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Protection of Workers Against Exposure Due to Radon

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New Safety Guide

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CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. Exposure due to radon might occur in all types of workplaces and facilities, ranging from conventional offices, naturally occurring radioactive material processing industries, underground facilities, and nuclear fuel cycle facilities.

1.2. IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [1], presents the fundamental safety objective and principles of protection and safety. Requirements designed to meet the fundamental safety objective and to apply the safety principles specified in SF-1 [1], including requirements for the protection of workers exposed to sources of radiation, are established in IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [2], jointly sponsored by the IAEA and seven other international organizations.

1.3. This Safety Guide was prepared jointly by the IAEA and the International Labour Office (ILO) to provide specific recommendations on meeting the requirements of GSR Part 3 for protection against exposure to radon.

1.4. The requirements in GSR Part 3 [2] are based on the recommendations of the International Commission on Radiological Protection (ICRP) Publication 103 [3]. Specific recommendations related to protection against exposure to radon were provided by the ICRP in the recent years both for protection of the public and occupational safety [4,5,6]. These recommendations of the ICRP have been taken into account in preparing this Safety Guide.

1.5. The prerequisites for protection of all workers from all types of hazard in work environments set by the ILO in its Radiation Protection Convention (No. 115) [7] and Code of Practice on Radiation Protection of Workers [8] have also been taken into account in this Safety Guide.

1.6. Guidance on meeting the requirements of GSR Part 3 [2] for protection against exposure to radon is provided in this Safety Guide. It addresses issues of identification of workplaces where exposure to radon might occur, establishment and implementation of radiation protection requirements applying graded approach and optimisation of protection and safety. Specific recommendations on building a protection strategy and addressing the protection of workers against exposure to radon is needed for different involved parties, considering that many may not have a background in radiological protection. . It provides specific guidance on the exposure conditions for which radiation protection programmes are required to be established, including the setting up of monitoring programmes to assess radiation doses to workers arising from exposure due to radon. It also provides specific guidance on the assessment of doses from exposure due to radon in combination with other external sources of radiation or from exposure due to intake of radionuclides.

OBJECTIVE

1.7. The objective of this Safety Guide is to provide recommendations on protection of workers against exposure due to radon in workplaces, in planned and existing exposure situations, including the case of combined exposure to radon and other sources. The recommendations in this Safety Guide are based on the application of the graded approach.

1.8. The recommendations provided in this Safety Guide are aimed at governments, regulatory bodies or other relevant competent authorities, employers, licensees, registrants, workers and service providers.

SCOPE

1.9. This Safety Guide covers protection of workers against exposure due to radon, thoron and its progeny, when relevant, in all types of workplace including workplaces in above ground buildings , underground workplaces , and industrial processes involving naturally occurring radioactive material where occupational exposure to radon might occur. Protection of the public entering workplaces with radon exposure is also addressed.

1.10. This Safety Guide addresses the responsibilities of the government, regulatory body or other competent authorities, employers, licensees and/or registrants, workers and service providers, for protection of workers exposed to radon in existing and planned exposure situations.

1.11. The scope of this Safety Guide is limited to the exposure of workers and members of the public, entering workplaces, due to radon. All exposure pathways and sources are covered in IAEA Safety Guide GSG-7, Occupational Radiation Protection [9]. Exposure due to natural sources of radiation, and due to the specific nature of radon regarding its occurrence in various types of workplace, as well as its characteristics as a particular exposure pathway affecting the arrangements needed for appropriate worker protection, are also addressed through the specific safety reports for different industrial activities involving naturally occurring radioactive material (NORM).

1.12. Details on specific methods of radon prevention and remediation in buildings are outside the scope of this Safety Guide and are provided in IAEA publication TECDOC 1951 Radiation Protection against Indoor Radon and Building and Construction Materials – Methods of Prevention and Mitigation [10].

1.13. Recommendations on exposure of workers to thoron in workplaces is also covered in this Safety Guide.

STRUCTURE

1.14. Section 2 of this Safety Guide describes the basic framework for protection of workers against radon in workplaces, explaining the approach for both existing exposure situations and planned exposure situations. Section 3 provides guidance to governments, the regulatory body or other competent authority, employers and service providers on control of radon in workplaces in existing exposure situations. Section 4 provides guidance to governments, the regulatory body or other competent authority, employers, workers, and service providers on control of radon in workplaces in planned exposure situations. Specific guidance is also provided for situations where radon activity concentration is above the national reference levels, and it is the only source of exposure to ionizing radiation for the workers. Section 5 gives an overview of thoron exposure issues and their significance for occupational radiation protection.

1.15. Annexes I and II provide guidance on radon measurement techniques and protocols, and general methodology of dose assessment, respectively.

2. OVERVIEW OF APPROACHES FOR PROTECTION OF WORKERS AGAINST EXPOSURE DUE TO RADON

WORKERS AND OCCUPATIONAL EXPOSURE

2.1. Based on the recommendations of the ICRP publication 103 [3], the IAEA Safety Standards distinguish between three different types of exposure situations: planned exposure situations, existing exposure situations and emergency exposure situations. For the radiological protection of workers against exposure due to radon, this Safety Guide focuses on planned and existing exposure situations.

2.2. IAEA Safety Standards GSR Part 3 [2] defines a "worker" as any person who works, whether full time, part time or temporarily, for an employer and who has recognized rights and duties in relation to occupational radiation protection, while a self-employed person is regarded as having the duties of both an employer and a worker (GSR Part 3, Definitions).

2.3. "Occupational exposure" is defined as follows in the same document: "Exposure of workers incurred in the course of their work" (GSR Part 3, Definitions [2]).

2.4. Article 2 of the Radiation Protection Convention (No. 115) by ILO [7] states that: "This Convention applies to all activities involving exposure of workers to ionising radiations in the course of their work".

2.5. The ILO code of practice on radiation protection of workers [8] states that: "For the purpose of this code there are two categories of workers with regards to radiation exposure:

(a) workers engaged in radiation work; and

(b) workers not engaged in radiation work, but who might be exposed to radiation because of their work".

2.6. Based on the definitions in the IAEA safety standards and the general provisions in Refs [7, 8], the requirements of GSR Part 3 and the recommendations in this Safety Guide apply to the protection of all workers against occupational exposure due to radon in all workplaces.

2.7. Para. 3.78 of GSR Part 3 [2] states:

> **"Employers, registrants and licensees shall ensure that workers exposed to radiation from sources within a practice that are not required by or directly related to their work have the same level of protection as members of the public."**

Therefore, in terms of protection against exposure, workers working outside of controlled or supervised areas, and where the workers' exposure arises from sources that are not required by, or directly related to, the work, are provided with the same level of protection as members of the public and the dose limit of 1 mSv/a applies. For exposure due to radon in the workplace other than the exposure due to a licensed practice, the national reference levels for radon at workplaces apply. For example, nuclear power plant employees, that work outside of controlled and supervised areas, are subject to a dose limit of 1 mSv/a from the operation of the nuclear power plant, while for radon exposure in their workplaces, the national reference levels for radon in workplaces apply.

RADON AND RADON PROGENY

2.8. In GSR Part 3 radon is defined as "any combination of isotopes of the element radon" [2] and refers to ^{220}Rn and ^{222}Rn for the purposes of the Safety Standards. ^{219}Rn is derived from the natural radioactive decay chain headed by ^{235}U. In accordance with IAEA Safety Standards Series No. SSG-32, Protection of the Public against Exposure Indoors due to Radon and Other Natural Sources of Radiation [11], the dose from exposure due to ^{219}Rn is negligible and is therefore not of radiological concern.

2.9. The short-lived radioactive decay products of ^{222}Rn and of ^{220}Rn are called radon progeny and are of concern from the point of view of radiological protection. For ^{222}Rn, this includes the decay chain up to but not including ^{210}Pb, namely ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po, plus traces of ^{218}At, ^{210}Tl and ^{209}Pb. Radionuclide of ^{210}Pb, which has a half-life of 22.3 years, and its radioactive progeny — ^{210}Bi and ^{210}Po, plus traces of ^{206}Hg and ^{206}Tl — are, strictly, progeny of ^{222}Rn, but they are not included in this listing because they will not normally be present in significant amounts in airborne form. For ^{220}Rn, this includes ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po and ^{208}Tl [2].

Uranium-238, thorium-234, protactinium-234, uranium-234, thorium-230, radium-226, radon-222, polonium-218, lead-214, bismuth-214 and polonium-214, lead-210, bismuth-210, polonium-210 and (stable) lead-206, plus traces of astatine-218, thallium-210, lead-209, mercury-206 and thallium-206.

Fig. 1 Decay chain of U-238 [IAEA safety glossary]

Thorium-232, radium-228, actinium-228, thorium-228, radium-224, radon-220, polonium-216, lead-212, bismuth-212, polonium-212 (64%), thallium-208 (36%) and (stable) lead-208.

Fig. 2 Decay chain of Th-232 [IAEA safety glossary]

2.10. In accordance with the requirements in GSR Part 3, for the regulatory control of existing exposure situations measurement of radon activity concentration is required, while for the regulatory control of planned exposure situations the measurement of radon decay products may be required for the purpose of dose assessment of the workers.

2.11. Dose conversion factors are used for assessing doses from exposure to radon or radon decay products. These are based on the scientific information published by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [12] and recommendations issued by the International Commission on Radiological Protection (ICRP) [4]. These published dose conversion factors serve as a reference for States when developing their relevant national regulations on radiation protection. An overview of relevant dose conversion factors is provided in a joint overview publication issued by the Inter-Agency Committee on Radiation Safety [13].

GENERAL FRAMEWORK FOR PROTECTION OF WORKERS

2.12. Paragraph 3.4 of GSR Part 3 [2] states:

> **"Exposure due to natural sources is, in general, considered an existing exposure situation and is subject to the requirements in Section 5. However, the relevant requirements in Section 3 for planned exposure situations apply to:**

(a) Exposure due to material in any practice specified in para. 3.1 where the activity concentration in the material of any radionuclide in the uranium decay chain or the thorium decay chain is greater than 1 Bq/g or the activity concentration of ^{40}K is greater than 10 Bq/g;

(b) Public exposure due to discharges or due to the management of radioactive waste arising from a practice involving material as specified in (a) above;

(c) Exposure due to ^{222}Rn and to ^{222}Rn progeny and due to ^{220}Rn and to ^{220}Rn progeny in workplaces in which occupational exposure due to other radionuclides in the uranium decay chain or the thorium decay chain is controlled as a planned exposure situation;

(d) Exposure due to ^{222}Rn and to ^{222}Rn progeny where the annual average activity concentration of ^{222}Rn in air in workplaces remains above the reference level established in accordance with para. 5.27 after the fulfilment of the requirement in para. 5.28.”

2.13. In accordance with para. 3.4 of GSR Part 3 and with the graded approach, exposure due to natural sources (i.e. naturally occurring sources of radiation) is mostly managed by applying the requirements for existing exposure situations. For the exposures specified in paras. 3.4 (a)–(d) of GSR Part 3, the relevant requirements for planned exposure situations apply (e.g. dose limits, dose constraints, other relevant requirements for planned exposure situations). By this logic, the concept of the graded approach is reflected in regulatory control. This difference is further explained in Section 4 of this Safety Guide. For the workplaces, where the annual average concentration of ^{222}Rn remains below the reference level, requirements of existing exposure situation apply.

2.14. For all workplaces, the relevant requirements of planned exposure situations are applied in the following cases:

(a) When the activity concentration of uranium or thorium decay series in material exceeds the levels of para. 3.4 (a) of GSR Part 3 [2]; or

(b) When the annual average activity concentration of ^{222}Rn in air in workplaces exceeds the levels established according to para. 5.27 of GSR Part 3 [2].

2.15. Industrial activities, involving naturally occurring radioactive material, could be subject to the requirements for planned exposure situations based on the activity concentration of uranium or thorium decay series in materials (see para. 3.162 of GSG-7 [9]). For example:

(a) Mining and processing of uranium ore;

(b) Extraction of rare earth elements;

(c) Production and use of thorium and its compounds;

(d) Production of niobium and ferro-niobium;

(e) Mining of ores other than uranium ore;

(f) Production of oil and gas;

(g) Manufacture of titanium dioxide pigments;

(h) Activities in the phosphate industry;

(i) Activities in the zircon and zirconia industries;

(j) Production of tin, copper, aluminium, zinc, lead, and iron and steel;

(k) Combustion of coal;

(l) Water treatment.

2.16. Paragraph 5.29 of GSR Part 3 [2] states:

> **"If, despite all reasonable efforts by the employer to reduce activity concentrations of radon, the activity concentration of ^{222}Rn in workplaces remains above the reference level established in accordance with para. 5.27, the relevant requirements for occupational exposure in planned exposure situations as stated in Section 3 shall apply."**

2.17. Examples of workplaces that might become subject to some or all requirements for planned exposure situations, based on the annual average activity concentration of ^{222}Rn, could include:

(a) Workplaces where the radon levels might be elevated due to the geological conditions or due to limited ventilation;

(b) All below and partially-below ground workplaces (including basements);

(c) Any of the industries involving naturally occurring radioactive material listed in para 2.15;

(d) Underground mines;

(e) Tunnels and galleries;

(f) Tourist caves;

(g) Fish hatcheries;

(h) Food, agriculture and storage caves (e.g. for production of wine or cheese, for cultivation of mushrooms).

2.18. Recommendations on occupational exposure to ^{220}Rn (thoron) and ^{220}Rn progeny is provided in Section 5 of this Safety Guide.

2.19. Paragraph 3.6 of GSR Part 3 [2] states:

> **"The application of the requirements of these Standards shall be in accordance with the graded approach and shall also conform to any requirements specified by the regulatory body. Not all the requirements of these Standards are relevant for every practice or source, or for all the actions specified in para. 3.5".**

2.20. In accordance with Requirement 6 and para. 3.6 of GSR Part 3 [2], the application of regulatory requirements for the protection of workers from exposure due to radon and its progeny are required to be based on the graded approach and are required to be commensurate with the radiation risks associated with the exposure situation.

2.21. Radiation is one of many occupational health and safety hazards faced by workers, and it is a good practice to ensure that all hazards remain in perspective and are part of hazard assessment and management. The role of the national competent authorities, such as occupational safety authorities and public health authorities, is important for an effective and comprehensive regulatory regime and for enforcement mechanisms for the protection of workers in the workplace.

2.22. The regulatory body should implement actions and measures such as the following:

(a) Setting the national reference level for radon;

(b) Prioritizing the workplaces based on the potential exposure of workers;

(c) Verifying compliance with regulatory requirements;

(d) Determining the frequency of periodic measurements of radon in workplaces;

(e) Determining the retention period of records for the exposure of workers and data from radon measurements,

(f) Establishing notification or reporting requirements for the employer,

(g) Determining timescales for implementing corrective actions to reduce exposure of workers due to radon.

2.23. In accordance with Requirement 8 of GSR Part 3 [2], the national authority may exempt from regulatory control industrial activities involving naturally occurring radioactive material with activity concentrations above the ones stated in para 3.4(a) of GSR Part 3. However, further actions with regard to the protection of workers against the exposure due to ^{222}Rn, ^{220}Rn or their progeny in such workplaces may be required.

2.24. Industrial activities involving naturally occurring radioactive material where activity concentrations are below the levels outlined in para 3.4(a) of GSR Part 3 [2] could be exempt from regulatory control. However, protection of workers against the exposure to ^{222}Rn, ^{220}Rn or their progeny in such workplaces may still be required.

2.25. Independent of whether an industrial activity involving naturally occurring radioactive material is considered to be a planned exposure situation or an existing exposure situation, the exposure of workers to radon should be assessed and relevant requirements should be applied.

2.26. Figures 1 and 2 summarize the approach for the protection of workers against occupational exposure due to radon at workplaces. Further details are provided in Sections 3 and 4.

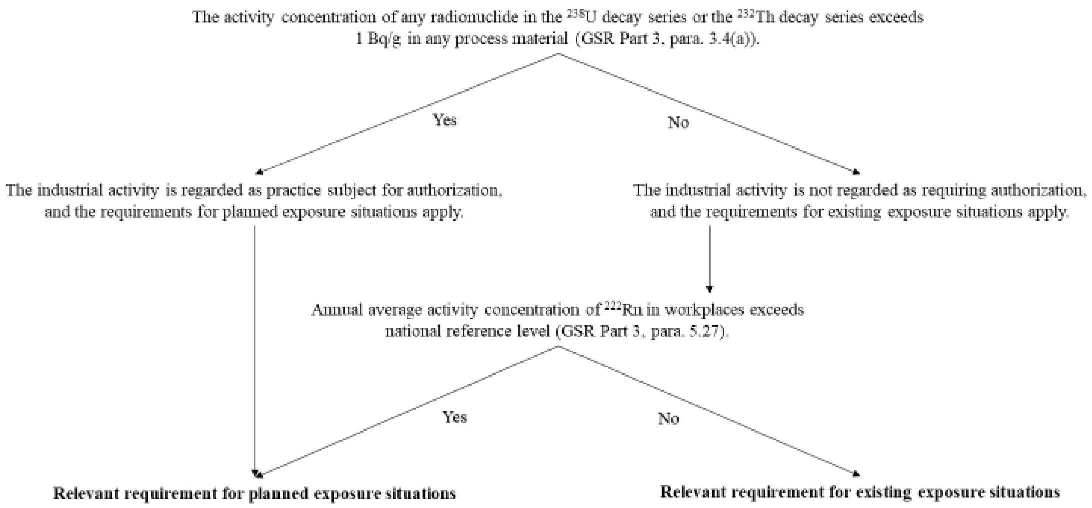

FIG. 1. Flow chart illustrating how to select approach for protection of workers against radon exposure based either on the activity concentration in material of uranium or thorium decay series or activity concentration of radon.

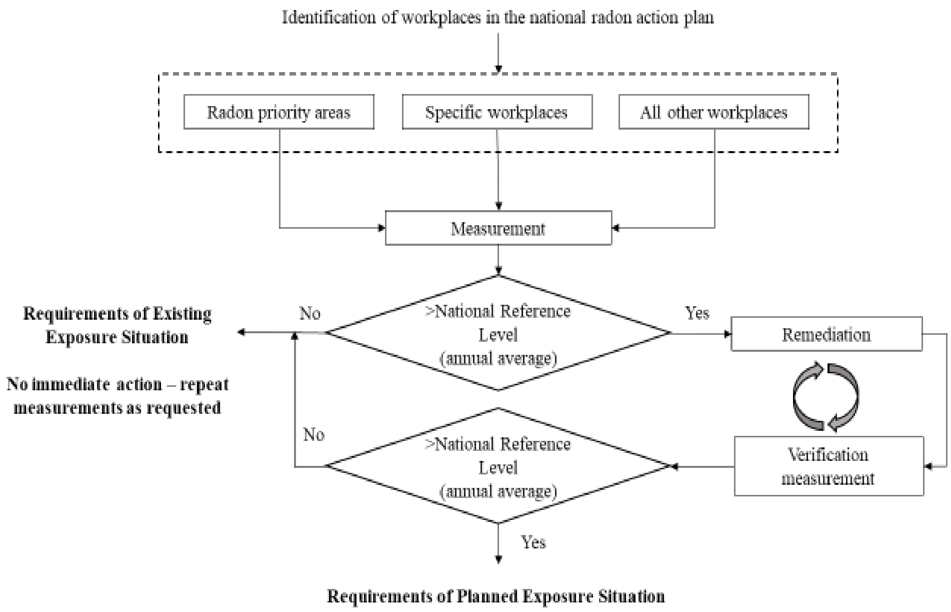

FIG. 2 Flow chart illustrating how to select approach for protection of workers against radon exposure based on the annual average activity concentration of ^{222}Rn in air in workplaces. OBS! For industrial processes with NORM remediation could be impossible.

2.27. For management of exposure due to radon in workplaces, there is a distinct difference between existing and planned exposure situations as shown in Table 1. For existing exposure situations, exposure to radon is managed by reference levels for radon concentration and for planned exposure situations, exposure to radon is managed through dose assessment of the workers.

TABLE 1. ASPECTS OF REGULATORY REQUIREMENTS APPLICABLE IN DIFFERENT EXPOSURE SITUATIONS.

Aspect	Existing Exposure Situation	Situations GSR Part 3 (para 3.4 d)	Planned Exposure Situation
Compliance level	Reference level not exceeding 1 000 Bq/m^3	Average annual effective dose limit of 20 mSv (Schedule III of GSR Part 3 [2])	Average annual effective dose limit of 20 mSv (Schedule III of GSR Part 3 [2])
Protection Strategy	Reducing radon concentration ALARA	Reducing exposure to radon ALARA Development of radiation protection programme Dose assessment or exposure assessment and recording Authorisation of practice	Optimisation of protection from all sources of exposure Development of radiation protection programme Dose assessment and recording Authorisation of practice
Assessment Method	Average annual radon concentration	Annual effective dose Or Exposure	Annual effective dose

2.28. Safety requirements of GSR Part 3 promotes the application of the graded approach to regulatory control in all exposure situations. This means, in relation to workplaces that fall under the category GSR Part 3 para 3.4 d, that the regulatory body or competent authority would need to decide which requirements of the planned exposure situation are appropriate and would apply.

3. FRAMEWORK FOR PROTECTION OF WORKERS AGAINST EXPOSURE DUE TO RADON IN EXISTING EXPOSURE SITUATIONS

3.1. This section provides recommendations on establishing and implementing measures for protection against exposure due to radon in workplaces in existing exposure situations, including recommendations on the identification of such workplaces, provision of information to workers and the public defining roles and responsibilities in the system of protection.

3.2. The following list provides some examples of workplaces not normally associated with regulatory control for radiation exposure (i.e. planned exposure situations), that may require risk assessment of the exposure of workers to radon:

(a) Enclosed buildings (e.g. hotels, factories);

(b) Workplaces where the radon levels might be elevated due to the geological conditions or due to limited ventilation;

(c) All below and partially-below ground workplaces (including basements);

(d) Public places (e.g. schools, childcare centres, hospitals);

(e) Office blocks (modern buildings with in-built ventilation system, 'old style' buildings);

(f) Enclosed raw materials production facilities (e.g. quarries, material processing facilities, processes involving NORM);

(g) Underground mines;

(h) Tourist caves;

(i) Food, agriculture and storage caves (e.g. for production of wine or cheese, for cultivation of mushrooms).

GOVERNMENT

3.3. Requirement 47: Responsibilities of the government specific to existing exposure situations of GSR Part 3 [2] states that:

> **"The government shall ensure that existing exposure situations that have been identified are evaluated to determine which occupational exposures and public exposures are of concern from the point of view of radiation protection."**

3.4. In accordance with Requirement 47, the government could assign the responsibility and provide resources to one or more competent authorities for the evaluation and assessment of radon exposure in workplaces. The results from this evaluation should be used to determine the level of regulations, and the resources needed for the application of regulatory control and verification of compliance. Recommendations on identifying workplaces where exposure of workers to radon may require regulatory control are given in paras 3.14– 3.19 of this Safety Guide.

3.5. In accordance with GSR Part 1 [14] and GSR Part 3 [2], the Government is required to assign responsibility for establishing regulatory control and its enforcement to a regulatory body or any other competent authority. The Government should also make provision for the effective coordination of regulatory functions where more than one national competent authorities are assigned responsibilities for protection of workers against radon. See paras 3.27– 3.32 of this Safety Guide.

3.6. In accordance with para. 5.3 of GSR Part 3 [2], the government is required to include in the legal and regulatory framework for protection and safety provisions for the management of exposure to radon in workplaces.

3.7. The legal framework of a country should include provisions for a competent authority to set the national reference level for exposure to radon in workplaces, which includes establishing the responsibilities of employers with regard to protection of workers against radon. This legal framework could be included in the domains of radiation protection, work environment safety or public health, depending on which is identified as the most appropriate authority to be assigned responsibility for the regulatory control of radon in workplaces for existing exposure situations.

3.8. In the national legal framework, references to other laws and ordinances could be given, such as labour protection, radiation protection and public health protection, in order to facilitate and co-ordinate the efforts and legal responsibilities among relevant competent authorities.

3.9. When establishing the legal framework for protection against exposure due to radon in workplaces, the government should consider the most efficient way of allocating resources and utilising existing competences. This is particularly relevant for control of radon in workplaces in existing exposure situations due to the large number of workplaces that fall under this category.

3.10. Para. 5.3 of GSR Part 3 [2] states that:

> **"The government, in the legal and regulatory framework, as appropriate:**
> **(b) Shall specify the general principles underlying the protection strategies developed to reduce exposure when remedial actions and protective actions have been determined to be justified".**

3.11. The government should develop (or assign responsibility for developing) and set national protection strategies for protection against radon in workplaces.

3.12. The protection strategy for radon in workplaces could efficiently be part of the action plan for controlling public exposure due to radon indoors (see Requirement 50 of GSR Part 3 [2]). This national radon action plan could include sections on identification of workplaces of concern from the point of view of radiation protection for radon exposure, risk communication for exposure due to radon and actions for promoting optimization of protection and safety. For further guidance on this action plan, see paras 3.60–3.61 of this Safety Guide and SSG-32 [11].

3.13. Since protection against radon involves different types of competencies, the government should make provision, where necessary, for technical services, such as services for personal dosimetry, monitoring and the calibration of equipment for radon measurement.

Identification of workplaces of concern

3.14. All workplaces contain some radon activity in the air. Depending on parameters such as the geological conditions, type of workplace, construction characteristics of the workplace, and the type of operation in the workplace, the level of radon concentration may vary from tens of Bq/m^3 to thousands of Bq/m^3. Radon levels at all workplaces should be determined in order to identify workplaces that are at risk of exceeding the national reference level for radon.

3.15. Radon exposure is proportional to the radon concentration and the duration of the exposure. For example, workers or members of the public might be exposed to radon continuously during an entire workday or intermittently for short periods of time (in the case of workers who move to different offices or locations, or members of the public who only visit a building or site occasionally).

3.16. The identification and evaluation of workplaces of concern from the occupational protection point of view could be based on various data such as the results of the residential radon surveys (see Ref. [15]), research data, geological and topsoil data, type of industry and type of industrial sector, construction stock and climate conditions.

3.17. The identification of workplaces of concern should be assigned to a competent authority or other relevant organization in a Member State, such that it does not raise conflict of interests. For instance, an organization providing commercial radon measurement services is generally not appropriate to be responsible for the survey.

3.18. The results of the initial study and evaluation should be documented and made publicly available.

3.19. Based on the results of the evaluation, the government should decide on the need and the extent of regulatory control for the protection of workers against radon in existing exposure situations. The conditions within the country and the results of the evaluation could be such that major efforts and resources are not necessary and could be limited to specific workplaces.

Provision of information to the workers and the employers

3.20. Government organizations, competent in radiation related issues should make available information on the health effects of exposure to radon (including the risk of lung cancer due to radon exposure, the increased risk of lung cancer due to the combination of smoking and radon), and of other inhalation hazards, as well as information on mitigation measures. This information could be made available online on their website, but could also be made available in print for members of the public that do not have internet access. Face-to-face meetings could be arranged regularly to update the information and involve new individuals in the task.

3.21. Information on radon could also cover the temporal variability of radon and the importance of long-term radon measurements for assessing the need to remediate a workplace and the effectiveness of remedial actions.

3.22. Information campaigns could be organised and information materials could be developed for employers on the following:

(a) The requirements for protecting employees or visiting members of the public from radon exposure at the workplace;

(b) The applicable reference levels for radon;

(c) The methods of control and optimization of protection against exposure due to radon;

(d) Means of enforcement of compliance.

3.23. The employees need to receive information about their right to be protected against exposure to radon in workplaces and their right for safe working environments.

3.24. Paragraph 5.5 of GSR Part 3 [2] states:

"The regulatory body or other competent authority shall implement the protection strategy, including:

…

(b) Ensuring that information is available to individuals subject to exposure on potential health risks and on the means available for reducing their exposures and the associated risks".

3.25. Paragraph 5.3 of GSR Part 3 [2] states:

"The government, in the legal and regulatory framework, as appropriate:
(d) Shall provide for the involvement of interested parties in decisions regarding the development and implementation of protection strategies, as appropriate".

3.26. All interested parties should be involved in further development and setting the protection strategies for radon in workplaces. These interested parties should include, but not be limited to: authorities with responsibility for workplace safety, radiation protection and public health protection, representatives of employers and representatives of employees, competent organizations for radon reduction measures, technical service providers, and scientific and educational establishments.

Assignment of responsibilities and resources

3.27. Paragraph 5.2 of GSR Part 3 [2] states: "The government shall ensure that, when an existing exposure situation is identified, responsibilities for protection and safety are assigned and appropriate reference levels are established."

In accordance with para. 5.2 of GSR Part 3 [2], the government is required to establish the legal framework for regulatory control of radon in workplaces.

3.28. Paragraph 5.3 of GSR Part 3 [2]:

"The government, in the legal and regulatory framework, as appropriate:
(c) Shall assign responsibilities for the establishment and implementation of protection strategies to the regulatory body and to other relevant authorities[51] and, as appropriate, to registrants, licensees and other parties involved in the implementation of remedial actions and protective actions.

"[51] In existing exposure situations that do not fall under the jurisdiction of the regulatory body, another relevant authority such as a health authority may have authority for implementing measures for protection and safety."

3.29. Requirement 3 of GSR Part 1 [14] states:

"The government, through the legal system, shall establish and maintain a regulatory body, and shall confer on it the legal authority and provide it with the competence and the resources necessary to fulfil its statutory obligation for the regulatory control of facilities and activities".

In accordance with GSR Part 1 [14], the regulatory body is required to have sufficient financial resources, sufficient competent staff, and an enforcement policy. In accordance with Requirement 4 of GSR Part 1 [14], the government is required to ensure that regulatory body is independent.

3.30. The responsibility for the establishment and enforcement of regulatory control of radon in workplaces in existing exposure situations should be assigned to the relevant competent authority, according to the most efficient way of utilizing competent resources. This does not necessarily need to be the regulatory body for radiation protection but might be a health authority or an occupational safety authority.

3.31. The role of a building and construction safety authority is equally important for protection of the public and workers in newly commissioned and existing buildings. This authority has competence in structures and ventilation systems and have means of enforcement of regulatory requirements for building ('building codes') on construction companies and operators of the buildings.

3.32. The government should assign responsibilities and additional resources to the relevant competent authority to establish and implement the national protection strategy for radon in the workplace. This strategy could be efficiently implemented as a part of a national radon action plan, described in SSG-32 [11].

REGULATORY BODY OR OTHER COMPETENT AUTHORITY

3.33. Paragraph 2.26 of GSR Part 1 [11] states:

> **"The regulatory body shall provide any necessary inputs for the protective action, including advising the government or exercising regulatory control over protective actions. It shall establish the regulatory requirements and criteria for protective actions in cooperation with the other authorities involved, and in consultation with interested parties, as appropriate".**

For protection against exposure due to radon in workplaces, the national competent authorities should provide expert advice to the government regarding the content, scope and extent of the national protection strategy, for which the government is responsible.

3.34. Paragraph 5.4 of GSR Part 3 [2] states:

> **"The regulatory body or other relevant authority assigned to establish a protection strategy for an existing exposure situation shall ensure that it specifies:**
>
> **(a) The objectives to be achieved by means of the protection strategy;**
>
> **(b) Appropriate reference levels."**

3.35. Paragraph 5.5 of GSR Part 3 [2] states:

> **"The regulatory body or other relevant authority shall implement the protection strategy, including:**
>
> **(a) Arranging for evaluation of the available remedial actions and protective actions for achieving the objectives, and for evaluation of the efficiency of the actions planned and implemented;**

(b) **Ensuring that information is available to individuals subject to exposure on potential health risks and on the means available for reducing their exposures and the associated risks".**

Regulatory framework

3.36. Requirement 52: Exposure in workplaces of GSR Part 3 [2] states that:

> **"The regulatory body shall establish and enforce requirements for the protection of workers in existing exposure situations."**

3.37. Paragraph 5.27 of GSR Part 3 [2] states:

> **"The reference level for ^{222}Rn shall be set at a value that does not exceed an annual average activity concentration of ^{222}Rn of 1000 Bq/m^3, with account taken of the prevailing social and economic circumstances[57].**

Footnote 57 of GSR Part 3 [2] provides the background to the value of the proposed reference level of 1 000 Bq/m^3 for existing exposure situations: "On the assumption of an equilibrium factor for ^{222}Rn of 0.4 and an annual occupancy of 2 000 h, the value of activity concentration due to ^{222}Rn of 1 000 Bq/m^3 corresponds to an annual effective dose of the order of 10 mSv".

3.38. In view of recent re-evaluations of the health risk from radon by ICRP and UNSCEAR [4, 5, 6, 12], the regulatory body or other competent authority should consider adopting a reference level below 1000 Bq/m^3 for radon at workplaces. Aspects of prevailing social and economic circumstances are still to be taken into account.

3.39. The regulatory body or other competent authority may also consider setting reference levels lower than 1000 Bq/m^3 for special buildings, such as schools, kindergartens, orphanages, places of detention and hospitals for the protection of members of the public. In this case, in accordance with Requirement 50 of GSR Part 3 [2] for public exposure due to radon indoors in buildings with high occupancy, the regulatory body or other competent authority should apply a reference level not exceeding 300 Bq/m^3.

3.40. The reference levels should be periodically reviewed by the regulatory body or other competent authority to ensure that the reference levels remain appropriate under the prevailing circumstances.

3.41. The national regulatory framework should also include requirements on the following:

- frequency of radon measurements in workplaces (see para 3.42);
- Specifying conditions for follow-up measurements of radon in the workplace (see para 3.43);
- time for retention of records of radon measurements (see para 3.44, 3.66 and 3.52;
- reporting results of radon measurements (3.66 and 3.52);
- conditions of approval for service providers of radon measurements (see paras 3.62–3.66);
- measurement methodology to compare with the reference level, see paras 3.45 and 3.67–3.71);

- optimization of protection and safety (see paras 3.46–3.49);
- specification of notification or reporting to the regulatory body or other competent authority (see para 3.50);
- means of enforcement.

3.42. The regulatory body or other competent authority should define the frequency of radon measurements at workplaces taking into consideration the radon levels in the country, the results available from previous measurements of radon activity concentration. The frequency of radon measurements may, for example, vary between 5 and 10 years.

3.43. The regulatory body or other competent authority should specify the conditions for conducting periodic follow-up measurements of radon in workplaces. These conditions should be specified taking into account parameters such as change of ventilation system, renovation of foundations and floors, change of doors and windows, and physical changes to the building or use of the building that might impact the radon concentration inside the building.

3.44. The regulatory body or other competent authority should define the period for the retention of records of radon measurements, taking into account factors such as relevant International Standardization Organization (ISO) standards, specifications on record keeping, requirements for maintaining health records by employers, or two periods of mandatory repeated measurements as outlined in 3.42.

3.45. The regulatory body or competent authority should define minimum duration of the measurement for estimation of an annual average radon concentration. The ISO recommends conducting measurements of radon concentration for periods over 2 months for the assessment of the annual average radon concentration [16]. Further details on methods and protocols for radon measurements are provided in Annex I.

3.46. The protection strategy for the management of exposure to radon in existing exposure situation should be commensurate with the radiation risk associated with the radon exposure of workers. The regulatory approach and corrective actions should yield sufficient benefits to outweigh the detriments associated with the exposures. Guidance on corrective methods for radon ingress is provided in TECDOC 1951 [10].

3.47. Paragraph 5.28 of GSR Part 3 [2] states:

> **"Employers shall ensure that activity concentrations of ^{222}Rn in workplaces are as low as reasonably achievable below the reference level established in accordance with para. 5.27, and shall ensure that protection is optimized."**

If the activity concentration of ^{222}Rn in the workplace is above the reference level, the regulatory requirements should stipulate the need for remedial actions (or any temporary protective actions if relevant) and should contain provisions for the responsibility of employers and the urgency for the implementation of these measures.

3.48. In the optimization of the protection and safety for radon exposure in workplaces, priority should be given to those groups for whom the annual average concentration level of ^{222}Rn exceeds the reference level.

3.49. The urgency of the remedial actions (or any temporary protective actions if relevant) should be determined taking into account factors such as the radon activity concentration, occupancy of the workplaces, complexity of measures needed, number of workers exposed.

3.50. Where, despite all reasonable remedial actions, the activity concentration of radon exceeds the reference level, the regulatory requirements should include provisions on accountability and time frame for the implementation of remedial actions, and the type of information to be included in the notification of the regulatory body by the employers. The notification may include the description of the activities undertaken in the workplace to reduce exposure due to radon, the name and legal data of the company, the results of the radon measurements and other documents specified by the regulatory framework.

3.51. The competent authority should make regulatory requirements available. It might consider establishing a programme for communicating new requirements to the affected parties as a part of the radon action plan. However, it is the responsibility of the employer to regularly review the list of applicable regulations and requirements for the protection of workers.

3.52. The regulatory body should establish provisions so that workers and employers are informed of the results of radon measurements, for both initial measurements and any subsequent follow-up measurements, including those made after remedial actions for radon have been undertaken.

3.53. Although, radon measurements should be conducted at all workplaces, certain workplaces may be prioritized for verification checks through, for example, inspections or surveillance visits. Prioritization can be done taking into consideration areas known to have higher radon potential, results from previous radon surveys for dwellings, or the type of workplace (see also paras 2.15–2.17).

3.54. Verification of compliance with radon reference levels may be conducted by labour safety authorities during routine inspections of workplaces or as a result of the prioritization of specific workplaces identified by the radon risk assessment.

3.55. Competent authorities, with responsibilities for building and construction safety, should establish requirements for radon protection in building codes and enforce these requirements. These requirements might be expressed in terms of a reference level, necessity of radon protection in new and existing buildings, conditions of radon measurements in new and existing buildings or others.

3.56. Competent authorities for construction safety may provide information on methods for prevention of exposure due to radon and for the remediation of buildings and workplaces for radon. The methods for reducing exposure to indoor radon can vary from source control (e.g. variants of soil depressurization techniques), dilution techniques (e.g. ventilation), or reduction of exposure time (e.g. working hours, re-location). Information on radon remediation and reducing exposure should include an evaluation of the typical effectiveness of various techniques for reducing radon below the reference level to levels that are as low as reasonably achievable, economic, societal, and environmental factors being taken into account. Practical guidance on radon prevention and mitigation methods is provided in TECDOC 1951[10].

3.57. Building codes may include requirements for the optimization of protection and safety in new workplaces including the implementation of measures for prevention of radon exposure in all new constructions. Established provisions in building codes for reducing radon ingress in new buildings are considered good practices.

3.58. The competent authorities for construction safety may specify ways for monitoring and documentation of changes made to the building or workplaces for remediation (e.g. soil depressurization, ventilation) to ensure the continued effectiveness of remedial actions.

3.59. When renting a building or office or any other facility for the purpose of work, the employer should request the results of radon measurement from the owner. The owner should provide information on previous radon measurements, if available, to tenants. Compliance with the reference level would be a consideration of any rental agreement with agreement and cooperation of all parties.

Elements of the Radon Action Plan

3.60. For the National Radon Action Plan, as outlined in para 3.12, the Government should assign responsibility and provide resources for its establishment and implementation. The radon action plan should be coordinated by the national competent authority and could include the following actions in relation to radon at workplaces:

(a) Establish an appropriate reference level for ^{222}Rn at workplaces (if not established yet);

(b) Support development of national radon competencies;

(c) Provide information on radon at workplaces as part of the overall radon communication strategy;

(d) Decide which types of workplaces may require additional attention,

(e) Facilitate the measurement of ^{222}Rn at workplaces, including measurement protocols, provisions for quality assurance of service providers for radon measurements;

(f) Introduce specific requirements in building codes or in other regulatory documents for new buildings and for radon remediation;

(g) Develop guidelines for remedial actions at workplaces;

(h) Prioritize actions for reducing activity concentrations of ^{222}Rn in situations for which such actions are likely to be most effective.

3.61. The national radon action plan may include additional resources for establishing national capabilities for radon measurements (if no competent service provider is available in the country, or if no commercial interest exists for establishing such services in the country), for accreditation of service providers for radon measurements, for the support of the development of building codes.

Service providers for radon measurements

3.62. Similar to requirement 20, para 3.73 of GSR Part 3 for planned exposure situations [2], measurement service providers should be either accredited or approved for radon measurement by the competent authority. The competent authority should specify the requirements for approval of service providers for radon measurements and should approve the providers based on these requirements.

3.63. These regulatory requirements could include provisions for the following:

- Laboratory accreditation for radon measurements;

- Quality standards and traceability calibration,
- Competence of staff;
- Measurement protocols,
- Reporting to the national radon database for workplaces (if applicable);
- Management systems of the service provider.

3.64. Further guidance on radon indoor measurements is provided in Refs. [15, 17] and Annex II.

3.65. Measurement service providers may be approved by the national authority either based on the established requirements or based on the accreditation, or a combination of both.

3.66. A national database for radon measurements in workplaces may be established and managed by the competent authority. The competent authority should provide the service providers with details on formatting specifications for reporting the results of radon measurements. Special considerations on information management should be taken in case the service provider is outside the country.

Methodology for radon measurements

3.67. The competent authority should approve methodologies ('protocols') for radon measurements to be used for determining the radon concentrations in workplaces. The competent authority could also provide guidance for the development of such methodologies if the country has limited experience for radon measurements.

3.68. The methodology for radon measurement should include recommendations on the placement of detectors, number of detectors, type of detector (specificity for radon), the measurement duration, application of seasonal correction factors, acceptable uncertainties of the results, frequency of duplicate measurements for quality control.

3.69. The methodology should also address how to compare measurements to the reference level for the purposes of demonstrating compliance or assessing the need for remedial actions.

3.70. The competent authority should establish requirements and should provide guidance for repeating radon measurements in workplaces if the service provider fail to demonstrate compliance for quality control.

3.71. Further details and guidance on radon measurement techniques and methodology is provided in Annex I.

EMPLOYER

3.72. The employer is responsible for the health and wellbeing of their employees. This responsibility is both a legal and moral obligation in accordance with national legislation, GSR Part 3 [2] and the ILO convention [7].

3.73. Workers can be exposed to radiation via inhalation of radon and its decay products, external exposure to gamma radiation (e.g. from building materials) and ingestion of radon in drinking water. The employer is responsible for ensuring that exposure of workers to radiation is controlled.

3.74. To effectively provide for the radiation protection of employees (and members of the public who might be exposed as a result of entering the workplace) against exposure to radon, the employer should consider radon as one of the many potential health and safety issues for their work activities. Radiation exposure from radon is therefore just one of the hazards that the employer must properly manage.

3.75. The employer is responsible for ensuring that monitoring of radon concentrations in all workplaces is conducted. The sampling and analysis should be conducted using a method and a service provider approved by the competent authority. If an employer is able to undertake their own radon measurements, then the competent authority should verify and approve that capability.

3.76. In accordance with para. 5.28 of GSR Part 3 [2], employers are required to ensure that protection in the workplace is optimized using reference levels for the radon concentration. Protective measures in respect to radon exposure may include corrective mitigation measures, preventive measures, relocation of workers or limiting exposure time.

3.77. If the workplace radon concentration is below the reference level, then the employer should aim to seek opportunities to optimize by further reducing radon concentrations as low as reasonably achievable. However, this should be done with thought given to the other hazards and risks in the workplace. The additional resources of further reducing radon concentrations should be balanced with overall hazard and risk control.

3.78. If, despite all reasonable efforts the radon concentration remains above the reference level, the employer should notify the authority within the established time frame and provide the required information in accordance with the regulations (see para 3.102).

Assessing radon exposures against the reference level

3.79. The employer is required to comply with the national regulatory requirements for measurement methodology for radon in the workplace, the frequency of radon measurements and how to interpret the measurement results against the reference levels to demonstrate compliance (see para 3.41).

3.80. The employer is required to conduct follow-up measurements for conditions specified by the competent authority such as new construction activities, refurbishments, renovation and workplace ventilation changes (see paras 3.42–3.43).

3.81. The employer is required to securely store the records of the measurement results in accordance with the regulatory requirements. Submitting data to a national radon database might also be required. Records of worker exposure should also be kept, including any necessary information on locations where workers work and the time they spend there (see paras 3.44 and 3.66).

3.82. The employer is also responsible for providing information on radon exposure to the employees and any corrective measures undertaken.

3.83. In some cases, workers from one employer may undertake work in other workplaces. It is the responsibility of the employer to seek information about radon concentration from the responsible persons of other workplaces and provide it to employees. Understanding the hazards and risks in any workplace where a worker undertakes work is generally part of the occupational health and safety management system.

3.84. The frequency of radon measurements should be prescribed by the national regulatory framework. However, with the graded approach to risk management in mind, the employer may decide to conduct measurements more frequently, for example:

(a) Where radon concentrations were found to be significantly lower than the reference level during the initial measurements, the employer would conduct follow-up measurements at the frequency established by the regulations;

(b) Where radon concentrations were found to be just below the reference level, the employer would choose to increase the frequency of measurements, for example, double the frequency specified by the regulations (e.g. every 2–3 years, if is the requirement is 5 years);

(c) Where radon concentrations were initially found to be above the reference level, and remedial actions were taken to reduce radon exposure below the reference level, the employer may choose a higher frequency of follow-up measurements in order to verify the continued effectiveness of these actions (e.g. every 2–3 years).

3.85. An employer may have workplaces across different countries, where the reference levels for radon might be different and legal requirements might differ. The employer is responsible for identifying radon requirements and appropriate reference level that applies to the workplace area in each country.

3.86. When the annual average ^{222}Rn concentration exceeds the national reference level, and the employer is unable to reduce the radon concentrations below the reference level, then the employer should be required to notify the competent authority (see para 3.102) and should be required to implement the prescribed requirements for occupational exposure in planned exposure situation (see Section 4).

3.87. Workplaces involving the mining and processing of raw materials are potential places where radon concentrations could be elevated. This is because all materials contain some amount of naturally occurring radioactive material. The physical processes involved in mining and processing and the nature of processing are likely to increase radionuclide concentrations in the product or the by-products and therefore impact radon release and indoor radon concentrations. Therefore, the employer should ensure that radon measurements are conducted in accordance with the regulatory requirement to identify potential elevated radon concentrations in all workplaces associated with the operation. Specific guidance for industries that could be affected by naturally occurring radioactive material is provided in Refs [18, 19, 20, 21].

Justification of remediation

3.88. Where the average annual concentration of ^{222}Rn exceeds the reference level, the employer is required to undertake actions to reduce the radon concentration. This is known as radon remediation or radon mitigation. The aim is to bring radon concentrations below the reference levels, to reduce worker exposure and to avoid a situation to the extent possible where the requirements of planned exposure situation may apply to a workplace.

3.89. Activities to reduce radon concentrations to levels below the reference levels are generally accepted as being justified. Further reducing radon concentrations that are below the reference level may be justified in the context of continual improvement of work safety conditions.

3.90. There are workplaces (e.g. tunnels, historical buildings protected by heritage, tourist caves, industrial processes involving NORM), where it is not practicable or cost efficient to implement remedial actions for radon. Actions for worker exposure reduction remains justified and consideration should be given to limiting these exposures by, for example, relocating the work activity or limiting its duration. If the radon concentration is above reference levels, then the relevant requirements for occupational exposure in planned exposure situations apply (see para. 5.29 of GSR Part 3 [2]). The employer should notify the regulatory body of this situation as required.

Remediation and optimization

3.91. For workplaces with ^{222}Rn concentrations above the reference level, the employer is required to reduce radon concentrations below the reference level. The remedial actions to reduce the radon concentrations should be optimized to ensure that the most effective use of resources is obtained. In some cases, immediate protective actions may need to be taken to reduce occupational exposures pending any decision the employer may take to reduce the radon levels by engineered means.

3.92. A competent person with experience in radon mitigation and prevention should normally be consulted about how to manage radon levels in workplaces with ^{222}Rn concentrations above the reference level. For long term or permanent solutions, the employer may need to consult with engineering control specialists, experienced in radon remediation. It might be appropriate to control the access to areas with high radon concentrations at least until the reduction measures have been put in place and their effectiveness has been demonstrated.

3.93. A graded approach should be utilized for hazard reduction in radon remediation. Radon remediation can generally include a range of activities or actions such as the following:

(a) Active ventilation of workplaces, including powered extraction systems, air dilution systems, soil depressurization[1];

(b) Passive ventilation of workplaces, such as roof, foundation or basement ventilators, and isolation;

(c) Control of the sources of radon (e.g. placing source material outside in the open air, enclosing the source, sealing the source of radon, coating across a bare floor or wall).

3.94. When implementing controls for radon, management measures should be put in place to monitor and maintain these controls to ensure that they remain effective over time.

3.95. Further details on methods of indoor radon prevention and remediation are provided in TECDOC 1951 [10].

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[1] The soil depressurization technique is extremely effective for reducing radon levels despite the fact that it really only deals with radon (and sometimes methane in the soil or other VOCs in contaminated soil). Fresh air dilution and ventilation techniques may serve to also improve other indoor air quality issues.

3.96. For control of radon in underground workplaces (e.g. mines, caves, carparks, basements and tunnels), the employer should seek the advice of a ventilation engineer with appropriate knowledge and competence in radon mitigation.

3.97. If engineering solutions are not possible or reasonable for certain workplaces, the employer could limit exposure time. For example, guides in caves could have limited number of hours of work.

3.98. When implementing measures to reduce radon concentrations which are already below the reference level, other hazards should also be considered (e.g. noise, dust, temperature).

3.99. The process of optimization involves the continuous review of the workplace situation. This includes the application of controls to verify whether the levels of radon are as low as reasonably achievable under the circumstances and the decision whether a balance has been achieved between risk and benefit. The ICRP recommends in its publications 103 and 126 [3, 5] and the IAEA endorses in GSR Part 3 [2], that the process of optimization take into account the societal and economic factors of the measures. The records of the review should be documented in the management system of the employer.

3.100. No one standard measure for optimization exists and optimization does not need to be a complex process. Optimization is about finding the balance for each individual situation and providing the highest level of safety that can reasonably be achieved. Involvement of employees in the optimization process allows for better understanding and acceptance of the measures implemented.

Notification

3.101. In order to meet Requirements 7 and 52 of GRS Part 3 [2], the competent authority should establish a system of notification for workplaces where radon concentrations is required to be managed. Employers are responsible for ensuring that they are aware of any notification requirements of the regulatory body or other competent authority.

3.102. Following national requirements on notification, the employer should include the information on the results of ^{222}Rn activity concentration measurements, description of the radon reducing activities undertaken in the workplace, names of responsible persons and legal data of the company and other, as prescribed. For workplaces with radon levels above the reference level, the competent authority will then be able to make a decision regarding the applicable requirements or exemption from those.

4. FRAMEWORK FOR PROTECTION OF WORKERS AGAINST EXPOSURE DUE TO RADON IN PLANNED EXPOSURE SITUATIONS

4.1. Paragraph 3.4 of GSR Part 3 [2] states:

> **"Exposure due to natural sources is, in general, considered an existing exposure situation and is subject to the requirements in Section 5 [of GSR Part 3]. However, the relevant requirements in Section 3 for planned exposure situation apply to:**
>
> **(c) Exposure due to ^{222}Rn and ^{222}Rn progeny and due to ^{220}Rn and ^{220}Rn progeny in workplaces in which occupational exposure due to other radionuclides in the uranium decay chain or the thorium decay chain is controlled as a planned exposure situation;**

4.2. **(d) Exposure due to ^{222}Rn and to ^{222}Rn progeny where the annual average activity concentration of ^{222}Rn in air in workplaces remains above the reference level established in accordance with para. 5.27 after the fulfilment of the requirement in para. 5.28. "**Workplaces that fall under the conditions stated in para. 3.4. (a) and (b) of GSR Part 3 [2], are under regulatory control as planned exposure situations. For these situations, radon is required to be taken into account for the assessment of the total dose and the total dose (including radon exposure) is required to comply with the dose limits established in GSR Part 3 [2].

4.3. In accordance with para. 3.4 (c) of GSR Part 3 [2], and as shown in Figure 1, for workplaces in which occupational exposure due to other radionuclides in the uranium and thorium decay chains is controlled as a planned exposure situation, exposure to radon should be considered as a planned exposure situation, regardless of the radon concentration level.

4.4. In accordance with para. 3.4 (d) of GSR Part 3 [2], and as shown in Figure 2, some of the requirements of planned exposure situations are applicable to workplaces where the concentration of radon remains above the reference level. The specific requirements will depend on the radon concentrations and the situation in accordance with a graded approach to the level of risk (see paras 4.88–4.100).

4.5. This Safety Guide provides recommendations on the identification and management of exposure due to radon and does not cover other exposure pathways in workplaces (e.g. external exposure due to gamma radiation, inhalation of airborne particulates containing radionuclides, ingestion of materials containing radionuclides). Recommendations on occupational radiation protection are provided in GSG-7 [9].

GOVERNMENT

Assignment of responsibilities and resources

4.6. The responsibilities of the government with regard to protection and safety are set out in paras 2.13–2.28 of GSR Part 3 [2]. These include:

(a) Establishing and maintaining an appropriate and effective legal and regulatory framework for protection and safety in all exposure situations;

(b) Establishing and providing for maintaining an independent regulatory body with clearly specified functions and responsibilities for the regulation of protection and safety;

(c) Establishing legislation that provides for coordination between authorities with responsibilities relevant to protection and safety for all exposure situations;

(d) Establishing mechanisms to ensure that interested parties are involved as appropriate in regulatory decision-making process or regulatory decision aiding process;

(e) Establishing requirements for education, training, qualification and competence in protection and safety of all persons engaged in activities relevant to protection and safety.

4.7. The government should assign responsibilities and resources regarding exposure of workers to ^{222}Rn and ^{222}Rn progeny and ^{220}Rn and to ^{220}Rn progeny in situations stated in paras 3.4.(c) and (d) of GSR Part 3 [2] and for all other occupational exposures in planned exposure situations by national law and/or ordinances. Occupational health and safety authorities or other competent authorities in the field of occupational safety should be involved and resources should be assigned to the competent authorities for additional responsibilities.

4.8. Responsibilities for the protection of workers against exposure due to radon should be clearly defined, through a legal and regulatory framework.

4.9. Sufficient human and financial resources should be made available to the regulatory body or other competent authority for the effective implementation of the legal requirements. Human resources should be competent in the area of radiation protection, in particular for protection against exposure due to radon.

4.10. Resources and responsibilities for occupational exposure due to radon may exist within the broader occupational health and safety and radiation protection infrastructure that exists in a country.

Legal and regulatory framework for safety

4.11. The government should ensure that a legal and regulatory framework is established or modified that includes requirements for protection against radon exposure in workplaces, including control, management and assessment of doses due to radon and the inclusion of these doses in the total effective dose.

4.12. Dose limits for occupational exposure are required to be established by the government or the regulatory body in accordance with Requirement 12 and Schedule III of GSR Part 3 [2], which also apply to occupational exposure to ^{222}Rn and ^{222}Rn progeny and ^{220}Rn and ^{220}Rn progeny in situations according to paras. 3.4.(c) and (d) of GSR Part 3 [2].

4.13. The dose limits for occupational exposure in planned exposure situations should apply to the sum of all internal and external dose contributions, including the internal exposure from the inhalation of ^{222}Rn and ^{222}Rn progeny and ^{220}Rn and ^{220}Rn progeny from the authorized practice. The dose contribution from ^{222}Rn and ^{220}Rn progeny should be taken into account, independent of the level of activity concentration of ^{222}Rn and ^{220}Rn.

4.14. The government or the regulatory body should establish and enforce requirements for the optimization of protection and safety in relation to the exposure to ^{222}Rn and ^{222}Rn progeny, to ^{220}Rn and ^{220}Rn progeny and in relation to the total effective doses. Optimization of protection and safety is a prospective and iterative process for ensuring that the likelihood and the magnitude of exposures and the number of individuals exposed are as low as reasonably achievable, with economic, societal and environmental factors taken into account.

Justification of introduction of new practices involving exposure due to radon

4.15. GSR Part 3 [2] is based on the fundamental safety principles [1], including principle 4 which states that "Justification of facilities and activities: Facilities and activities that give rise to radiation risks must yield an overall benefit".

4.16. The general principle for justification of practices is outlined in Requirement 10 of GSR Part 3 [2], which states that:

> **"The government or the regulatory body shall ensure that only justified practices are authorized."**

4.17. IAEA Safety Standards Series No. GSG-5, Justification of Practices, Including Non-medical Human Imaging [22] provides recommendations on justification principles in the case of occupational exposure in planned exposure situations, including guidance on justification of practices.

4.18. In the case of operations or facilities where naturally occurring radioactive material is being handled or processed and where the activity concentration in the material of any radionuclide in the uranium decay chain or the thorium decay chain is greater than 1Bq/g or the activity concentration of ^{40}K is greater than 10Bq/g, the industrial activity is regarded as a practice and relevant requirements as specified in Section 3 of GSR Part 3 [2] apply.

4.19. If the introduction or the continuation of a practice involving exposure to radon in workplaces is not justified, the government should ensure that a legal mechanism exists to prohibit and terminate these occurrences.

4.20. For the cases where an enhanced level of radon concentration is intentionally applied for health purposes, the requirements on justification for medical exposure provided in Requirement 37 of GSR-Part 3 are applicable [2]. In such cases, three steps of justification could be applied as follows:

(a) Level 1 justification: The government is responsible for assessing the justification and should determine whether the application of a radioactive source for certain practices is justified. For the assessment, the government takes into account health impacts[2] and the potential benefits, including social and economic considerations.

(b) Level 2 justification: The regulatory body reviews the application for authorization of a practice, where the entity that plans to conduct the activity, provides justification for the practice and demonstrates why the application of radon is a preferred method compared to other methods that do not use ionizing radiation. Scientific evidence of proof of effectiveness for medical treatments (e.g. double blind test) needs to be provided in support of the application.

(c) Level 3 justification: The exposure of each individual patient is required to be justified based on the individual diagnosis and expected outcome or treatment.

[2] It is worth noting that known health effects of exposure to radon are provided by UNSCEAR, ICRP and WHO. Radon is radioactive gas, cause of lung cancer.

REGULATORY BODY OR OTHER COMPETENT AUTHORITY

4.21. The responsibilities of the regulatory body for protection against exposure due to radon in planned exposure situations are the same as for any other occupational exposure and include activities such as establishing the regulatory framework for protection against the exposure in the workplace, enforcement of requirements, establishing requirements on technical service providers, approving methods of dose assessment.

Regulatory requirements on the control of occupational exposures from radon

4.22. Requirement 20 of GSR Part 3 [2] states that:

> **"The regulatory body shall establish and enforce requirements for the monitoring and recording of occupational exposures in planned exposure situations."**

Requirement 24 of GSR Part 3[2] also says:

"Employers, registrants and licensees shall establish and maintain organizational, procedural and technical arrangements for the designation of controlled areas and supervised areas, for local rules and for monitoring of the workplace, in a radiation protection programme for occupational exposure".

4.23. For radon (and radon progeny), the regulatory body should establish specific requirements to be included in any radiation protection programme for the following:

(a) Demonstrated competence for radon;

(b) Assignment of responsibility to the radiation protection officer for radon protection (e.g. designation of a radon protection officer);

(c) Competencies of the radiation protection officer for radon protection;

(d) Radon dosimetry;

(e) Conduct of dose assessment for workers and retention of relevant records;

(f) Identification of areas with elevated radon levels (for example supervised areas);

(g) Special arrangements for the protection of female workers during pregnancy and during breast-feeding, as necessary, for embryo and fetus and breastfed infants and for persons under 18 years of age who are undergoing training;

(h) Measures for protection of workers against radon;

(i) Optimization of protection of workers.

Requirements on radon exposure in situations of multiple sources of exposure

4.24. In planned exposure situations, there might be working environments where the worker is exposed to concentrations of radon that exceed the national reference level. In cases where the radon-222 concentration in the workplace exceeds the national reference level or any other criteria set by the national authorities despite all corrective and optimisation measures taken, the individual dose due to inhalation of radon and its progeny by each worker should be assessed, recorded and included in the total dose assessment with respect to the dose limits set in Schedule III of GSR Part 3 [2]. When radon-222 activity concentration is below the national reference level or any other criteria set by the national authorities, requirements on optimisation of protection still apply (see para 4.49 - 4.54).

4.25. Special consideration in regulatory requirements should be given to workers that do not have a permanent workplace, such as workers undertaking non-destructive testing of systems and structures, industrial cleaners, specialist contractors and labourers. The provisions for ensuring the protection of these workers against exposure due to radon need to be established and the responsibility of the employer should be clearly stated.

4.26. Regulatory requirements should include provisions for including the contribution of radon in the dose assessment, dose records and into the report to the national dose registry. It is advised that the recent recommendations of the ICRP are considered by the competent authority in choosing the applicable DCFs. Since different Member States may use different dose conversion factors for radon dose assessment, it is advised that records of exposure are kept in addition to assumptions used in dose calculation. This information should be stored in the national dose registry and as part of the dose records for employees who move between the workplaces.

Requirements on measurement methodology

4.27. Similar to the requirements described in paras 3.67–3.71, the regulatory body should set criteria for and approve, or, when applicable, develop the methodology for dose assessment and dose monitoring (also called protocols) to be followed by the approved measurement service providers. The criteria for the approval of the radon measurement methodology at a minimum should include requirements on the following:

(a) Dose assessment and dose monitoring procedures (e.g. individual monitoring, surveillance of workplace, recording of occupancy hours);

(b) Type of the measurement device (e.g. passive or active personal dosimeters, instruments for continuous radon and radon progeny measurements at the workplace or instruments for passive radon measurements);

(c) Duration of radon measurements and reporting periods;

(d) Assumptions made for dose calculations and factors used in dose calculation (e.g. effective dose, equilibrium factor, dose conversion factor, occupancy factor);

(e) Specific situations for dose assessment;

(f) Uncertainties to be recorded;

(g) Format and content for reporting dose assessments and radon measurements to the national dose registry.

Further details on methodologies for radon measurements and radon dose assessments are provided in Annex I and Annex II.

4.28. The methodology recommended by the regulatory body for radon measurements and for dose assessment (e.g. parameters for dose assessment as equilibrium factor, dose conversion factor, occupancy factor, measurement methods) should be in line with the state of knowledge or state of technology as defined by international organizations (e.g. ICRP, UNSCEAR, ISO).

4.29. The contribution to the dose to the lung arises almost entirely from the short-lived progeny of radon, rather than from radon itself. The short-lived progeny are unlikely to be in equilibrium with the parent radionuclide. Therefore, for the purposes of radiation protection, special quantities are used for expressing the concentration of radon progeny in air and the resulting exposure due to their inhalation. This is the potential alpha energy exposure (PAEC) or equilibrium equivalent concentration (EEC). Recommendations on monitoring of short-lived progeny of ^{222}Rn is given in paras 2.60–2.70 of GSG-7 [9].

4.30. Regulatory requirements should also include instructions on how the measurement and dose assessment results are compared to the dose limits and dose constraints.

Requirements on measurement service providers and dose records

4.31. Paragraph 3.73 of GSR Part 3, [2] states that:

> **"The regulatory body shall be responsible, as appropriate, for: …**
>
> **c) Authorization or approval of service providers for individual monitoring or calibration services."**

4.32. The regulatory body should establish the requirements for approval of measurement service providers (see also paras 3.62 - 3.65), calibration service providers and radon competence for providers of advice in relation to radon. The requirements can be accreditation or approval by the responsible authority.

4.33. The regulatory body should specify the requirements for approval of radon measurement providers as explained in paras 3.62–3.66. The additional competence to be included in the requirements for the dose assessments in planned exposure situation is in relation to radon progeny.

4.34. Measurement service providers may be approved by the regulatory body either based on the established requirements or based on the accreditation, or a combination of both.

Requirements for public exposure

4.35. For the purposes of assessing the total dose to the public from planned exposure situation and in order to determine whether these are in compliance with the dose limit for the public of 1 mSv/a, whenever relevant, the regulatory body should include radon impact from the authorized practice in regulatory requirements or license conditions, as well as set requirement on methodology for assessment of radon impact.

4.36. The regulatory body should stipulate situations where doses due to radon (and progeny) from the authorised practice are included in the assessment of the total dose of the public representatives visiting a workplace. This could be relevant for workplaces, such as uranium mining or production industry, industrial processes involving NORM or similar.

EMPLOYERS

4.37. For planned exposure situations specific requirements for employers are established in GSR Part 3 [2]. The employer has a general duty to establish a safe workplace and a system of worker protection. Workers also have a responsibility to comply with all rules and regulations and to report issues relevant for safety [7]. There is also a general requirement for employers and workers to work together to achieve a safe workplace.

4.38. Registrants and licensees are responsible for establishing a safety system for authorized practices and sources, regularly review and verify that they comply with the requirements. Requirement 9 of GSR Part 3 [2] states that:

"Registrants and licensees shall be responsible for protection and safety in planned exposure situations."

Requirement 14 of GSR Part 3 [2] states:

"Registrants and licensees and employers shall conduct monitoring to verify compliance with the requirements for protection and safety."

4.39. Requirement 15 of GSR Part 3 [2] states:

"Registrants and licensees shall apply good engineering practice and shall take all practicable measures to prevent accidents and to mitigate the consequences of those accidents that do occur."

Requirement 16 of GSR Part 3 [2] states:

"Registrants and licensees shall conduct formal investigations of abnormal conditions arising in the operation of facilities or the conduct of activities and shall disseminate information that is significant for protection and safety."

4.40. Requirement 21 of GSR Part 3 [2] states that:

"Employers, registrants and licensees shall be responsible for the protection of workers against occupational exposure. Employers, registrants and licensees shall ensure that protection and safety is optimized and that the dose limits for occupational exposure are not exceeded."

4.41. There are specific Requirements in GSR Part 3 [2] related to the responsibilities of employers. In general, employers are responsible for the protection of workers against occupational exposure due to radon, as to any other health hazard at workplace, and for ensuring that protection and safety is optimized. Employers ensure that a system of safety is in place in a workplace to control exposures and prevent accidents. The system includes regular review and assessment of the effectiveness of controls, assessment of doses, and also a means for information dissemination.

4.42. In accordance with para. 3.78 of GSR Part 3 [2], employees working in areas not classified as "controlled or supervised", still require protection against exposure to indoor radon. The system of protection against exposure due to radon (see also para. 3.73), is the same as for existing exposure situations covered in Section 3, if the activity concentration of ^{222}Rn is below the reference level. If the levels of ^{222}Rn, after all reasonable measures exceed national reference levels, the requirements for planned exposure situations apply.

4.43. The employer, registrant or licensee should aim at a primary objective to implement controls to minimize the number of workers exposed in all work situations. Measures should be considered that limit both the number of workers exposed and their potential exposures.

4.44. The employer is responsible to ensure that assessments of radon exposure for these workplaces are conducted, and that protective measures commensurate with the radon risk are implemented (see also paras 4.49–4.54).

Consideration of Workplaces with naturally occurring radioactive material

4.45. Workplaces involving the mining or processing of raw materials, bulk waste or residues are potential workplaces where radon concentration could be elevated. This is because all materials contain naturally occurring radioactive materials. The processes involved in mining and processing and the nature of processing (for example, break up of materials to produce higher surface area materials, concentration of unwanted elements and materials into waste or by product streams), are likely to increase radon emission rates or increase radionuclide concentrations in materials and, therefore potentially result in increased radon concentrations.

4.46. Mining and processing of raw materials that involve exposure due to radiation are subject to the requirements of planned exposure situations. Materials, containing the naturally occurring radionuclides of uranium or thorium decay chain that exceed an activity concentration of 1 Bq/g or 10 Bq/g of ^{40}K are subject to regulatory control. Operations and practices subject to regulatory control, would be required to assess the impacts of radon and other radiation exposure pathways to workers.

4.47. Workplaces, containing elevated concentrations of naturally occurring radioactive material, that do not exceed 1 Bq/g, are regarded as existing exposure situations in accordance with para. 5.1(c) of GSR Part 3 [2]. In these cases, the radon concentrations should be measured to determine whether any workplaces exceed the reference level and therefore require the operation to implement controls in order to optimize the radon concentration (see Fig. 1 and Section 3).

4.48. References [18-21] provide advice on those industries that could be affected by naturally occurring radioactive material listed in para. 2.15.

Optimization and safety assessment

4.49. Radiation is one of the hazards that the employer should properly manage through the operational management system and through protection plans. To optimize the overall protection of workers, the employer should generally consider radiation as one of the many potential health and safety issues for their work activities. An understanding of how radon concentration is built up in the workplace and possible control mechanisms is necessary for ensuring the appropriate protection of workers.

4.50. The optimal protection requirements for radon in a workplace should be developed in accordance with a graded approach. For planned exposure situations, documented control of radon is required.

4.51. The employer should establish specific criteria, based on which optimization is assessed. Such criteria include the number of employees exposed to certain radon levels, the doses received by different groups of workers, and the cost for the implementation of controls.

4.52. For occupational exposure due to radon, appropriate dose constraints or health risk constraints should be established and, if appropriate, should be approved by the regulator. The dose constraint may be expressed as the total dose constraint, or as a constraint for radon dose only. The health risk constraint should provide a level of protection for those most exposed to radon at workplace and should take into consideration the probability for occurrence of lung cancer.

4.53. There is no unique method for implementing a graded approach or optimisation. Each employer and regulatory body would have to identify the key requirements and extent of application of those requirements that would need to be addressed for a particular circumstance or workplace.

4.54. For workplaces regulated as planned exposure situations that have not previously considered the contribution from radon to the dose, an assessment of the radon concentrations is required in order to determine the level of exposure and associated risk and provide the basis for optimisation of protection.

Radiation Protection Programme

4.55. Requirement 24: Arrangements under the radiation protection programme of GSR Part 3 [2] states:

> **"Employers, registrants and licensees shall establish and maintain organizational, procedural and technical arrangements for the designation of controlled areas and supervised areas, for local rules and for monitoring of the workplace, in a radiation protection programme for occupational exposure."**

4.56. The arrangements under a radiation protection programme for planned exposure situations are detailed in GSR Part 3 (paras 3.88–3.98) [2] and further recommendations are provided in GSG-7 [9]. The main areas that are required to be addressed are as follows:

(a) Description of the exposure situation and a safety assessment;

(b) Defining the scope of the radiation protection programme (defining the areas to which the radiation protection programme applies);

(c) Qualified experts (either retained or to whom organization has access);

(d) Statement of the accountabilities for radiation protection;

(e) Classification of areas (i.e. unrestricted, supervised or controlled);

(f) Local rules for radiation protection and supervision;

(g) Personal protective equipment and assurances on its effective use (including maintenance programmes for the equipment and training programmes for the workers);

(h) Work planning and work permits;

(i) Monitoring for radiation and the methods used to assesses exposures and doses;

(j) Information, instruction and training for exposed workers;

(k) Workers qualification;

(l) Systems for audits and reviews;

(m) Health surveillance of workers.

4.57. In accordance with para. 3.96 of GSR Part 3 [2], workplace monitoring is required as a part of the radiation protection programme. One of the purposes of monitoring is to make an assessment of workers occupational exposure.

4.58. Requirement 25: Assessment of occupational exposure and health assessment of GSR Part 3 [2] states that:

“Employers, registrants and licensees shall be responsible for making arrangements for assessment and recording of occupational exposures and for workers’ health surveillance.”

4.59. In a workplace, the radon concentrations can be determined either through real time continuous radon measurements or passive radon measurements. Instruments can be used to determine the radon or radon decay product concentrations. Continuous radon measurements provide information on the variability with time and location, while measurements with passive detectors are able to provide long term average concentrations. Care should be taken to ensure that monitoring occurs in areas where workers are present, and consideration has to given to the workers breathing zone. Further guidance on monitoring and instruments is provided in Annex I.

4.60. Employer at workplaces, that are already regulated as planned exposure situations, are likely to have internal radiation expertise or access to such expertise that would provide qualified advice on radon exposure. In addition, such workplaces are likely to have a mature relationship with the regulator and therefore able to discuss the possible ways of implementing the requirements.

4.61. Annex II of this document provides a simplified overview for the assessment of radon related doses for workers.

4.62. Paragraph 3.103 of GSR Part 3 [2] states that:

“Employers, registrants and licensees shall maintain records of occupational exposure for every worker for whom assessment of occupational exposure is required…”.

4.63. For the records of occupational exposure of workers due to exposure to radon and its progeny, detailed information should be included such as the measured activity concentration of radon, concentration of radon decay products (if relevant), dose conversion factors used in the calculation, working hours and type of work. The record should also contain assumptions, uncertainties or other information relevant to the dose assessment. This information enables the employer (or the regulatory body) to retrospectively recalculate the effective dose if any of the associated parameters used for dose assessment change.

4.64. When developing the radiation protection programme, which includes radon, for the planned exposure situation, it is important to ensure that controls and dose estimates are based on the monitoring and measurement of the radon or radon decay product concentrations in air. This is because for planned exposures, radiation control is implemented through dose control. In practice, a workplace might have elevated radon concentrations, but the radon decay product concentrations might be low due to the use of ventilation (i.e. low equilibrium factor) and thus do not contribute too much to the total radon dose.

4.65. It is important to decide, whether workplace radon monitoring and dose assessment should be based on radon only or radon decay products measurements. Such a decision will be justified by the specific characteristics of the workplace, exposure pathways, source of radon (natural or as a result of uranium material management), and equilibrium factors.

4.66. A graded approach for reduction of exposure due to radon may involve the implementation of practical measures such as use of cost-effective monitoring, use of respiratory personal protective equipment for particular tasks (which is effective at removing radon decay products from the air inhaled by the worker) and use of controls that provide combined protection from several hazards at once.

4.67. Employers should engage employees in discussions regarding optimization of protection and safety, collect input on measures of continuous improvements of safety, as well as provide the system for reporting non-compliances or risk observations.

Protection of pregnant or breast-feeding workers, itinerant workers

Workers During Pregnancy and During Breast Feeding

4.68. Requirement 28 of GSR Part 3 states:

> **"Employers, registrants and licensees shall make special arrangements for female workers, as necessary, for protection of the embryo or fetus and breastfed infants. Employers, registrants and licensees shall make special arrangements for protection and safety for persons under 18 years of age who are undergoing training."**

4.69. Paragraph 3.114 of GSR Part 3 states [2]:

> **"Notification of the employer by a female worker if she suspects that she is pregnant or if she is breast-feeding shall not be considered a reason to exclude the female worker from work. The employer of a female worker, who has been notified of her suspected pregnancy or that she is breast-feeding, shall adapt the working conditions in respect of occupational exposure so as to ensure that the embryo or fetus or the breastfed infant is afforded the same broad level of protection as is required for members of the public."**

4.70. For occupational exposure of workers during pregnancy and during breast-feeding, the embryo or fetus and breastfed infants are required to be protected as members of the public. This means that neither the effective dose nor the equivalent dose to tissues or organs for the embryo or fetus and breastfed infants from the authorized practice exceeds any relevant dose limit specified in Schedule III of GSR Part 3 [2] (e.g. effective dose of 1 mSv in a year).

4.71. In accordance with para. 3.113 of GSR Part 3 [2], the employer is required to inform workers of the importance and means to declare pregnancies. The workers are not required to report pregnancies.

4.72. The assessment of the potential dose to pregnant workers in planned exposure situations should include the contribution to dose from inhalation of radon and its progeny. However, as radon progeny mainly affect the lungs the embryo or fetus is not significantly exposed to radon, therefore dose assessments from radon are not necessary [24]. Also, the Agency for Toxic Substances and Disease Registry states that no maternal or fetal reproductive effects in humans have been attributed to exposure to radon and its progeny [25].

4.73. For infants (that may require breastfeeding during working hours by a mother)in an occupational work setting, there is the potential for the infant to be exposed in several pathways. When assessing doses, it is not relevant to simply apply the adult dose conversion factors. This is because the infants' inhalation rate is significantly lower than that of an adult.

Itinerant Workers

4.74. Itinerant workers are occupationally exposed persons who work in supervised areas or controlled areas at various locations and who are not employees of the management of the facility where they are working (see GSG-7 [9] and Ref. [23]). These can be specialist workers or unskilled labourers, contractors, employees hired for specific roles, trained apprentices or occasional service providers. Exposure of apprentices below age 16 is not allowed, however, apprentices aged 16 to 18 can be considered to be itinerant workers. Itinerant workers can be self-employed or can be employed by a contractor (or similar legal entity) that provides services at the facilities of other employers.

4.75. GSR Part 3 [2] does discriminate between permanent workers and part time or itinerant workers. The requirements apply to all workers and the same level of protection is required to be provided. The employer of the itinerant workers should cooperate with registrants and licensees to ensure protection and safety of itinerant workers.

4.76. Paragraphs 6.21–6.100 of GSG-7 [9] provide detailed recommendations on the protection of itinerant workers in planned exposure situations, to ensure that adequate tracking of such personnel occurs, in order to perform accurate dose assessment and provide protection to the workers. Employers should ensure that the time that itinerant workers spend on site is recorded, measurements are undertaken that adequately represent the exposure to the workers and workers are informed of the potential risks of exposure due to radon.

Application of requirements for the control of public exposure in workplaces with public access

4.77. Workplaces with elevated radon concentrations may be visited from time to time by members of the public or by workers not classified as occupationally exposed workers as part of their work. These workers are required to be provided the same level of protection as members of the public, in accordance with GSR Part 3 [2]. It is the responsibility of the employer to ensure that the exposures of the public are as low as reasonably achievable and well controlled.

4.78. In accordance with the requirements for a planned exposure situation (GSR Part 3 [2]), the dose to the public cannot exceed 1mSv per year from all sources under control in an authorized practice. For example, a practical approach for the protection of the public in such workplaces would be to use the national reference level for radon as an appropriate tool for places where the public might have access (i.e. visitors from the public will be allowed to enter only those workplaces where radon concentration is below the national reference level for workplaces). Such practical approaches need to be discussed and agreed with the regulatory body.

4.79. Control measures for protection of the public, visiting a workplace, may include:

(a) Providing information on potential risks to visitors;

(b) Providing instructions on how to behave and minimize exposures;

(c) Providing personal protective equipment for visitors when justified;

(d) Ensuring that visitor areas are well designated;

(e) Providing adequate ventilation of visitor areas.

WORKERS

4.80. Requirement 22: Compliance by workers of GSR Part 3 [2] states that**:**

"Workers shall fulfil their obligations and carry out their duties for protection and safety."

4.81. The requirements for workers set out in paras 3.83–3.84 of GSR Part 3 [2] are consistent for both existing and planned exposure situations and include:

(a) Following the rules and procedures;

(b) Using the monitoring equipment provided;

(c) Using personal protective equipment as appropriate;

(d) Cooperating in workers' health surveillance programmes;

(e) Receiving training and instructions;

(f) Reporting identified situations that might affect health and safety at workplace;

(g) Acting responsibly with regard to health and safety (and radiation safety).

4.82. Workers have the right to request that radon measurements in workplaces and dose estimates be undertaken and records be made available to them.

4.83. Employees have the right to engage through the representative bodies in discussions on optimization of protection and safety with their employers and registrants or licensees, as well as participate in the process of continuous improvement of working safety.

SERVICE PROVIDERS

4.84. Service providers for radon may provide measurements, qualified advice or remediation activities. All service providers are required to comply with requirements set by the regulatory body (see paras 4.31–4.34) and implement a quality management system. Service providers for measurements should be independent of service providers for remediation activities to avoid conflict of interest.

4.85. Recommendations on the quality management for service providers of technical services for radiation protection are provided in GSG-7 [9]. All measurements service providers and services for protection and safety should be qualified in accordance with procedures approved by the regulatory body.

4.86. Radon and its behaviour, measurement, control and management are complex areas, that need expertise and knowledge. Service providers that provide general radiation protection services might not have adequate competence with respect to radon and its progeny. For example, a service provider for gamma calibration might be accredited by the competent authority for calibration services, however, this does not mean that this provider can provide advice on radon.

4.87. Employers should ensure that when seeking advice on protection against exposure due to radon, they select service providers competent in radon and radon dose assessment issues.

REGULATORY CONTROL IN CASES WHERE THE REFERENCE LEVEL CONTINUES TO BE EXCEEDED DESPITE REMEDIAL ACTIONS

4.88. There can be instances of workplaces with elevated radon concentrations above the national reference levels, despite all reasonable corrective measures or, because corrective measures are not applicable (see Section 3).

4.89. The regulatory body should establish requirements for employers to conduct radon surveillance in the workplace and to report the results to the competent authority, as appropriate. Where a workplace, despite all reasonable efforts, still exceeds the prescribed radon reference levels, the regulatory body should notify the employer and provide information on the applicable requirements for planned exposure situations.

4.90. The regulatory body or other competent authority should ensure that controls in these workplaces follow a graded approach, which can be based on the assessed dose values. The graded approach can be implemented through actions such as authorization, optimization of protection of workers by reducing exposure due to radon, development and implementation of a radiation protection programme, access to radon competence, assessment of doses and retention of dose records.

4.91. The difference of applicable requirements in planned and existing exposure situation is presented in Table 1.

4.92. For workplaces where radon concentrations exceed the reference levels, the regulatory body should establish procedures for notification to include the following:

(a) Specifying the competent authority to be notified;

(b) Establishing the responsibility for notification;

(c) Defining the information and documentation to be included in the notification;

(d) Establishing the timeframe for notification.

4.93. The documentation provided by the employer should provide sufficient information to the competent authority to decide on further actions.

4.94. The regulatory body should develop, if appropriate, or approve a dose assessment methodology for radon exposure, and define measurement protocols commensurate with the graded approach.

4.95. Normally, the dose assessment for radon is based on the following three approaches:

- Radon progeny measurements;
- Radon gas measurements;
- Radon exposure (activity concentration during a specified period of time).

4.96. For workplaces where radon concentrations exceed the reference levels, as part of a graded approach, the regulatory body or the competent authority may decide that only exposure is to be assessed and recorded.

4.97. The regulatory body should establish a requirement for the employer to report on a regular basis the results of the dose assessments or exposure to be included in the national dose registry.

4.98. The regulatory framework should include requirements for measurement service providers and their competencies (including the competencies of a radon protection officer) for the control of radon exposure (see paras 4.31–4.34).

4.99. The regulatory body should establish requirements on the authorization of workplaces that fall under the conditions of para. 3.4(d) of GSR Part 3 [2]. The regulatory body should specify the content of the application for authorization, for example whether it should include results of prior radiological evaluations or safety assessments. In workplaces where radon is not used as a source for operations, the regulatory body could consider registration as an appropriate level of authorization.

Radiation Protection Programme

4.100. The primary requirement for planned exposure situations is the establishment of a radiation protection programme (see paras 4.55–4.67). However, all aspects of a radiation protection programme might not be necessary for a situation falling under the conditions of para. 3.4(d) of GSR Part 3 [2]. Table 2 summarizes the components of a radiation protection programme and identifies whether these are required to be included in accordance with GSR Part 3 [2].

TABLE 2. COMPONENTS OF RADIATION PROTECTION PROGRAMME FOR WORKPLACES AS DESCRIBED IN GSR PART 3, para. 3.4d)

Component of a radiation protection programme	Consideration
Defining the scope of the radiation protection programme	Required
Qualified experts	Required
Accountability	Required
Classification of workplaces	Required only for areas with elevated radon concentrations
Local rules and supervision	Considered
Personal protective equipment	Considered
Work planning and work permits	Considered
Monitoring and assessment of exposures	Required
Information, instructions and training	Required (could be part of general health and safety instructions)
Workers qualification and certification	Not required
Audits and reviews	Considered
Health surveillance	Considered

5. OCCUPATIONAL EXPOSURE DUE TO THORON

GENERAL DESCRIPTION OF THE EXPOSURE DUE TO THORON AND ITS CONTRIBUTION TO THE TOTAL EFFECTIVE DOSE

5.1. Thoron is the common name for the isotope of radon (^{220}Rn) from the ^{232}Th decay chain. It is present everywhere in the atmosphere in varying concentrations.

5.2. While the characteristics of radon and its decay products are generally well understood and documented as a result of many years of workplace studies and environmental studies, the practical knowledge and experiences with thoron are limited. Further studies occur every year, in particular in relation to monitoring, which help to build the knowledge base. However, the characteristics of thoron and thoron decay products remain less well understood than those of radon and its decay products.

5.3. The Government or regulatory body may set requirements in relation to the exposure to ^{220}Rn and ^{220}Rn progeny and in relation to the total effective doses if necessary.

5.4. The IAEA provides recommendations and guidance on thoron management in the following publications:

(a) Reference [17] that briefly deals with thoron in Annex II;

(b) SSG-32 [11] that briefly deals with public exposure to thoron;

(c) Reference [21] that deals with thoron as a part of radon exposure of employees in the uranium mining and processing industry;

(d) Reference [20] that deals with thoron as a part of naturally occurring radioactive material residues.

5.5. Publication 142 of ICRP [26] notes the importance of thoron in workplaces within naturally occurring radioactive material industries and recommends that both radon and thoron are managed as a single source irrespective of the source. In Publication 137 [4], ICRP notes that "^{220}Rn gas makes a negligible contribution to doses" [4], but it is recognized that in some specific circumstances ^{220}Rn progeny could be important contributors to the total effective dose.

5.6. Natural airborne thoron concentrations are extraordinarily variable, ranging over orders of magnitude in a typical 24-hour cycle, from 1 Bq/m^3 to 1000 Bq/m^3. UNSCEAR 2000 reports the worldwide average of thoron as 10 Bq/m^3 [27]. Thoron concentrations are also spatially variable with concentrations varying markedly across a distance of 1m.

5.7. Elevated thoron concentrations usually occur in areas where naturally occurring thorium concentrations are elevated, such as in areas where there are mineral sands or products containing thorium.

5.8. Unlike ^{222}Rn, the isotope of ^{220}Rn has a relatively short half-life (< 1 minute). This means that it has a relatively high specific activity, and does not diffuse far in air before decaying. Experimental work indicates that the concentration of thoron decreases by half at approximately 40 cm from the emanation surface [28].

5.9. As for the dose assessment for thoron, surveys conducted in China, where natural level of ^{238}U and ^{232}Th in soils are 53.4 Bq/kg and 11.68 Bq/kg, respectively, and the average radon and thoron decay product concentrations (equilibrium equivalent exposure) measured in dwellings were 12.9 Bq/m^3 and 0.87 Bq/m^3. This indicates that thoron and its decay products contribute about 20% of the estimated effective dose of 1.28 mSv/a from radon and thoron combined [29].

5.10. Given that there are differences between the behaviour of thoron and the more well-known radon, an overview of the mechanisms of thoron emission is provided in this Section.

5.11. Thoron exhalates from the soil or building materials if no cover is applied. The number of atoms exhaling from soil or materials is relatively small due to the high specific activity. The short half-life results in a short diffusion length. Hence unlike radon, only thoron produced in a thin layer beneath the surface can come out to the environment. Thus, thoron exhalation is primarily a surface phenomenon.

5.12. Because of the high specific activity, the atoms of thoron that do escape into the air result in relatively high activity concentration, therefore, there can be a relatively high activity exhalation rate.

5.13. The first decay product of thoron is ^{216}Po which grows in almost instantaneously, due to its very short half-life (0.15 s), therefore, the activity concentrations in air of thoron and ^{216}Po are always the same. Polonium-216 decays quickly because of its short half-life, producing ^{212}Pb. The number of atoms of ^{212}Pb produced is basically the same as the number of ^{220}Rn atoms coming out of the soil or material. However, due to the longer half-life of ^{212}Pb (10.6 h), the activity concentration of ^{212}Pb is much lower than the activity concentration of thoron.

5.14. In a very stable air, with a thoron source, the ^{212}Pb concentration would slowly climb towards equilibrium over many hours (>30 h). However, any atmospheric turbulence at all will cause the ^{212}Pb atoms to dilute and disperse before they can come to equilibrium. Therefore, in the atmosphere, thoron activity concentrations may be high, but the thoron decay product concentrations even in still air are always much lower, except when the air is very stable over long periods of time (days).

Equilibrium Factor

5.15. The major factor that differentiates radon and thoron and consequently their contribution to doses, is the equilibrium factor.

5.16. The short half-life of thoron contributes to the relatively low equilibrium factor, estimated to be, on average, 0.02 [30]. The low equilibrium factor is due to the much longer half lived thoron decay products which take a lot longer to come into equilibrium with thoron and are removed by air exchange long before the equilibrium is reached. In comparison, for ^{222}Rn, with short lived decay products, the equilibrium factor is reported as 0.6 for outdoor air and 0.4 for indoor air [27].

5.17. Earlier work presented at a tutorial session on environmental radiation protection by the Commission of the European Communities (CEC 1993) [31], gives calculated equilibrium factors for ^{222}Rn and ^{220}Rn and their decay products of between 0.4 to 0.6 and 0.04 to 0.05 respectively. This difference can be attributed to the relatively long half-lives of thoron decay products as compared to radon decay products.

5.18. Studies by Wasiolek and James 1996 [32] and Prasad et al 2015 [33] also note outdoor thoron equilibrium factors of approximately 0.03 to 0.04. They note that the reason for the very low equilibrium factors is the longer half-life of the thoron decay product ^{212}Pb and notes that "^{212}Pb can be carried to greater heights than thoron, diluting its concentration at ground level".

5.19. Hosoda et al 2017 report mean equilibrium factors from between 0.008 and 0.07 from several countries [28].

5.20. The practical relevance of the equilibrium factor can be seen in Ref. [34], which shows the calculated equilibrium factor as a function of air exchange rates ('age of air') for both radon and thoron.

5.21. To conclude the information above, even low airflow is sufficient to dilute thoron decay product concentrations and therefore reduce the equilibrium factor. It is thus important to study each situation of thoron exposure, before conducting a dose assessment.

Relevance of Thoron

5.22. UNSCEAR notes that it is not possible to assess risks due to the inhalation of ^{220}Rn decay products by epidemiological means and refers to dosimetric modelling to support the dose conversion factor for ^{220}Rn gas concentrations of 40 nSv/h per Bq/m^3 equilibrium equivalent exposure (which implies an equilibrium factor of 1) [27]. The ^{220}Rn gas dose factor may be linearly scaled based on a knowledge of the equilibrium factor. From a practical perspective, it is important to remember that ^{220}Rn concentrations are highly variable, therefore a representative concentration should be obtained.

5.23. To assess doses from decay product measurements, the ICRP has provided updated dose factors for ^{222}Rn and ^{220}Rn [4]. For indoor workplaces, the dose factor for ^{220}Rn is 1.6 mSv/(mJhm^{-3}), which is lower, compared to the dose factor for ^{222}Rn of 5.7 mSv/(mJhm^{-3}). The dose factor is based on measurements of the ^{220}Rn decay product concentration, which, for this dose factor, is measured in units of mJhm^{-3}.

5.24. Due to large variation in equilibrium factors, thoron gas measurements are not representative of the potential dose from thoron decay products. For a correct assessment of an effective dose in a situation when ^{220}Rn and its progenies are of importance, measurement of the thoron decay product concentrations should be undertaken. A dose calculated from a thoron concentration will significantly overestimate the actual dose and may lead to unnecessary constraints and controls.

5.25. It is well documented that assessing the concentration of thoron in indoor air of a workplace could be important because it may interfere with measurements of radon concentrations [35]. In particular, not all passive radon detectors discriminate against thoron, thereby implying that radon measurements might be overestimating the actual ^{222}Rn concentrations. Thoron interference can be regarded as one of the major uncertainties of radon measurements in radon studies. Any measurements for evaluation of health effects without discriminative detection of radon isotopes might result in risk estimates that include high uncertainties.

5.26. However, new detectors are available which have a filter for thoron and when used side by side with detectors without filters, a passive measurement of the average radon and thoron concentrations can be obtained.

5.27. To determine whether thoron is important from a dose perspective, the thoron decay product concentrations should be directly measured, and various techniques exist to do this.

Existing Exposure Situations

5.28. GSR Part 3 defines radon as: "Any combination of isotopes of the element radon" and further explains that "For the purposes of these Standards, radon refers to ^{220}Rn and ^{222}Rn" [2]. As previously noted, thoron concentrations vary significantly both spatially and temporally, therefore, the duration of sampling and the location of sampling are very important. Thoron measurements should be time integrating, rather than grab samples, and should be undertaken in areas where workers are present.

5.29. In States, where thoron concentrations at workplaces might be of concern, the regulatory body should establish national reference levels for exposure to thoron. Care should be taken to the fact that exposure to both ^{220}Rn and ^{222}Rn occurs and the national reference levels for these two radionuclides should be based on a reasonable level of annual effective dose. Optimisation of protection and safety should also apply.

5.30. Consideration can be given to the use of both locational and personal thoron monitors to adequately assess the workplace conditions. Where average thoron concentrations exceed the national reference level, then measures will need to be implemented to reduce concentrations.

Planned Exposure Situation

5.31. The general advice for the worker dose assessment (as noted previously in paras 5.22–5.24) is that due to the large variation in equilibrium factors, thoron gas measurements are not representative of the potential dose from thoron decay products. For correct assessment of an effective dose in situation when ^{220}Rn and its progenies are of importance, measurement of the thoron decay product concentrations should be undertaken.

5.32. If thoron gas measurements are the only available means of assessing worker doses, the use of default equilibrium factor for converting a thoron gas concentration to a thoron decay product concentration can be used. The particular equilibrium factor used should be discussed and agreed with the regulatory body. The assumptions and data used for the individual dose assessment should be recorded in the dose registry entry.

5.33. Special consideration needs to be taken with regards to thoron measurement equipment and this is due to the short half-life of ^{220}Rn meaning that the concentration will vary significantly between the source of emanation or exhalation to the respiratory zone of the worker. Workplace monitoring equipment, placed near a source of thoron, will not necessarily be representative of workers exposure and might result in overestimation of thoron exposure.

5.34. Workplace monitoring can be implemented utilizing passive or active measurement techniques. Individual dose monitors could also be worn by workers or located where workers spend their working time, similar to the radon monitoring methods described in paras 4.22–4.23.

Management of exposure to thoron

5.35. The application of the approach to management of radon in workplaces can be generally applied to thoron. It is assumed, that when corrective or preventive measures are taken to manage radon exposures, thoron exposures are also likely to be reduced. Special considerations should be taken into account for construction materials that are a source of thoron.

5.36. Filtration is a potential control for thoron decay products, however, as soon as thoron has penetrated the filter, it immediately establishes its first decay product. Therefore, filtration is ineffective as a control mechanism if thoron is still present in the air. If the source of thoron is removed, then unsupported thoron decay products can be filtered away.

Measurement of ^{220}Rn and its decay products

5.37. Thoron concentrations can be measured using real time commercially available thoron monitors.

5.38. An example of thoron decay products measurements can be a so called “Rock method” based on single delayed alpha count procedure [36].

5.39. The method involves using a personal air pump to collect a sample on a filter paper. The pump samples for 20 minutes at rate of 2 liters per minute. The filter paper with the filtered decay products is then enclosed in a plastic container for a delay period of 5 hours. After the delay period the filter paper is gross alpha counted for a period of 10 minutes. A background count is usually conducted prior to the filter count. The count data is then used to calculate the potential alpha energy concentration (PAEC) of the thoron decay products using the following equation [36]:

$$PAEC\ (\mu J/m^3) = \frac{[(C_S - C_B) \text{ x } 20.8]}{(\text{E x f x V x T})}$$

Where:

C_S = gross count in interval T,
C_B = background count in interval T,
E = efficiency of detection equipment expressed as a fraction (cps/dps),
f = average factor to convert from counts per minutes to WL (working level),
V = volume of air sampled,
T = counting time in minutes,
20.8 - factor to convert from WL (working level) to µJ/m^3.

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ANNEX I RADON MEASUREMENT PROTOCOLS AND MEASUREMENT TECHNIQUES

I-1. This Annex provides an overview of various measurement devices, measurement techniques and protocols for measurement of radon and radon decay products. Whilst radon decay products are responsible for most of the radiation dose from ^{222}Rn, radon gas concentration can give an indication for the concentration of the radon decay products. Radon gas measurements are generally simpler and more cost effective than measurements of decay products.

I-2. The requirements for workplaces for planned exposure situations and existing exposure situations are somewhat different and different approaches are needed for workplace monitoring techniques and protocols.

I-3. In regulating the protection of workers in planned exposure situation, the aim is to assess and control the dose and focus on the measurement of the activity concentration of radon decay products.

I-4. For regulatory control of the protection of workers in existing exposure situations, the radon concentration reference levels are used and measurements of average annual radon concentrations are required.

RADON MEASUREMENT PROTOCOLS

Purposes of radon measurements at workplaces

I-5. In accordance with GSR Part 3 [I-1], radon in workplaces is required to be controlled and national competent authorities are responsible for establishing the general framework for this. In general, there are number of reasons why workplace monitoring might be undertaken:

- To identify elevated levels of radiation that require control;
- To understand and quantify worker exposures;
- To confirm that the radiation controls are in place and effective;
- For investigative purposes;
- For authorisation conditions;
- For dose assessment and epidemiology studies.

I-6. Radon measurements at workplaces are not undertaken in isolation. The measurement results are used to inform management and employees on the level of radon exposure, the protection to be provided, optimisation considerations. In practice, workplace radon monitoring is an integral part of the overall radiation protection programme.

I-7. Guidance regarding how the annual average activity concentration of ^{222}Rn at workplaces indoors could be determined and evaluated (measurement protocols), has proven to be helpful. The availability of a harmonized national guidance allows for all relevant workplaces to be assessed in a similar manner with a similar level of quality. Such guidance needs to take the following details into account:

- Measurement systems;
- Calibration and quality assurance;
- Sampling duration;

- Season of measurements and applicability of seasonal correction factor;
- Location and number of measurement points;
- Estimation of uncertainties of the measurements;
- Specific regulatory requirements for specific workplaces;
- How to compare the measured activity concentration with the reference level for the purpose of demonstrating compliance;
- Frequency of evaluation or other conditions for repeated measurements or necessary additional investigations.

Measurement systems

I-8. In general, radon activity concentration measurements at workplaces are done utilizing long-term passive measurements such as solid- state nuclear track detectors (SSNTD), electrets and activated charcoal canisters. These measurements are relatively cheap and easy to conduct. The measurements provide the average radon activity concentration for the exposure period.

I-9. "Continuous active radon monitors can also be utilized for the purpose and provide high quality results. Historically, the cost of the equipment has limited its wide application; however, the cost of this equipment is currently decreasing, and it may be used more widely in the future. Active measurement instruments can show either average activity concentration or time-resolved values (e.g. every hour, every 15 min). The advantage of active time-resolved long-term measurements is the ability to evaluate the variation of the radon activity concentration (e.g. daily, seasonal, activities, occupancy periods) and ability to better assess the actual exposure of the workers.

I-10. For certain workplaces, where higher radon concentrations are anticipated (e.g. underground, workplaces, water works), it has to be evaluated, whether passive radon detectors are capable of performing with a stable quality during the whole sampling period of several months without being overexposed, and whether the memory capability of active measurement instruments is adequate.

Calibration and quality assurance

I-11. The measurement systems, which are accepted for the evaluation of the annual average activity concentration of 222Rn at workplaces needs to be supported by a quality assurance system: calibrated equipment, verified measurement methodology and approved measurement service providers.

I-12. All establishments that provide radon measurement services need to have and maintain quality assurance (QA) plans. The QA plan will include standard operating procedures together with systems for recording the measurements [I-2, I-3].

I-13. Continuous monitors are to be calibrated individually by an authorized body, which could be the manufacturer or a calibration service provider. The calibration process will be dependent on the specific detector, but the process should include at a minimum:

- Voltage check;
- Battery check;
- Determination of discriminator settings and voltage settings on photo multiplier tubes;

- Background determination in a radon-free environment;
- Calibration against known radon concentrations.

I-14. Following calibration, a certificate including the date of calibration needs to be provided and a calibration label could be affixed to the measurement instrument. The measurement instrument needs to be calibrated at regular intervals as recommended by the manufacturer (typically annually) and also following any repair or maintenance.

I-15. As part of the approval process for calibration facilities the regulatory authority may establish requirements for the calibration facilities to take part in performance tests and intercomparison measurements with other facilities.

I-16. Passive devices, such as track etch, electret and activated charcoal detectors, are calibrated in batches under different parameters, such as known and controlled radon concentration, and controlled physical conditions (temperature and humidity).

I-17. The specifications for calibration of radon detectors are provided in Ref. [I-4].

Sample duration

I-18. To evaluate the annual average activity concentration of ^{222}Rn, the measurement characteristics (time, duration, setting) need to be representative of the annual average activity concentration at the workplace under examination. The most reliable way to fulfil this is to measure for one year. However, shorter sampling durations can be decided, if assessed that they are representative for the annual average (e.g. two months during the heating season in Sweden is considered to provide representative result for the whole year) [I-5].

Season of measurements and applicability of seasonal correction factor

I-19. Seasonal correction factors can be applied for shorter sampling durations, if the influence of the different seasons is known. Seasonal correction factors are dependent on the specific situations (e.g. climate, building style, building use habits, specific workplace) and are not to be adopted from other countries or other situations (e.g. dwellings vs. workplaces) without evaluation.

I-20. The international standard ISO 11665-8 defines long-term measurements as measurements with a minimum duration of 2 months. According to this standard, at least half of the measurement period has to be in the winter or during the heating season and the measurements are to be performed during a period when the number of consecutive days during which the premises are unoccupied does not exceed 20 % of the adopted period [I-6].

I-21. Longer sampling periods can be split in several phases and instruments replaced in between. Also, for specific workplaces, if the sampling duration is not covering an entire year, the best sampling time has to be estimated, taking into account the specific situation, which can be different from normal seasonal behaviour in general buildings (e.g. specific natural or non-permanent mechanical ventilation situation in underground workplace, times with higher water capacity in water works, higher or lower occupancy factors during specific seasons, for example touristic places, schools). In addition, care needs to be taken to ensure that the selected measurement instruments are suitable for the specific conditions such as humidity, heat, dust.

Location and number of measurement points

I-22. Radon measurements need to be carried out within the workplace at all locations, where workers spend relevant part of their work time (e.g. office, workshop) or where higher exposure due to radon is likely (e.g. underground, water works). It also has to be evaluated and defined in the national regulations and in measurement protocols, whether locations with very low occupancy time can be excluded from radon measurements.

I-23. In addition, zones within buildings, which have identical or very similar characteristics (e.g. type of wall, floors, basement, foundations, building level, water supply, water usage patterns, ventilation, openings, temperature), and are expected to have a homogeneous radon concentration, could be defined [I-6].

I-24. The evaluation of the annual average radon activity concentration could be done for the defined zones and not for each single workplace in the building.

I-25. As radon measurements using passive detector techniques are relatively inexpensive nowadays, it can be cost-efficient to measure all workplaces instead of the assessment and definition of homogeneous zones.

I-26. Where a workplace consists of a number of different work area types, each has to be considered separately for the purpose of determining the number of detectors.

I-27. Basement and ground floor rooms are likely to have the highest radon concentrations and so workplace measurements have to be made on the ground floor and in basement levels, where these are occupied.

I-28. It might not be necessary to carry out measurements in areas which are unoccupied or occupied infrequently. As a general rule, an infrequently occupied area is one where an individual is unlikely to spend more than defined hours (e.g. 50 to 100 hours) per year of their working time.

I-29. The number of passive detectors per measurement point is usually 2 [I-5, I-7]. For continuous active monitor devices one device per measurement point is appropriate.

I-30. Radon concentrations can vary significantly between adjacent buildings. Therefore, it is necessary to measure levels in each separate building.

I-31. For multi-storey buildings, measurements made on the ground and basement levels would normally be sufficient for assessing compliance with the reference level for all workplaces in the building. However, it might be prudent to undertake some measurements on upper floors where different employers are responsible for different floors, unless they can confirm that the measurements on the ground floor do not exceed the reference levels, or for their own assurance.

I-32. The location of any detector needs to be such as to be representative of that workplace. Detectors are not to be placed in enclosed spaces nor directly in a source of fresh air, such as a ventilation intake. Detectors have to be placed in the breathing zone or at least one metre above the floor, away from heat sources, and not close to walls or openings.

I-33. Consider placing detectors in safe locations, where they do not interfere with health and safety rules or are at risk of being stolen.

I-34. The detectors are to be left in place for the prescribed measurement period and are not to be moved during this time. Several ways to ensure secure position of detectors may be utilized. For example, temper-tape is used in the position of a detectors and if the detector is moved during the measurement period, a tear in the tamper-tape is made.

I-35. As part of any measurement programme the details of the location of the detectors together with the dates of installation and removal have to be recorded.

I-36. A number of guidance or methodological documents have been published in the Member States [I-5, I-7, I-8, I-9]. Table I-1 provides an example of the UK guidance on the number of passive monitors required for assessment of radon levels in different workplaces. [I-8].

TABLE I-1. PUBLIC HEALTH ENGLAND GUIDANCE ON NUMBERS OF DETECTORS FOR RADON MEASUREMENTS AT DIFFERENT WORKPLACES (reproduced with the permission of the Public Health England).

Workplace type*	Number of monitors	Examples
Office, individual or small	One per 100 m^2, generally corresponds to between a half and third of all ground floor rooms	Banks, small shops, professional practice (solicitors, etc), residential homes, schools
Open plan office, and retail or workshop up to about 1000 m^2, also public access areas	One per 250 m^2	Administrative and call centres, light industry, hotels
As above, up to 5000 m^2	One per 500 m^2	Large retail etc
Very large areas of several thousand m^2	One for each distinct area with obviously different environmental conditions, not less than 1 per 1000 m^2.	Manufacturing or process plant, warehouses
Basements	Should be monitored if occupied for more than 50 hours per year (~ an hour per week). One monitor for each occupied room, section or area. Basements with generally high occupancy should be monitored using the rules as for ground floors	Retail, bank and professional storage areas
Wholly underground	As a guide at least one in each main working area, and other normally occupied areas, but seek specialist advice	Water industry, mines and caves

Uncertainty in the estimation of measurements

I-37. National measurement guidelines or measurement protocols need to outline how the measurement values will be processed and reported. The sampling period needs to be given together with the measurement value, as well as how the annual average activity concentration of ^{222}Rn at workplace was determined. The annual average activity concentration of radon also has to be accompanied by an uncertainty value. According to ISO 11665-8 expanded uncertainty with an expansion factor, *k*, equal to 2 is applied [I-6].

Compare the measured activity concentration with the reference level for the purpose of compliance demonstration

I-38. National measurement guidelines or measurement protocols have to outline how to do the evaluation against the reference level. For instance, it could define whether the evaluation is done for the entire building (e.g. average of all measurements), or for each workplace or measurement location separately, and whether the uncertainty is taken into account or not.

Frequency of evaluation or other conditions for repeated measurements or necessary additional investigations

I-39. The necessity of repeating the evaluation of the radon level at the workplace in case of compliance with the reference level, has to be set in the regulations. If iteration is considered to be necessary, the frequency has to be defined (e.g. every 5 – 10 years). In addition, criteria have to be defined, at which repeated measurement and evaluation of radon level are needed (e.g. following modification or remediation of the building, relevant changes in usage or organisational issues).

Radon Decay Product Measurements

I-40. The protocol for radon decay measurement is similar to radon gas measurement. Radon decay product measurement technique is usually more complicated than radon gas measurement. This is because the radon decay products in air are mainly attached to fine dust particles in air and have relatively short half-lives. This means that they need to be sampled and analysed relatively quickly (within approximately 30 minutes). This is done by taking an air sample through a filter paper and then radiometrically analysing the filter paper. As shown below, a number of standard methods and instruments are available to do these measurements.

I-41. Once worker exposures to the radon decay product concentrations have been measured, it is possible to then estimate the worker doses as described in Annex II.

TYPES OF RADON MEASUREMENT EQUIPMENT

I-42. There are several different types of radon monitoring systems based on active or passive measurement principles. They may also be capable of discriminating radon and thoron activity and active monitors may also be designed to measure respective decay products:

- Passive measurement instruments
  - Alpha-track detectors
  - Electret

    - Activated charcoal
- Active continuous monitors
    - Air sampling
    - Lucas cells
    - Pulse ionization chambers.

I-43. Special guidance on utilisation of passive and active measurement devices for radon is also provided in ISO standards [I-4, I-10].

I-44. Passive devices are simple in use, inexpensive and are suitable for the large scale (e.g. hundreds to thousands) measurements at a time. However, though the exposure of passive detectors is simple and relatively inexpensive, the analysis of the detectors can be a complicated process, demanding high level of competence and proficiency.

I-45. Radon measurement devices may be used either for a static measurement at a workplace or worn by an individual for a defined period of time. When worn, by an individual the radon detector is referred to as a personal radon gas monitor (RGM). In this case the radon gas monitors performs a function of an individual dosimeter.

I-46. Passive dosimeters rely on the natural diffusion of radon gas through a filter (to remove radon progeny) into the sensitive volume of the detector. Passive alpha track dosimeters use solid-state nuclear track detectors (a small piece of alpha-sensitive plastic foil) that are exposed for a specified period and then analysed by a chemical and/or electrochemical etching process. The number of tracks formed on the foil can be counted to assess the integrated exposure level. The integrated exposure to radon gas in Bqm-3 h is proportional to the number of tracks.

I-47. Electret ion chambers are passive devices that measure average radon concentration during the measurement period. The electret contains a positively charged plate inside an ionisation chamber. Radon gas, but not the decay products, enters the ionisation chamber by diffusion through a filter. Radon and the decay products formed in the chamber ionize the air in the chamber. The negative ions are collected on the positive electrode. The discharge of the electret over a known time is related to the radon concentration.

I-48. Another passive method for measuring radon in air is to use activated charcoal, which absorbs radon from air within the pore space of the charcoal granules for a defined period. Once the sampling has concluded, the charcoal is sealed (to prevent further absorption of radon) and the higher energy gamma rays from the radon decay products are analysed. The results are then converted to radon concentration using a calibration factor. One needs to be aware of a fact that these measurements are sensitive to humidity changes and also biased by the equilibrium of the adsorption and desorption, and generally are suited only for short term measurements.

I-49. Electronic integrating devices are active devices that use solid state detectors within a diffusion chamber for counting of alpha particles emitted by the radon decay products.

I-50. Continuous radon monitors are active devices and collect air for analysis via a pump or allow air to diffuse into a sensor chamber. The collected air, containing radon and its decay products, is analysed inside the scintillation chamber. Various types of sensor are available, such as current or pulse ionization chambers, scintillation cells and solid state detectors.

Measurement of radon in water

I-51. Methods of measuring radon in water can include electret ion chambers or gamma counting

I-52. Liquid scintillation counting is used widely for measuring radon in water. The method has high precision and a low limit of detection. Liquid scintillation counting allows for fast measurement of a large number of samples.

I-53. De-emanation counting can be used for radon in water measurements. The water sample is bubbled with a radon free gas, such as nitrogen, resulting in the de-emanation of water. A scintillation cell is filled with gas including the extracted radon. The scintillation cell is counted after a few hours to allow for radioactive equilibrium between the radon and decay products to be reached.

Types of Radon Decay Product Monitoring

I-54. Workplace monitoring of radon progeny concentrations generally involves active air sampling in which a known volume of air is drawn through a filter. Alpha and/or beta activity on the filter is counted during and/or after sampling.

I-55. Some methods allow to determine gross activities, while others determine the individual radon decay product concentrations. For gross alpha counting, the detection is often done simply with a scintillator disc mounted on a photomultiplier tube and placed a short distance from the filter at atmospheric pressure. Alpha spectroscopy can be used to determine the activity of individual radon progeny.

I-56. The frequency of measurements, historical results, expected variations in measurements and the degree of hazard need to be taken into account for the establishment of a monitoring programme.

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ANNEX II. GENERAL METHODOLOGY FOR RADON RELATED DOSE ASSESSMENT

II-1. This Annex provides an overview of the various methods for assessing the dose from exposure due to radon and its decay products in workplaces, including examples. Details of the measurement instruments, that could be used in different work environments, are provided in Annex I and in Refs [II-1, II-2, II-3, II-4].

II-2. In accordance with GSR Part 3, the assessment of the impacts of exposure due to radon and radon decay products is different for the two exposure situations as follows:

- For planned exposure situation, it is required to assess doses;
- For existing exposure situations, there is no requirement to assess dose, but assessment of exposure might be required.

II-3. In the case of existing exposure situations, the measured radon concentration is used as the method of control of health impacts and health risk assessment. However, in some workplaces, regulated as existing exposure situations, it may be prudent, or the employer may wish to assess a dose. Methods outlined in this annex can be used for dose assessment in planned and existing exposure situations. Assessment of exposure may be an option for workplaces regulated as existing exposure situations as well as planned exposure situations, where radon is the only source of exposure.

DOSE ESTIMATION FROM RADON AND ITS DECAY PRODUCTS

II-4. In general, there are two main ways for assessing the dose from exposure to radon and its decay products measurement of radon activity concentrations, and direct measurement of the concentration of radon decay products.

II-5. Measurements of radon in the workplace can be performed in a number of ways. The measurement has to follow an approved protocol (see Annex 1). Two principle approaches to measurements of radon and its decay products are utilised:

- Passive integrating devices which can be placed in workplaces and provide a time weighted average radon concentration for the exposure period. These devices are relatively inexpensive and are usually placed for a period of 1 to 3 months.
- Active real time measurements of radon concentrations can be undertaken using specialised monitoring equipment. This equipment can be programmed to provide average concentrations over fixed periods of time (for example, hourly) and may also be used for long time measurement, if supply to power is provided.

II-6. Once radon activity concentration at a workplace is determined, the individual dose can be calculated using standard and recognized methods.

II-7. Radon concentrations are variable, therefore it is more useful to obtain a time-weighted average radon concentration, for example, average workplace concentrations over a one month or three-month period. (As noted in Annex 1, it is important to ensure that a control is used so that average concentrations do not take into account time periods when workers are not present in the workplace).

II-8. To calculate annual effective dose from the average radon concentrations, a dose conversion factor (DCF) and the estimated exposure time (in hours) are needed. Example calculations are as follows:

$$E_{eff} = C_{Rn} * T * DCF * F \qquad (1)$$

Where

E_{eff} is the annual effective dose [mSv/a]

T is the exposure time [h]

DCF is the dose conversion factor [nSv/(Bq h.m^{-3})]

F is the equilibrium factor

C_{Rn} is the average radon activity concentration over time period T [Bq/m^3].

II-9. Recent publications on the applicable dose conversion factors are provided in Ref. [II-5]. Also, UNSCEAR has provided an updated overview of applicable dose conversion factors in Ref. [II-6]. An overview of these dose conversion factors is provided in Ref. [II-7] and in a joint information overview prepared by the Inter-Agency Committee on Radiation Safety [II-8]. In October 2019, the IAEA Technical Meeting on the Implications of the New Dose Conversion Factors for Radon, proposed the use of a dose conversion factor of 10 mSv per WLM [II-5] as the default for workplaces unless a different dose conversion factor is justified by specific aerosol characteristics. Table II-1 summarises dose conversion factors published by ICRP and UNSCEAR.

TABLE II-1. RECENTLY PUBLISHED CONVERSION FACTORS FOR RN-222

Exposure situation	**Dose Conversion Factor Per PAEC**	**Dose Conversion Factor Per EEC**	**Dose conversion Factor Per Rn-222 concentration**[3]
ICRP 137 Indoor workplaces where workers are engaged in substantial physical activities [II-5]	6 mSv/mJh.m^{-3} 20 mSv per WLM	33 nSv/Bq.h.m^{-3} (F value of 0.4)	13 nSv/Bq.h.m^{-3}
ICRP 137 Underground mines and in buildings [II-5]	3 mSv/mJh.m^{-3} 10 mSv per WLM	17 nSv/Bq.h.m^{-3} (F value of 0.4) 34 ηSv/Bq.h.m^{-3} (F value of 0.2)	6.7 nSv/Bq.h.m^{-3}
UNSCEAR 2019 [II-6]	1.6 mSv/mJh.m^{-3} 5.7 mSv per WLM	9 nSv/Bq.h.m^{-3}	

II-10.The nominal risk coefficient is defined in ICRP 103 as a sex-averaged and age-at-exposure-averaged lifetime risk estimates for a representative population [II-9]. It is used for converting ^{222}Rn exposure, expressed in Bq.h.m^{-3}, into effective dose based on an assumed equilibrium factor 0,4. The DCF converts radon decay product exposure into effective dose.

II-11.It is important to refer to the national competent authority to obtain the approved dose conversion factor to be used for occupational dose assessment. Record of used dose conversion factors need to be maintained in the individual dose records along with other factors and assumptions used (see para 4.63 of this document).

[3] These values have been calculated from the dose conversion factor per EEC and the assumed F value

II-12.Additional considerations such as particle size and unattached fractions are generally taken into account by the ICRP in deriving dose conversion factors [II-5]. However, there might be circumstances where accurate assessment of these parameters might be needed with the agreement of the regulatory body.

II-13.An electronic tool of ICRP for dose estimation was published as supplementary material to Publication 137 "OIR data viewer" [II-5].

II-14.Examples of dose assessment for different types of workplace are provided below.

<u>Example 1</u>: Estimation of Dose from an Annual Average Radon Concentration

II-15.In this example, passive radon monitors were located in a factory workshop for period of three month and annual average radon concentration of 200 Bq/m3 was estimated, using the national measurement methodology. The workshop is occupied by day shift and night shift, and therefore the result was not adjusted to take into account when workers were present in the workplace.

II-16.The annual average radon concentration is below the national reference level, however management wanted to understand the doses.

II-17.For the three months period, the average workhours by the workforce were 500 hours, with the maximum hours worked by one individual being 800 hours. The following calculations were performed to determine the average doses for workers during the quarter and the dose to the most exposed worker. The dose conversion factor given in Ref. [II-6] was used for dose calculation.

II-18.Effective dose calculation is performed using Eq. (2):

$$E_{eff} = C_{Rn} / F * T * CF \qquad (2)$$

- Average workplace radon concentration of 200 Bq/m^3
- Average workplace exposure hours of 500 hours per exposure period
- The UNSCEAR conversion factor (CF) is 9 $nSv/Bq.h.m^{-3}$
- Equilibrium factor (F) is estimated 0,4
- The calculated dose is 2,3 mSv/exposure period.

II-19.Maximum Dose Calculation:

- Average workplace radon concentration of 200 Bq/m^3
- Worker exposure hours of 800 hours per exposure period
- The UNSCEAR conversion factor (CF) is 9 $nSv/Bq.h.m^{-3}$
- Equilibrium factor (F) is estimated 0,4
- The calculated dose is 3.5 mSv/exposure period.

II-20.The calculated doses are for the period of three months.

II-21.If the dose conversion factor from ICRP 137 for indoor workplaces is used in the calculations, the average effective doses for workers is 2.7 mSv/a and the maximum is 4.3 mSv/a respectively.

<u>Example 2</u>: Estimation of Dose in a Part Time Occupied Workplace

II-22.In the second example, work only occurred during day shift (6AM to 6PM) and the workshop was not occupied in the evenings. To take account of this, the passive radon detector was placed into an evacuated airtight container at the end of shift and then placed back into the workplace at the beginning of shift. Another way to do it is to open and close the radon detector during the corresponding working hours.

II-23.Analysis of the detector at the end of the exposure period gave an average annual concentration of a 100 Bq/m3, using the national measurement methodology. The annual average radon concentration continued to be below the national reference level.

II-24.For the three-month period, the average workhours by the workforce were 500 hours, with the maximum hours worked by one individual being 800 hours. The following calculations were performed to determine the average effective doses for workers during the quarter and the dose to the most exposed worker. The dose conversion factor from Ref. [II-6] is used in this example for dose calculation.

II-25.Effective dose calculation is performed using equation (2)

- Average workplace radon concentration of 100 Bq/m^3
- Average workplace exposure hours of 500 hours per exposure period
- The UNSCEAR dose factor is 9 $nSv/Bq.h.m^{-3}$
- Equilibrium factor (F) is estimated 0,4
- The calculated dose is 1.1 mSv/exposure period

II-26. Maximum Dose Calculation:

- Average workplace radon concentration of 100 Bq/m^3
- Maximum worker exposure hours of 800 hours per exposure period
- Equilibrium factor (F) is estimated 0,4
- The calculated dose is 1.8 mSv/exposure period

II-27.The two example calculations show the method for calculating dose from a radon concentration. The calculations also show that the monitoring needs to be representative of the exposures to ensure that accurate dose estimates are made if required.

II-28.The calculated doses are for the period of three months.

II-29.If ICRP 137 DCF for indoor workplaces is used in the calculations, the average effective doses for workers is 1.3 mSv/a and the maximum is 2.1 mSv/a.

II-30.The two example calculations show the method for calculating dose from a radon concentration. The calculations also show that the monitoring needs to be representative of the exposures to ensure that accurate dose estimates are made if required.

Dose estimation based on radon decay products concentration

II-31.Measurements of radon decay product concentrations in the workplace can be performed in a number of ways as explained in Annex I.

II-32.By using the radon decay product concentrations, a more accurate assessment of effective dose can be obtained because the decay products of radon deliver the majority of dose (rather than the radon isotope itself), and thus dose calculation is independent of equilibrium factor [II-5, II-6].

II-33.Just like radon concentrations, the radon decay product concentrations are variable, therefore it is important to ensure that any measurements are representative of workers exposure. This may require a number of grab sample measurements across a shift and then averaging. Real time continuous monitoring can also be used.

II-34.Once representative measurements of radon decay product concentration are obtained, the dose can be calculated using exposure hours and the recognized dose conversion factor for radon decay products.

<u>Example 3</u>: Estimation of Dose from an Average Radon Decay Product Concentration

II-35.In this example, a workplace manager contracted a service provider to undertake a radon decay product survey in their workplace. The service provider designed a monitoring programme which included 30 air samples across a one-month period at different times of the day and at the main work locations.

II-36.The report from the service provider showed that in one area of the workplace, radon decay product concentrations averaged 3.5µJ/m3 (which is with 1 WL = 2.08E-5 Jm-3 approximately 0.17 WL), while all other areas recorded an average of 0.4µJ/m^3 (which is approximately 0.02 WL). The workplace manager, then proceeded to calculate the annual effective doses to workers in these areas using the method below.

$$E_{eff}=C* T*DCF \qquad (3)$$

Where

E_{eff} is annual effective dose [mSv/a]
C is the radon decay product concentrations [µJ/m^3]
T is exposure time, [h]
DCF is dose conversion factor [mSv per mJhm^{-3}].

II-37.The factors in the calculation are as follows:

- Average radon decay product concentration is 3.5µJ/m^3, - workplace 1
- Average radon decay product concentration is 0.4µJ/m^3, - workplace 2
- Work exposure hours of 160 hours per month
- DCF is 3 mSv per mJhm^{-3} [II-5].

II-38.The calculated worker doses in the two workplaces for the month are therefore as follows:

Workplace 1 = 1,7 mSv/month
Workplace 2 = 0,19 mSv/month.

II-39.In examples 1 and 2 an annual effective dose was calculated based on three months of radon measurements. This assumption is possible because most of the approved radon concentration methods allow an estimate of annual radon average concentration based on a shorter period of time, and include applying seasonal correction factors, when appropriate.

II-40.However, in the case of radon decay product measurements, this assumption would be inappropriate. For a correct annual effective dose estimation, the measurements of radon decay products has to be done for each period of time separately.

Example 4: Radon Exposure Estimation

II-41.In this example, only an estimate of the radon exposure is being made. Passive radon detectors were again used to measure average radon concentrations over a three-month period in a factory. The average measured concentration is estimated 200 Bq/m3, using the approved national measurement methodology and the exposure time is 500 hours.

II-42.Therefore, the radon exposure for the workers for the three-month period is 100 000 Bq*h/m^3. Over a full year, the radon exposure is 400 000 Bq*h/m^3 or 400 kBq*h/m3.

OTHER FACTORS INFLUENCING DOSE ESTIMATION

II-43.When assessing annual effective doses, there are other factors that need to be considered to different degrees.

Characteristics of the radioactive elements

II-44.The most important factor is the variable nature of both radon and radon decay product concentrations. The variations are due to a range of factors including natural factors such as time of day and year, geology of the area, weather and natural ventilation conditions, workplace design and mechanical ventilation.

II-45.The influence of these factors on the measurement results is covered in detail in Refs [II-10, II-11]. However, from a practical perspective and a dose assessment perspective, an understanding of the variability assists in providing confidence that dose estimates are accurate. An understanding of the variation can be obtained through the implementation of an appropriate monitoring programme, where monitoring is conducted at different times and under different conditions. Dose assessment is generally based on monitoring results and therefore representative monitoring is important.

Equilibrium Factor

II-46.Equilibrium factor (F) is the ratio between radon decay product concentration and radon concentrations. The equilibrium factor is important for dose assessment when measurements of only radon concentration are available.

II-47.In UNSCEARpublication [II-6], F for radon is assumed 0.4 for indoor radon and 0.6 for outdoor radon. The ICRP publication 137 recommends application of two different equilibrium factors, depending on the type of workplace 0.2 for mines and 0.4 for in door workplaces and tourist caves.

II-48.If the actual workplace equilibrium factor is substantially different from the assumed F values, then the chosen DCF may be inappropriate and need to be replaced.

II-49.The equilibrium factor for a workplace or an area can be measured by conducting side by side monitoring (or simultaneous monitoring) of both radon and radon decay product concentrations. Like both radon and radon decay product concentrations, long term average F values can be determined.

Unattached Fraction

II-50.Radon decay products formed from radon in air are charged and therefore are likely to attach themselves to fine dust particles in air. The attached decay products are referred to as the “attached fraction”, while the unattached decay products are referred to as the “unattached faction”.

II-51.The difference between the two fractions is basically particle size. The attached fraction particle size is related to the particle size of the finer dust in air, while the unattached fraction is much smaller.

II-52.The ICRP reference aerosol parameter values for different exposure scenarios for 222Rn progeny are summarized in Table A3 of Publication 137 [II-5].

II-53.From a lung dose perspective, the unattached radon is able to penetrate deeply into the lung to deliver the dose. The dose per unit intake for radon decay products is generally higher at smaller particle sizes. The ICRP Publication 137 [II-5] provides dose factors for the range of progeny particle sizes.

The standard dose coefficients for different exposure situations are calculated assuming typical unattached fractions and aerosol conditions. In situations where the aerosol conditions, particularly the activity size distribution, are significantly different from typical conditions, site specific dose coefficients can be calculated. *Thoron DCF’s*

II-54.The methods outlined above for dose assessment are applicable for both 222Rn and 220Rn. However, the main difference is the dose conversion factor.

II-55.UNSCEAR recommends 40 nSv/(Bq h.m-3) for conversion of a thoron concentration total dose [II-6].

II-56.The ICRP Publication 137 Table 12.7 provides dose coefficients following the inhalation of thoron progeny calculated for two situations of exposure: indoor workplaces and mines [II-5]:

- DCF for thoron decay products for workplaces like mines is 1.4 mSv per mJhm^{-3}.
- DCF for thoron decay products in indoor workplaces is 1.6 mSv per mJhm^{-3}.

II-57.On the basis of these calculations, the ICRP recommends a single value of 1.5 mSv per mJ h m-3 (5 mSv WLM-1) to be used for all situations of occupational exposure to thoron.

II-58.Also, the ICRP advises for cases when sufficient, reliable aerosol data are available and estimated doses warrant more detailed consideration, a calculation of site-specific dose coefficients to be carried out using the dosimetric data provided in the electronic annex of the same publication [II-5].

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