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International Atomic Energy Agency

IAEA SAFETY STANDARDS

No. SSG-91

for protecting people and the environment

Protection of Workers Against Exposure Due to Radon

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SPECIFIC SAFETY GUIDE

IAEA SAFETY STANDARDS AND RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

Information on the IAEA's safety standards programme is available on the IAEA web site:

http://www-ns.iaea.org/standards/

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at: Vienna International Centre, PO Box 100, 1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by email to Official.Mail@iaea.org.

RELATED PUBLICATIONS

The IAEA provides for the application of the standards and, under the terms of Articles III and VIII.C of its Statute, makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

Reports on safety in nuclear activities are issued as **Safety Reports**, which provide practical examples and detailed methods that can be used in support of the safety standards.

Other safety related IAEA publications are issued as **Emergency Preparedness and Response** publications, **Radiological Assessment Reports**, the International Nuclear Safety Group's **INSAG Reports**, **Technical Reports** and **TECDOCs**. The IAEA also issues reports on radiological accidents, training manuals and practical manuals, and other special safety related publications.

Security related publications are issued in the **IAEA Nuclear Security Series**.

The **IAEA Nuclear Energy Series** comprises informational publications to encourage and assist research on, and the development and practical application of, nuclear energy for peaceful purposes. It includes reports and guides on the status of and advances in technology, and on experience, good practices and practical examples in the areas of nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning.

PROTECTION OF WORKERS AGAINST EXPOSURE DUE TO RADON

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA SAFETY STANDARDS SERIES No. SSG-91

PROTECTION OF WORKERS AGAINST EXPOSURE DUE TO RADON

SPECIFIC SAFETY GUIDE

JOINTLY SPONSORED BY THE INTERNATIONAL ATOMIC ENERGY AGENCY AND INTERNATIONAL LABOUR OFFICE

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FOREWORD

by Rafael Mariano Grossi
Director General

The IAEA's Statute authorizes it to "establish…standards of safety for protection of health and minimization of danger to life and property". These are standards that the IAEA must apply to its own operations, and that States can apply through their national regulations.

The IAEA started its safety standards programme in 1958 and there have been many developments since. As Director General, I am committed to ensuring that the IAEA maintains and improves upon this integrated, comprehensive and consistent set of up to date, user friendly and fit for purpose safety standards of high quality. Their proper application in the use of nuclear science and technology should offer a high level of protection for people and the environment across the world and provide the confidence necessary to allow for the ongoing use of nuclear technology for the benefit of all.

Safety is a national responsibility underpinned by a number of international conventions. The IAEA safety standards form a basis for these legal instruments and serve as a global reference to help parties meet their obligations. While safety standards are not legally binding on Member States, they are widely applied. They have become an indispensable reference point and a common denominator for the vast majority of Member States that have adopted these standards for use in national regulations to enhance safety in nuclear power generation, research reactors and fuel cycle facilities as well as in nuclear applications in medicine, industry, agriculture and research.

The IAEA safety standards are based on the practical experience of its Member States and produced through international consensus. The involvement of the members of the Safety Standards Committees, the Nuclear Security Guidance Committee and the Commission on Safety Standards is particularly important, and I am grateful to all those who contribute their knowledge and expertise to this endeavour.

The IAEA also uses these safety standards when it assists Member States through its review missions and advisory services. This helps Member States in the application of the standards and enables valuable experience and insight to be shared. Feedback from these missions and services, and lessons identified from events and experience in the use and application of the safety standards, are taken into account during their periodic revision.

I believe the IAEA safety standards and their application make an invaluable contribution to ensuring a high level of safety in the use of nuclear technology. I encourage all Member States to promote and apply these standards, and to work with the IAEA to uphold their quality now and in the future.

PREFACE

Requirements for the protection of people from harmful consequences of exposure to ionizing radiation, for the safety of radiation sources and for protection of the environment are established in IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards (GSR Part 3), which is jointly sponsored by the European Commission, the Food and Agriculture Organization of the United Nations (FAO), the International Atomic Energy Agency (IAEA), the International Labour Organization (ILO), the OECD Nuclear Energy Agency (OECD/NEA), the Pan American Health Organization (PAHO), the United Nations Environment Programme (UNEP) and the World Health Organization (WHO).

The present Safety Guide provides recommendations and guidance on meeting the requirements of GSR Part 3 for protection of workers against exposure due to radon in existing exposure situations and in planned exposure situations.

Recommendations and guidance are provided for dealing with exposure in workplaces such as buildings, underground locations and industrial premises involving the processing of naturally occurring radioactive material (NORM). The protection of workers in buildings with high occupancy factors for members of the public, such as schools, kindergartens and hospitals, is also addressed.

Recommendations and guidance are provided for the implementation of requirements for radiation protection through the application of a graded approach and the principles of justification and optimization of protection and safety, in order to identify workplaces of concern in a practical way. Recommendations on the protection of workers against exposure due to thoron are also provided.

This Safety Guide is jointly sponsored by the IAEA and the ILO. The IAEA gratefully acknowledges the contribution of experts from several Member States and from the ILO to the drafting and review of the text.

THE IAEA SAFETY STANDARDS

BACKGROUND

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subject to standards of safety.

Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences.

States have an obligation of diligence and duty of care, and are expected to fulfil their national and international undertakings and obligations.

International safety standards provide support for States in meeting their obligations under general principles of international law, such as those relating to environmental protection. International safety standards also promote and assure confidence in safety and facilitate international commerce and trade.

A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, are a cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions.

THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for their application.

With a view to ensuring the protection of people and the environment from harmful effects of ionizing radiation, the IAEA safety standards establish fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur. The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

Safety measures and security measures[1] have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. They are issued in the IAEA Safety Standards Series, which has three categories (see Fig. 1).

Safety Fundamentals

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. Requirements, including numbered ‘overarching’ requirements, are expressed as ‘shall’ statements. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it

[1] See also publications issued in the IAEA Nuclear Security Series.

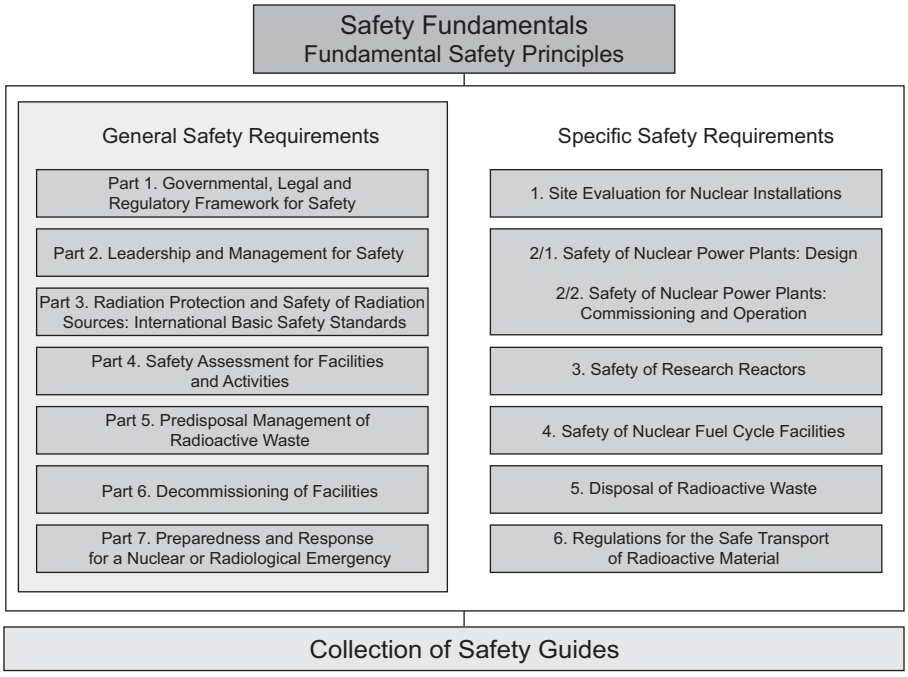

FIG. 1. The long term structure of the IAEA Safety Standards Series.

is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as 'should' statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

The IAEA safety standards are applicable, as relevant, throughout the entire lifetime of all facilities and activities — existing and new — utilized for peaceful purposes and to protective actions to reduce existing radiation risks. They can be

used by States as a reference for their national regulations in respect of facilities and activities.

The IAEA's Statute makes the safety standards binding on the IAEA in relation to its own operations and also on States in relation to IAEA assisted operations.

The IAEA safety standards also form the basis for the IAEA's safety review services, and they are used by the IAEA in support of competence building, including the development of educational curricula and training courses.

International conventions contain requirements similar to those in the IAEA safety standards and make them binding on contracting parties. The IAEA safety standards, supplemented by international conventions, industry standards and detailed national requirements, establish a consistent basis for protecting people and the environment. There will also be some special aspects of safety that need to be assessed at the national level. For example, many of the IAEA safety standards, in particular those addressing aspects of safety in planning or design, are intended to apply primarily to new facilities and activities. The requirements established in the IAEA safety standards might not be fully met at some existing facilities that were built to earlier standards. The way in which IAEA safety standards are to be applied to such facilities is a decision for individual States.

The scientific considerations underlying the IAEA safety standards provide an objective basis for decisions concerning safety; however, decision makers must also make informed judgements and must determine how best to balance the benefits of an action or an activity against the associated radiation risks and any other detrimental impacts to which it gives rise.

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and five Safety Standards Committees, for emergency preparedness and response (EPReSC) (as of 2016), nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

All IAEA Member States may nominate experts for the Safety Standards Committees and may provide comments on draft standards. The membership of the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards.

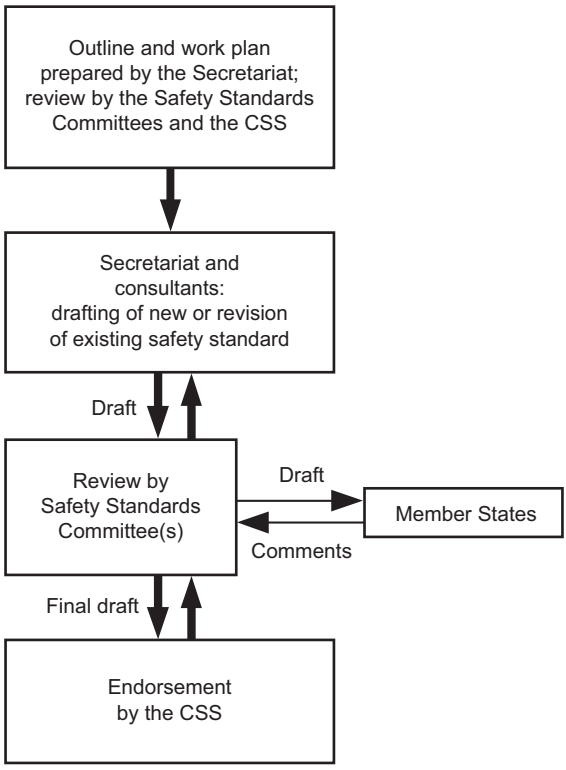

FIG. 2. The process for developing a new safety standard or revising an existing standard.

It articulates the mandate of the IAEA, the vision for the future application of the safety standards, policies and strategies, and corresponding functions and responsibilities.

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

The findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the recommendations of international expert bodies, notably the International Commission on Radiological Protection (ICRP), are taken into account in developing the IAEA safety standards. Some safety standards are developed in cooperation with other bodies in the United Nations system or other specialized agencies, including the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

INTERPRETATION OF THE TEXT

Safety related terms are to be understood as they appear in the IAEA Nuclear Safety and Security Glossary (see https://www.iaea.org/resources/publications/iaea-nuclear-safety-and-security-glossary). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

The background and context of each standard in the IAEA Safety Standards Series and its objective, scope and structure are explained in Section 1, Introduction, of each publication.

Material for which there is no appropriate place in the body text (e.g. material that is subsidiary to or separate from the body text, is included in support of statements in the body text, or describes methods of calculation, procedures or limits and conditions) may be presented in appendices or annexes.

An appendix, if included, is considered to form an integral part of the safety standard. Material in an appendix has the same status as the body text, and the IAEA assumes authorship of it. Annexes and footnotes to the main text, if included, are used to provide practical examples or additional information or explanation. Annexes and footnotes are not integral parts of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material under other authorship may be presented in annexes to the safety standards. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

CONTENTS

1. INTRODUCTION

BACKGROUND

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

1.2. The World Health Organization has stated that radon is the second leading cause of lung cancer in the general population after smoking [3]. Early studies on underground miners demonstrated an increased incidence of lung cancer in uranium miners exposed to very high concentrations of radon and its progeny. Epidemiological studies summarized in reports of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [4, 5] and in publications of the International Commission on Radiological Protection (ICRP) [6, 7] have shown a significant association between workers' exposure due to radon and lung cancer. These studies reflect the importance of protecting workers from exposure due to radon.

1.3. GSR Part 3 [2] establishes requirements for the protection of workers against exposure due to radon. Recommendations on occupational radiation protection, including protection of workers against exposure due to radon, are provided in IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [8].

1.4. Recent ICRP publications [6, 7, 9] have also been considered in preparing this Safety Guide. The prerequisites for protection of workers from all sources of radiation are set out by the International Labour Organization (ILO) [10]. The ILO's code of practice on the radiation protection of workers [11] has also been taken into account in this Safety Guide.

OBJECTIVE

1.5. This Safety Guide provides recommendations on meeting the requirements of GSR Part 3 [2] for protection of workers against exposure due to radon[1] in existing exposure situations and planned exposure situations.

1.6. This Safety Guide focuses on the identification of workplaces of concern with regard to exposure due to radon and on the implementation of requirements for radiation protection through the application of a graded approach and the principles of justification and optimization of protection and safety. The recommendations provided in this Safety Guide are intended for governments, regulatory bodies and other relevant authorities (especially those with little or no experience in radiation protection), employers, workers and service providers.

SCOPE

1.7. This Safety Guide provides recommendations on the protection of workers against exposure due to radon in existing exposure situations and planned exposure situations. This includes exposure in workplaces such as buildings, underground locations and industrial premises involving the processing of naturally occurring radioactive material (NORM)[2]. The protection of workers in buildings with high occupancy factors for members of the public, such as schools, kindergartens and hospitals, is also addressed. Exposure to ^{220}Rn (thoron) and its progeny is also considered in Appendix I. Recommendations on protection of the public against exposure due to radon in existing exposure situations are provided in IAEA Safety Standards Series No. SSG-32, Protection of the Public Against Exposure Indoors due to Radon and Other Natural Sources of Radiation [16].

[1] In this Safety Guide (and in the IAEA safety standards in general), the general phrase "exposure due to radon" is used, and this includes exposure to both ^{222}Rn and its progeny.

[2] Specific information on protection from radon in workplaces, including those involving different industrial processes involving NORM, is provided in Refs [12-15].

1.8. The recommendations on specific remedial actions[3] and protective actions[4] provided in SSG-32 [16] are also applicable in workplaces. Further information is provided in Ref. [17].

STRUCTURE

1.9. Section 2 of this Safety Guide describes the framework for the protection of workers against exposure due to radon. Section 3 provides recommendations on the protection of workers against exposure due to radon in existing exposure situations. Section 4 provides recommendations on the protection of workers against exposure due to radon in planned exposure situations. The Appendices provide recommendations on the protection of workers against exposure due to thoron. The Annex provides information on radon measurement protocols and measurement equipment.

2. FRAMEWORK FOR PROTECTION OF WORKERS AGAINST EXPOSURE DUE TO RADON

TYPES OF EXPOSURE SITUATION

2.1. Based on the recommendations of ICRP Publication 103 [18], the requirements established in GSR Part 3 [2] address three different types of exposure situation: planned exposure situations, existing exposure situations and emergency exposure situations. For the protection of workers against exposure due to radon, this Safety Guide considers existing exposure situations and planned exposure situations. Radon is not likely to give rise to an emergency exposure situation.

2.2. An existing exposure situation is a situation of exposure that already exists when a decision on the need for control needs to be taken (see para. 1.20(c) of

[3] A remedial action is defined as "The removal of a source or the reduction of its magnitude (in terms of activity or amount) for the purposes of preventing or reducing exposures that might otherwise occur in an emergency or in an existing exposure situation" [2].

[4] Protective actions are defined as "An action for the purposes of avoiding or reducing doses that might otherwise be received in an emergency exposure situation or an existing exposure situation" [2].

GSR Part 3 [2]). Existing exposure situations include exposure due to natural sources as well as exposure due to residual radioactive material from past practices that were not subject to regulatory control or that remains after an emergency exposure situation.

2.3. Radon in dwellings and in many workplaces are considered examples of existing exposure situations. Paragraph 5.1(c) of GSR Part 3 [2] states:

> "The requirements for existing exposure situations…apply to:
>
> …….
>
> (c) Exposure due to natural sources, including:
>
> (i) ^{222}Rn and its progeny and ^{220}Rn and its progeny, in workplaces other than those workplaces for which exposure due to other radionuclides in the uranium decay chain or the thorium decay chain is controlled as a planned exposure situation, in dwellings and in other buildings with high occupancy factors for members of the public".

A planned exposure situation arises from the planned operation of a source or from a planned activity that results in an exposure due to a source (see para. 1.20(a) of GSR Part 3 [2]). Since provision for protection and safety can be made before embarking on the activity concerned, the associated exposures and their likelihood of occurrence can be restricted from the outset. The primary means of controlling exposure in planned exposure situations is by good design of facilities, equipment and operating procedures, and by training.

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

> "Exposure due to natural sources is, in general, considered an existing exposure situation.... However, the relevant requirements…for planned exposure situations apply to:
>
> …….
>
> (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 [of GSR Part 3].”

Figure 1 illustrates the approach for the protection of workers against exposure due to radon in accordance with para. 3.4(d) of GSR Part 3 [2].

2.5. Exposure due to radon is determined in terms of the time integral of the activity concentration of radon over a defined period of time. To determine which of the requirements for exposure situations apply, the average annual activity concentration is the quantity of interest.

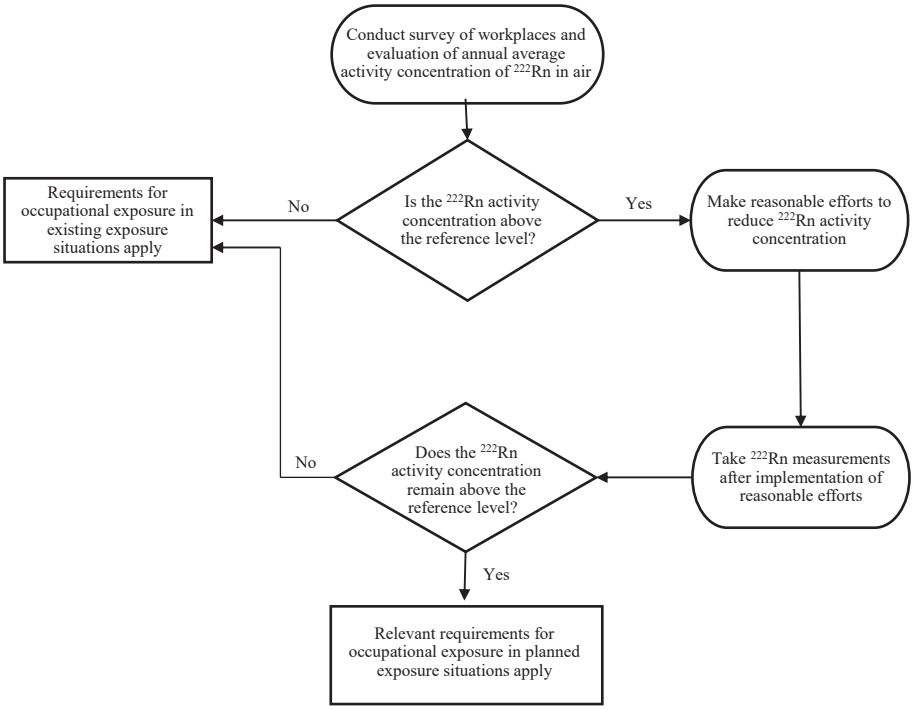

FIG. 1. Approach for the protection of workers against exposure due to radon in accordance with para. 3.4(d) of GSR Part 3 [2].

PRINCIPLES OF RADIATION PROTECTION

2.6. The main principles of radiation protection are expressed in Safety Principles 4–6 and 10 of SF-1 [1]. Requirement 1 of GSR Part 3 [2] states that "**Parties with responsibilities for protection and safety shall ensure that the principles of radiation protection are applied for all exposure situations.**" The fundamental principles of radiation protection apply during the protection of workers from exposure due to radon and its progeny.

Justification

2.7. For planned exposure situations, Requirement 10 of GSR Part 3 [2] states that "**The government or the regulatory body shall ensure that only justified practices are authorized.**"

2.8. For planned exposure situations, para. 3.16 of GSR Part 3 [2] states (footnotes omitted):

> "The government or the regulatory body, as appropriate, shall ensure that provision is made for the justification of any type of practice and for review of the justification, as necessary, and shall ensure that only justified practices are authorized."

2.9. For existing exposure situations, para. 2.9 of GSR Part 3 [2] states:

> "For…existing exposure situations, each party with responsibilities for protection and safety shall ensure, when relevant requirements apply to that party, that protective actions or remedial actions are justified and are undertaken in such a way as to achieve the objectives set out in a protection strategy."

2.10. For existing exposure situations, Requirement 48 of GSR Part 3 [2] states that "**The government and the regulatory body or other relevant authority shall ensure that remedial actions and protective actions are justified and that protection and safety is optimized.**" Moreover, para. 5.7 of GSR Part 3 [2] states:

> "The government and the regulatory body or other relevant authority shall ensure that the protection strategy for the management of existing exposure situations…is commensurate with the radiation risks associated with the existing exposure situation; and that corrective actions or protective actions

are expected to yield sufficient benefits to outweigh the detriments associated with taking them, including detriments in the form of radiation risks."

Optimization

2.11. Paragraph 1.15 of GSR Part 3 [2] states that optimization "is a process for ensuring that the likelihood and magnitude of exposures and the number of individuals exposed are as low as reasonably achievable, with economic, societal and environmental factors taken into account."

2.12. Paragraph 1.24 of GSR Part 3 [2] states that "Reference levels are used for optimization of protection and safety in…existing exposure situations. They are established or approved by the government, the regulatory body or another relevant authority." For existing exposure situations, para. 5.8 of GSR Part 3 [2] states that "The regulatory body or other relevant authority and other parties responsible for remedial actions or protective actions shall ensure that the form, scale and duration of such actions are optimized."

2.13. The value for the radon reference level for the protection of workers against exposure due to radon depends on the prevailing circumstances under consideration. Priority should be given to those workplaces in which the reference level is exceeded, to ensure that radon activity concentrations in these workplaces are reduced below the reference level and then optimized to ensure that they are as low as reasonably achievable, with economic, societal and environmental factors taken into account. Cost effective actions should be considered in the optimization process.

Dose limit

2.14. Dose limits apply only for planned exposure situations. Paragraph 3.26 of GSR Part 3 [2] states that "The government or the regulatory body shall establish and the regulatory body shall enforce compliance with the dose limits…for occupational exposures and public exposures in planned exposure situations." Dose limits for workers are detailed in Schedule III of GSR Part 3 [2].

PROTECTION STRATEGY

2.15. The government, regulatory body or other relevant authority is required to establish a legal and regulatory framework for protection of workers against exposure due to radon based on a graded approach. Depending on the magnitude

of exposures, the number of workers exposed and the authorities that are involved, a comprehensive radon protection strategy may be needed. The strategy should include measures to prevent the accumulation of radon in workplaces and to protect workers in areas with high radon levels. The roles of relevant authorities, such as those for occupational health and safety and public health authorities, should be described in order to establish and maintain an effective and cooperative regulatory regime.

2.16. Attention should be given to the characteristics of and contributors to the exposure due to radon. The exposure is almost entirely from inhalation of the short-lived progeny of ^{222}Rn, which are unlikely to be in equilibrium with the parent radionuclide. Therefore, special quantities, such as potential alpha energy concentration, are used for expressing the concentration of radon progeny in air and for estimating the resulting exposure. Recommendations on monitoring of short-lived progeny of ^{222}Rn are given in paras 2.60–2.70 of GSG-7 [8].

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

RESPONSIBILITIES AND FUNCTIONS OF THE GOVERNMENT

3.1. Paragraph 5.3 of GSR Part 3 [2] states that "The government shall include in the legal and regulatory framework for protection and safety…provisions for the management of existing exposure situations." This includes exposure due to radon in workplaces in existing exposure situations. This legal and regulatory framework should be included in the domains of radiation protection, occupational health and safety or public health, depending on which is identified as the most appropriate authority to be assigned responsibility for the control of radon in these workplaces.

Identification of workplaces of concern

3.2. Requirement 47 of GSR Part 3 [2] states:

> "**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."

The identification of workplaces of concern should be based on the results of radon surveys, measurements in workplaces, research data, geological and topsoil data, the types of industrial operation or processing method involving NORM, the construction materials used in buildings and the local climate conditions.

3.3. Footnote 49 of GSR Part 3 [2] states:

> "In the case of exposure due to radon, the types of situation that are included in the scope of existing exposure situations will include exposure in workplaces for which the exposure due to radon is not required by or directly related to the work, and for which annual average activity concentrations due to ^{222}Rn might be expected not to exceed the reference level".

There are two categories of workplace that should be considered: above ground workplaces and below ground workplaces.

Above ground workplaces

3.4. Examples of above ground workplaces that should be assessed to determine the exposure of workers due to radon include the following:

(a) Enclosed buildings;
(b) Workplaces where the radon levels might be elevated due to the geological conditions or due to limited ventilation;
(c) Workplaces with high occupancy factors for members of the public (e.g. schools, childcare centres, hospitals);
(d) Enclosed raw material production facilities (e.g. processing facilities involving NORM);
(e) Water treatment facilities;
(f) Fish hatchery buildings;
(g) Thermal spas.

3.5. It is not normally practical to measure radon in every above ground workplace. Therefore, representative local surveys for given types of workplaces with similar characteristics should be performed. The results of radon surveys of dwellings can be used to identify regions where workplaces with elevated radon levels might be located. Radon levels in dwellings generally provide a useful indication of areas in which workplaces with elevated radon levels might be

expected, since it is likely that the radon prone areas in above ground workplaces coincide with the radon prone areas identified in dwellings. This information, if available, can help States in identifying those areas that contain workplaces with elevated radon concentrations. Surveys of above ground workplaces should be designed so that information is representative of the radon activity concentration levels in the area. The survey data collected should be evaluated to identify workplaces of concern. If no workplaces of concern are identified, no further action is necessary. If workplaces with exposures of concern are identified, the government should ensure that measures to address exposures in workplaces are included in the action plan (see paras 3.15 and 3.16). The results of these surveys and their evaluation should be documented and made available to the public. Information on the design of a radon survey can be found in Ref. [19].

Below ground workplaces

3.6. Examples of below ground workplaces that should be surveyed to determine the exposure of workers due to radon include the following:

(a) Underground mines;
(b) Tunnels;
(c) Basements;
(d) Underground laboratories;
(e) Tourist caves;
(f) Food storage caves (e.g. for production of wine or cheese, for cultivation of mushrooms).

A survey to determine radon levels in a representative sample for a given type of below ground workplace should be performed. The results of the survey should be used to decide if radon levels should be measured in all below ground workplaces of that type.

Justification of remedial actions and protective actions

3.7. To meet Requirement 48 of GSR Part 3 [2] (see para. 2.10 of this Safety Guide), the government should ensure that the benefits of remedial actions and protective actions against exposure due to radon outweigh the detriments. For workplaces in existing buildings or facilities, where the annual average activity concentration of radon is below the reference level, exposure should be optimized (see para. 1.24 of GSR Part 3 [2]). As such, actions that are expected to yield the greatest benefits and outweigh the detriments should be implemented. These actions should be adapted to national circumstances. Detriments include any

radiation risks introduced by taking the action, the cost of taking the action, and any harm or damage caused by the action.

3.8. In the majority of circumstances, it is not considered appropriate to allow exposures in workplaces above the radon reference level to continue (see para. 1.24 of GSR Part 3 [2]). Remedial actions and protective actions are required to be justified and optimized (see paras 5.3(b) and 5.28 of GSR Part 3 [2]) and should be implemented in the context of continual improvement of workplace safety. Workers should be informed of these actions before implementation. These actions should not conflict with other existing regulatory requirements such as energy efficiency and indoor air quality.

3.9. Remedial actions are intended to act on the source of exposure; protective actions are intended to avoid or reduce exposures, for example by acting on the exposure pathways. Exposures can occur due to inhalation of radon from the earth's crust or from building materials. As stated in para. 2.10, the government is required to justify the measures for the control of radon, such as controls on building materials. Further recommendations are provided in paras 5.45–5.72 of GSG-7 [8].

Assignment of responsibilities and resources

3.10. Requirement 3 of IAEA Safety Standards Series No. GSR Part 1, Governmental, Legal and Regulatory Framework for Safety [20], 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.**"

3.11. The government should assign responsibility to the regulatory body or other relevant authorities to establish and implement a protection strategy for the protection of workers against exposure due to radon. Where responsibilities for the protection of workers are assigned to more than one authority, the government should make provision for the effective coordination of regulatory functions. The protection of workers from exposure due to radon may involve several other parties, including employers, service providers (see Appendix II) and workers.

3.12. Paragraph 5.2 of GSR Part 3 [2] states that "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." The government should develop a plan for achieving long term objectives such as conducting radon surveys, evaluating exposures in radon prone areas, establishing radon requirements in building codes, taking remedial actions and protective actions, and communicating with the public. Sufficient financial support should be provided to support the implementation of the plan for the protection of workers from exposure due to radon.

Involvement of different parties in the development and implementation of the protection strategy for workplace exposure due to radon

3.13. In accordance with para. 5.3(d) of GSR Part 3 [2], the government is required to provide for the involvement of interested parties in decisions regarding the development and implementation of protection strategies, as appropriate. As the protection of workers against exposure due to radon involves different competencies, the interested parties should include authorities with responsibility for radiation safety, occupational safety, public health and building construction, as appropriate.

3.14. As part of the protection strategy for existing exposure situations, the regulatory body or other relevant authority is required to ensure that information is available to workers on the potential health risks of exposure due to radon (see para. 5.5(b) of GSR Part 3 [2]). This should include information on the risk of lung cancer due to radon exposure and the increased risk of lung cancer due to the combination of smoking and radon. This information should also cover the importance of assessing the radon levels in workplaces, the temporal variability of radon levels, the use and interpretation of short term measurements and long term measurements, the remedial actions and protective actions in existing buildings and new buildings, and their effectiveness.

Establishment and implementation of an action plan for radon in workplaces

3.15. Paragraph 5.2 of GSR Part 3 [2] states that "The regulatory body shall establish and enforce requirements for the protection of workers in existing exposure situations." The action plan established for controlling public exposure to radon indoors should also cover the implementation of a protection strategy for exposure due to radon in workplaces. It should include identification of workplaces of concern, risk communication, actions for reducing radon levels in buildings and optimization of remedial actions and protective actions. The action plan should be updated and approved periodically.

3.16. The regulatory body or other relevant authority should be directed to include the following actions in relation to radon in workplaces in the action plan:

(a) Establish an appropriate reference level for radon in workplaces;
(b) Determine which types of workplace might be of concern, such as workplaces in a radon prone area and workplaces located below ground;
(c) Provide information on health effects and on radon levels in workplaces as part of the communication strategy;
(d) Facilitate radon measurements at workplaces, including establishment of measurement protocols, and provisions for quality assurance of service providers of radon measurements;
(e) Introduce specific requirements in building codes or in other regulatory documents for new buildings to reduce radon levels in workplaces;
(f) Develop guidelines for remedial actions and protective actions in workplaces;
(g) Prioritize actions for reducing radon levels in situations for which such actions are likely to be most effective.

RESPONSIBILITIES AND FUNCTIONS OF THE REGULATORY BODY OR OTHER RELEVANT AUTHORITY

3.17. 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."

3.18. Recommendations on the provision of information on radon are provided in paras 3.13–3.17 of SSG-32 [16]; these are also applicable for the protection of workers.

3.19. 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."

This includes establishing and implementing a strategy for the protection of workers against exposure due to radon.

3.20. Paragraph 5.27 of GSR Part 3 [2] states that "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." [5]

3.21. In accordance with para. 5.20 (a) of GSR Part 3 [2], the reference level for dwellings and other buildings with high occupancy factors for members of the public is required to not exceed an annual average activity concentration of ^{222}Rn of 300 Bq/m^3, taking into account the prevailing social and economic circumstances. To avoid setting different reference levels for workers and the public who occupy such buildings, the regulatory body or other relevant authority should consider a reference level that does not exceed an annual average activity concentration of ^{222}Rn of 300 Bq/m^3. These buildings include schools, childcare centres and hospitals.

3.22. The reference level for radon in workplaces should be periodically reviewed to ensure that it remains appropriate for the protection of workers. The effectiveness of actions for protecting workers from radon should be evaluated and updated as part of this review.

3.23. The regulatory body or other relevant authority should establish provisions so that employers and workers are informed of the results of radon measurements for both initial measurements and any subsequent follow-up measurements, including those made after all reasonable efforts to reduce radon levels have been

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[5] The value of activity concentration of 1000 Bq/m^3 corresponds to an annual effective dose of the order of 10 mSv, on the assumption of an equilibrium factor for ^{222}Rn of 0.4 and an annual occupancy of 2000 h.

undertaken by employers. The regulatory requirements for employers should specify the following:

(a) The types of workplaces in which radon measurements are needed;
(b) The measurement protocols for radon in workplaces (see Annex);
(c) Conditions for follow-up measurements of radon in workplaces;
(d) The retention time for records of measurements of radon;
(e) The procedures for comparison of measured radon levels with the reference level;
(f) The procedures for optimization of protection and safety.

3.24. The national or regional authority with responsibilities for building and construction safety should establish and implement building code requirements to prevent the accumulation of radon indoors. These authorities should have competence in structures and ventilation systems and means for implementing and enforcing building code requirements for construction companies and building owners. The relevant authority for construction safety should specify methods for monitoring and documenting remedial actions made to buildings to ensure their continued effectiveness. Practical guidance on actions to prevent the ingress of radon is provided in Ref. [17].

3.25. Radon measurements should be performed in the locations where workers spend a majority of their working time or where higher exposure due to radon is likely. The regulatory body or other relevant authority should establish or approve guidelines or measurement protocols to be used for radon measurements. The measurement protocols should define how to measure and interpret radon activity concentrations in workplaces.

3.26. The measurement protocols (see para. 3.25) should include guidance on the type of detector, number and placement of detectors, measurement duration, application of seasonal correction factors, acceptable uncertainties, and frequency of duplicate measurements for quality control. They should also include guidance on interpreting the results to ensure that they are representative of the annual average concentration of radon in the workplace. Guidance on the measurement of ^{222}Rn and its progeny is provided in Refs [21–32].

3.27. The regulatory body or other relevant authority should specify the conditions for conducting long term follow-up measurements after the implementation of measures to reduce radon levels in the workplace. These conditions should be specified by parameters such as change of ventilation system, renovation of foundations and floors, change of doors and windows, and physical changes to

the building that might affect the activity concentration of radon in the workplace. The Annex provides information on radon measurement protocols and equipment.

RESPONSIBILITIES AND FUNCTIONS OF EMPLOYERS

3.28. Paragraph 5.28 of GSR Part 3 [2] states that "Employers shall ensure that activity concentrations of ^{222}Rn in workplaces are as low as reasonably achievable below the reference level…and shall ensure that protection is optimized." The responsibility for providing adequate protection of workers against radiation rests with the employer, even if the employer is a subcontractor [10].

3.29. Employers are expected to comply with any requirements specified by the regulatory body or other relevant authority on the control of exposure due to radon in workplaces. Employers should implement the reference level set by the regulatory body or other relevant authority, the measurement protocols for radon in the workplace, and any remedial actions and protective actions necessary to comply with the reference level and to optimize protection. Employers who do not have the capability to take radon measurements themselves should seek a qualified service provider.

3.30. Workplaces involving the mining or processing of materials containing NORM might have elevated radon activity concentration levels. In some cases, the processes involved can increase radionuclide activity concentrations and therefore affect radon levels in the workplace. Practical guidance for specific industries involving NORM is provided in Refs [12–15].

3.31. In addition to the information provided by the government and/or regulatory body, the employer should inform workers of the health risk of exposure due to radon if exposure to elevated levels of radon is associated with their work. An information campaign should be organized, and informational material should be developed for workers on the following topics:

(a) The nature of potential health risks associated with exposure due to radon;
(b) The radon activity concentration levels to which workers are exposed, and (for comparison) the reference level;
(c) The requirements for protecting workers;
(d) The methods of controlling radon levels and for optimization of protection against exposure due to radon.

3.32. If the annual average activity concentration of radon in the workplace is below the reference level, the employer should assess whether exposures are optimized. The optimization of protection and safety should be done in consideration of other hazards and risks in the workplace, such as noise, dust and heat.

3.33. The records of radon measurements should include information on locations occupied by workers and the occupancy time. Employers should seek information from the employers or outside contractors of other workplaces in which their workers may work.

3.34. Follow-up measurements should be conducted in workplaces after construction activities, refurbishment and renovation, and after changes have been made to workplace ventilation. When renting a building, office or any other facility for the purpose of work, the employer should request the results of any radon measurements from the owner. The owner should provide tenants with information on previous radon measurements, if available.

3.35. Employers should consult a qualified expert for advice on implementing remedial actions for existing buildings to reduce exposure due to radon. Factors such as the annual average radon activity concentration, occupancy, complexity of remedial actions and number of workers affected should be considered before implementing actions. Typical actions include the following:

(a) Control of the ingress of radon gas into the workplace, such as by sealing floors;
(b) Active ventilation of workplaces, including through powered extraction systems, air dilution systems and soil depressurization;
(c) Passive ventilation of workplaces, such as through roof, foundation or basement ventilators, and isolation.

For control of radon in below ground workplaces (e.g. mines, caves, basements, tunnels), ventilation is of crucial importance in ensuring occupational safety and also in reducing elevated levels of radon. For workplaces with large areas, such as factories, a combination of actions should be considered. Recommendations on ventilation in the workplace are provided in paras 9.10–9.19 of GSG-7 [8].

3.36. Cost effective remedial actions and protective actions should be implemented by the employer. However, for workplaces where it is not always practicable to implement such actions (e.g. tunnels, historic heritage-protected buildings, tourist caves), other administrative measures should be considered for the protection of workers (e.g. restricting working time). Recommendations on

the cost effectiveness of radon control measures are provided in SSG-32 [16], and more detailed information is provided in Ref. [3].

3.37. For the construction of new buildings in radon prone areas, measures include membrane technology and air pressure control. Sometimes it is not easy to evaluate the effectiveness of preventive measures for workplaces before they are constructed, and the advice of experts on this subject should be obtained.

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

4.1. Paragraph 3.4(c) of GSR Part 3 [2] states that the relevant requirements for planned exposure situations apply to exposure due to radon "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." Such workplaces include mines and processing facilities for uranium and may include other industrial activities involving other types of NORM [8]. Workers in such workplaces are considered occupationally exposed, and their exposure should therefore be managed using the relevant requirements established for occupational exposure in planned exposure situations. Recommendations on the protection of workers in such facilities are provided in paras 3.159–3.181 of GSG-7 [8], and supporting practical guidance is provided in Refs [12–15]. The protection of workers against exposure due to radon in such workplaces is not considered further in this Safety Guide.

4.2. Paragraph 3.4(d) of GSR Part 3 [2] states that the relevant requirements for planned exposure situations apply to "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". The recommendations in this section apply to such workplaces.

RESPONSIBILITIES AND FUNCTIONS OF THE GOVERNMENT

4.3. Paragraph 2.17 of GSR Part 3 [2] states that "The government shall ensure that the regulatory body has the legal authority, competence and resources to fulfil

its functions and responsibilities." The government should assign responsibilities to relevant authorities regarding exposure of workers due to radon in planned exposure situations. The government should assign sufficient human and financial resources to any such other relevant authorities.

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

> "The government shall establish mechanisms to ensure that:
>
> (a) The activities of the regulatory body are coordinated with those of other governmental authorities…and with national and international organizations that have related responsibilities;
> (b) Interested parties are involved as appropriate in regulatory decision making processes or regulatory decision aiding processes."

RESPONSIBILITIES AND FUNCTIONS OF THE REGULATORY BODY OR OTHER RELEVANT AUTHORITY

4.5. Requirement 3 of GSR Part 3 [2] states that "**The regulatory body shall establish or adopt regulations and guides for protection and safety and shall establish a system to ensure their implementation.**"

4.6. Requirement 6 of GSR Part 3 [2] states:

> "**The application of the requirements of [GSR Part 3] in planned exposure situations shall be commensurate with the characteristics of the practice or the source within a practice, and with the likelihood and magnitude of exposures.**"

4.7. Protection of workers against exposure due to radon should focus on workplaces with high radon levels and high occupancy, such as underground mines, tunnels, and ground floor and below ground offices and laboratories. The regulatory body or other relevant authority implement a graded approach in selecting the relevant requirements for planned exposure situations that apply, such as requirements for authorization and for implementation of a radiation protection programme.

4.8. 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.**" The regulatory body

or other relevant authority should determine which of these requirements apply to workers who receive exposure due to radon.

4.9. The regulatory body or other relevant authority should establish requirements for notification and authorization for workplaces in which the radon activity concentration remains above the reference level (i.e. as specified in para. 3.4(d) of GSR Part 3 [2]). These requirements should specify the regulatory body or other relevant authority that is to be notified, the responsibility of employers to undertake the notification, the information to be included in the notification and the time frame. With regard to applications for authorization, the information to be supplied (e.g. the results of prior radiological evaluations or safety assessments) should be specified by the regulatory body or other relevant authority.

4.10. The regulatory body or other relevant authority should provide guidance on the methodology for the assessment of exposure due to radon. The guidance should include information on how to address parameters such as the equilibrium factor, dose conversion factor, occupancy factor, breathing rate, distribution of the aerosol and the unattached fraction, as appropriate. The values for these parameters should be realistic and specific to the type of workplace. Recommendations relating to the service providers are provided in Appendix II.

4.11. A dose conversion factor for calculating the effective dose from occupational exposure due to radon is necessary where the exposure is subject to the requirements for planned exposure situations.

4.12. UNSCEAR undertook a comprehensive review of epidemiological studies of lung cancer resulting from inhalation of radon and its progeny and also of the results of dosimetric models since 2006 [5]. Given that the uncertainties from both dosimetric and epidemiological studies give rise to a broad range of risk estimates and that values from the current dosimetry and epidemiological reviews are consistent with those used in previous UNSCEAR reports, UNSCEAR recommends the continued use of the dose conversion factor of 9 nSv per h Bq m^{-3} equilibrium equivalent concentration of ^{222}Rn, which corresponds to 1.6 mSv per mJ h m^{-3} (5.7 mSv per working level month) of radon progeny, for estimating radon exposure levels to a population [5]. UNSCEAR's review of the evidence was compatible with its previous assessment of lung cancer risk due to radon. Therefore, UNSCEAR concluded that there is no reason to change the established dose conversion factor [5].

4.13. The ICRP recommends a dose conversion factor of 3 mSv per mJ h m^{-3} (approximately 10 mSv per working level month) to apply to most circumstances

of exposure to radon and its progeny in workplaces and homes, equivalent to 6.7 nSv per Bq h m^{-3} using an equilibrium factor of 0.4 (16.8 nSv per Bq h m^{-3} equilibrium equivalent concentration) [9]. The ICRP considers this dose conversion factor to be applicable to the majority of circumstances with no adjustment for aerosol characteristics. If specific occupational exposures warrant more detailed consideration and reliable alternative data are available, site specific doses can be assessed using the methodology provided by the ICRP in Ref. [9].

4.14. In 2021, the Inter-Agency Committee on Radiation Safety issued an overview document on managing exposure due to radon at home and at work [33], in which it was indicated that it was up to individual national authorities to decide whether and when to implement the new ICRP dose conversion factor for radon contained in Ref. [9].

4.15. If a national dose registry is established (see para. 7.265 of GSG-7 [8]), the results of individual monitoring of workers for exposure due to radon should be incorporated. The data provided to the national dose registry should include the method used in the dose assessment, the results of dose assessment and characteristics of the workplaces.

RESPONSIBILITIES AND FUNCTIONS OF EMPLOYERS

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

> **"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."**

In optimizing the overall protection and safety of workers in planned exposure situations, the employers should consider other occupational health and safety issues. Optimization of protection and safety is a prospective and iterative process for ensuring that the likelihood of incurring exposures, the number of the people exposed, and the magnitude of exposures are kept as low as reasonably achievable, taking into account prevailing circumstances.

4.17. When implementing controls for radon in planned exposure situations, a management system should be established to monitor and maintain these controls to ensure that they remain effective over time. Employers should develop a

system that includes regular review and assessment of the effectiveness of radon controls, radon measurements, dose assessment and information sharing. Employers should also take steps to progressively develop an understanding of how radon builds up in the workplace and the specific actions that are necessary for protection of workers.

Workplace monitoring

4.18. The radon activity concentration in the workplace should be monitored, either by active real time measurements or by long term passive measurements. Real time measurements should be used when information on the variability of ^{222}Rn with time and location is needed, while passive detectors should be used when long term average activity concentrations in the workplace are needed. Monitoring of ^{222}Rn progeny is encouraged, as appropriate. For example, monitoring of ^{222}Rn progeny more precisely assesses the exposure of miners.

4.19. For workplaces where annual average radon activity concentrations are above the reference level on the basis of measurements with passive systems, active monitoring should be considered in order to identify whether high radon levels occur during working hours. Employers should consider estimating exposure due to radon on the basis of monitoring during working hours in areas where workers are present, taking into account the breathing zones of workers.

4.20. The calibration of passive radon detectors and continuous active monitors should be traceable to primary or secondary radon standards. National or international intercomparisons should be performed.

Notification and communication

4.21. The employer should notify the regulatory body or other relevant authority either when the annual average radon activity concentration is above the reference level or when it remains above the reference level despite all reasonable efforts by the employer, depending upon national regulations. The information and documentation to be provided as part of the notification should include the following:

(a) The methods used to measure the activity concentrations of ^{222}Rn and, where appropriate, its progeny, and the results of these measurements;
(b) Identification and description of the workplaces, including a description of the arrangements for the ventilation of these workplaces;

(c) Estimate of maximum annual working hours for workers in the areas with elevated radon levels, and the associated estimated individual doses;
(d) A description of the remedial actions and protective actions taken to reduce radon activity concentrations, and their effectiveness.

Instruction and training

4.22. Paragraph 3.110 of GSR Part 3 [2] states:

> "Employers, in cooperation with registrants and licensees:
>
> (a) Shall provide all workers with adequate information on health risks due to their occupational exposure in normal operation, anticipated operational occurrences and accident conditions, adequate instruction and training and periodic training in protection and safety, and adequate information on the significance of their actions for protection and safety".

4.23. The employers should provide workers with information about the health risks of radon and strategies for managing exposure. Special attention should be paid to newly recruited workers; this information should be included in their introductory training before they take up their assignments. The following should be included in the instruction and training:

(a) Health effects of exposure due to radon;
(b) The radon reference level;
(c) Information on the working areas with elevated radon levels based on measurements;
(d) Arrangements for monitoring of workplaces or workers;
(e) Arrangements for record keeping;
(f) Any arrangements for health surveillance of workers;
(g) Methods for evaluating the exposure of workers due to radon.

Radiation protection programme

4.24. Requirement 24 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.**"

When developing the radiation protection programme, employers should ensure that assessment and control of occupational exposure due to radon are based on radon measurements (including, as appropriate, progeny), the characteristics of the workplace and exposure pathways.

4.25. Administrative controls to reduce the occupancy of workers in areas with high radon levels may be part of the radiation protection programme. Restricting access to the area with elevated levels of radon is suitable only for those areas within workplaces where occupancy is already low or when it is not possible to implement actions to reduce radon levels.

4.26. Job rotation should not be used as a substitute for reducing the radon activity concentration in the workplace. However, in some cases, job rotation may need to be considered as part of the radiation protection programme to restrict the exposure of individual workers in work areas with high radon levels. Job rotation should be carefully planned before being implemented.

4.27. Requirements for the radiation protection programme are established in paras 3.88–3.98 of GSR Part 3 [2], and further recommendations are provided in paras 3.49–3.158 of GSG-7 [8]. The main components that should be considered in a radiation protection programme for occupational exposure due to radon are as follows:

(a) Scope and description of the programme;
(b) Assignment of responsibilities for protection and safety for workers;
(c) The use and functions of qualified experts;
(d) Designation of areas and workplace monitoring;
(e) Local rules and supervision;
(f) Personal protective equipment (as appropriate);
(g) Work planning;
(h) Monitoring and assessment of exposure due to radon;
(i) Health surveillance (if appropriate);
(j) Information, instruction and training (including qualification and certification of workers, as appropriate);
(k) Notifications and authorizations (as appropriate) and record keeping;
(l) Arrangements for quality assurance, audit and review.

Protection of pregnant workers

4.28. Requirement 28 of GSR Part 3 [2] states that "**Employers, registrants and licensees shall make special arrangements for female workers, as necessary, for protection of the embryo or fetus and breastfed infants.**" As the exposure

due to radon is mainly to the lungs, the embryo or fetus is not significantly exposed [34, 35]. Therefore, additional controls in relation to exposure to radon should not be necessary for pregnant workers.

Protection of itinerant workers

4.29. The requirements of GSR Part 3 [2] apply to all workers, so the same level of protection against exposure due to radon is required to be provided to itinerant workers as to full-time workers. Employers should consider itinerant workers when addressing exposure due to radon.

4.30. Itinerant workers should be provided with the same information on the risks associated with exposure due to radon as that provided to full-time workers. The relevant procedures, records and arrangements for monitoring and health surveillance should be made available to itinerant workers by their employers. More information is provided in Ref. [36].

4.31. The measurement programme for radon in workplaces and relevant records should not discriminate between itinerant workers (whether self-employed or employed by a contractor) and workers employed by the management of the workplace. The programme should be made available to itinerant workers and their employers. The arrangements for protection of itinerant workers should be reviewed periodically to ensure effective optimization of protection and safety. Further recommendations on the protection of itinerant workers are provided in paras 6.21–6.100 of GSG-7 [8].

COMPLIANCE BY WORKERS

4.32. Requirement 22 of GSR Part 3 [2] states that "**Workers shall fulfil their obligations and carry out their duties for protection and safety.**" Further requirements for compliance by workers are established in paras 3.83–3.84 of GSR Part 3 [2]. In addition, Section 2.3.1(1) of the ILO code of practice on the radiation protection of workers [11] states:

> "Workers should follow, as instructed by the employer, all rules, regulations and working procedures for the control of exposure to radiations and radioactive materials in the working environment in order to protect their own health as well as that of their colleagues."

This guidance applies to work in areas with elevated radon levels. Workers are encouraged to discuss with employers the optimization of protection and safety

and the process of continuous improvement of working safely in accordance with Ref. [11].

Appendix I

PROTECTION OF WORKERS AGAINST EXPOSURE DUE TO THORON

GENERAL DESCRIPTION OF EXPOSURES DUE TO THORON

I.1. Thoron (^{220}Rn) has a half-life of 55.6 seconds and can migrate only a short distance before decay. For this reason, indoor activity concentrations depend primarily on the emanation of thoron from the surface of walls and floors. Concentrations vary markedly across distances as short as one metre. Earth walls and floors have been found to be significant sources of thoron in some cases. Special attention should be paid to the production of construction materials that are a source of thoron.

I.2. In enclosed workplaces, the spatial distribution of thoron is very different from that of its progeny. The magnitude of the consequent doses depends on the amount of ^{232}Th present in the soil and in building materials, the rate of emanation of thoron and the occupancy factor for the building (see para. 3.60 of SSG-32 [16]). 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.

I.3. The worldwide average activity concentration of thoron (indoors and outdoors) is approximately 10 Bq/m^3 [37]. Airborne thoron activity concentrations in a room are highly variable due to the very short half-life of thoron and changes in ventilation, ranging over orders of magnitude in a typical 24 hour cycle, from 1 Bq/m^3 to 1000 Bq/m^3. Because of its short half-life, the thoron decays before it can migrate very far from its source, and the activity concentration of thoron decreases sharply with increasing distance from the walls. Measurements in specific regions with high natural background levels indicate thoron activity concentrations up to 2300 Bq/m^3 [38–41].

I.4. The dose conversion factors for thoron and its progeny are higher than for radon and its progeny. Of the various thoron progeny, ^{212}Pb and ^{212}Bi contribute 91% and 9%, respectively, to the total potential alpha energy. Because ^{212}Pb contributes almost all of the total potential alpha energy, its activity concentration can be used as a surrogate for potential alpha energy concentration. The assessment of risks needs to take the presence of thoron and its progeny into account [42].

I.5. If there are workplaces where significant occupational exposure due to thoron could occur, the government or regulatory body should establish requirements relating to the protection of workers against such exposure. Recommendations and guidance on the management of public exposure due to thoron are provided in SSG-32 [16], and information on occupational exposure due to thoron is provided in Refs [12, 43].

MANAGEMENT OF EXPOSURE DUE TO THORON

I.6. Attention should be given to occupational exposure due to thoron in workplaces involving minerals containing elevated levels of ^{232}Th, such as monazite mines and processing facilities. The exposure in such workplaces is required to be controlled as a planned exposure situation rather than an existing exposure situation (see para. 3.4(a) of GSR Part 3 [2]).

I.7. The approach to managing radon in workplaces can also be applied to thoron. For example, it may normally be assumed that the same remedial actions and protective actions that are taken to reduce exposure due to radon will also reduce exposure due to thoron.

I.8. In most countries, exposure due to thoron does not need to be subject to regulatory control because of the low activity concentrations of thorium found in building materials. In countries where high activity concentrations of thoron are found in some workplaces, the regulatory body or other relevant authority should consider establishing a reference level for thoron. The recommendations provided in SSG-32 [16] on setting a radon reference level are also applicable to setting a reference level for thoron. Exposure due to thoron should be either assessed through individual monitoring or estimated from workplace monitoring results. Ref. [5] provides further information.

I.9. In workplaces where high activity concentrations of thoron progeny are present, these concentrations can normally be substantially reduced by the methods applied to reduce the indoor activity concentrations of thoron. Owing to the high spatial variability (see para. I.1), ensuring that rooms are occupied away from the walls is effective in reducing the inhalation of thoron.

Preventive measures for workplaces in new buildings

I.10. Consideration should be given to preventive measures that can be applied during the construction of new buildings in thoron prone areas. The regulatory

body or other relevant authority should establish a basis for identifying such buildings and ensure that appropriate measures are taken in their design and construction. The effectiveness of the measures should be checked. Appropriate building codes and guidance on construction practices should be developed by the relevant authority. Particular consideration should be given to building materials that have elevated concentrations of ^{232}Th.

I.11. The regulatory body or other relevant authority should consider whether restrictions are required on the use of building materials that have been found to emit significant quantities of thoron (see para. 5.22 of GSR Part 3 [2]). Further recommendations are provided in paras 3.65–3.67 of SSG-32 [16].

Appendix II

QUALIFICATION OF SERVICE PROVIDERS FOR PROTECTION OF WORKERS AGAINST EXPOSURE DUE TO RADON

II.1. Paragraph 3.73(c) of GSR Part 3 [2] states that "The regulatory body shall be responsible, as appropriate, for…[a]uthorization or approval of service providers for individual monitoring or calibration services".

II.2. Service providers have to comply with requirements set by the regulatory body or other relevant authority. The services provided might include radon measurement, calibration of radon detectors, guidance on remedial actions for existing buildings, design of measures to reduce radon levels in new buildings and the provision of advice as qualified experts on radon exposure. The service providers for radon measurements, calibration, consultancy or techniques to reduce radon levels in buildings should be qualified in accordance with procedures approved by the regulatory body. Recommendations on the management system for providers of technical services are provided in section 8 of GSG-7 [8].

II.3. Service providers should provide only services for which they can demonstrate competence. Providers of general radiation protection services might not have adequate competence with respect to protection against exposure due to radon (e.g. a provider of calibration services might not have the competency to provide services related to the selection and implementation of remedial actions and protective actions against exposure due to radon). Operating organizations should therefore ensure that the selected service providers are competent in the specific area. Service providers should be able to demonstrate impartiality and independence in relation to the services they provide.

II.4. With regard to the assessment of occupational exposure due to radon, the regulatory body or other relevant authority should verify that the service provider has an adequate management system and is technically competent to provide results. Requirements for management systems should take into account the requirements set out in Ref. [44] or an equivalent national validation scheme or protocol.

II.5. The regulatory body or other relevant authority should establish requirements for providers of radon measurement services. These requirements should cover the following:

(a) The service provider's management system, including its organizational structure, and arrangements for training personnel, and for acquiring, calibrating, operating and maintaining equipment;
(b) Methods and procedures for radon measurement that follow appropriate codes and standards;
(c) Accreditation in accordance with national requirements or relevant standards;
(d) Reporting to the national radon database, as appropriate.

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Annex

PROTOCOLS AND EQUIPMENT FOR MEASUREMENT OF RADON

A–1. This Annex provides an overview of protocols for the measurement of radon and its progeny and of measurement equipment and techniques. Though radon progeny contribute most of the dose, measurements of radon are generally simpler and more cost effective than measurements of its progeny.

RADON MEASUREMENT PROTOCOLS

Objective and contents of radon measurement protocols

A–2. The results of radon measurement are used to inform both employers and workers on the level of exposure of workers (and hence the associated health risks) and the need to optimize protection to keep exposures as low as reasonably achievable.

A–3. The objective of radon measurement is to assess the activity concentration of radon and, where appropriate, its progeny. The measurement protocol may include the following:

(a) Criteria for measurement systems;
(b) Quality assurance;
(c) Method for determining the location and number of measurement points;
(d) Sampling duration;
(e) Approach to dealing with measurement uncertainties;
(f) Application of seasonal correction factors, if appropriate;
(g) Comparison of the annual average activity concentration with the reference level;
(h) Frequency of, or other conditions for, repeat measurements;
(i) Criteria for additional investigations.

Measurement systems for radon in workplaces

A–4. The detectors for radon are usually not sensitive to thoron. Passive detectors such as solid state nuclear track detectors are commonly used for long term radon measurements in workplaces. The measurements provide results over a specific period. Continuous radon monitoring can also be used for the measurement of

radon activity concentration in workplaces. This type of monitor provides a time series of the radon activity concentration over the measurement period. Continuous radon monitors identify the variation of radon activity concentration (e.g. daily, seasonal, activities, occupancy periods) so as to provide information to better assess the exposure of workers.

Calibration and quality management for radon measurements

A–5. Continuous radon monitors are usually calibrated individually by an authorized organization, which could be the manufacturer or a service agent. Equipment used for radon measurements needs to be calibrated at regular intervals, as recommended by the manufacturer (typically annually), and following any repair or certain types of maintenance. Following calibration, a certificate needs to be provided, which includes the calibration date, results of the test and the traceability to international or national standards.

A–6. Passive devices are calibrated in batches under different conditions, such as a controlled radon concentration and at a specified temperature and humidity. In certain cases, calibration at different activity concentrations can be performed. Recommendations on service providers are provided in Appendix II.

Duration of radon measurements

A–7. Measurements need to be capable of determining the annual average activity concentration of ^{222}Rn in the workplace (e.g. taking into account the measurement season and duration of exposure). The most reliable way is to take measurements for a whole year. However, shorter sampling durations can be used if they are considered capable of providing results that are representative of the annual average radon level. This can be achieved by placing detectors for an entire year, or else using a series of detectors placed for periods of a few months to cover the whole year.

Seasonal correction factor for radon measurements

A–8. In some countries, seasonal correction factors are applied to measurement results so that the results of measurements taken over part of a year can be extrapolated to provide an annual average. Seasonal correction factors are dependent on local factors such as climate, the type of building and the characteristics of the workplace. They are not applicable to other situations unless they have been evaluated as also being appropriate for wider use.

A–9. Reference [A–1] provides methodologies for radon measurements, including long term measurements with a minimum duration of two months. According to Ref. [A–1], at least half of the measurement period needs to be in the annual cold season when heating is used. In addition, the measurements need to be taken during a period when the number of consecutive days during which the premises are unoccupied does not exceed 20%.

A–10. If the sampling duration does not cover an entire year, the best time to perform sampling needs to be determined; this can be different from that derived from the normal seasonal behaviour in buildings (e.g. due to specific variations in natural or mechanical ventilation in underground workplaces, times with higher work capacity and workplaces with different occupancy factors during specific seasons, such as tourist sites and schools).

Location and number of radon measurement points

A–11. The evaluation of the annual average activity concentration of radon may involve measurements in different zones within the workplace. Passive detectors are relatively inexpensive. Therefore, it can be cost effective to take measurements in several locations within the workplace to establish a more targeted protection strategy. Where a workplace consists of different types of working area, each area could be considered separately for the purpose of radon measurements.

A–12. Basement or ground floor rooms are likely to have the highest radon concentrations. It is not necessary to carry out measurements in areas that are unoccupied or are occupied infrequently. An infrequently occupied area is generally not expected to be used by individuals for more than 50 hours per year [A–2].

A–13. The radon activity concentration can vary significantly between adjacent buildings. Consequently, it is usually necessary to take measurements in each separate building. For multi-storey buildings, measurements taken on the ground floor and in basements (all levels) are the most important for assessing compliance with the reference level for workplaces. Nevertheless, it may also be useful to perform some measurements on upper floors (see also Table A–1).

A–14. The locations of radon detectors need to be representative in terms of the exposure of workers. Usually, the detectors are not placed in enclosed spaces or directly in a source of fresh air, such as a ventilation intake. Ideally, detectors are placed in the breathing zone of workers but, in any case, at least one metre above the floor, away from heat sources and at least 20 cm from walls or openings.

TABLE A–1. INDUSTRIAL RADON MEASUREMENT GUIDELINES ON THE PLACEMENT OF RADON DETECTORS IN A WORKPLACE (based on Ref. [A–2]).

Location	Number of radon detectors
Basement and ground floor	One detector in all rooms or areas. For larger rooms or areas, specialist measurement advice needs to be sought on the number of detectors needed.
Higher floors	At least two detectors per floor and at least one detector per 250 m^2.

Radon detectors are not to be moved during the measurement period. Several ways to ensure secure positioning of detectors may be used, for example, tamper-proof tape.

A–15. As part of the radon measurement protocol, the details of the measurement location and the dates on which measurement started and ended are recorded. Locations in workplaces to be considered for measurement of radon include:

(a) Rooms or areas that are occupied on a regular basis for more than four hours a day;
(b) All underground rooms and areas that could be used by individuals for more than 50 hours per year (about one hour per week);
(c) Any other rooms or areas where there are reasons to believe that radon levels might be of concern.

A–16. References [A–3, A–4] provide examples of guidance and methodologies used for radon measurements in two Member States. Reference [A–2] contains guidelines for the locations for radon measurements in industrial workplaces. Table A–1 summarizes the guidelines on the number of radon detectors needed. According to Ref. [A–2], the rooms and areas considered for measurement are those that are occupied on a regular basis for more than four hours a day. Other areas to be considered include underground basement rooms or areas where there is a significant risk of radon and that could be used by individuals for more than 50 hours per year (about one hour per week).

Comparing radon measurement results with the reference level

A–17. The measurement protocol is expected to describe how to evaluate the results of radon measurements in the workplace against the reference level.

This includes determining the annual average radon activity concentration to compare directly with the reference level. The protocol may also define whether the evaluation is conducted for the entire workplace, whole buildings or defined areas, whether a reliable estimate of the annual average activity concentration can be obtained with short duration measurements, and how to ensure that any uncertainties are acceptable.

Repeated or follow-up measurements

A–18. The need to repeat measurements of radon levels in the workplace is normally specified by the regulatory body or other relevant authority. In some cases, it may be necessary to perform follow-up measurements in the workplace, for example using active instruments to evaluate exposure during and outside working hours.

Measurements of radon progeny

A–19. Measurements of radon progeny are usually more complicated than measurements of radon gas. Radon progeny are mainly attached to fine dust particles in air and have relatively short half-lives. As such, they need to be sampled and analysed relatively quickly (within approximately 30 minutes). This is normally done by taking an air sample through a filter and then analysing the filter.

A–20. The measurement of radon progeny generally involves active air sampling in which a known volume of air is drawn through a filter. The alpha or beta radiation emitted from radon progeny in the filter is counted during or after sampling. Some methods determine gross activity, while others determine the concentrations of individual radon progeny. For gross alpha counting, the detection is often done simply with a scintillator disc that is 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.

RADON MEASUREMENT EQUIPMENT

Types of radon measurement

A–21. There are several different types of radon monitoring equipment, which are selected on the basis of the intended use of the measurement results. Such

equipment may also be capable of discriminating between radon and thoron, and some equipment is designed to measure radon progeny. It is important that the selected measurement instruments be suitable for the environmental conditions (e.g. humidity, temperature, dust) in which they will be used. The main types of radon measurement equipment are as follows [A–5]:

(a) Electret ion chambers;
(b) Solid state nuclear track detectors;
(c) Gamma spectrometry (e.g. using activated charcoal sampling);
(d) Scintillation detectors;
(e) Alpha spectrometry.

A–22. Passive detectors are simple to use, inexpensive and suitable for large scale surveys (e.g. involving hundreds or even thousands of measurements). However, the analysis of the results may be more complicated.

A–23. Passive radon 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 that are exposed for a specified period and then assessed using a chemical or electrochemical etching process. The number of tracks formed on the foil can be counted to assess the radon exposure.

A–24. Electret ion chambers are passive devices that measure average radon activity concentration during the monitoring period. The electret contains a positively charged plate inside an ionization chamber. Radon gas enters the ionization 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 the given period is related to radon concentration.

A–25. Another passive method for measuring radon uses activated charcoal, which absorbs radon from the air within the pore space of the charcoal granules for a defined period. Once the sampling has concluded, the charcoal is sealed and the gamma rays from the radon decay products are analysed using gamma spectrometry. The results are then converted to radon activity concentration using a calibration factor. These measurements are sensitive to humidity and biased by the equilibrium between adsorption and desorption and are generally suited only to short term measurements.

A–26. Electronic integrating devices are active devices that use solid state nuclear track detectors within a diffusion chamber to count alpha particles emitted by radon decay products. This provides a cumulative value that represents the average concentration over the monitoring period.

A–27. Continuous radon monitors are active devices that collect air for analysis via a pump or allow air containing radon and its decay products to diffuse into a sensor chamber. The air sample containing radon and its progeny is analysed inside the chamber. Continuous radon monitors also include electrical current or pulse ionization chambers, scintillation cells and solid state nuclear track detectors.

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