ORIGINAL ARTICLE

Radioactive legacies and radon – recommendation of the German commission on radiological protection

Rainer Gellermann[1]* and Joachim Breckow[2]

[1]Nuclear Control & Consulting GmbH. Hinter dem Turme 24, Braunschweig, Germany; [2]Institut für Medizinische Physik und Strahlenschutz (IMPS), Technische Hochschule Mittelhessen (THM), Gießen, Germany

Abstract

In connection with the legal term of radioactively contaminated sites, the SSK recommended in 2022 that the reference value of 1 mSv effective dose in a calendar year specified in the Radiation Protection Act should be supplemented by a reference value for radon that is independent of this. The SSK suggested applying a reference value for Rn-222 (annual average concentration) of 300 Bq per m³ in buildings and 80 Bq per m³ in outdoor air.

The article describes the rationale for this recommendation and explains the contents of the SSK recommendation from the background of radiation protection conflicts arising from the current system of radiation protection. Because the protection against radon is detached from the dose as the uniform tool of judgment and forms a distinct approach, new problems arise. In particular, the common comparison of additional exposures with natural exposures via the uniform effective dose, frequently used in communication with the public, becomes questionable.

Keywords: *Dose limit*; *effective dose*; *indoor radon*; *outdoor radon*; *public*; *radioactive legacies*; *radon*; *Rn-222*; *reference value*

The German Radiation Protection Act (StrlSchG) (1) implemented Directive 2013/59/Euratom (2), which itself is based on basic recommendations of the International Commission on Radiological Protection (ICRP 2007) (3). In ICRP 2007, radiation protection is organized on the basis of three exposure situations (planned, existing, emergency). Since contaminated sites are characterized by the fact that they already exist when a decision on their control has to be taken, they are classified as existing exposure situations.

Through StrlSchG (1), radioactively contaminated sites were defined on a legal basis for the first time in Germany. According to § 136 (1) StrlSchG, radioactively contaminated sites are 'land, parts of land, buildings or water bodies contaminated by terminated human activity if the contamination causes or may cause exposure that exceeds the effective dose reference value of 1 Millisievert per calendar year for individuals of the population'.

The dose included in this legal definition was described in the models of the Calculation Guide Mining (4) as an additional dose caused by the contaminated site and covering the dose caused by Rn-222.

Since Ra-226 is a component of the contamination in most radioactively contaminated sites in Germany, such contamination may release radon (Rn-222) and contribute to exposure in this way.

Radon represents a special issue in the current radiation protection system in some essential aspects and is, therefore, treated separately to a large extent. In particular, part of the special feature arises from problems in converting activity concentrations to dose values and, in turn, relating dose to a corresponding risk (5). Due to some related fundamental conflicts for the radiation protection system, the German Commission on Radiological Protection (SSK) developed proposals for solutions concerning the valuation of radioactively contaminated sites. Because the SSK is an advisory board to the Federal Ministry for the Environment (currently BMUV), its recommendations give proposals to the regulators. They are not binding in any legal sense.

This paper aims to outline the radiation protection conflicts, present the SSK's recommendation (6), and discuss some of the consequences of this recommendation.

The SSK and its recommendations regarding contaminated sites and radon in the past

In the early 1990s, the SSK already recommended procedures for radioactively contaminated sites from uranium

ore mining, which had become a radiation protection issue with German reunification. In (7), the 'contamination of various environmental areas with uranium and its derived products' was characterized as a 'given situation' in which exposures can only be subsequently controlled, limited, and reduced under optimization considerations. As a primary benchmark for assessing exposures, the SSK recommended an 'additional potential radiation exposure of 1 mSv/a (effective dose)'. This value corresponds to the dose limit of additional radiation exposures for members of the public recommended by the ICRP (3), which essentially is based on the fluctuation range of natural radiation exposure.

The radiation protection conflicts

The regulation of radioactively contaminated sites is part of the radiation protection of the public in existing exposure situations. In principle, no limit values are provided for existing exposure situations. Reference values serve here as an instrument of optimization in radiation protection, which allow a flexible procedure in the process of optimization adapted to the situation.

The aim is to identify controllable exposure situations that lead to an exposure of members of the public that cannot be disregarded according to radiation protection standards. Another significant aspect of the regulation is the assignment of responsibility for this situation and, thus, for any necessary measures and costs.

Two fundamentally different approaches are used to assess whether or not an existing exposure situation requires action for radiation protection reasons.

1. The dose approach is applied as standard in determining radioactively contaminated sites in § 136 para. 1 StrlSchG, but also in connection with radioactivity in building materials or other existing exposure situations. It refers to additional exposure from a controllable radiation source. Therefore, the effective dose as a quantity of protection is usually the increment ('net value') of a ubiquitous (natural) exposure.
2. In contrast, the protection of members of the public against radon, as treated in the StrlSchG, is linked to a measurand, the annual mean value of the radon concentration. Due to the reference to a 'gross value' of a measurand, the protection against radon differs fundamentally in its conceptual approach from the dose approach.

An advantage of using an effective dose as a protective quantity is its applicability to different exposure situations and the possibility of comparing the associated risks. An advantage of using radon concentration as a measurand is that it is easier to determine and also easier to communicate about this value.

For the protection of the public from naturally occurring radon, Directive 2013/59/Eutatom stipulates that the reference value for the Rn-222 activity concentration in the air in rooms should not exceed 300 Bq m^{-3}. This reference value became the standard for the assessment of radon in common rooms (dwellings) with § 124 StrlSchG. The same value is used for indoor workplaces (§ 126 StrlSchG).

The following conflicts arise from these issues:

1. Retaining the effective dose of 1 mSv per year as the sole protective parameter for assessing risks from exposure leads to a need for measures at legacy sites that would have to lower radon concentrations to a level far below the reference value of 300 Bq m^{-3}. Applying the 'old' dose coefficient of 3.1 mSv per (Bq h m^3), the additional contribution of the contaminated ground should be less than 50 Bq m^{-3}, that is, in a region with a background Rn-222 concentration of 50 Bq m^{-3}, the total Rn-222 should be less than 100 Bq m^{-3}. If the dose coefficient of ICRP (8) is used, these values reduce to less than 25 Bq m^{-3} for legacy-caused radon, respectively 75 Bq m^{-3} for total radon. Thus, persons living on a site with a radioactively contaminated site would be in a significantly better position in terms of radiation protection than persons in the general national territory. The person responsible for such a contaminated site would be able to be obliged to take measures that go far beyond (below) the otherwise tolerated level of Rn-222 activity concentration. The principle of equality before the law and the principle of commensurability would most likely be violated.
2. The use of the reference value for the Rn-222 activity concentration excludes one radon isotope (Rn-222) from other radiation protection and assigns it a special role. The concept of effective dose, which has been established so far as a supporting concept in radiation protection, is thus broken. The comparison of additional exposures with natural exposures via the uniform reference dose, which is frequently used in communication with the public, becomes questionable.

The SSK recommendation on radon and legacies

In March 2022, the SSK adopted the recommendation 'Radon exposure associated with radioactive legacies' (6). The SSK first stated:

> 'In the protection of the population in existing exposure situations, both the general radiation protection principles and the concept of protection from radon should be applied on an equal footing. It follows that inhalation of radon must be considered separately from all other exposure pathways'. Based on this, it formulated:

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Recommendation 1: The SSK recommends the following procedure for the classification of a radioactively contaminated site according to § 136 StrlSchG: the reference value for the effective dose to the population of 1 mSv in a calendar year is calculated for all exposure pathways with the exception of inhalation of radon. Exposure due to radon is considered separately.

Recommendation 1 excludes radon from the effective dose calculation, reflecting the intent to align with the approach to protection from radon. The protection of the population against radon is ensured by the following reference values with reference to the activity concentration:

Recommendation 2: For the classification of a radioactively contaminated site according to § 136 StrlSchG, the SSK recommends applying the following reference values for the radon-222 activity concentration averaged over the year in addition to the reference value of the effective dose according to recommendation 1:

1. 300 Bq m^{-3} in the air in dwellings,
2. 80 Bq m^{-3} in ambient air at relevant outdoor exposure sites.

   Exceeding at least one of the reference values mentioned in Recommendations 1 and 2 thus leads to classification as a radioactively contaminated site.

Since these recommendations reach far into the principles of the radiation protection system, this paper will explain some of the reasons that led to this recommendation and discuss their consequences. Regarding the reasoning, we follow the justifications that the SSK itself lists in its recommendation (6). However, some of the aspects and consequences we discuss in the following go beyond this and are opinions of the authors.

Discussion

Rationale for considering Rn-222-activity concentrations in a separate manner

With its recommendation (6), the SSK has decided to separate radon in contaminated sites from the uniform dose concept and to consider it as an independent parameter. It should be noted that the recommendation only serves to examine an existing exposure situation regarding its status under radiation protection law ('radioactively contaminated site'). The conversion of measured Rn-222-activity concentrations into dose values is not 'forbidden' and can certainly be included in communication about radiation risks.

Some reasons that resulted in the separation of Rn-222 from the effective dose for determining whether a radioactive legacy is considered a radioactively contaminated site are:

1. Radon-222 and its progeny require a specific radiation protection strategy because they cause the highest doses of all radionuclides under normal circumstances. In its publication 126 (9), the ICRP recommended an annual dose in the order of 10 mSv as a benchmark for setting a reference level for radon exposure, and in its publication 142 (10) ICRP stated that a reference level of doses from NORM of the order of a few mSv per year, or below, have to exclude exposures from radon or thoron.
2. It is a (widespread) misinterpretation of the radiation protection standards that the dose limit of 1 mSv per calendar year restricts any controllable exposure of persons of the public to doses less than this limit.

   It should be pointed out that if, within the framework of the legal regulations, the level of protection in planned exposure situations is determined by effective dose limits for members of the public, radiation exposures from activities that are neither subject to licensing nor notification are excluded from the determination of the effective dose. If, for example, an occupational activity involving naturally occurring radioactivity results in an exposure of 0.9 mSv in a calendar year, there is no classification as an occupationally exposed person (§ 56 StrlSchG). If, in addition, this person lives in a house whose building material meets the requirements of § 133 StrlSchG and, as an existing exposure situation, leads to an additional exposure of 0.9 mSv in a calendar year, this exposure is also not taken into account. Therefore, a level of protection that generally limits the additional exposure of individuals of the population to 1 mSv in a calendar year is not specified in the radiation protection system.

3. In its recommendation concerning the radon dose coefficient (5), the SSK stated that the new radon dose coefficients proposed in ICRP Publication 126 (8) still show certain conceptual breaks. Some of these breaks we briefly outline in the following. All in all, in its recommendation (5), the SSK did not see a conclusive, closed picture, and this statement seems valid for us up to the present.

In its Publication 65 (11), ICRP recommended an exposure related Rn-222 dose coefficient for members of the public of 4 mSv per WLM based on an epidemiological approach that considered observed relations of Rn-222 exposure versus lung cancer risk. In this publication, ICRP did explicitly not recommend the use of the dosimetric approach for the assessment and control of radon exposures. In Publication 115 (9), however, ICRP changed this position and recommended *that radon and its progeny should be treated in the same way as other radionuclides within the system of protection. That is, doses from radon and its progeny should be calculated using ICRP biokinetic and dosimetric models, including the HRTM and ICRP systemic models.* This new recommendation was justified with a renewed analysis of

epidemiological data, in particular from big metastudies in Europe, North America, and China (cf. 9 para. 15).

However, the scientific discussions about the basics of the ICRP recommendations on radon are not yet terminated. In (5), the SSK mentioned that new studies, especially the WISMUT miner studies (12, 13), have been insufficiently considered by ICRP. Other more recent studies (e.g. 14, 15) raise new questions. Moreover, evaluations by Sommer et al. (16) have shown that the new ICRP dose coefficient of Rn-222 represents the risk of heavy smoking more than light smoking populations.

Because of these many uncertainties separating Rn-222 from the dose seems a more justifiable step than retaining the dose as the decisive reference value, which is disproportionate for other reasons. However, the disadvantages that this step entails must not be ignored:

1. The effective dose loses its argumentative power as the central measure of radiation risk. However, clearer communication about the specificity of the Rn-222 dose coefficient as a measure that is not purely radiation-related could mitigate this break in the system.
2. The separation of the background from the assessment-relevant additional (!) dose is also cancelled by the reference to the directly measurable activity concentration. However, it can be argued that radon is not covered in the basic concept of exclusion in the system of radiation protection. Definitely excluded are only the cosmic radiation on the earth's surface and K-40 in the body (3). Radon indoors is part of the civilized altered exposure.

Reference value of 300 Bq per m³ in buildings

In principle, it would be possible to recommend the reference value of radon-222 activity concentration at suspected contaminated sites deviating from the values of 300 Bq m^{-3} otherwise contained in German radiation protection law. Well known is the recommendation of the WHO to establish a national annual average residential radon concentration reference level of 100 Bq m^{-3} (17). The German Federal Ministry of Environment recommended the same value in 2004 (18).

The geometric mean of the radon activity concentration in dwellings in Germany is about 45 Bq m^{-3}. A value of 300 Bq m^{-3} is exceeded only in less than 2% of the dwellings (19).

Since elevated radon concentrations can occur in buildings as well as in the ambient air in the case of mining or industrial legacies compared to the general environmental radioactivity, the task to be solved in the context of radioactively contaminated sites is the assessment of radon as part of a complex radiation exposure proceeding via different exposure pathways. In this context, the orientation should be towards adequate radiation protection, the standards of which ensure equal protection for the entire national territory and do not protect those affected by contaminated sites more than other individuals of the population.

A radiological evaluation of contaminated sites by the effective dose, including radon, would require measures in cases where radon-222 activity concentrations in dwellings are far below 300 Bq m^{-3} and would establish a more restrictive level of protection compared to dwellings at other sites. This level of protection would oblige the polluter to take measures and would thus put him at a disadvantage compared to persons responsible in other cases with similar exposure situations (e.g. employers as obligated parties according to § 131 StrlSchG).

In the case of radon-222 activity concentrations in dwellings below the reference value of 300 Bq m^{-3}, an assessment that deviates from the otherwise tolerated value in the case of contaminated sites leads to a regulatory asymmetry that should be avoided.

In order to meet the aforementioned objective, the conceptual difference in the assessment of existing exposure situations on the one hand by radon and on the other hand by other radionuclides should, therefore, also be applied to the assessment of contaminated sites. The recommendation of the SSK implements this idea.

In its justification for the recommendation, the SSK explicitly points out that the character of the reference value permits a case-related design of radiation protection, in which concentrations above the reference value can be tolerated, and concentrations below the reference value can be reduced within the framework of optimization.

Radon-222-activity concentration in the outdoor air

Radon activity concentrations in the outdoor air that are elevated due to contaminated sites differ from those in buildings due to a stronger mixing in the atmosphere. According to the BfS, the radon-222 activity concentration outdoors in Germany ranges from 3 Bq m^{-3} to 31 Bq m^{-3} and can be approximated by a logarithmic normal distribution with a geometric mean of 8.2 Bq m^{-3} with a geometric standard deviation of 1.9 (20). The geometric mean value of radon outdoors is thus about six times lower than the geometric mean value of radon in dwellings of 45 Bq m^{3} (19).

An outdoor radon activity concentration of 80 Bq m^{-3} more than doubles the range of naturally occurring values in Germany, with a maximum value of 31 Bq m^{-3} (20). Extrapolated with the log-normal model of BfS based on measured data (22), this corresponds to the 99.8th percentile. With long-term averaged measured values of this level, a natural cause can thus be practically excluded. Regardless of the exposure involved, the SSK considers it appropriate to consider measures aimed at reduction by appropriate means in cases where such concentrations occur at relevant impact sites.

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A radon-222 activity concentration at relevant outdoor impact sites of 80 Bq m ^{3} was already proposed in 1994 by the SSK as a guideline value for checking the influence of legacies of uranium ore mining in Saxony and Thuringia (21). The value was based on the upper end of the normal range of natural variation in outdoor radon activity concentration and includes the natural background contribution to the outdoor radon activity concentration.

The SSK continues to regard the nearest residential areas, possible development areas, and permanent residence areas as relevant impact points.

Radon and soil contamination

The definition of radioactively contaminated sites in § 136 StrlSchG refers exclusively to 'land, parts of land, buildings or waters contaminated by terminated human activity if exposure is or can be caused by the contamination'. Radioactive soil contamination is thus assigned a decisive role as the cause of a contaminated site.

The SSK recommendation did not take up this aspect further. In its Recommendation 2, SSK only states: *The exceeding of at least one of the reference values mentioned in Recommendations 1 and 2 thus leads to the classification as a radioactively contaminated site*.

By the preceding reference to the StrlSchG, this recommendation can be understood in such a way that exclusively radon concentrations are included, which originate from anthropogenic-caused contaminations.

The separate reference value for the radon-222 activity concentration of 300 Bq m^{-3} exempts from the necessity to check activity concentrations below this reference value in buildings at suspected contaminated sites to determine whether they are caused by contamination. If, however, the radon-222 activity concentration exceeds the reference value, measures to reduce the concentration (if necessary, also only the exposure) are justified for radiation protection reasons, and, as far as they can be implemented with proportionate means, they are also to be carried out.

Elevated radon concentrations in buildings can be a consequence of both the natural geological composition of the subsoil and the composition of the building structure. In such a case, the question arises regarding the causes and, thus, the responsibility. If the building structure is responsible for an increased Rn-222 activity concentration in the building due to cracks or other entry points, the responsibilities are regulated in Part 4 Chapter 2 StrlSchG.

For the assignment of responsibility at contaminated sites, anthropogenic changes from meanwhile (legally) completed activities are the decisive reference. Such changes can be deposits of radium-containing substances near buildings or radium-containing contamination in the building. In connection with radon, however, pathways in the subsurface, through which radon-rich air can be conducted to building structures, are known to be the cause of elevated radon concentrations in buildings (22). Consequently, the restriction of the term 'radioactively contaminated site' in § 136 StrlSchG to land, parts of land, buildings, or bodies of water contaminated by terminated human activity does not cover the possible anthropogenic causes in the case of radon. The SSK did not comment on this aspect. In the authors' opinion, however, anthropogenic changes outside of a building, particularly pathways in the subsoil created by mining, which may cause a reference value exceedance, should be included in the definition of contaminated sites.

In this context, it should be pointed out that a purely geographical reference to (old) mining areas is not sufficient to prove that anthropogenically created pathways cause a radon-222 activity concentration exceeding the reference value and is thus to be regarded as a radioactive legacy. A corresponding suspicion would have to be examined and evaluated on a case-by-case basis.

Summary and conclusions

The recommendation of the SSK to consider radon as a separate assessment parameter in addition to dose when deciding on the status of a radioactively contaminated property is a consequence of the independent treatment of radon also otherwise in the radiation protection system. It prioritizes the principle of equality before the law because otherwise, a person responsible for a radioactively contaminated site would be obliged to take measures that go far beyond the generally tolerated level of Rn-222 activity concentration.

With the abandonment of a dose calculation and with the exclusive reference to a radon-222 activity concentration, the protection against radon is detached from the general concept of radiation protection ('risk limitation by dose limitation') and forms a separate approach ('risk limitation by limitation of activity concentration'), which is analogous to the approach in environmental protection. We are aware that this pragmatic approach leads to new problems. In particular, the common comparison of additional exposures with natural exposures via the uniform effective dose, frequently used in communication with the public, becomes questionable.

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***Rainer Gellermann**

Nuclear Control & Consulting GmbH
Hinter dem Turme 24,
38114 Braunschweig, Germany
Email: rainer.gellermann@nuclear-cc.de