaction to now existing regulation ([1,2,3]).

The hitherto RL=100 Bq/m³ position of the BfS is supported by the WHO (Radon Handbook, section 6.3, p.90, WHO, 2009)). The German Committee on Indoor Guide Values (Ausschuss für Innenraumrichtwerte, AIR, 2020) recommended a RL=100 Bq/m³ in its session 4/5 November 2014 (AIR 2014; agenda 3.2). The policy of the AIR is to set the concentration RL for carcinogens corresponding to a maximal lifetime risk 10^{-6}. For IRC, this would correspond to unachievably low radon concentration in the order of Bq/m³, i.e. equal or lower than typical outdoor radon concentration. In such case, the 95% percentile of the actual frequency distribution is proposed, which is about 100 Bq/m³ in Germany and thus happens to coincide with the WHO RL. However, since this corresponds to risk $1.7\ 10^{-4}$, i.e. far above the target 10^{-6}, according to the AIR, optimization should be attempted also below 100, as far as feasible, and robust data about the statistical distribution of IRC in Germany should be generated.

In the Radioprotection Act ([1], §5 (29)) the definition of RL is weaker than in the BSS. The Act states: A RL is a value which serves as reference for checking whether a measure is appropriate. In the BSS (Art. 4 (84)): the RL is the level, "above which it is judged inappropriate to allow exposures to occur as a result of that exposure situation".

Radon priority areas and priority aspect

Priority concept

The main question of conflict was, and continues to be by mid 2020, delineation of radon priority areas. In the new German radioprotection law, the priority aspect (e.g., BSS art. 7/1, Annex XVIII (6), implicitly preamble (36) about "graded approaches" and definition of RL, art. 4, definition (84) as, while exposure above RL is "inappropriate", it does not say that exposure below RL be "appropriate", and Bochicchio et al. 2017) was practically ignored in the paragraphs about RPA, although this appears quite fundamental in the BSS, as it is in radioprotection altogether (a consequence of the ALARA principle). In an earlier draft (shown in a presentation in a meeting June 2013), Annex XVIII (then still XVI) (2) still explicitly used the term "priority", but this has disappeared later (We can at the moment not say on whose initiative this happened). In the Radioprotection Act ([1] § 121) RPAs have no particular name, but are unofficially termed radon prevention (provision, precaution) areas (approximate translation of German "Radonvorsorgegebiet"). Some interpret this term as an implicit reference to the priority concept.

In consequence, RPA thresholds were practically understood by both Ministry and administrations (but not by the BfS, and although not stated in the Radioprotection ordinance, [2]§ 153, nor in the Radon Action Plan brochure [3], p. 9, which explicitly mentions the priority aspect) as a kind of delineation between "risk" and "no risk", which is in stark contrast to reality and to the concept of RPA. *Practical* means that, although of course known that RPA zones represent regions of different degree of risk or hazard (potential risk), "green" areas were understood as ones which would not require any action. In contrast, the RPA concept consists in defining areas which for pragmatic reasons (i.e. limited resources, such as measurement and remediation capacities) should be considered first; one natural choice is areas, in which the frequency of high-radon dwellings is increased; hence the conceptual RPA definition of the BSS (article 103/3).

Similar to the Radon Action Plan brochure, in October 2020, a presentation by the Ministry at a regional radon meeting (BMU 2020b) summarized the strategy to RPA delineation, as laid down in the radiation protection Act [1], the Ordinance [2] and the Action Plan [3], i.e. the strategy to ensuring compliance with BSS Art. 103 (3) and Annex XVIII (2). In this document, the term prioritization reappears explicitly, additionally stating that this means that RPA status indicates particular need for action.

Proposals for RPA definition

The further consequence of the wrong understanding of the RPA concept was that administrations bargained for as small as possible RPAs. This led to a proposal of the Ministry (elaborated by the BfS, fig.3, upper left), defining RPAs as areas, in which with 90% confidence, dwellings would have frequency RL>300 of 10%. Non-RPAs were areas in which with 90% confidence, the same frequency would be <10%. The undecided area between the two (yellow in the figure) was meant to be left for further investigation. The proposal was meant to serve for planning but not for public risk communication. Classification with more than two levels (RPA / non-RPA) was not wanted from the beginning, probably for the sake of clarity, although in principle possible in the BSS.

Even this very un-conservative approach was not accepted. It is un-conservative, because a probability 90% to see an effect (RPA status=yes) means, in statistical terms, that the first kind error chance (i.e. labelling an area RPA although it is not) is at most 10%. This implies, on the other hand, that the second kind error chance is high, almost 60% in this case, that is, with 60% probability a true RPA may not be recognized as such. The suggestion led to an RPA map, Figure 7 in section 8 (Case studies; Germany) and Figure 3, upper-left.

The idea of basing limits of RPA on misclassification probabilities was skipped early 2019, as it became clear that some FSs would not accept it. Instead, the Ordinance ([2]§ 153 (2)) now says: The competent authority can assume that the annual mean IRC in living spaces (includes dwellings) and workplaces exceeds the RL in a significant number of buildings (i.e., that it is RPA), if based on a scientifically founded prediction, in at least 75% of the territory of an administrative unit (municipality or district, to be defined by the FSs) one can expect that in at least 10% of buildings of the RL is exceeded.

How this is determined is left to the FSs which are the competent authorities; the GRP prediction map (generated by the BfS) serves as guidance. Also, how it is decided whether the RL is exceeded in 10% of buildings, or likewise, how large the exceedance probability is in a given administrative unit, is not ordained, except that it be based on a scientific method ([2] § 153 (1)).

Methodology is however crucial if the RPAs are defined based on the GRP. It remains to be seen how the FSs will implement this paragraph of the Ordinance; there is chance that it leads to RPAs which are actually more conservative than the ones of the first proposal; first promising attempts have been shown (Heinrich et al. 2010; Sachsen 2020). The 75% rule has no scientific base and is not supported by the BfS. During discussions some FSs asked for a more conservative rule (e.g. 50% instead of 75%). Instead, the BfS proposed that regional authorities consider local circumstances that are only assessable locally, such as, which part of a municipality or district is actually built-up area, or presence of local peculiarities like mines, tunnels, small-scale geological features etc.

Summing up, the latest, but perhaps not last state of the RPA discussion is that Federal States themselves decide about the criteria on how to define RPAs, guided by a national GRP map issued by the BfS. Probably this will lead to a patchwork of RPA definitions. This procedure is scantily supported by radioprotection considerations and has little scientific base. Rather, it appears to be the outcome of political haggling. The final decision should be published end-2020, following the Radioprotection Act ([1] § 121 (1)) which says that the RPAs shall be defined before 2 years after publication of the Radioprotection Ordinance [2].

At the time of writing (September-October 2020), in spite of the reluctance, not to say resistance, of the FSs in previous phases, their contributions became increasingly constructive and cooperative for about 2-3 years, so that currently slight optimism prevails about their role in achieving an efficient radon mitigation policy. On the other hand, the in tendency misunderstanding of the RPA concepts seems to persist and negotiation about every m² labelled RPA - or rather not - has sometimes absurd traits.

Individual and collective protection

Implementation of the BSS in the legislation mainly considers protection of individuals by caring for high individual exposures (through establishing a RL and obligatory measures in RPAs), but less so for collective exposure which causes an overwhelming fraction of risk attributable to radon, although called for by BSS article 5b and in spite of annex XVIII (13), saying that the long-term goal of radon action is reducing lung cancer risk, and in spite of section 122 (1) and (4) of German Radioprotection Act [1].

This objective is also addressed directly in the title of the radon Action Plan brochure [3], "for the sustainable reduction of radon exposure" and later (p.7f.) "The measures presented below are intended to sustainably reduce the number of lung cancer cases caused by exposure to radon..." (cf. BSS Annex XVIII (13)); also indirectly, in that the population has to be informed about radon risk and mitigation possibilities, hoping that this would eventually lead to reduction of collective exposure. Also including the building industry in the implementation process is expected to serve this end.

Applying the priority principle to protection of the public and taking the goal seriously to reduce health impact would lead to priority action in areas with high collective exposure per unit area, i.e. basically, where the product of RL exceedance probability and population density is high (This RPA concept has first been proposed by Elío et al. 2018). Examples of tentative maps of PPAs according these considerations are shown in Figure 3. The Radon Action Plan brochure [3] responds to the call to reduce mean exposure only by announcing information of the public, and that radon protection "should become an aspect to be considered in quality assurance and financial support measures for construction projects" (following BSS Annex XVIII (12)). (pp. 8, further expounded p. 18).

Radon Action Plan

It was attempted to include the topics of the list "to be considered" of BSS Annex XVIII into Radiation protection Act and Ordinance. This is explained in a brochure issued by the Ministry in 2019 [3], further discussed in section 6. Some interpret this strategy as potentially even stronger than the BSS (which, ironically, years ago Germany attempted to weaken).

On the other hand, measures and targets sometimes appear vague and rather calling for good will than for legally founded action. For example, it says (p.7) that “it should be sought to keep exposure as low as reasonably achievable, also below the reference level” (which correctly addresses the topic of collective exposure). It is true, however, that linking targets and measures which are by nature political, such as public information and support of further research, to quantitative margins is difficult. Referring to the above example, defining quantitative, legally based action which would reduce collective exposure and risk for a certain percentage, is impossible with today’s knowledge, and probably also legally difficult as it would imply encroaching upon many different areas of law. Still, one may have slight doubts about the efficiency of measures which largely rely on voluntary action or information, given that radon prevention, and even more so, mitigation and prevention costs money. However, the possibility of financial support for such action is under “review” ([3] p. 18).

Again on the other hand, evaluation of the law is obligatory which some interpret in the sense that the legislator understands that final wisdom on radon policy has not yet been found.

Regarding evaluation, the BfS has been commissioned to provide quantitative metrics for assessing the efficiency of radon action.

Political constraints

The political respects mentioned above are the following:

- Being labelled RPA might lead to an area being less attractive for investment, tourism and property value. In the discussions, the term “stigmatization” has been used recurrently. (This is due to bad experiences which have been made with sensationalist media coverage of legacy contaminated sites mainly in former East Germany.)
- Radon action which is obligatory in an area labelled RPA costs money (measurement in work places and public buildings, possibly remediation (BSS article 54/2, annex XVIII (7), preamble (25)).
- “encouraging“ (BSS wording) radon prevention and remediation in dwellings in general (art. 74/2, annex XVIII (8)) and with priority in RPAs (annex XVIII (6)); in practice this means (although not said explicitly in the extant BSS, in contrast to the first proposal of 2011) implementing construction codes also for residential buildings. This may have effects which represent partly competing, partly coinciding stakeholder interests: (1) additional costs reduce profits of property investors; (2) they increase costs for tenants. Both is politically undesired, if for different motives. Disentangling them is difficult (not only) in this particular case.

It is true that according the BSS (preamble (42), article 5, annex XVIII (14)), in designing the Radon Action Plan (BSS preamble (23), article 103), radioprotection concerns should be deliberated against societal aspects. This also corresponds to the ALARA principle. Naturally, every decision represents a compromise between stakeholder interests; however, the deliberation which leads to the compromise has never been demonstrated by administrations.

Since there is no public pressure on the administrations, the impression remains that they decided to rate economic and political arguments above health arguments, in general. In other words, there seems to be a certain under-explained asymmetry between stakeholder interests. Future discussion will tell whether or to which degree this impression is correct, and how administrations will defend their decisions in the case of the public or NGOs eventually waking up on the radon issue.

Communication

Responding to Annex XVIII (10), a brochure has been issued in 2019 in which the Radon Action Plan is presented and explained [3] (see also above).

- Reference level: 100 Bq/m³, as also favoured by the BfS in accordance with WHO (see above) is said not to be feasible “due to specific national circumstances” (p. 7), without naming them. The choice 300 Bq/m³ is not further explained.
- Radon priority areas: The actual definition and methods of their determination is not included, probably because this was still under discussion at the time of publication. Assessment shall be reviewed every 10 years and / or (not clear) if the database has improved (p. 15, further p. 24; [1] § 121 (1)). Ironically, in the English version of the brochure the term “radon prone area” reappears, whose purging from the BSS was a non-negotiable condition of Germany few years ago. Additional measurements of ground and indoor radon have already be performed during 2019-20 and entered the new GRP map proposed by the BfS in autumn 2020 (unpublished as yet, Oct. 2020). Further quite large measurement campaigns are ongoing or planned for the next years, including creation of a nationally representative IRC database that shall serve as reference to validate the effect of radon action.
- The Plan includes a quite extensive list of measures for radon prevention (new buildings) and mitigation (existing buildings). The measures are sound; see however in the radon action plan section on considerations about their efficiency.

Altogether, this brochure is well done. Its structure essentially follows the issues of BSS Annex XVIII. It also contains a timeline for the implementation of measures (a kind of to-do list) which follow the requirements of the Plan (p. 14 and p. 26ff.). On the other hand, critical and potentially controversial topics are not discussed, i.e. choice of RL, definition of RPAs, deliberation of radioprotection against economic (and other societal) factors (this point is not addressed at all).

As another element of information to the public, a folder has been released, BMU 2020a. In several FSs, radon information brochures have been published for some years.

Summary and outlook

Evidently, radon policy is a long-term endeavour. Hence only an interim conclusion is possible by autumn 2020. In this contribution, we described an about 10 year’s journey from almost fundamentalist refusal of mandatory radon policy over partly controversial discussions between German administration and the EU and between stakeholders within Germany to a respectable albeit not overly courageous result. However, its efficiency in meeting the overall target of the BSS, namely reduction of radon risk, remains to be seen in the future. It will certainly not least depend on the participation of stakeholders, in particular of the general public and the civil society.

The first draft of the BSS seems to be from 24 February 2010. The documents are found in https://ec.europa.eu/energy/topics/nuclear-energy/radiation-protection/scientific-seminars-and-publications/group-experts_en. The first version which resembles the final version seems to be from September 2011. It is found in https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0593:FIN:EN:PDF

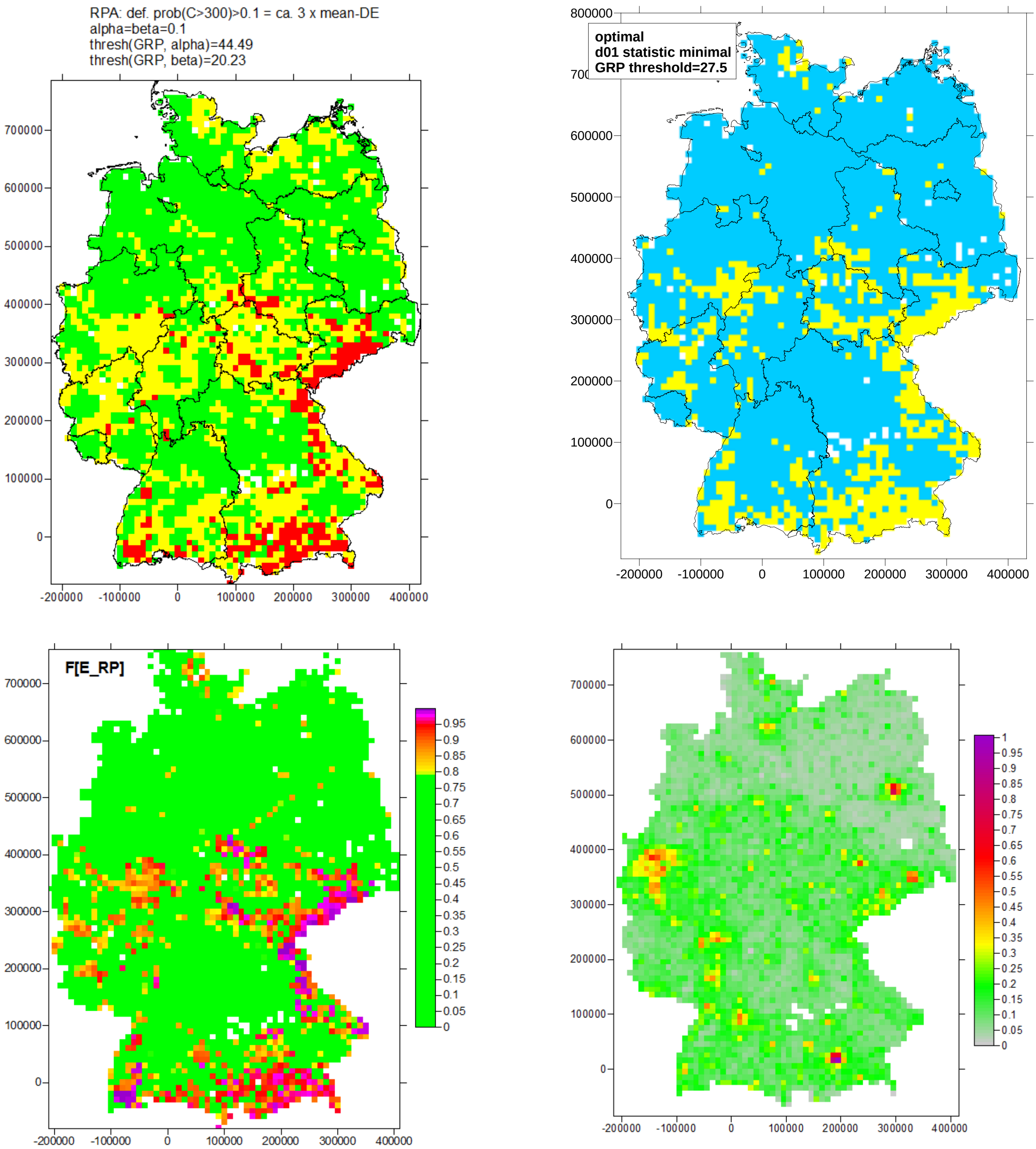

Figure 3: Upper left: BfS proposal for RPA, 2016 (see also section 8, case study Germany); Upper right: Classification RPA (yellow) optimal according d01 minimization in ROC space; Lower left: percentiles of the GRP; Lower right: distribution of the collective exposure (scaled to unity). (All based on the GRP map 2013; 10 km × 10 km cells; white cells: not assigned; axis units: m. The GRP map based on data available mid-2020 looks slightly different.)

References to German legal and government documents:

[1] https://www.gesetze-im-internet.de/strlschg/ ; Concerning radon: part 4, chapter 2, paragraphs 121 - 132; issued 27 June 2017, latest amendment 19 June 2020; English translation: https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Gesetze/strlschg_en_bf.pdf

[2] http://www.gesetze-im-internet.de/strlschv_2018/ , Concerning radon: Part 4, chapter 1, sections 1 and 2, paragraphs 153 – 158; issued 31 December 2018, latest amendment 27 March 2020; English translation: https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Gesetze/strlschv_en_bf.pdf

[3] Radon action plan for the sustainable reduction of radon exposure. Published by Federal Ministry for the Environment, Conservation and Nuclear Safety (BMU), Division for Public Relations, Online Communication and Social Media, 2019. www.bmu.de/publikation/radon-action-plan/

[4] German Grundgesetz (de facto constitution): Basic Law for the Federal Republic of Germany, English version: https://www.gesetze-im-internet.de/englisch_gg/index.html

6. RPA derived from dwellings vs. workplaces

Motivation

A particular problem consists in the fact that the legal and administrative consequences of having an area declared RPA concern workplaces and public buildings in the first place (BSS Art. 54). On the other hand, RPAs are, in most cases as far as known, defined per indoor concentration in dwelling and estimated from indoor data in dwellings. The reason is that most data are available for dwellings. So far, radon data for workplaces (except schools) and public buildings are scarce.

Apart from this practical reason, there are many different types of workplaces and public buildings. Even hypothetically located on the same site and thus subject to the same geogenic radon influence, their "building physics" concerning air circulation and radon accumulation and dilution, is very different among them, and from the one of residential buildings, and consequently their indoor radon concentrations. It is evident that, say, schools, shops, police stations, ancient castles, workshops, metro stations, industrial production halls, museums, etc. etc., have different physical characteristics and have little in common, apart from being workplaces. A typology of workplaces regarding radon is still missing. It is therefore not clear, how correct or adequate RPAs derived from residential buildings and dwellings are with respect to the RPA definition applied to workplaces altogether or to a certain type of workplace. Also in this case discussion is ongoing. Among literature comparing workplaces and dwellings is Bucci (2011) and Žunić et al. (2017) and references there.

Methodology

In order to compare radon levels in dwellings and in workplaces in a given area and to evaluate if they have different distributions and different mean levels an international pilot study has been initiated in 2018. An expert group under JRC umbrella is working on data (radon annual activity concentrations in dwellings and workplaces) provided by Austria, Italy, Germany and Finland.

The discussion among experts is ongoing with the aim to identify a suitable methodology and the national available datasets are adequate for statistical analysis, the coverage of territory (national, regional) and the measurement methodology (e.g. measurement duration). Nationally, available data sets consisted in radon annual activity concentrations in dwellings and radon annual activity concentrations in general workplaces (Italy and Finland) or in particular kind of workplaces, such as administrative buildings, schools and kindergartens (Austria and Germany). Moreover, in case of Finland and Italy database covered the entire national territory, while in case of Austria and Germany the available data were on regional scale (Upper Austria and Saxony).

Another question regarded the influence of inhomogeneous methodological aspects: for example, the duration of sampling and period of sampling (season) and the order of magnitude of available data (sample size). In Table 1 a summary of the main characteristics of national datasets is given.

Table 1: Summary of the main characteristics of the national radon datasets

	Italy	Finland	Germany	Austria
Duration of measurements/ dwellings	12 months	60-70 days	4 – 12 months	6 months (*half winter half summer*)
Duration of measurements/ workplaces	12 months	60-70 days	12 months	3 months for schools 6 months (*half winter half summer*) for administrative buildings
Workplaces included in the dataset	General workplaces (*including administrative buildings, schools, kindergartens)*	General workplaces (*including administrative buildings, schools, kindergartens)*	Public buildings (*administrative buildings, schools, kindergartens*)	Public buildings (*administrative buildings, schools, kindergartens*)
Sample size (dwellings/workplaces)	15.000/9.500	200.000/6.000	1.700/300	7.000/2.000

Workplace data have been aggregated in the same grid as already done on data related to dwellings to update of the European Indoor Radon Map (EC, 2019), based on 10 km × 10 km grid cells. The same statistics were collected, viz. AM, SD, AML, SDL, Median, Min, Max and number of data n (AML(x)=AM(ln x)=ln(GM x), SDL(x)=SD(ln x)=ln(GSD x)).

In this way, two structurally equal datasets were generated, which can then be compared statistically.

Results

Analysing national datasets, dwelling and workplace datasets have a different frequency distribution of sample size (dwelling and workplaces) in cells (see Figure 4): typically, dwelling datasets have a higher number of radon measurements in cells; the range of frequency classes is very wide (from some tens to several hundreds of samples in a cell). Conversely, in workplace datasets radon measurements are few compared to dwellings and the size is generally 20 up to 80 samples within a cell.

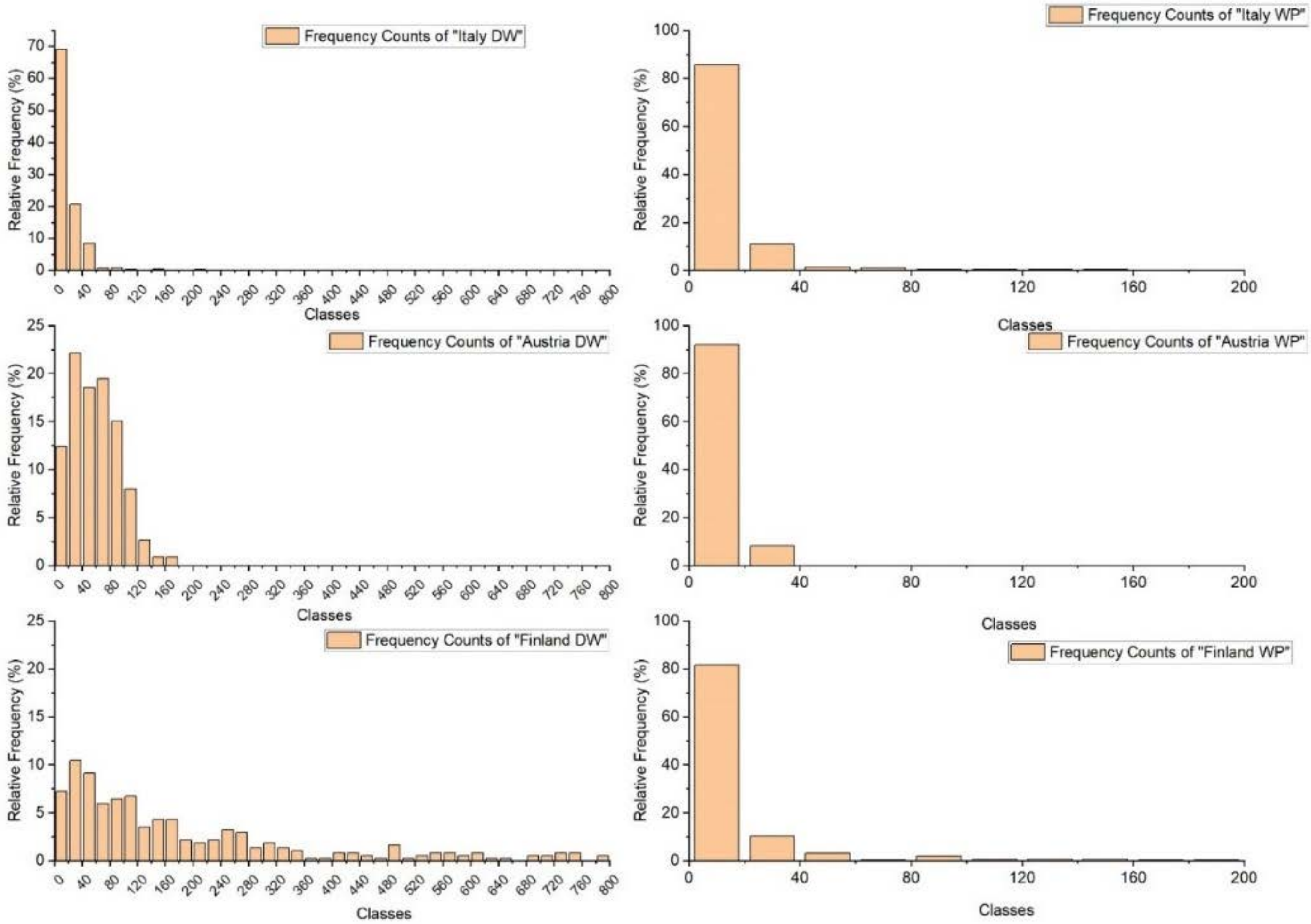

Figure 4: Frequency distribution of sample size in cells in each national dwelling and workplaces dataset (Italy, Austria and Finland)

Among statistical parameters, the AM(ln) and SD(ln) are good parameters for statistical analysis, when there is no information about the distribution of data (radon annual average concentration) within cells. On national final datasets, the dwelling and workplace data were compared - as paired observations - by using statistical tests (Student's t-test, in case of normal distribution of parameters, or Mann-Withney’s non parametric test).

First results put in evidence that radon levels in workplaces and dwellings are statistically different: as considering the effect of geology (comparison of data referred to the same grid cell) [paired test], as considering the effect of sample sizes [test on data weighted on sample size].

Moreover, respect to dwellings, in “general” workplaces radon levels are significant lower and more variable, in terms of a wider distribution and greater standard deviation: in Figure 5, as example, the box plot of Finnish AM(ln)s related to dwellings and “general” workplaces (DW/WP)is given. Comparing dwellings and schools, radon levels do not statically differ, even if mean radon levels in dwellings tend to be less scattered than in schools.

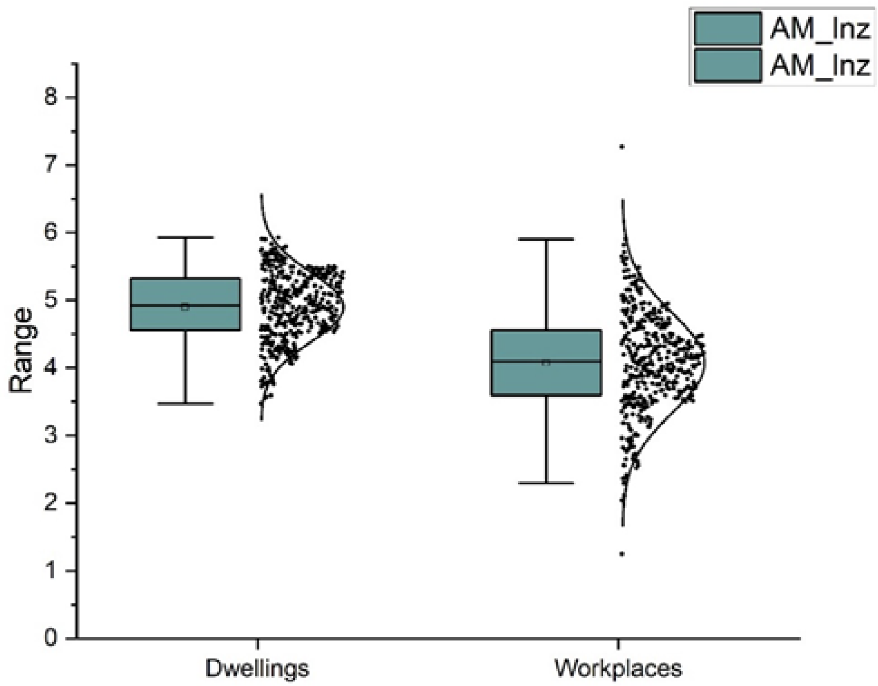

Figure 5: Box Plot of AM(ln)s related to dwellings and "general" workplaces (DW/WP): Finnish data

Hence, dwellings seem more suitable than workplaces to represent radon distribution (less internal variability, less CV, etc.) in a territory (mapping).

Three different linear regression models were tested: the simple regression, the orthogonal (or Deming) regression and the Passing-Bablok regression. Best results were achieved with the application of a linear regression (linear model), in which the radon level in workplaces is a dependent variable while the radon level in dwellings is independent. This analysis confirmed that dwelling sample size and workplaces sample size are independent variables: in all countries, participating to the pilot project (Austria, Finland, Germany and Italy), radon levels in dwellings and in workplaces seem have a statistically significant positive correlation. It means that when the radon levels in dwellings increase, radon levels in workplaces increase, too.

In conclusion, the international pilot project, still ongoing, showed that in the same area the distributions of radon in workplaces and dwellings are statistically different and positive correlated: this phenomenon has to be taken into account in the RPA identification since it introduces legal and administrative obligations in workplaces and public buildings located in areas declared RPAs. Further details about the "cross-usage of concepts" are discussed in chapter 7.

7. Cross-usage of concepts

As discussed in the previous chapters, different concepts and definitions of RPA and methods to delineate RPA exist and are used and implemented in Europe. The purpose of this activity was to evaluate and review the different approaches. But also to evaluate, if and how certain methods, developed in one country for a specific purpose, could be used or adapted for other purposes or in other countries or regions. This is discussed in this chapter, based on the results from chapter 6 and MetroRADON activity 4.4.2, where different mapping methods were applied to the same data and the results were compared.

Cross-usage of concepts - workplaces vs. dwellings

As first example of a cross-usage of concepts, the cross-usage of workplace and dwelling radon data has been tested with the aim to evaluate if different mapping methods deliver similar RPAs.

In particular, in the framework of the pilot project described in chapter 5, national data about radon in dwellings and workplaces were used to run an exercise focusing on one possible definition of RPA (i.e. 10% above 300 Bq/m3): results were evaluated „consistent“ or not by means several parameters. The exercise involved data from Austria, Finland, Germany and Italy: a summary of main results is in .

In , it can be observed that Finnish and Austrian results show a similar trend, as well as Italian and German ones. For Finland and Austria, the proportion of positive cases (TPR= True Positive Rate, in other words, is when an area is defined RPA as from workplaces as from dwelling data) is very high (>80%): this is a measure of the *sensitivity* of the RPA estimation method; however, the proportion of negative cases (TNR= True Negative Rate, that is when an area is non-RPA from workplaces and non-RPA from dwellings) is in the range 30-40%: this means that at the same time the method is not very *specific*.

In case of Italy and Germany, the trend is opposite. Indeed, the proportion of positive cases (TPR) is around 45% and the proportion of negative cases (TNR) is very high (near 90%): in these cases, the RPA estimation method is not very sensitive but highly specific.

Logically, where the estimation method is very *sensitive*, the percentage false negative case (estimated by FNR - False Negative Rate, that is the proportion of positive cases - RPA from workplaces - are wrongly predicted negative or predicted non-RPA from dwellings), is low and viceversa.

Analogously, if the method is very *specific*, the number or percentage of false positive case is high: it is expressed by the FPR values, (FPR= False Positive Rate, the proportion of negative cases - non-RPA from workplaces - which are wrongly predicted positive - RPA from dwellings-).

In all countries the „*precision*“ of the RPA estimation method, expressed by PPV (PPV= Positive Predicted Value, that is the proportion of positively predicted cases on the base of dwelling data, which is confirmed by workplace data) is in the range 40-60% and the accuracy (ACC), which accounts for true positive and the true negative cases, ranges between 55% and 78%.

Running the same excercise with other two different criteria (5% and 15% above 300 Bq/m3), it is possible to observe the robustness of the RPA estimation methods. A synthesis is given in Table 3. In the table only the main parameters are shown (TPR, TNR, PPV, ACC).

Typically, different criteria influence all parameters (sensitivity, specificity, precision and accuracy) but do not change the order of magnitude of each single parameters: in general, the trends observed by using the first criterion (10%) is confirmed with few exceptions.

Table 2: Results of a cross-usage of dwelling and workplace radon data to estimate RPAs. TPR: True Positive Rate; FNR: False Negative Rate; TNR: True Negative Rate; FPR: False Positive Rate; PPV: Positive Predicted Value; FDR: false discovery rate ; ACC: accuracy; FOR: False omission rate.

	sensitivity		**specificity**		**precision**		**accuracy**	
	TPR	**FNR**	**TNR**	**FPR**	**PPV**	**FDR**	**ACC**	**FOR**
FINLAND	87%	13%	40%	60%	51%	49%	59%	19%
AUSTRIA	81%	19%	35%	65%	42%	52%	55%	28%
ITALY	45%	55%	89%	11%	58%	42%	78%	29%
GERMANY	44%	56%	86%	14%	67%	33%	70%	17%

Table 3: Comparison of a cross-usage of dwelling and workplace radon data to estimate RPAs with different criteria of identification of RPAs (5%, 10% and 15% above 300 Bq/m3; respectively). TPR: True Positive Rate; TNR: True Negative Rate; PPV: Positive Predicted Value; ACC: accuracy.

	sensitivity			***specificity***			***precision***			***accuracy***		
	TPR			**TNR**			**PPV**			**ACC**		
	0.05	**0.1**	**0.15**	**0.05**	**0.1**	**0.15**	**0.05**	**0.1**	**0.15**	**0.05**	**0.1**	**0.1 5**
FINLAND	94%	87%	81%	32%	40%	47%	50%	36%	23%	65%	59%	57%
AUSTRIA	94%	81%	71%	18%	35%	55%	51%	35%	24%	59%	55%	60%
ITALY	65%	54%	50%	77%	84%	88%	27%	16%	9%	72%	75%	78%
GERMANY	46%	44%	35%	81%	86%	90%	26%	17%	13%	62%	70%	70%

This exercise is an interesting example of a "cross-usage of concepts": a cross-usage between workplace and dwelling radon data has been tested by using data provided by some countries. The overall results have been analysed and discussed by means of many parameters. They highlighted that RPA estimation methods, based on radon measurements in dwellings, can lead to sensitive but not specific estimation of areas, in terms of RPA, also from a workplaces point of view and vice versa. This experience suggest that each country should carefully consider the distribution of indoor radon in workplaces and public buildings in its own territory, often statistically different from the one in dwelling. This is important, because the definition of RPAs influence further political and technical decisions, such as mandatory radon measurements in workplaces in these areas.

Cross usage of concepts - different mapping methods and RPA definitions

Within the MetroRADON project one task was, to evaluate mapping methods and RPA definitions for their comparability and their usability for other countries, which is another example for the “cross usage of concepts”. For this purpose existing mapping methods used in different countries were applied using harmonised data sets of various variables (e.g. indoor radon, gamma dose rate, geology, soil gas radon). Afterwards the mapping and classification results for the provided data sets in the relevant areas were compared and the usability evaluated. The activity is referred to as “the radon mapping exercise” and is discussed in detail in the MetroRADON activity report 4.4.2, which is also part of the Deliverable D5.

Two data sets were used for the exercise, different in geology, scale, co-variables, etc. to increase the scope and benefit of the exercise. One data set is from an extensive survey in six municipalities in Austria, the second data set is from Cantabria, Spain. The data include indoor radon measurements, building characteristics of measured dwellings, soil air radon activity concentration, permeability estimation, activity concentration of soil samples, ambient dose rate and maps of geogenic parameters derived from other sources (e.g. geology, soil type, airborne radiometry). The data sets differ in basic characteristics as size, sample density, data extent, quality and resolution. Methods to characterize radon priority areas for the two data sets may require adequate data manipulations for different methods. But the comprehensive radon data sets provided in the exercise aim to be a solid basis for different strategies to identify RPAs.

Different mapping methods were applied to the data sets in the exercise. The basic analysis based on indoor radon data showed, that the indoor radon concentration (IRC) distributions differ in the regions of the exercise data sets and the concentrations are considerable higher in Austria than Cantabria. This is of course also true for the aggregates of the distributions that might be used for basic radon risk prediction. Other methods used were a generalized additive mixed model (GAMM), based on the methodology used in Austria for the delineation of radon areas. The idea is to identify relevant explanatory variables to predict the expected indoor radon concentration for a specified grid. Another method was the empirical Bayesian kriging (EBK) regression prediction, which is a geostatistical interpolation with known explanatory variable rasters to affect the value of the data that should be interpolated. Also ordinary kriging (OK) and Indicator Kriging (IK) was used to predict the indoor radon concentrations in areas. The last method which was applied was based on the Belgian radon risk mapping method (BRRMS), which map the variations of the radon risk within geological units with the moving average method, while geological units with significantly different levels of risk are considered separately.

To apply the different mapping methods the data sets may require adequate data manipulations and not all data is used for each mapping method, and also not every mapping method can be used for the data set. In general, mapping methods are mostly specified to use either IRC as target variable (e.g. basic statistics methods, Kriging IRC) or geogenic variables (EBK regression, Kriging GRP). BRRMS, the Belgium mapping method, combines IRC and geogenic variables, by taking into account geological units. The methods using IRC with building characteristics could be only applied for the Austrian data sets, as no information about building characteristics is included in the Cantabrian data set. Only the GAMM method used all available variables as well for the Austria and the Cantabrian data set. Except the basic statistic methods (IRC mean over threshold and probability of IRC over threshold per municipality or geological unit) all methods used interpolations to map the radon concentration or radon potential or radon risk.

It can be summarised that in general, the selection of a mapping method for a certain area, will be highly depend on the available data sets. Not all mapping methods are applicable to all data and all areas as depending on data quality, sample density, heterogeneity of the area, etc. In our example, the methods using building characteristics for the prediction of IRC were not possible to use for the Cantabrian data set, where this information was not available. On the other hand, methodologies based on differences between geogenic factors (e.g. EBK regression) could not be adapted to the very small, quite geogenic homogeneous areas of Austria. Also for the BRRMS, taking into account information of geological units, had problems within the Austrian area with only very few geological areas. All this information needs to be evaluated and taken into account when choosing a mapping method for a certain area or a certain available data set. If a survey for delineation of RPA (as requested in the EU-BSS) is started from scratch, the mapping method and display/classification method for the map (e.g. % above RL in administrative area) should be decided at the beginning, so that the survey (measurement density, analysed parameters, etc.) can be optimised to these requirements. For harmonisation of mapping or delineation of areas (e.g. on a European basis) a method using less parameters might be preferable, as easier to apply to different data sets.

The delineation of radon priority areas is a multiple-step process – collecting and preparing the available data or in practice, performing the measurement campaign to get the data, selecting or developing the best mapping method for the situation and applying it to the data, and classifying the results according to the definition of RPA. As discussed earlier, different definitions of RPA concepts are adapted in the individual countries.

In the mapping exercise it was also evaluated how the different results provided by different mapping methods would have an impact on the classification or delineation of RPAs. As a summary, the chosen threshold for the classification of RPA has a major impact, depending on the level of radon concentration in the area. For Cantabria, which has a very low radon concentration, the differences in the results of the different methods do not impact the RPA classification. Whereas the Austrian municipalities show radon concentrations in the range about 150 to 400 Bq/m³, depending on municipality and mapping method. Therefore, the differences (even when small) in the radon concentration for the different methods for the same municipality can have an impact in RPA classification, when the threshold is chosen in the range of the variability of the results (e.g. 300 Bq/m³, the reference level, established in most of the member states). If the threshold is set with 100 Bq/m³ all six municipalities in Austria are classified the same, as this threshold does not lie within the range of the measurement/prediction results and therefore the variability of the results of the different methods do not have an impact on the classification of RPAs.

Final conclusions about the cross-usage of concepts are made in chapter 9.

8. Case Studies

Austria

In Austria, a radon potential map exists already since the early 2000s, based on radon measurements in dwellings in the Austrian national radon programme (OENRAP, 1992-2001, Friedmann, 2005). The radon potential was defined as an expected radon concentration in a standard situation and characterises the radon risk from ground with the influences of different living situations eliminated. Information about specific construction features, building materials and living style was collected via questionnaires and a standard living situation was defined. A mean radon potential was then computed for every municipality based on the standard situation and the results were displayed as a map with three classes (0-200 Bq/m³, 200 - 400 Bq/m³, > 400 Bq/m³). This radon potential map, only updated with new data over the years, was used for communication and a graded approach for radon protection measures in Austria until present.

The radon map of Austria reflected the geogenic radon potential because of the innovative method of normalising the measurement data to a standard situation. The measurement data on the other hand have the potential for improvement, as different measurement methods were used, including short-term measurements and only few dwellings per municipality were tested.

In the framework of the implementation of the EU-BSS regarding RPA in Austria, it was decided to carry out a new national indoor radon survey, as basis for the reliable delineation of RPA. The survey was carried out between 2014 and 2019 with indoor radon measurements in selected private dwellings of members of the voluntary fire brigades. The voluntary fire brigade in Austria has a lot of members (4 % of the Austrian population) and is well organised, so a nationwide efficient sampling was provided. The dwellings were selected based on the coordinates of the dwellings, according to defined criteria to assure a uniform distributed, area-wide sampling. The main criteria were at least 12 dwellings per municipality and at least 1-3 dwellings per 2x2 km grid cell, dependent on the diversity of the geology. Two measurements were carried out per dwelling in the most used rooms with track-etch detectors for 6 months, half winter and half summer time to represent the annual mean radon concentration. Information about building characteristics was collected via a questionnaire. In total, measurements in about 28,000 dwellings were carried out (about 1% of the dwellings in Austria).

For mapping the radon potential the radon influencing factors (building characteristics, measurement duration, geology) needed to be taken into account. The used approach to generate normalized indoor radon concentrations was outlined by Borgoni et al. (2014) and was applied already in the past in a similar form for the Austrian radon potential map (Friedmann, 2005). A generalized additive mixed model (GAMM) was applied, using the measured indoor radon concentrations and factors as building characteristics and geology. With the model, the radon concentration can be predicted for a selected house type for every location in Austria. For the delineation of RPA a representative standard house was selected and the radon concentration was predicted for each inhabitated 250 x 250 m grid cell. The arithmetic mean of the predicted radon concentration of all grid cells within a municipality is set as the predicted radon concentration for each municipality.

Following the example of the radon potential map of Austria, which has been used for 20 years, the idea is to continue the graded approach for radon protection measures based on the classification of municipalities. The EU-BSS require the delineation of RPA, where measurements in workplaces in the basement and groundfloor are mandatory. In Austria these areas are named “radon protection areas”, and cover all municipalities with a predicted radon concentration above the Austrian reference level of 300 Bq/m³ (Figure 6). 104 municipalities (approximately 5% of all municipalities) are classified as “radon protection area”. In addition, radon preventive measures in new buildings should follow a graded approach, so it is planned to classify the municipalities according to their predicted radon concentration in more detail for different recommended preventive measures.

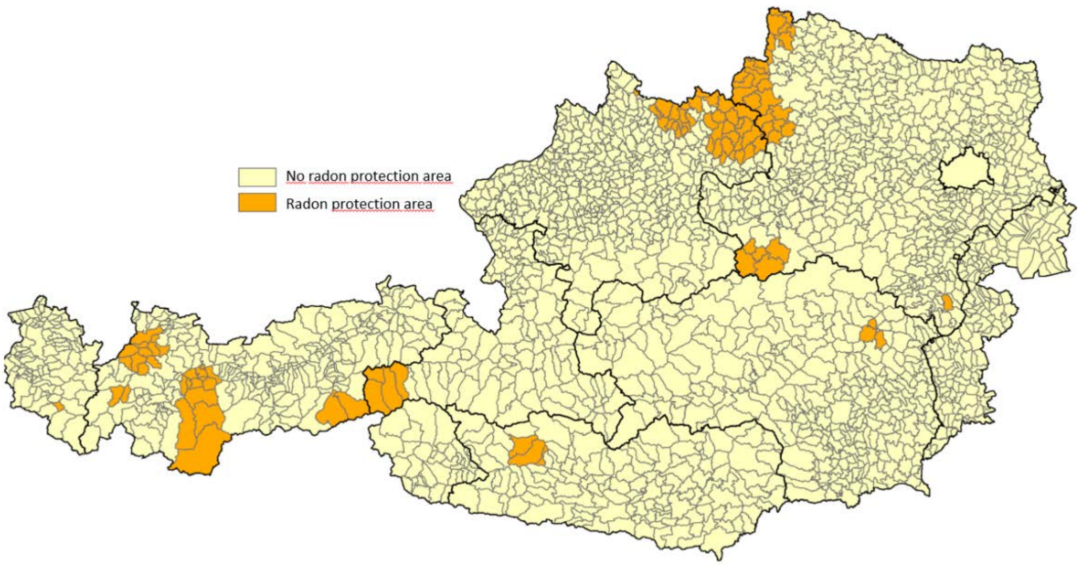

Figure 6: „Radon protection areas“ in Austria (orange), Status September 2020

Germany

The basic definition of RPA in Germany is: an area is labelled RPA, if prob(C>RL)>γ p_1 otherwise, non-RPA, i.e. a binomial scheme was chosen. C – long-term mean indoor concentration in ground floor dwellings of houses with basement, RL – reference level; p_1 – the same probability estimated for the entire territory of Germany. RL has been set 300 Bq/m³, the multiplier γ = 3, and p_1 ≈3%. The definition is in approximate accordance with the one applied by other countries, prob(C>300)>10%. Since the German indoor radon database is fragmentary and insufficient for direct RPA estimation from indoor radon data, the geogenic radon potential (GRP) is used as secondary variable, because a dataset (about 4,500 locations) covering the territory about representatively is available. (This approach has also a conceptual advantage, see above). The task consists in finding a derived or secondary threshold for the GRP, so that classification according this threshold conforms with the (hypothetical) one according the primary RPA definition.

However, the federalist structure of Germany has it that the last word is with the Federal States (Bundesländer). The procedure is laid down in an ordinance which states that the RPAs have to be delineated until end-2020. Therefore, at the time of writing (finalization early 2020) no final answer can be given.

One approach for a gross RPA map on federal level has been proposed between 2016 and 2017 in several stages and is presented in the following. (In this reasoning, the final legally binding RPAs shall be defined on district or municipality level or even below, taking advantage of locally available knowledge about geology and settlement patterns, which central planning on federal level cannot deliver. In the non-assigned areas (yellow in Figure 7), further measurements shall clarify the situation.) For the state of RPA definition in Germany by Sept. 2020, see section 5, case report Germany.

Estimation support is a grid of 10 km × 10 km cells (identical to the grid of the European Atlas of Natural Radiation). The task of finding a secondary threshold of the RPA has been achieved by cross-tabulation, based on for which indoor radon data are available. The GRP has been estimated by geostatistical means including geology as categorical deterministic trend predictor, Bossew (2015).

Additionally, a constraint on estimation confidence has been imposed: first and second-kind classification error rates shall be below 10%. Practical implementation was via a ROC-type procedure on the 2×2 truth table (more details see in D5). The result is factually a trinomial classification, as apart from cells assigned RPA (red) and non-RPA (green) with 90% confidence, some cells remain un-classified, shown in yellow, because confidence is not sufficient.

Being estimates (and hence the RPA being “random objects”, see more details in D5), the class limits have uncertainty. By bootstrapping one finds that the 90% confidence limits for the upper limit are (41.2, 48.0) and for the lower limit, (14.3, 23.5).

An open question consists in the fact that also in non-RPAs a certain risk of indoor concentration above RL is present that would go undetected since in these areas no action is envisaged.

Currently (early 2020), a more refined approach to generating a federal-level RPA map is under way. It is based on machine learning, more specifically by application of the random forest technique. A greater number of geogenic covariates is included, exceeding what is possible with traditional geostatistical means. Higher resolution (1 km × 1 km grid) seems possible. Here, coupling between indoor and geogenic radon is done by logistic regression.

Further, several Federal States have initiated sampling campaigns to fill gaps in soil radon data. These will be integrated into new federal-level maps later in 2020. The results can therefore not be reported here.

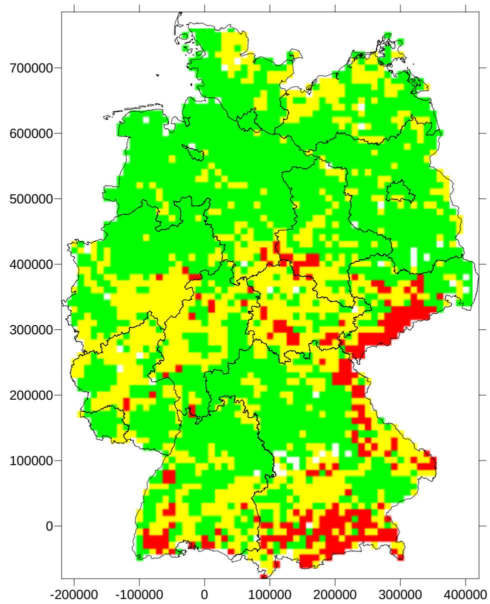

Figure 7: Radon priority areas in Germany (red), defined by GRP>44.5. Green: non-RPA, GRP<20.2. Yellow: undecided.

France

In France, the first maps produced were based on measurements of indoor radon concentration. A national radon survey, beginning in the nineteen-eighties and consisting in more than 10,000 measurements of indoor radon concentration in dwellings, was conducted by the Institute for Radiological Protection and Nuclear Safety (IRSN) in collaboration with the French Ministry of Health. Housing characteristics and information on the lifestyle of the dwelling residents were also collected during the survey. National and regional maps of indoor radon concentration (Gambard at al., 2000) were realized on the basis of this data. The Authorities defined priority areas for radon risk management from the national map of the arithmetic mean of indoor radon concentrations by "department" (district). However, radon mapping based solely on indoor measurements requires a large number of data. In France, some limitations of the above-mentioned national map were discussed (e.g. representativeness of the data, lack of data in several areas/district) and different needs (better precision of the map for local risk management, complementary data) were identified.

For more than 15 years, different studies and research programs have also been realized by the IRSN on the different parameters influencing the radon emanation and transport in the geosphere, as well as on modeling of radon transport in rocks, soils and buildings (Ferry at al. 2001, 2002, Richon et al., 2007, Ielsch et al., 2001, 2002). The results of those studies allowed assisting the Authorities by proposing a complementary method, geologically based, for radon mapping at a national scale. This deterministic and indirect approach was harmonized over the whole French territories and aimed to estimate a geogenic radon potential of the ground. It consisted of determining the capacity of the geological units to produce radon and to facilitate its transfer to the atmosphere, based on the interpretation of existing geological data (uranium content, lithology, petrography, main parameters which control the preferential pathways of radon through the ground as faults, cavities and thermal sources). This methodology has been applied to France (Ielsch et al., 2010) (Figure 8) and to all French Overseas Territories (Ielsch et al., 2014). This mapping supplied of further information in the radon map based solely on indoor measurements. The maps allow defining areas at the scale of the "commune" corresponding to the smallest French administrative unit. They were used to re-define the list of priority areas for radon risk management, by defining a classification of the municipalities according to the radon geogenic potential. This classification is currently used in the French regulation (www.irsn.fr/carte-radon) (Figure 9).

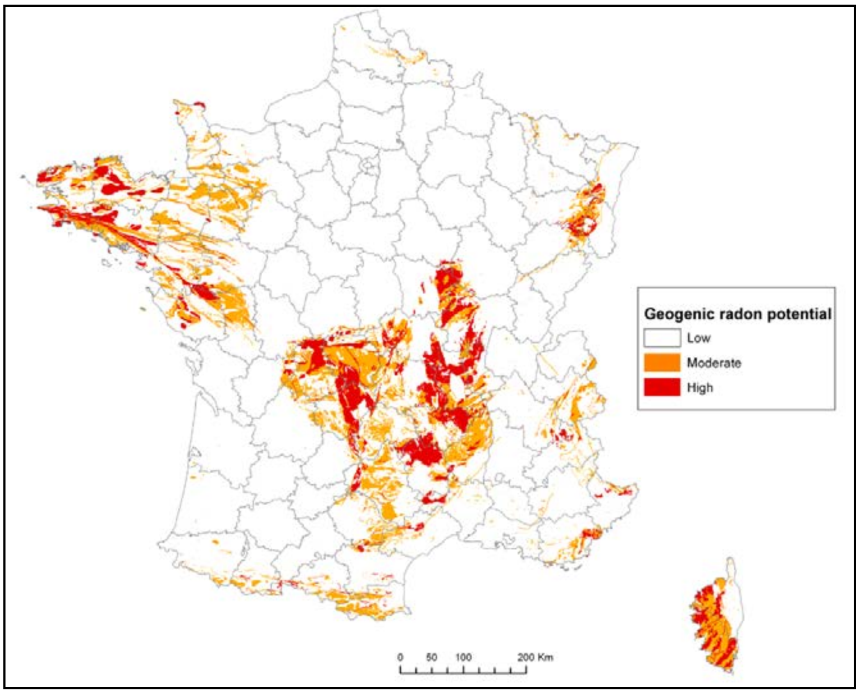

Figure 8: Geogenic radon potential map of France (source: IRSN)

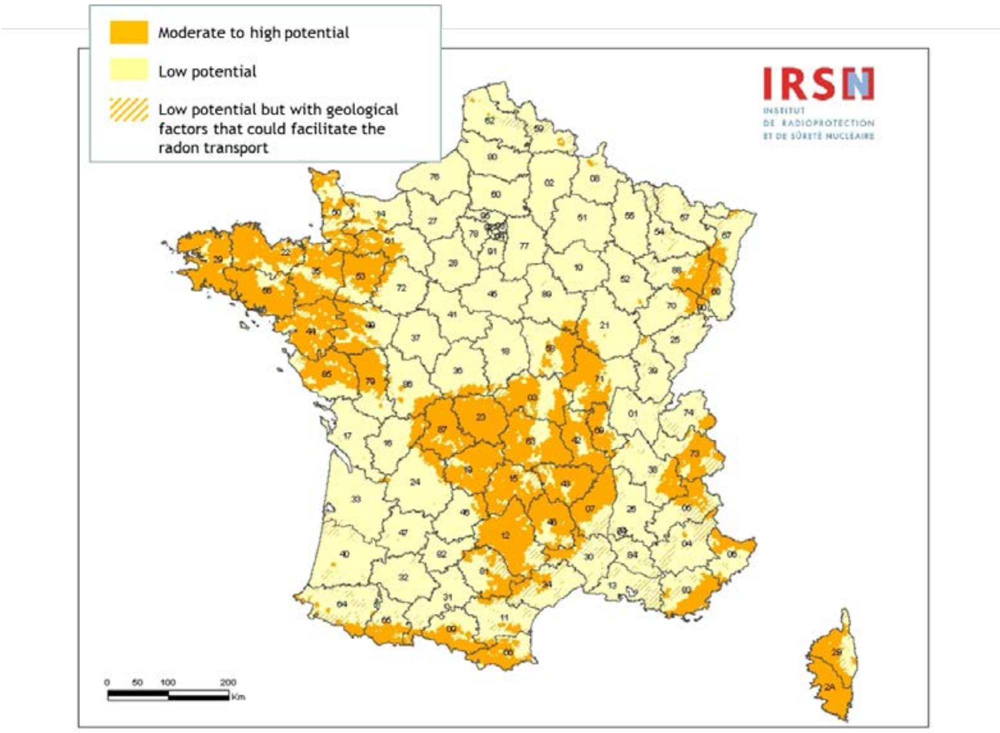

Figure 9: Classification of the municipalities of France according to the geogenic radon potential. (source: IRSN - www.irsn.fr/carte-radon)

More recent studies carried out by the IRSN aimed to combine both datasets, indoor radon measurements from the national survey and geogenic radon potential, by using statistical and geostatistical modeling.

A study notably investigated the factors influencing indoor radon concentrations (geogenic radon potential, house-specific factors and lifestyle characteristics) using statistical modeling (Demoury et al., 2013). The geogenic radon potential was found to have the most significant influence on indoor radon concentrations. The prevalence of exposure to radon above specific thresholds and the average exposures to radon clearly increased with increasing classes of geogenic radon potential. Housing/lifestyle characteristics explained only 7.9% of radon concentration variability. When geological information was added, 20% was explained. The objective of the study was also to determine the optimum use of the information on geogenic radon potential that showed the best statistical association with indoor radon concentration. Combining the datasets enabled improved assessment of radon exposure in a given area in France.

Different geostatistical models (kriging, co-kriging, kriging with external drift) were also tested to obtain more precise estimates of the spatial variability of indoor radon concentration in France and produce maps of probability to exceed different thresholds (100, 300, 400 Bq.m^{-3}) (Ielsch et al., 2015). The results also provided useful data for recent or current epidemiological investigations in France related to radon and gamma radiation exposure, such as lung cancer and other cancers which have been studied more recently (radon and childhood cancers, childhood leukemia, quantitative risk assessment, radon and lung cancer in never smokers) (Ajrouche et al., 2018, Demoury et al. 2013, 2014, Laurent et al., 2013). The data were also used to estimate the exposure of the population to natural radioactivity in France (IRSN Report 2015).

Complementary research program is currently in progress at IRSN to improve the national geogenic map in some particular areas. A regional study is carried out on the impact of karstic areas on the geogenic radon potential. This study combines field investigations and modeling of radon transport by using TOUGH2-Rn code (Saadi et al., 2014, 2015, 2017), from the karstic caves and structures to the soil surface (Greau et al., 2017, Mansouri et al. 2018). Moreover, another study was launched in 2019 in order to determine more precisely the areas that could be concerned by very high radon levels by using statistical and geostatistical tools, indoor radon measurements and geogenic data.

Spain

The Nuclear Safety Council (CSN) is the competent body in Spain in terms of nuclear safety and radiation protection. Its mission is to protect workers, the population and the environment from the harmful effects of ionizing radiation.

The CSN has developed the Radon Potential Map of Spain from the use of the 90th percentile (P90) of estimated radon concentration (CSN, 2017a; 2017b). Each area is grouped according to its P90, given a radon concentration level this means that the 90% of the radon distribution would be below that level and the 10% would be above it. Therefore the Radon Priority Area (RPA) is obtained directly from the Radon Potential Map for the P90 of a radon level of 300 Bq/m^3 established as reference level in the European Council Directive 2013/59/EURATOM.

The Spanish Radon Potential Map has been obtained from three parameters: radon in air measurements in dwellings, the Lithostratigraphic units and the gamma exposure rate map.

Radon in air Spanish database: The database used has 12,000 radon in air measurements in dwellings done in the ground floor. In case of uninhabited house the measurements were carried out in the first floor. In general, the associated risk increases in basements and it decrease about a 20% every floor in flats. Most of measurements were done using passive detectors CR-39 among the period 1991-2016.

Geology: The Lithostratigraphic and hydrogeology Spanish map has included the permeability in order to group the lithostratigraphic units in a homogeneous way, categorizing such units with similar permeability. Lithostratigraphic, permeability and hydrogeological map of Spain developed by the Spanish Geological Survey (IGME) is available at a scale of 1: 200,000 (IGME, 2009).

Gamma exposure rate: The Spanish gamma exposure rate map provides information about the gamma exposure rate expressed in µR/h at 1 meter high from the soil in scale 1:1,000,000 (CSN, 2001). It was elaborated from the correlation between field and aerial measurements within the MARNA project (CSN, 2000). It was used about 250,000 gamma exposure rate measurements from uranium prospecting campaigns among 30 years carried out by the Spanish National Uranium Company ENUSA.

The CSN combined and took into account the three variables presented above to obtain the Spanish Radon Potential Map (Figure 10). Accordingly to the P90, it was established 5 categories: P90 > 400 Bq/m³; P90 (301-400 Bq/m³); P90 (201-300 Bq/m³); P90 (101-200 Bq/m³) and P90 < 100 Bq/m³. Accordingly to this, there are two categories considered as RPA in Spain, where P90 > 300 Bq/m³.

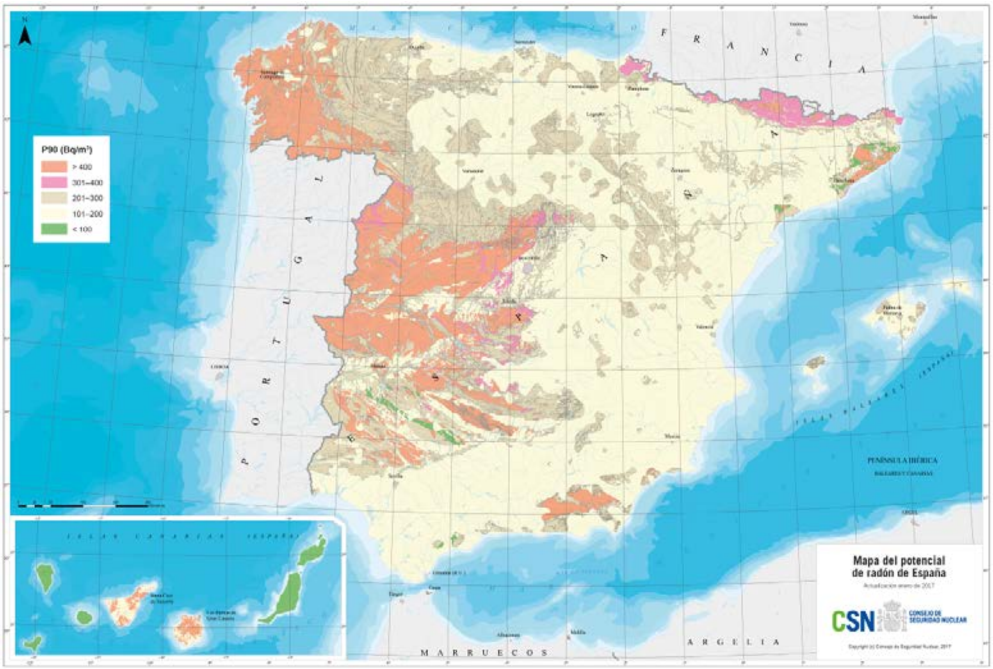

Figure 10. Spanish Radon Potential Map (CSN, 2017a).

Implementation on European level

Earlier knowledge

Discussions about RPA definition and estimation methods are still ongoing in many European countries. Therefore, we cannot give an authoritative overview about this matter. It seems, however, that the most popular definition is of the probabilistic type (b), RPA: prob(C>RL)>p_0 (see chapter 4).

Examples of (b) are Finland, Germany, Greece, Montenegro (also some non-EU members adopted the BSS) and Spain which chose RL=300 Bq/m³ and p_0=10% (for Germany, derived from ground-floor rooms in buildings with basement only; for Spain, from ground or first floor rooms only). Ireland has chosen RL=200 Bq/m³, p_0=10%.

Belgium and Luxemburg chose RL=300, but 3 priority levels, p_0^{I}: prob<1%; p_0^{II}: prob between 1 and 5%; p_0^{III}: prob>5%. Note that this information reflects discussions from 2018 and final legal decisions may turn out different.

Alternatively, some chose definitions of the type (a), i.e., an area is labelled RPA, if the mean indoor concentration in it exceeds the RL. Example is Switzerland, which opted for two priority levels with thresholds 100 and 200 Bq/m³. For comparison, assuming log-normal distribution with GSD=2 within a 10 km × 10 km cell (about realistic by experience), AM(C)=300 corresponds to prob(C>300)=36%. The earlier state of discussion of about mid-2017 has been summarized in Bossew (2017a).

Knowledge acquired in the present project

Evaluation of a questionnaire in the context of the MetroRADON project (more details in chapter 6) (Activity 3.1.2, Annex 3 in Deliverable 3) sent to the competent authorities of all European countries. A short discussion on the replies given to the questions about RPA is reported below.

It reflexes discussions or decisions by about mid-2018. Missing countries: no response, or matter is under discussion. Varying or missing response should certainly not be understood as negligence, but as indication that the subject is considered serious and sensitive, requiring careful deliberation and discussion.

Figure 11 shows the results of the MetroRADON project questionnaire - Question 5.8 *"Have you identified radon priority areas (in the sense of art. 103 of the European Council Directive 2013/59/EURATOM)?"*

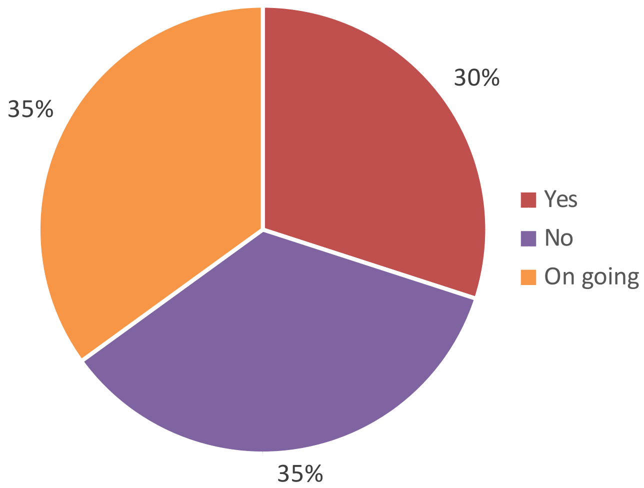

Figure 3: Answers to the question 5.8. of the MetroRADON questionnaire: „ *Have you identified radon priority areas (in the sense of art. 103 of the European Council Directive 2013/59/EURATOM)*

For Question 5.9 *"Which input data have you used to identify radon priority areas/classes?"* the institutions could select select multiple choices between the list:

- Indoor radon data
- Geology
- Radon in soil gas
- Soil permeability
- Gamma dose rate

- Uranium concentration
- Other

All the received answers (16) contained "indoor radon data". In eight cases they used only indoor radon data. In three cases they used also geology information and in the remaining cases they used also radon in soil gas and gamma data.

To the Question 5.10 *"How do you define a radon priority area/class?"* six Institutions reported that the radon priority areas have not been defined yet. 13 Institution described briefly their definition of radon priority area:

- Municipalities, where >5% of the dwellings > RL
- Areas where concentrations of Rn-222 are likely to be higher than average
- Municipalites, where the probability of exceeding RL in the workplace is higher than 30 %
- >10 % of measurements indicate levels above reference level
- The radon potential is estimated with a geostatistical procedure in a grid
- Significant percentage of dwellings exceed the reference level
- 10 km grid square where 10% or more of homes are predicted to have radon levels above the 200 Bq/m3 reference level
- 10 % of all dwellings are above reference level
- Area where more than 5% of the dwellings are above the reference level
- Number of dwellings with concentrations higher than 200 Bq/m^3 exceeds 1%
- NRPA define all of Norway to be a radon priority area
- Municipalities at the radon priority areas are listed in legislation
- % probability of homes exceeding the Action Level of 200 Bq/m^3

Eight institutions answered to Question 5.11 *"Please briefly describe the classification criteria you used"* and their answers are:

- % of the dwellings > RL
- >10 % of measurements indicate levels above reference level
- 10 % excess probability of the reference level
- 10 % of the dwellings above reference level
- Areas where 10% or more of homes have been found to have radon levels above 200 Bq/m3 in the 2002 National Radon Survey
- Administrative regions
- Geology (rock and soil type) in combination with radon concentration measurements
- >1% probability = radon Affected Area (AA)

Nine institutions answered to the Question 5.12 *“How do you apply the classification criteria to your data?”* and reported their applied classification criteria:

- Modelling
- Mathematical model employing neuronal networks
- >10 % of measurements indicate levels above reference level
- The federal states provide and publish lists with administrative areas on the basis of the estimate of the radon potential and own knowledge about local geological formations with high radon potential or other causes for enhanced radon concentrations in buildings (like mining)
- An area is characterized as non-priority area if more than 90% of the measured dwellings have radon concentration lower than the reference level in 90% conf. level
- Data has been mapped to produce a radon predictive map
- Administrative regions
- High Radium-226 content of rock and soil confirmed with average annual radon concentration over 300 Bq/m^3
- Address data is linked to AA probability banding. Information is supplied by address search (on-line by payment) or linked to highest for each 1 km square using GIS (online free of charge or downloadable as a dataset

In Question 5.13 it was asked “*Which action will be/have been taken in radon priority areas?*” The actions that have to be take (or have been taken) in radon priority areas are described by 11 Institutions. Their answers are reported below:

- Preventive measures for new buildings; obligatory measurements in general workplaces in ground floor and basement
- Measurements in workplaces, protection of new buildings
- Obligatory measurement at workplaces on the first floor and in the basement
- At work places, measurements are obligatory
- Obligatory measurements at workplaces in radon areas in cellars and in the ground floor, information of owners and inhabitants of dwellings, building industry, architects and regional and local authorities, to encourage to take measurements
- Public awareness
- Building regulations requiring radon preventive measures in place since July 1998
- Preparation of additional Radon Action Plan for the identified radon priority areas
- Information campaigns
- Communication to increase public awareness, information to local decision makers, additional measurements financed by competent authority, guidance on methods of remedial measures
- Targeted advice and surveys including as part of the buying and selling process. Installation of radon protective measures in new buildings and conversions - as part of the Building Regulations

Tabelle 4: Definition of RPA and support unit in different countries (status mid-2018, basis: questionnaire of MetroRADON activity 3.1.2)

country	RL	support	definition
AT	300	municipality	modelled AM>RL
BE	300	municipality	prob(C>RL)>5%
CY		"area"	AM(C)>national average
CZ	300	municipality	prob(C>RL)>30%
DE	300	"area"	prob(C>RL)>10% with 90% confidence; non-RPA: prob(C>RL)<10% with 90% conf. Remaining: undecided status
FI	200 (dwellings), 300 (workplaces)		prob(C>RL)>10%
GR	300	"area"	prob(C>RL)>10%; non-RPA: prob(C<RL)>90% with 90% confidence
IE	200	10 km x 10 km cell	prob(C>RL)>10%
LT	300	"administrative region"	prob(C>RL)>10%
LU	300	"area"	prob(C>RL)>5%
MT	200		prob(C>RL)>1%
NO			all NO declared RPA
UK	200	"Rn affected area"	prob(C>RL)>1%

A very enlightening analysis of the influence of choice of support (the area unit which is labelled RPA or assigned a certain priority level) has been shown by Fojtiková et al. (2017), on the example of the Czech Republic.

9. Summary and Conclusion

Within this task of the MetroRADON project the motivation and legal background of RPA delineation was reviewed, as well as RPA concepts and definitions. Concepts were illustrated with several national examples. The role of stakeholders, in particular of authorities in RPA definition was addressed and illustrated with several national examples.

As conclusion, it appears that conceptual and theoretical work about RPAs is well advanced. This concerns understanding of the concept, definitions which serve to translate the concept into a workable subject and estimation methods. For the latter, quite a variety has been developed, depending on the data which are available for the purpose. Available data depend on national policies of surveying radon related variables, from indoor concentrations in dwellings to various geogenic quantities, which control geogenic and indoor radon to different extent. Several of these details are extensively discussed in other parts of MetroRADON.

The research on RPA concepts, definitions and development of RPA maps are in general performed by specialists/experts and researchers. Then, the regulators and decision makers have to take decisions that best fits to the country-region based on experts' proposals and advises. These decisions will then affect the population and workplaces. Therefore, it is fundamental that a good communication and trust will be established between the different actors: expert- regulator-population. A fundamental evaluation of all relevant stakeholders and their interests and concerns is very important in the process of implementation of EU-BSS and RPAs. Developing communication strategies adapted to the relevant stakeholder groups and the country specific needs are essential. International associations and co-operations like HERCA, SHARE, ERA and research programs (MetroRADON, RADONORM, etc.) and their recommendations, work and results are very helpful for efficient implementation of EU-BSS requirements, including delineation of RPA and stakeholder communication, in the member states.

An important result is the comparison of residential buildings and workplaces regarding their radon characteristics. These were found to be different, in general. This is relevant, because RPAs are mostly estimated based on data of indoor radon concentration in dwellings, but legal consequences as stated in the BSS largely pertain to workplaces.

RPA estimation methods, based on radon measurements in dwellings, can be sensitive but not specific from the distribution of radon in workplaces point of view, or vice versa. This suggests that each country should carefully consider also the distribution of indoor radon in workplaces and public buildings in its own territory, in general statically different from the one in dwellings.

In the MetroRADON project, statistical groundwork on this topic has been laid, but further elaboration is necessary. This concerns the fact that workplaces are no homogeneous statistical population, i.e. have different radon characteristics between their different types, and the regulatory consequences, which the finding may imply.

Within this task of the MetroRADON project, in the light of a cross-usage of concepts, different mapping methods were compared and the agreement of the different methods was discussed by means of several parameters. As known and shown also within this exercise and this report, mapping methodologies are various and so are the definitions of RPAs. As a general conclusion about the cross-usage of concepts, it can be said, that applying a mapping method using data sets, which were not designed for the specific requirements of the mapping method, is challenging. Usually, data sets always have specific characteristics and are rarely comparable, even not for the same variable. Therefore, harmonisation is always a challenge. In general, the selection of a mapping method for a certain area will be highly depend on the available data sets. Not all mapping methods are usable for all data sets or areas, depending especially on data quality, sampling density, or heterogeneity of the mapping area. For harmonisation of mapping (e.g. on a European basis) a method using less parameters might be preferable, as it would be easier to apply to different data sets.

Usually the final goal of mapping is the delineation of RPA, as this is requested in the EU-BSS. It was discussed, that independent of the applied method for large intervals of classification threshold the same RPA classification is predicted. Different methods often deliver the same results in RPA classification, depending on the definition of RPAs. So, the definition of thresholds is a very important factor in the process of delineation of RPA and might be as relevant as harmonising mapping methods.

The overall results put in evidence the role of the adopted method for the definition of RPA, the set criteria for the definition of RPA and also the radon risk/potential of the country. All those factors influence the reliability and comparability of the delineation of RPAs.

10. References

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