

IAEA Safety Standards

for protecting people and the environment

Protection of the Public against Exposure Indoors due to Radon and Other Natural Sources of Radiation

Jointly sponsored by the IAEA, WHO



Specific Safety Guide

No. SSG-32



IAEA
International Atomic Energy Agency



Documents
Document Sharing Hub

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 Internet 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 THE PUBLIC
AGAINST EXPOSURE INDOORS
DUE TO RADON AND OTHER
NATURAL SOURCES OF RADIATION



Documents
Document Sharing Hub

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-32

PROTECTION OF THE PUBLIC AGAINST EXPOSURE INDOORS DUE TO RADON AND OTHER NATURAL SOURCES OF RADIATION

SPECIFIC SAFETY GUIDE

JOINTLY SPONSORED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY AND THE
WORLD HEALTH ORGANIZATION

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2015

COPYRIGHT NOTICE

All IAEA scientific and technical publications are protected by the terms of the Universal Copyright Convention as adopted in 1952 (Berne) and as revised in 1972 (Paris). The copyright has since been extended by the World Intellectual Property Organization (Geneva) to include electronic and virtual intellectual property. Permission to use whole or parts of texts contained in IAEA publications in printed or electronic form must be obtained and is usually subject to royalty agreements. Proposals for non-commercial reproductions and translations are welcomed and considered on a case-by-case basis. Enquiries should be addressed to the IAEA Publishing Section at:

Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 2600 29302
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
<http://www.iaea.org/books>

© IAEA, 2015

Printed by the IAEA in Austria
May 2015
STI/PUB/1651

IAEA Library Cataloguing in Publication Data

Protection of the public against exposure indoors due to radon and other natural sources of radiation. — Vienna : International Atomic Energy Agency, 2015.

p. ; 24 cm. — (IAEA safety standards series, ISSN 1020-525X ; no. SSG-32)

STI/PUB/1651

ISBN 978-92-0-102514-2

Includes bibliographical references.

1. Radon — Safety measures. 2. Gamma ray sources — Safety measures. 3. Radiation sources — Safety measures. 4. Radiation, Background. I. International Atomic Energy Agency. II. Series.

IAEAL

15-00958

FOREWORD

by Yukiya Amano
Director General

The IAEA's Statute authorizes the Agency to “establish or adopt... standards of safety for protection of health and minimization of danger to life and property” — standards that the IAEA must use in its own operations, and which States can apply by means of their regulatory provisions for nuclear and radiation safety. The IAEA does this in consultation with the competent organs of the United Nations and with the specialized agencies concerned. A comprehensive set of high quality standards under regular review is a key element of a stable and sustainable global safety regime, as is the IAEA's assistance in their application.

The IAEA commenced its safety standards programme in 1958. The emphasis placed on quality, fitness for purpose and continuous improvement has led to the widespread use of the IAEA standards throughout the world. The Safety Standards Series now includes unified Fundamental Safety Principles, which represent an international consensus on what must constitute a high level of protection and safety. With the strong support of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its standards.

Standards are only effective if they are properly applied in practice. The IAEA's safety services encompass design, siting and engineering safety, operational safety, radiation safety, safe transport of radioactive material and safe management of radioactive waste, as well as governmental organization, regulatory matters and safety culture in organizations. These safety services assist Member States in the application of the standards and enable valuable experience and insights to be shared.

Regulating safety is a national responsibility, and many States have decided to adopt the IAEA's standards for use in their national regulations. For parties to the various international safety conventions, IAEA standards provide a consistent, reliable means of ensuring the effective fulfilment of obligations under the conventions. The standards are also applied by regulatory bodies and operators around the world to enhance safety in nuclear power generation and in nuclear applications in medicine, industry, agriculture and research.

Safety is not an end in itself but a prerequisite for the purpose of the protection of people in all States and of the environment — now and in the future. The risks associated with ionizing radiation must be assessed and controlled without unduly limiting the contribution of nuclear energy to equitable and sustainable development. Governments, regulatory bodies and operators everywhere must ensure that nuclear material and radiation sources are used beneficially, safely and ethically. The IAEA safety standards are designed to facilitate this, and I encourage all Member States to make use of them.

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 the IAEA Safety Requirements for Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards (IAEA Safety Standards Series No. GSR Part 3). Safety Standards Series No. GSR Part 3 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 the public against exposure indoors due to natural sources of ionizing radiation. Recommendations and guidance are provided on application of the requirements for justification and for optimization of protection by national authorities in considering the control of natural sources of radiation indoors, such as radon gas and radionuclides of natural origin in building materials. Recommendations and guidance are also provided on the establishment by States of national ‘radon action plans’ for the control of exposure of the public indoors due to radon.

This Safety Guide is jointly sponsored by the IAEA and the WHO. The IAEA gratefully acknowledges the contribution of experts from several States and from the WHO 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 measures¹ 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.

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

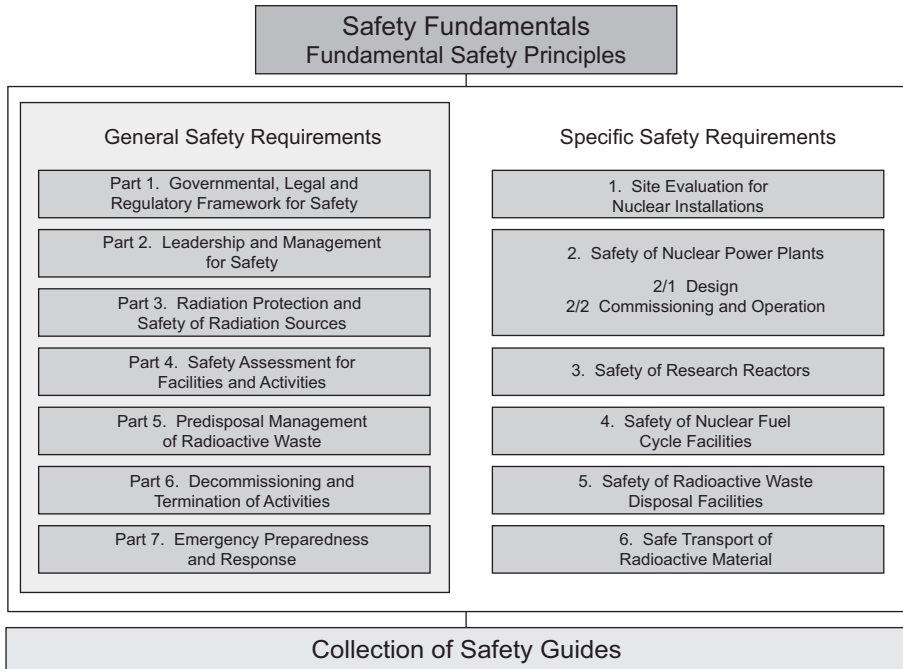


FIG. 1. The long term structure of the IAEA Safety Standards Series.

Safety Guides

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

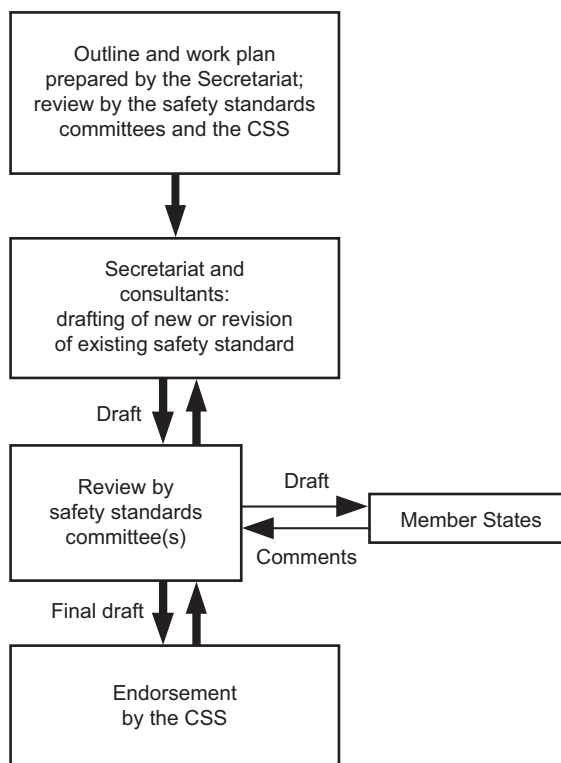


FIG. 2. The process for developing a new safety standard or revising an existing standard.

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. 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 defined in the IAEA Safety Glossary (see <http://www-ns.iaea.org/standards/safety-glossary.htm>). 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	1
	Background (1.1–1.8)	1
	Objective (1.9)	3
	Scope (1.10–1.11)	3
	Structure (1.12–1.13)	5
2.	NATIONAL POLICY AND THE ROLE OF THE NATIONAL AUTHORITY (2.1–2.9)	5
3.	CONTROL OF EXPOSURE INDOORS DUE TO RADON	8
	General (3.1–3.2)	8
	Exposure due to ^{222}Rn	8
	Origin and concentrations of ^{222}Rn indoors (3.3–3.12)	8
	Provision of information on radon (3.13–3.17)	11
	Surveys of radon indoors (3.18–3.22)	12
	Action plan on radon (3.23–3.59)	14
	Exposure due to ^{220}Rn	25
	Origins and concentrations of ^{220}Rn indoors (3.60–3.61)	25
	Surveys of ^{220}Rn indoors (3.62–3.64)	25
	Control and reduction of exposure due to ^{220}Rn (3.65–3.67) ...	26
4.	CONTROL OF EXPOSURE INDOORS DUE TO GAMMA RADIATION	27
	Natural sources of gamma radiation (4.1–4.9)	27
	Methods for the measurement of gamma radiation (4.10–4.12)	28
	Surveys of gamma radiation (4.13–4.14)	29
	Control and reduction of exposure to gamma radiation	30
	Gamma radiation from soils (4.15–4.16)	30
	Gamma radiation from building materials (4.17–4.27)	30
	Gamma radiation from building materials in existing buildings (4.28–4.30)	33
	REFERENCES	35

ANNEX I: RADON SURVEYS AND MAPPING OF ^{222}Rn PRONE AREAS.....	39
ANNEX II: MEASUREMENT TECHNIQUES FOR ^{222}Rn AND ^{220}Rn	47
ANNEX III: PREVENTIVE MEASURES TO REDUCE CONCENTRATIONS OF ^{222}Rn FOR NEW DWELLINGS AND OTHER NEW BUILDINGS	59
ANNEX IV: CORRECTIVE ACTIONS TO REDUCE CONCENTRATIONS OF ^{222}Rn IN EXISTING DWELLINGS AND OTHER BUILDINGS	64
ANNEX V: PUBLIC INFORMATION PROGRAMMES ON RISKS DUE TO RADON	71
ANNEX VI: APPLICATION OF THE COMPLIANCE ALGORITHMS FOR BUILDING MATERIALS	75
CONTRIBUTORS TO DRAFTING AND REVIEW	89

1. INTRODUCTION

BACKGROUND

1.1. The IAEA Safety Fundamentals publication Fundamental Safety Principles [1] establishes the safety objective and safety principles for the protection of people and the environment from harmful effects of ionizing radiation. Principle 10 states that: “Protective actions to reduce existing or unregulated radiation risks must be justified and optimized.” One type of situation covered by this principle is exposure due to natural sources of radiation, including exposure due to radon¹ in dwellings and workplaces, and external gamma exposure due to radionuclides of natural origin in building materials.

1.2. The IAEA Safety Requirements publication Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards (GSR Part 3) [2] specifies requirements for the protection of people against exposure to ionizing radiation (hereinafter termed radiation) and for the safety of radiation sources. IAEA Safety Standards Series No. GSR Part 3, the requirements of which are based on information on the detrimental effects attributed to radiation exposure provided by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [3] and the recommendations of the International Commission on Radiological Protection (ICRP) [4] are intended to provide the basis for the regulation of radiation protection.

1.3. Protection of the public, as specified in GSR Part 3, has always been part of the radiation protection requirements. However, there has been relatively little guidance provided specifically on the protection of the public against exposure due to natural sources of radiation. This Safety Guide is intended to fill that gap by focusing on the identification and implementation of appropriate measures for protection of members of the public against exposure indoors due to natural sources of radiation. Exposure indoors is usually higher than exposure outdoors, but is more readily controllable.

1.4. In Publication 103 [4], the ICRP specifically addresses public exposure indoors due to radon as an area where recommendations are necessary on the application of the requirements for radiation protection. In Publication 65 [5],

¹ In this Safety Guide, as in GSR Part 3, the term ‘radon’ is used to mean any combination of the two main isotopes of the element radon (²²²Rn and ²²⁰Rn).

the ICRP presents its recommendations for action levels in existing dwellings, new dwellings and aboveground and underground workplaces, as well as its recommendations for identifying radon prone areas, and for applying preventive measures and corrective actions. In its Statement on Radon in 2009 [6], the ICRP suggests an annual effective dose of around 10 mSv from ^{222}Rn as a level at which action would almost certainly be warranted to reduce exposure. The ICRP, taking account of the new findings, revised the upper value for the reference level for radon gas in dwellings from 600 Bq/m^3 — the value suggested in its 2007 Recommendations — to 300 Bq/m^3 .

1.5. The World Health Organization (WHO) addressed public health aspects of exposure indoors due to ^{222}Rn [7] by reflecting the epidemiological evidence that public exposure indoors due to ^{222}Rn is responsible for a substantial number of lung cancers in the general population. The WHO Handbook on Indoor Radon provides detailed recommendations on reducing health risks due to ^{222}Rn as well as policy options for preventing and reducing ^{222}Rn exposures. The WHO proposes a reference level of 100 Bq/m^3 to minimize health hazards of exposure indoors due to ^{222}Rn , adding that “if this level cannot be reached under the prevailing country specific conditions, the chosen reference level should not exceed 300 Bq/m^3 ”.

1.6. In Publication 82 [8], the ICRP addresses exposure due to gamma emitting radionuclides of natural origin in building materials and in the ground. The ICRP recommends a reference level of dose of around 1 mSv from a dominant type of commodity amenable to control by intervention — such as some building materials — which could in some circumstances be a significant cause of prolonged exposure. The ICRP recommends that concerned national and, as appropriate, relevant international organizations should derive reference levels for commodities, in particular for specific building materials.

1.7. The exposure of members of the public due to radionuclides of natural origin in food is generally low and is not usually amenable to control. If the concentration of radionuclides of natural origin in foodstuffs is enhanced, such as by discharges from the operation of a facility or from an activity, this is subject to the requirements for planned exposure situations. Guideline levels for radionuclides in foods traded internationally and destined for human consumption have been published by the Joint FAO/WHO Codex Alimentarius Commission [9], for foods that could have been contaminated following a nuclear or radiological emergency.

1.8. The presence of radionuclides of natural origin in drinking water has been addressed by the WHO in the most recent revision of its guidelines for drinking water quality [10]. The WHO has outlined an approach to controlling the ingestion of both radionuclides of natural origin and radionuclides of artificial origin in drinking water by using screening levels. It also sets out an approach to controlling the inhalation of radon released from drinking water into indoor air.

OBJECTIVE

1.9. This Safety Guide provides recommendations on meeting the requirements of Ref. [2] for exposure of the public indoors due to natural sources of radiation. Guidance is provided on the application of the requirements for justification and optimization of protection by national authorities when considering control of natural sources of radiation such as radon indoors and radionuclides of natural origin in building materials.

SCOPE

1.10. The scope of this Safety Guide covers exposure of the public indoors due to natural sources of radiation. It provides recommendations and guidance to be followed by the regulatory body and all other authorities and organizations with responsibilities in relation to exposure to radiation from natural sources (hereinafter referred to as the ‘national authority’ and defined in para. 2.3) in meeting the requirements of Ref. [2]. Specifically, the recommendations and guidance cover the following:

- (a) Public exposure due to ^{222}Rn in dwellings and other buildings with high occupancy factors for the public. This includes buildings such as kindergartens, schools and hospitals. High total occupancy by individuals (Ref. [1], para. 3.23) as well as high occupancy factors need to be considered. The exposure pathways considered are: ingress of ^{222}Rn from the soil; ^{222}Rn released from building materials used in the construction of the dwelling; and ^{222}Rn entering the dwelling via the water supply.
- (b) Public exposure due to ^{220}Rn in dwellings. The exposure pathways considered are: ^{220}Rn released from soil, and ^{220}Rn released from building materials used in the construction of the dwelling. Radon-220 entering the dwelling via the water supply is seldom a source of significant radiation exposure.

- (c) Public exposure to external gamma radiation from radionuclides of natural origin in the soil and in building materials. 'Building materials' are construction materials that are used for the construction of buildings such as dwellings, and offices, industrial premises and other workplaces.

1.11. This Safety Guide does not cover the following:

- (a) Exposure due to ^{40}K in the body and exposure due to cosmic radiation at the surface of the earth, which are considered not to be amenable to control and are therefore excluded from the scope of Ref. [2] (see Ref. [2], para. 1.42, footnote 7).
- (b) Occupational exposure of workers due to natural sources of radiation (see Ref. [2], para. 3.4(a)). Occupational exposure due to ^{222}Rn and ^{220}Rn can take place in workplaces such as offices and factories. The management of such occupational exposure is mentioned in this Safety Guide, but recommendations and guidance are provided in a Safety Guide on occupational radiation protection that is under development [11].
- (c) Public exposure due to discharges and public exposure due to the management of radioactive waste arising from natural sources (see Ref. [2], para. 3.4(b)). These public exposures are to be covered in Safety Guides on the regulatory control of radioactive discharges to the environment [12] and on the management of radioactive residues from mining, mineral processing and other NORM related activities [13].
- (d) Public exposure to cosmic radiation during airline travel. This is considered not to be amenable to control and it is therefore outside the scope of Ref. [2] and this Safety Guide.
- (e) Public exposure due to radionuclides of natural origin in foodstuffs and in drinking water.
- (f) Public exposure due to radon in workplaces with low occupancy factors for members of the public, such as offices and factories. Visitors to caves in which guides provide tours for the general public are likely to be exposed to radon for a short period only and this will usually not necessitate control.
- (g) Public exposure due to radionuclides of natural origin in construction materials that are used for the construction of infrastructural elements of the built environment such as roads, bridges, dams and sea defences. These do not give rise to significant exposure of the public because of the short time of exposure.

STRUCTURE

1.12. Section 2 provides recommendations and guidance on the governmental, legal and regulatory framework relating to policy development in this area and the role of the national authority. Section 3 gives an overview of exposures arising from ^{222}Rn and ^{220}Rn and provides recommendations and guidance on approaches to their management. Section 4 provides recommendations and guidance on the regulatory approach for controlling exposure to gamma radiation emitted by building materials.

1.13. Six annexes provide further guidance, in particular, on radon as the main contributor to exposure due to natural sources of radiation. Annex I provides guidance on surveys of radon indoors. Annex II discusses techniques for the measurement of radon. Annex III provides guidance on construction techniques to prevent the accumulation of radon in new dwellings and other buildings. Annex IV discusses corrective actions to reduce high concentrations of radon in existing dwellings and other buildings. Annex V gives an overview of public information programmes to raise awareness of risks associated with radon. Annex VI provides examples of the application of algorithms for controlling exposure indoors to gamma radiation from radionuclides of natural origin present in building materials.

2. NATIONAL POLICY AND THE ROLE OF THE NATIONAL AUTHORITY

2.1. Reference [14] requires that “The government shall establish an effective system for protective actions to reduce undue radiation risks associated with unregulated sources (of natural or artificial origin) and contamination from past activities or events, consistent with the principles of justification and optimization” (Ref. [14], Requirement 9). Such unregulated sources of natural origin include ^{222}Rn and ^{220}Rn in dwellings and other buildings with high occupancy factors, and radionuclides of natural origin present in building materials.

2.2. Reference [2] requires that “The government shall ensure that existing exposure situations that have been identified are evaluated to determine which occupational exposures and public exposures are of concern from the point of view of radiation protection” (Ref. [2], Requirement 47). For such situations,

the government is required to ensure that responsibilities for protection and safety are assigned and appropriate reference levels are established (Ref. [2], para. 5.2).

2.3. The implementation of an effective programme for protection of the public against exposure indoors due to natural sources of radiation could involve several different organizations. In this Safety Guide, the term ‘national authority’ is used to refer collectively to the regulatory body and all the other authorities and organizations with responsibilities in relation to exposure to radiation from natural sources. These organizations can include, but are not limited to, organizations involved in radiation protection and public health policy, public and private bodies specializing in radiation measurements, and bodies that set and implement building standards. Normally, the lead organization should be the organization responsible for radiation protection.

2.4. The national authority should initiate an assessment to determine whether exposure indoors due to natural sources of radiation such as ^{222}Rn , ^{220}Rn and gamma rays in dwellings necessitates the development of strategies for radiation protection measures to reduce exposure.

2.5. Once such an assessment has been performed and if a need for further action has been established, a comprehensive policy should be developed to ensure optimal protection of the public against exposure indoors due to natural sources of radiation.

2.6. The national authority is required to ensure that the protection strategy for the programme to protect the public against exposure indoors due to natural sources of radiation is commensurate with the radiation risks associated with the natural sources of radiation. The national authority is also required to ensure that the protective actions to be taken are expected to yield sufficient benefits to outweigh the detriments associated with taking them, including detriments in the form of radiation risks; i.e. it is required to ensure that the protective actions are justified (Ref. [2], para. 5.7). The national authority is also required to ensure that the form, scale and duration of such protective actions are optimized (Ref. [2], para. 5.8).

2.7. Exposure of the population indoors due to natural sources of radiation is usually dominated by ^{222}Rn . The national authority should determine the extent of ^{222}Rn exposure of the population by undertaking national and regional surveys using national and international standards that describe test methods for ^{222}Rn [15]. Such surveys are also useful to identify areas with higher than average concentrations of ^{222}Rn , often designated as ^{222}Rn prone areas

(see paras 3.42–3.45). Surveys of ^{220}Rn exposure (see paras 3.62–3.64) and surveys of exposure to gamma radiation from building materials (see Section 4) may be useful in some circumstances.

2.8. If the results obtained following completion of the actions outlined in para. 2.7 indicate that it is necessary, the national authority should:

- (a) Set reference levels for ^{222}Rn and, if considered necessary, for ^{220}Rn for dwellings² (see paras 3.35–3.40 and 3.65);
- (b) Set national standards for concentrations of radionuclides of natural origin in building materials on the basis of activity concentration levels specified in GSR Part 3 [2] (see Section 4);
- (c) Put in place measurement programmes to identify existing dwellings and other buildings with high occupancy factors for the public in which the reference levels for radon are exceeded;
- (d) Establish a programme to identify building materials that could lead to exposure of members of the public that is higher than the reference level for building materials;
- (e) Develop and put in place a framework for reducing exposure due to ^{222}Rn and ^{220}Rn in existing dwellings and new dwellings and in other buildings with high occupancy factors for the public (see paras 3.23–3.59, 3.65–3.67), and for the control of radionuclides in building materials (see paras 4.17–4.27). This framework should include approaches to evaluate the success of programmes for reducing concentrations of ^{222}Rn and ^{220}Rn indoors as well as economic evaluations that take into account the full range of costs associated with the programmes.

2.9. There are situations in which the national authority should consider whether regulation, as a means of controlling or reducing exposure indoors due to natural sources of radiation, would be appropriate. Recommendations and guidance for such situations are provided in Sections 3 and 4. In deciding on the need for regulation, the national authority should take account of the societal and economic consequences to be expected and of the potential difficulties in enforcement. In addition, the requirements for optimization will apply.

² The reference level for dwellings also applies to other buildings with high occupancy factors for the public.

3. CONTROL OF EXPOSURE INDOORS DUE TO RADON

GENERAL

3.1. Three radioactive isotopes of radon occur naturally in significant quantities: ^{222}Rn , ^{220}Rn and ^{219}Rn . Radon-222 has a half-life of 3.82 days and is derived from the natural radioactive decay chain headed by ^{238}U . Radon-220 has a half-life of 55.6 seconds and is derived from the natural radioactive decay chain headed by ^{232}Th . Radon-219 has a half-life of 3.96 seconds and is derived from the natural radioactive decay chain headed by ^{235}U . Owing to its short half-life and the usually low concentrations of ^{235}U in soils, the dose from exposure due to ^{219}Rn is negligible and is therefore not of radiological concern.

3.2. The radionuclides that give rise to ^{222}Rn and ^{220}Rn may be present in the environment naturally or as a result of past practices, or as a combination of both. In terms of the protection to be provided, no differentiation is made between these different causes of exposure. However, when action is required to reduce exposure, different approaches should be considered, depending on the exposure pathway.

EXPOSURE DUE TO ^{222}Rn

Origin and concentrations of ^{222}Rn indoors

3.3. Radon-222 is potentially the most significant source for radiation exposure indoors, because its half-life is long enough to allow it to accumulate indoors and because ^{238}U can be present in relatively high concentrations in the ground. Radon-222 is constantly released from the ground as a result of the radioactive decay of ^{226}Ra . When ^{222}Rn is released into the open air, it is quickly diluted to harmless concentrations. Typical concentrations of ^{222}Rn outdoors are 10 Bq/m^3 [16], although a range of long term average concentrations from 1 Bq/m^3 to in excess of 100 Bq/m^3 have been reported [17].

3.4. In the great majority of cases, the main origin of ^{222}Rn indoors is the ground underneath a building. Building materials can also be an origin of ^{222}Rn indoors, though usually they are a much less significant origin than the ground.

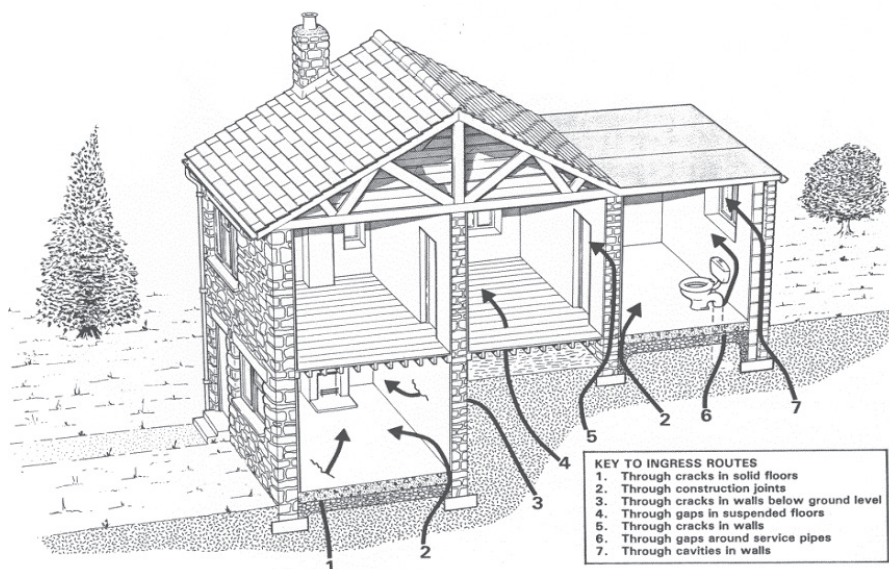


FIG. 1. Radon access routes (image courtesy of the Building Research Establishment (BRE), United Kingdom; reproduced with permission).

In some cases ^{222}Rn is carried indoors in the water supply and released when water is used.³

3.5. The air pressure at ground level in most buildings is slightly lower than the outdoor air pressure, as the indoor air is usually warmer. This causes air from the ground to be drawn into buildings, carrying ^{222}Rn with it. The access routes are principally gaps between floors and walls, cracks in floors and gaps around pipes and cables (see Fig. 1). There are seasonal variations in the indoor ^{222}Rn levels which correspond to variations in the average outdoor temperature (i.e. the ^{222}Rn levels in winter are usually higher than the levels in summer).

3.6. The distribution of concentrations of ^{222}Rn indoors in dwellings is very wide, typically covering several orders of magnitude. Distributions of concentrations of ^{222}Rn are often found to be log-normal, or close to log-normal, within a State or within a region of a State. In some instances, dwellings may have such high

³ Criteria for controlling exposure due to radon in drinking water can be found in Section 9 of the current WHO Guidelines for Drinking-water Quality [10].

concentrations of ^{222}Rn that the radiation doses received by the residents far exceed the annual dose limits that apply for occupational exposure.

3.7. The population weighted worldwide arithmetic mean concentration of ^{222}Rn of all origins in dwellings is estimated to be 39 Bq/m^3 [16].

3.8. Emanation of ^{222}Rn from the radium present in building materials will also contribute to the concentration of ^{222}Rn indoors. The relative contribution from building materials is generally more important where the total concentration of ^{222}Rn indoors is low. Radon-222 released from building materials is rarely the dominant contributor to high concentrations of ^{222}Rn indoors.

3.9. Calculations made for a model masonry house indicate that emanation of ^{222}Rn from building materials contributes, on average, about 10 Bq/m^3 to the concentration of ^{222}Rn indoors [17]. This represents approximately 25% of the worldwide average concentration of ^{222}Rn indoors. In the European Union, the typical contribution from building materials to concentrations of ^{222}Rn indoors is estimated to be in the range of $10\text{--}20 \text{ Bq/m}^3$ [18], corresponding to an annual individual effective dose in the range $0.3\text{--}0.6 \text{ mSv}$. In the USA, the contribution from building materials to concentrations of ^{222}Rn indoors is estimated to be in the range of $4\text{--}7 \text{ Bq/m}^3$ [19].

3.10. In some exceptional cases, the contribution of ^{222}Rn emanating from building materials to the concentration of ^{222}Rn indoors may be up to 1000 Bq/m^3 or higher [18]. In such cases, the corresponding effective dose rate from gamma radiation indoors is highly likely to exceed the maximum value of the reference level for building materials of about 1 mSv/a as specified in para. 5.22 of Ref. [2]. This is discussed in greater detail in para. 3.55 and in Section 4. Radon-222 emanation from building materials can also be controlled.

3.11. Surface waters usually contain ^{222}Rn in very low concentrations. Elevated concentrations of ^{222}Rn can be found in water drawn from groundwater and from private supplies. The contribution of ^{222}Rn from drinking water to the total concentration of ^{222}Rn indoors is not constant as emanation occurs only while water is being discharged through taps or showers. For this reason, ^{222}Rn released from water is seldom the dominant origin of ^{222}Rn in high concentrations indoors, although high concentrations may occur in the short term. The ingestion of water containing ^{222}Rn is also a potential exposure pathway. Information on reducing high concentrations of ^{222}Rn in drinking water supplies can be found in the WHO Guidelines for Drinking-water Quality [10].

3.12. It has been reported by UNSCEAR [3] that inhalation of ^{222}Rn released from drinking water contributes, on average, 90% of the estimated dose due to ^{222}Rn in drinking water. In addition, the average effective dose from inhalation of ^{222}Rn released from drinking water into air indoors is approximately 0.025 mSv/a, compared with an average total effective dose due to inhalation of 1.1 mSv/a from ^{222}Rn of all origins and its decay products [3, 17]⁴. Therefore, while inhalation is the dominant pathway by which exposure due to ^{222}Rn present in drinking water can occur, the average doses received are usually only a small fraction of the doses from ^{222}Rn indoors of other origins. However, for households with a water supply from deep drilled wells in uranium rich bedrock, the household water supply can be the most important contributor to elevated concentrations of radon in air indoors, giving rise to individual doses of several millisieverts [20, 21].

Provision of information on radon

3.13. Requirement 50 of Ref. [2] states that: “The government shall provide information on levels of radon indoors and the associated health risks and, if appropriate, shall establish and implement an action plan for controlling public exposure due to radon indoors.”

3.14. The requirement to provide public information applies irrespective of whether or not radon measurements are being carried out or are planned. Examples of the type of material to be provided include: generic information on the distribution of radon worldwide and its variability; scientific evidence on the health risks arising from long term exposure due to radon indoors, including the synergistic relationship between exposure due to radon and inhalation of tobacco smoke; the basics of preventing the accumulation of radon in new buildings and of implementing corrective actions to reduce high concentrations of radon in existing buildings; the relationship between policy on radon and policy on the quality of indoor air; and the possible conflict between provisions for energy saving and protective actions for radon. Where reliable data exist in the State on concentrations of radon indoors, such information should be made available

⁴ Reference [17] sets out the calculation of the total inhalation dose from ^{222}Rn . The calculation assumes equilibrium factors for ^{222}Rn of 0.4 indoors and 0.6 outdoors, an average activity concentration for ^{222}Rn indoors of 40 Bq/m³ and an average activity concentration for ^{222}Rn outdoors of 10 Bq/m³, an occupancy factor per year of 7000 hours indoors and 1760 hours outdoors, and a dose conversion factor of 9 nSv/(Bq·h·m⁻³) for equivalent equilibrium concentration.

to the public. Ideally, information should be made available on-line so that it can be accessed and downloaded by interested parties.

3.15. There is a well established synergy between lung cancer from smoking and radon exposure. Smokers and more recent ex-smokers have a much higher baseline risk of lung cancer than lifelong non-smokers. Radon exposure increases this risk still further. It is therefore appropriate for the national authority to consider these combined risks when providing information and advice about radon, and to coordinate with national tobacco control programmes [7].

3.16. Prior to carrying out radon measurement surveys, the national authority should prepare and distribute information of interest to householders, in particular to those householders who may be invited to participate in such surveys. This should include general information on the risks from radon as well as information on how the radon measurements will be carried out and how the results will be communicated to householders. Issues of the confidentiality of householders' radon measurements should also be covered. If a reference level has already been set, this should also be explained. In particular, it should be explained how concentrations of radon above the reference level can be reduced.

3.17. If a national policy to control public exposure due to radon needs to be developed, the national authority should prepare information and make it available to all interested parties. This includes decision makers, medical practitioners, building professionals (including architects, engineers, quantity surveyors and builders) and the public. Since the national authority may consist of a number of different agencies and government departments, each of which is responsible for different aspects of the national policy, there should be close coordination to ensure that all information provided is clear and consistent. Decision makers at both national level and local level should be kept fully informed.

Surveys of radon indoors

3.18. The government is required to ensure that "Information is gathered on activity concentrations of radon in dwellings and other buildings with high occupancy factors for members of the public through appropriate means, such as representative radon surveys" (Ref. [2], para. 5.19(a)). As a first step in evaluating the extent of measures that may be necessary for controlling public exposure indoors due to radon, the national authority should review any existing data on concentrations of radon indoors, in particular, measurements made in those areas of the State where high concentrations of radon indoors might be expected. This includes regions where the local geology indicates that there

might be elevated concentrations of uranium in the soil and regions of karstic limestone in which underground waters might contain elevated concentrations of radon originating from mineral deposits. In addition, high concentrations of radon indoors might be expected in areas where soil permeability is exceptionally high (such as eskers or ridges composed of permeable gravel), even when the uranium concentration in the soil is not elevated.

3.19. If no such data are available, the national authority should consider organizing localized surveys. In deciding on the areas where such surveys might be initiated, in addition to the geological criteria indicated in para. 3.18, the national authority should also evaluate the available information on concentrations of radon indoors in neighbouring States. The benefit of carrying out such localized surveys is that they might assist in making decisions about the sampling density necessary for a national survey. For example, if high concentrations of radon indoors have been identified and there are known to be many other areas with similar geological features within the State, a high density of measurements in the national survey would be justified. On the other hand, if only low concentrations of radon indoors have been identified in areas where high concentrations of radon indoors might be expected, a lower density of measurements in the national survey may suffice.

3.20. Even if a review of the existing data and the outcomes of localized surveys initiated by the national authority do not reveal elevated concentrations of radon indoors, the national authority should still evaluate the degree to which the population is exposed. Such an evaluation is referred to as a national radon survey. There are two principal considerations in undertaking a national radon survey:

- (a) To identify areas where a greater proportion of homes are expected to have high concentrations of radon indoors. This can be achieved by carrying out a geographically based survey. The results can be used to develop maps for the risks due to radon and to identify radon prone areas (see Annex II).
- (b) To estimate the average exposure of the population due to radon, and the range of exposures occurring, for purposes of comparison with exposures due to other sources of radiation. The most appropriate basis for this is a national survey of concentrations of radon indoors in randomly selected dwellings, with account taken of population density [5].

3.21. With careful consideration, a single survey can be designed to address both 3.20(a) and (b) simultaneously. Measurements for such surveys should be carried out over a period of several months, and ideally over a period of one year, in each dwelling surveyed, to minimize uncertainties [22]. The results obtained will define the levels of radon exposure and will provide the basis for

future decisions on the development and implementation of a national policy to control public exposure due to radon. Collectively, the various components of such a policy are referred to as an action plan (see paras 3.23–3.59).

3.22. The surveys described above will show the variation in the concentrations of radon in dwellings, irrespective of the origin of the radon. In the great majority of cases, the radon will originate in the ground underneath dwellings, but in some cases, it will originate in the building materials or in the water supply. The national authority should carry out separate surveys to identify and investigate situations in which radon from building materials or from the water supply could make a significant contribution to the concentration of radon in indoor air.

Action plan on radon

General considerations

3.23. “Where activity concentrations of radon that are of concern for public health are identified..., the government shall ensure that an action plan is established comprising coordinated actions to reduce activity concentrations of radon in existing buildings and in future buildings” (Ref. [2], para. 5.20). Such an action plan should be implemented by the national authority and would require the national authority to do the following:

- (a) To establish “an appropriate reference level for ^{222}Rn for dwellings and other buildings with high occupancy factors for members of the public” (Ref. [2], para. 5.20(a)).
- (b) To decide which other types of buildings with high occupancy factors for members of the public, such as kindergartens, schools and hospitals, are included in the scope of the action plan for radon.
- (c) To establish an appropriate reference level for ^{222}Rn for workplaces such as offices and factories.
- (d) To facilitate the measurement of ^{222}Rn in dwellings and other buildings with high occupancy factors for the public.
- (e) To identify ^{222}Rn prone areas.
- (f) To give “priority to actions to reduce activity concentrations of ^{222}Rn in those situations for which such action is likely to be most effective” (see Ref. [2], para. 5.20(c)). This should include measures to reduce concentrations of ^{222}Rn in drinking water supplies and to control the radium content of building materials, where appropriate.

- (g) To include “in building codes appropriate preventive measures and corrective actions to prevent the ingress of ^{222}Rn and to facilitate further actions wherever necessary” (see Ref. [2], para. 5.20(d)).
- (h) To implement measures to control and reduce exposure due to ^{222}Rn , including determining the circumstances under which such measures are to be mandatory or to be voluntary.
- (i) To evaluate the success of the action plan.

Further guidance on the preparation of an action plan on radon can be found in the WHO Handbook on Indoor Radon [7]. Examples of national action plans on radon can be found in Refs [23–26].

3.24. The national authority should ensure that the action plan on radon is closely coordinated with other national programmes for indoor air quality and energy efficiency. For example, the construction of energy efficient homes can result in a lower rate of exchange of air than for existing homes. This could result in either an increase or a decrease in the flow of soil gas (containing ^{222}Rn) into the building, depending on the requirements in national building codes. By improving the thermal efficiency in a building, the higher temperature of the air indoors may result in a decrease in the pressure inside the building and thus may lead to an increased inflow of ^{222}Rn from the soil into the building. Changes in building practices, such as those relating to indoor air quality or energy efficiency, should be investigated with regard to their effects on concentrations of radon indoors and on the performance of corrective actions and preventive measures for radon. Where such changes in building practices could lead to increases in concentrations of radon indoors, consideration should be given to further changes in building practices in the national building codes.

Justification and optimization of strategies for radiation protection measures

3.25. The government and the regulatory body or other relevant authority are required to ensure that corrective actions and protective actions are justified, and to ensure that protection and safety is optimized (Ref. [2], Requirement 48).

3.26. The protection strategy for the programme to reduce concentrations of radon indoors should achieve sufficient individual or societal benefit to offset the detriment that it causes. The responsibility for decisions on justification for implementing radiation protection measures rests with governments or with national authorities.

3.27. Arguments for the justification of radiation protection measures include: radon is a significant cause of radiation exposure and is the second most important cause of lung cancer in the general population after smoking tobacco; feasible techniques are available to reduce high concentrations of radon indoors; policy on radon supports other public health policies such as policy on indoor air quality, when other pollutants are also present, or on smoking [7, 27].

3.28. The optimization of protection below a reference level should be implemented through an ongoing, cyclical process that involves: evaluation of the situation to identify the need for action (framing of the process); identification of the possible protective actions based on the latest technical knowledge to keep exposures as low as reasonably achievable; selection of the best option under the prevailing circumstances; implementation of the selected option; and regular review to evaluate whether the prevailing circumstances necessitate corrective actions [28].

3.29. The optimization process is implemented through the national action plan on radon. The process should be applied to achieve concentrations of radon that are as low as reasonably achievable below the reference level.

3.30. Optimization of protection against exposure due to radon indoors can be carried out using standard cost–benefit techniques. Comparisons can be made between the financial costs associated with the estimated number of cases of lung cancer likely to be due to radon at different levels of exposure, the selection of protective actions, and the costs of preventive measures and corrective actions to reduce exposure due to radon indoors. Such analyses can be used to inform decisions on the cost effectiveness of measures to reduce concentrations of radon in existing buildings and in new buildings [7].

Measurement of concentrations of ^{222}Rn

3.31. Radon measurements in dwellings are required for national and regional surveys, and to determine whether individual dwellings have unacceptably high concentrations of radon [15]. Concentrations of radon can vary greatly between dwellings, so a low or high concentration of radon in one dwelling cannot be taken as a guide to the concentrations of radon in nearby dwellings. Measurements of concentrations of radon can also be carried out to confirm that measures taken to reduce high concentrations of radon have been effective [15]. These measurements could be carried out by the national authority or by other organizations such as technical support organizations, academic institutions or private companies, or by a combination of these.