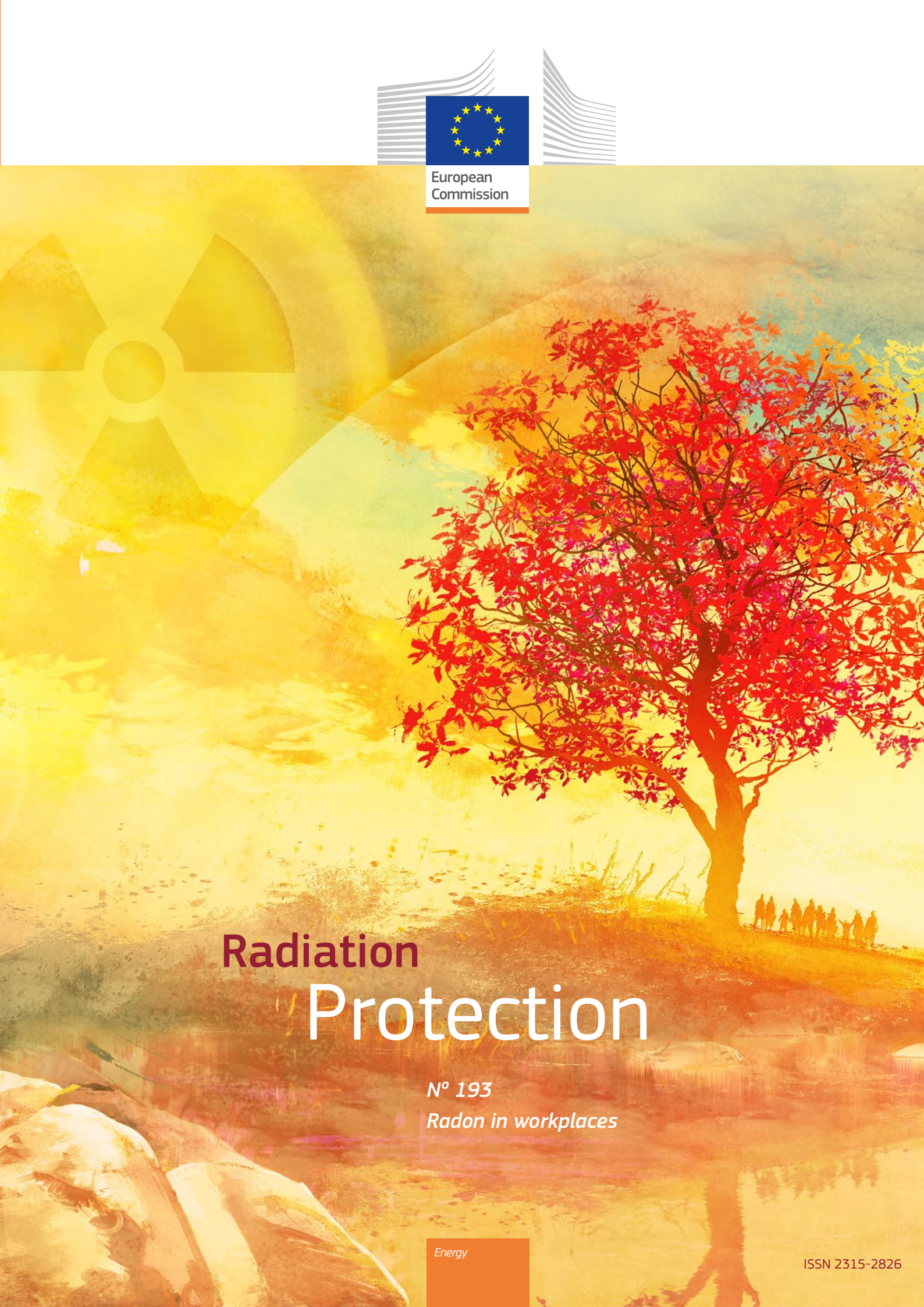

Radiation Protection

Nº 193

Radon in workplaces

Energy

ISSN 2315-2826

Luxembourg: Publications Office of the European Union, 2020

Print	ISBN 978-92-76-10530-5	ISSN 1681-6803	doi:10.2833/957131	MJ-XA-20-001-EN-C
PDF	ISBN 978-92-76-10531-2	ISSN 2315-2826	doi:10.2833/552398	MJ-XA-20-001-EN-N

EUROPEAN COMMISSION

RADIATION PROTECTION N° 193

Radon in workplaces

Implementing the requirements in Council Directive 2013/59/Euratom

Group of Experts referred to in Article 31 of the Euratom Treaty

Directorate-General for Energy
Directorate D — Nuclear Energy, Safety and ITER
Unit D3 — Radiation Protection and Nuclear Safety
2020

Foreword

Luxembourg, January 2020

Exposure to indoor radon constitutes an important part of the overall exposure to ionising radiation of members of the public and of workers, particularly in certain geographical areas or specific types of workplaces. Radon is also the second cause of lung cancer in the general population, after smoking.

Council Directive 2013/59/Euratom – the Basic Safety Standards Directive (BSS) – has introduced binding legal requirements to ensure an appropriate protection of individuals from the dangers arising from exposure to radon across the European Union. EU Member States are required to establish national radon action plans addressing long-term risks from radon exposures in dwellings, buildings with public access and workplaces from any source of radon ingress. Further to this, Member States need to establish national reference levels for indoor radon concentrations, which shall not be higher than 300 Bq m^{-3}.

In the coming years, implementing the specific provisions of the Directive on radon in workplaces represents a challenge for the radiation protection community as well as for the wider occupational health and safety community. In order to assist EU Member States in a successful implementation of the requirements on radon in workplaces, the European Commission asked the Group of Experts referred to in Article 31 of the Euratom Treaty, to develop this document.

The document discusses in detail the requirements on radon in workplaces in the Directive, as well as their relation to the safety requirements in the International Basic Safety Standards. It gives more insight into national radon action plans, the regulatory control of radon in workplaces, as well as into recognition, approval or accreditation of measurement services, dosimetry services and remediation services. Practical examples of regulatory control of radon exposure from European Union Member States and other countries complete the document.

The document was developed by a dedicated Working Party[1] and subsequently adopted by the Group of Experts referred to in Article 31 of the Euratom Treaty for publication in the Radiation Protection Series of the European Commission.

[1] The following members of the Working Party on Natural Radiation Sources of the Article 31 Group of Experts were involved in the preparation of this document: H. Janžekovič, F. Bochicchio, K. Gehrcke, P. Hofvander, J. Hůlka, M. Markkanen, M. Nettleton, C. Potiriadis, A. Rannou, and F. van de Put. They were assisted by S. Mundigl from the European Commission. Representatives from the International Atomic Energy Agency (IAEA), the World Health Organisation (WHO), the Heads of European Radiation Competent Authorities (HERCA), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the European Radon Association (ERA) participated as observers.

Contents

1 Introduction

Exposure to indoor radon constitutes an important part of the overall exposure to ionising radiation of members of the public and of workers particularly in certain geographical areas or specific types of workplaces.

Protection of the health of workers against dangers arising from ionising radiations is explicitly mentioned in Articles 2 and 30 of the Euratom Treaty [EU2010] recognising the importance of occupational radiation protection as a priority objective. These articles empower the Community to establish uniform basic safety standards to ensure the highest possible protection of workers. Therefore, already the first Euratom Basic Safety Standards Directive (BSS) adopted in early 1959 contains detailed provisions on occupational exposure. Taking account of the evolution of science, technology, and operational experience, the requirements on occupational exposure have evolved and strengthened over time but have always constituted an important part of all Euratom Basic Safety Standards Directives.

The requirements in the previous BSS – Council Directive 96/29/Euratom [EU1996] – already provided a very high level of occupational radiation protection mainly focussing on workers involved in planned exposure situations (previously called practices), i.e. working in the nuclear, medical or industrial sector, as well as in research and education. Council Directive 96/29/Euratom [EU1996] already included general requirements on the identification of work activities where workers could be exposed to thoron or radon, explicitly mentioning spas, caves, mines, underground workplaces and aboveground workplaces in identified areas[2]. Council Directive 2013/59/Euratom (the Directive) confirms the required high level of protection of the previous Directive, extending its scope to coherently and consistently cover the protection of workers in workplaces with enhanced natural radiation, e.g. workers exposed to radon in workplaces, workers in industries processing naturally-occurring radioactive materials (NORM), as well as aircrew and space crew.

With regard to radon, the Directive requires the establishment of a national radon action plan addressing long-term risks from radon in buildings and workplaces for any source of radon ingress, whether from soil, building materials or water. Further to this, the Directive contains detailed requirements on the protection of workers and members of the public from exposure to indoor radon.

In the coming years, implementing the specific provisions of the Directive on radon in workplaces represents a challenge for the radiation protection community as well as for the wider occupational health and safety community. The aim of this document is to provide pertinent materials and indications in order to assist European Union Member States for a successful implementation of the requirements on radon in workplaces. The requirements related to indoor radon in dwellings are not subject of this document, except in cases where a dwelling is also a workplace.

The document discusses in detail the requirements on radon in workplaces in the Directive, as well as their relation to the respective safety requirements in IAEA GSR Part 3 – the International Basic Safety Standards [IAEA2014]. It also provides more insight into national radon action plans, the regulatory control of radon in workplaces, the application of the system of radiation protection in case indoor radon concentrations remain above the reference level, as well as into recognition, approval or accreditation of measurement services, dosimetry services and remediation services. Practical examples of regulatory

[2] Guidance on the implementation of the provisions on radon in workplaces in Council Directive 96/29/Euratom [EU1996] has been published in 1997 as Radiation Protection N° 88 [EC1997].

control of radon exposure from European Union Member States and other countries complete the document.

In recent years, radiation protection related to radon in workplaces has experienced active developments in support of the optimisation of protection as set out in Article 5(b) of the Directive[3]. As Article 5(b) points out that the *current state of technical knowledge and economic and societal factors* shall be taken into account, the document also provides material that goes beyond the requirements of the Directive.

[3] Article 5(b) Optimisation in Council Directive 2013/59/Euratom reads: *Radiation protection of individuals subject to public or occupational exposure shall be optimised with the aim of keeping the magnitude of individual doses, the likelihood of exposure and the number of individuals exposed as low as reasonably achievable taking into account the current state of technical knowledge and economic and societal factors.*

2 Requirements on radon in workplaces in Council Directive 2013/59/Euratom

The exposure of workers and members of the public to indoor radon is explicitly taken up in the scope of Council Directive 2013/59/Euratom (Article 2(2d)). In addition, the Directive provides with Article 100, as a novelty, requirements to establish programmes on existing exposure situations in general and offers in Annex XVII (b) an indicative list of existing exposure situations that refers explicitly to *indoor exposure to radon and thoron, in workplaces, dwellings and other buildings*. Based on this, the Directive introduces legally binding requirements on protection from exposure to radon. All provisions in the Directive related to radon are given in Annex 1.

As major provision with regard to the radon protection strategy, the Directive requires in Article 103(1) that Member States establish a national action plan addressing long-term risks from radon in dwellings, buildings with public access and workplaces for any source of radon ingress, whether from soil, building materials or water. Annex XVIII of the Directive offers a detailed list of items to be considered in preparing the national action plan, some of which address particularly activities in relation to radon in workplaces. Further to this, Article 103(2) requires specifically that appropriate measures are in place to prevent radon ingress into new buildings. These measures may include specific requirements in national building codes. Finally, Article 103(3) requires Member States to identify areas where the radon concentration (as an annual average) in a significant number of buildings is expected to exceed the relevant national reference level.

Specific requirements on radon in workplaces are given in Article 54. It requires the establishment of a national reference level[4] for indoor radon concentration in workplaces. The reference level for the annual average activity concentration in indoor air shall not be higher than 300 Bq m^{-3}, unless it is warranted by national prevailing circumstances[5]. It is worth noting at this point that a Member State is free to establish different national reference levels for different types of workplaces, as well as different levels for workplaces and for buildings, as long as they are not higher than 300 Bq m^{-3}.

Article 54(2) addresses radon measurements. Member States are requested to establish programmes to carry out radon measurements in workplaces within the areas identified under the national action plan (see also Article 103(3)), and in specific types of workplaces also identified in the national action plan (see point 3 of Annex XVIII).

Article 54(3) specifies that if, despite all actions to optimise, the radon concentration in a workplace remains above the reference level, this workplace needs to be notified[6] to the competent authority (according to Article 25(2)) and Article 35(2) shall apply.

In this context, it is worth noting that Article 31(3)c requires Member States to arrange for a clear allocation of responsibilities to an undertaking, an employer or any other organisation for the protection of workers who are exposed to radon at work, in the situation specified in Article 54(3).

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4 It is useful to recall the definition of a reference level given in Article 4(84): *A "reference level" means in an emergency exposure situation or in an existing exposure situation, the level of effective dose or equivalent dose or activity concentration above which it is judged inappropriate to allow exposures to occur as a result of that exposure situation, even though it is not a limit that may not be exceeded.* Moreover, Article 7(1) on reference levels requires that *Optimisation of protection shall give priority to exposures above the reference level and shall continue to be implemented below the reference level."*

5 See also Recital (24) in Council Directive 2013/59/Euratom: *Where, due to national prevailing circumstances, a Member State establishes a reference level for indoor radon concentrations in workplaces that is higher than 300 Bq m^{-3}, the Member State should submit the information to the Commission.*

6 Notification is defined in Article 4(57): *"notification" means submission of information to the competent authority to notify the intention to carry out a practice within the scope of this Directive;*

Article 35(2) sets out the graded approach for workplaces with exposure to indoor radon as specified in Article 54(3), based on an assessment of the doses of workers (or of the time-integrated radon exposure value) due to radon exposure at a specific workplace. Workplaces where the exposure of workers is liable to exceed an effective dose of 6 mSv per year or a corresponding time-integrated radon exposure value shall be managed as a planned exposure situation and the Member States shall determine which requirements set out in Chapter VI of the Directive are appropriate. Workplaces where the effective dose to workers is less than or equal to 6 mSv per year or the exposure less than the corresponding time-integrated radon exposure value, the competent authority shall require that exposures are kept under review. A radon exposure assessment requires the application of radon conversion coefficients or factors. Annex 2 provides the status regarding such coefficients and factors developed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Commission on Radiological Protection (ICRP).

In case the exposures of workers need to be kept under review, Article 43 provides the requirements on appropriate recording and reporting of the monitoring results. In particular, Article 43(2)a requires recording of exposures to radon if decided by the Member State pursuant to Article 35(2) and 54(3). Article 43(4) specifies that exposures to radon pursuant to Article 35(2) and 54(3) shall be recorded separately in the dose record.

The graded approach to regulatory control of radon in workplaces is further discussed in Chapter 5.

It should be noted that Article 9 stipulates that the dose limits for occupational exposure apply to the sum of annual occupational exposures of a worker from all authorised practices, occupational exposure to radon in workplaces requiring notification in accordance with Article 54(3), and other occupational exposure from existing exposure situations in accordance with Article 100(3).

Finally, the Directive covers also Rn-220 (thoron) in the sense that it provides a definition of thoron and considers indoor exposure to thoron to be a type of existing exposure situation covered by the Directive. Annex XVII providing an *Indicative list of types of existing exposure situations as referred to in Article 100* explicitly mentions *indoor exposure to thoron, in workplaces, dwellings and other buildings*. Beyond this, the Directive does not contain any specific requirement on thoron.

3 Council Directive 2013/59/Euratom and IAEA GSR Part 3 Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards

Council Directive 2013/59/Euratom (the Directive) and IAEA GSR Part 3 Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards (International BSS) address radon exposure in a largely harmonised way offering a similar framework for radiation protection.

As stated in the recitals of the Directive[7], exposure to indoor radon at workplaces should be considered as an existing exposure situation. According to the International BSS para. 5.3 (a) and the associated footnote, radon exposure at workplaces where radon annual average activity concentration in air might be expected to be equal or to exceed the reference level is also considered to be an existing exposure situation. In addition, reference levels for Rn-222 are introduced in both documents, the establishment of a national radon action plan[8] is required and relevant requirements for occupational exposure in planned exposure situation shall be implemented.

The requirements in both documents are largely coherent and consistent, but with the following two differences:

- The main difference is the maximum permitted value for the reference level for indoor radon concentrations in workplaces. While Article 54(1) of the Directive requires that the reference level for the annual average activity concentration in air shall not be higher than 300 Bq m^{-3} unless it is warranted by national prevailing circumstances, the International BSS requires in para. 5.27 that the reference levels shall not exceed 1000 Bq m^{-3}.
- The Directive introduces a graded approach offering two levels of regulatory control of a workplace in case the radon annual average activity concentration in air continues to exceed the national reference level, despite the action taken in accordance with the principle of optimisation. At workplaces, where the effective dose of workers is less than or equal to 6 mSv per year, the exposures of workers need to be kept under review. For workplaces, where the exposure of workers is liable to exceed an effective dose of 6 mSv per year or a corresponding time-integrated radon exposure value, these shall be managed as a planned exposure situation. The International BSS does not contain similar requirements on the level of regulatory control[9].

It is worth noting, that the International BSS are jointly sponsored by several international organisations, including the European Atomic Energy Community (EAEC).

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7 See Recital (25) in Council Directive 2013/59/Euratom: *Where radon enters from the ground into indoor workplaces, this should be considered to be an existing exposure situation since the presence of radon is largely independent of the human activities carried out within the workplace. Such exposures may be significant in certain areas or specific types of workplaces to be identified by Member States, and appropriate radon and exposure reduction measures should be taken if the national reference level is exceeded. Where levels continue to remain above the national reference level, these human activities carried out within the workplace should not be regarded as practices. However, Member States should ensure that these workplaces are notified and that, in cases where the exposure of workers is liable to exceed an effective dose of 6 mSv per year or a corresponding time-integrated radon exposure value, they are managed as a planned exposure situation and that dose limits apply, and determine which operational protection requirements need be applied.*

8 As stated in GSR Part 3 requirement 50 [IAEA2014]. For further guidance, see also IAEA Specific Safety Guide No. SSG-32 on Protection of the Public against Exposure Indoors due to Radon and Other Natural Sources of Radiation, IAEA, Vienna (2015) [IAEA2015].

9 Additional IAEA guidance on the control of radon exposures in workplaces can be found in the IAEA Safety Guide GSG-7 “Occupational Radiation Protection”, IAEA, Vienna (2018) [IAEA 2018]

In November 2011, the Group of Experts established under Article 31 of the Euratom Treaty has given an Opinion on the coherence of the International Basic Safety Standards with the Commission's draft proposal for a new Euratom BSS Directive (COM(2011) 593final) and on the EAEC sponsoring of the International BSS. In the opinion of the Group of Experts, it is argued that the International BSS and the Euratom BSS offer a similar general framework of protection and are as a whole consistent, so that Member States that will transpose and implement the Euratom BSS will also be in agreement with the International BSS.

In 2012, the European Commission notified the IAEA of Commission Decision C(2012) 5311 final of 6.8.2012 on the endorsement of the International Basic Safety Standards: Radiation Protection and Safety of Radiation Sources [EC2012]. In this decision, it is stated that

1. The European Commission, on behalf of European Atomic Energy Community, supports the publication of the revised International Basic Safety Standards: Radiation Protection and Safety of Radiation Sources, as a co-sponsored document. This decision is without prejudice to the application of acts adopted under Articles 30 and 31 of the Treaty establishing the European Atomic Energy Community.

2. The European Commission, within the framework of external relations of the European Atomic Energy Community, will promote the implementation of these International Basic Safety Standards.

4 National radon action plan

A key provision with regard to the radon protection strategy is the requirement in Article 103 of Council Directive 2013/59/Euratom that Member States shall establish a national action plan addressing long-term risks from radon in dwellings, buildings with public access and workplaces for any source of radon ingress, whether from soil, building materials or water.

The national radon action plan should present the general and specific objectives driven by the Directive including the scientific background on radon and its health effects. The national action plan should further address long-term goals reducing lung cancer risks attributable to radon exposure (for smokers and non-smokers). Specific objectives could be to increase the rate of identifying workplaces with radon concentrations above the national reference level and to increase the number of workplaces that are successfully remediated. The national action plan could also establish a more ambitious "target" level (e.g. 100 Bq m^{-3}) for new buildings or encourage efforts for optimisation below the national reference level in existing buildings. Further to this, the national action plan could set specific measurable benchmarks (e.g. number of workplaces with measurement of radon concentration, number of workplaces where remedial action to reduce radon have been implemented) to allow an evaluation of the effectiveness of the national action plan.

Annex XVIII of the Directive offers a detailed list of items to be considered in preparing the national action plan, which cover for example:

- Strategy for conducting surveys of indoor radon concentrations;
- Delineation of areas with potentially high exposure to radon;
- Identification of types of workplaces and buildings with public access, where measurements are required;
- Strategy for reducing radon exposure in dwellings;
- Strategies for facilitating post construction remedial action;
- Strategy for preventing radon ingress in new buildings;
- Strategy for communication to increase public awareness;
- Guidance on methods and tools for measurements and remedial measures;
- Provision of financial support for radon surveys and for remedial measures;
- Long-term goals in terms of reducing lung cancer risk attributable to radon exposure.

This list covers activities related both to public and occupational exposure to radon, many of which are common to both types of exposures, while some of them are specific to dwellings and others specific to workplaces.

As this report focusses on radon in workplaces, the following issues are identified to apply specifically to workplaces and shall be discussed in more detail:

- Strategy for conducting surveys of indoor radon concentrations in workplaces;
- Delineation of areas with potentially high exposure to radon;
- Identification of types of workplaces where measurements are required;
- Basis for the establishment of reference levels for workplaces;
- Strategy for communication to increase awareness and inform employers and employees of the risks of radon, including in relation to smoking.

Strategy for conducting surveys of indoor radon concentrations in workplaces

An important part of the strategy for conducting surveys of indoor radon concentrations is an appropriate management of the measurement data and the related information on soil and building characteristics. It appears useful to collect and store all data obtained through the survey in a national or regional database. This would support the evaluation of the distribution of indoor radon concentration in workplaces, including the estimate of the number of buildings above the reference level, as well as the identification of soil and building parameters affecting radon concentration. Moreover, if information on implemented preventive and remedial actions are also collected, the data base would allow to evaluate the effectiveness of such actions and, more generally, of the national action plan in terms of quantitative indicators (e.g. number of identified workplaces exceeding the reference level and other relevant levels, number and percentage of such workplaces that have been effectively remediated).

Delineation of areas with potentially high exposure to radon

Radon concentrations in buildings can vary significantly depending on geogenic and anthropogenic factors. Geogenic factors are the radon source term in the ground (i.e. uranium or radium concentrations) and the permeability of the ground. Both factors together determine the availability of geogenic radon to enter buildings. Anthropogenic factors are the characteristics of a building and its use, e.g. the living habits, or working conditions and arrangements. Depending on the geology and the geogenic factors, indoor radon concentrations can show significant geographical variations. The delineation of geographical or administrative areas where radon concentrations in buildings are more likely to exceed the national reference level will allow to plan and to prioritise measures within the national action plan. These areas are often called “radon priority areas”. The delineation of these areas has implications in that radon measurements in workplaces located in these areas may be required (see next subchapter). Further to legally binding requirements, such a prioritisation can also be useful for radon prevention for new buildings (for example, through specific building codes), as well as the promotion of actions aimed at reducing exposure to radon. According to Article 103(3) of the Directive, Member States are obliged to *identify areas where the radon concentration (as an annual average) in a significant number of buildings is expected to exceed the relevant national reference level*. Member States may choose different approaches, data and criteria, according to their specific needs and preconditions.

The European Atlas of Natural Radiation, developed and maintained by the Joint Research Centre (JRC) of the European Commission, describes the different sources of natural radioactivity, e.g. radon. The Atlas contains a collection of maps displaying the levels of such sources including a European Indoor Radon Map, which provides an overview of the annual indoor radon concentration in ground-floor rooms of dwellings in Europe [EC2019].

Identification of types of workplaces where measurements are required

An important item to be considered in preparing the national radon action plan is the identification of workplaces with potentially high exposure to radon. Item 3 of Annex XVIII is explicitly addressing *Identification of types of workplaces and buildings with public access, such as schools, underground workplaces, and those in certain areas, where measurements are required, on the basis of a risk assessment, considering for instance occupancy hours.* According to Article 54(2) *Member States shall require that radon measurements are carried out: (a) in workplaces within the areas identified in accordance with Article 103(3), that are located on the ground floor or basement level, taking into account parameters contained in*

the national action plan as under point 2 of Annex XVIII, as well as (b) in specific types of workplaces identified in the national action plan taking into account point 3 of Annex XVIII.

Workplaces where measurements are required can be classified in two categories:

a. ***Workplaces situated in the area with potentially high exposure to radon***, the so-called radon priority areas (see above), identified in accordance with Article 103(3) *Member States shall identify areas where the radon concentration (as an annual average) in a significant number of buildings is expected to exceed the relevant national reference level*.

b. ***Specific types of workplaces*** identified in the national action plan independent of the delineated radon priority areas, where elevated radon concentrations can be expected. These specific types of workplaces include, for example, underground activities like maintenance and monitoring of traffic lanes in underground places, hydroelectric plants, thermal establishments, underground mining, processing of NORM material such as phosphate, waterworks, tourist caves and abandoned mines, wine cellars, metro lines, library depositories, etc. Further to this, Annex XVIII explicitly mentions buildings with public access, such as schools, hospitals, and museums. The latter deserve special attention both for the protection of workers and members of the public.

It is worth mentioning that further attention shall be paid to specific groups of workers moving from one workplace to another such as tunnel workers. The proper assessment of the occupational exposures of workers working in different workplaces with varying radon concentrations requires a dedicated approach. More generally, temporary underground construction sites should be investigated.

An important parameter that shall be considered in the exposure assessment of any workplace (according to Article 35(2)) is the occupancy factor. This is particularly true for workplaces below ground or workplaces containing an open water source. Typically, areas with an occupancy greater than 100 hours per year are included in the exposure assessments. However, the minimum occupancy threshold can range from 50 to 250 hours per year depending on national (or local) circumstances.

Basis for the establishment of reference levels for workplaces

The basis for establishing reference levels for workplaces may include risk evaluations, the expected number of workplaces involved, considerations on feasibility, cost-effectiveness, as well as approaches for implementing the optimisation principle above and below the reference level(s).

Member States may decide to choose the same reference level for workplaces in existing and in new buildings. In order to promote the installation of radon prevention measures, a Member State may opt for a lower reference value for workplaces in new buildings. This would account for the fact that preventive measures installed during the construction of a building tend to be more effective and less expensive than remedial actions on existing buildings. On the other hand, a higher reference level may be established for certain types of workplaces where significant difficulties are expected for reducing the radon concentration (provided it does not exceed 300 Bq m^{-3}). Finally, the World Health Organisation (WHO) recommended cost-effectiveness analysis as a useful tool to support the selection of appropriate values for reference level(s) [WHO2009]. Cost-effectiveness analysis has been applied in some countries for evaluating different policies on protection from radon in dwellings.

Strategy for communication

Annex XVIII of the Directive requires that the national action plan includes a *Strategy for communication to increase public awareness and inform local decision makers, employers and employees of the risks of radon, including in relation to smoking*. A set of core messages, which are simple, brief, and to the point shall be developed. Relevant stakeholders need to be identified and an appropriate communication strategy tailored to each group of stakeholders concerned needs to be developed. The active participation of stakeholders in the decision-making process is essential for increasing the efficiency of implementing the national action plan. Special attention shall be given to employers responsible for workplaces that may need to be tested for radon, and to employees at such workplaces. Communication strategies for employers shall aim at informing them about the need to test the workplace for radon, who can measure radon, and what has to be done depending on the measurement result.

The strategy shall allow to communicate information on radon and related health risks; that the risk is proportional to both the radon concentration in a building and the duration of exposure, and that radon concentrations can usually be significantly reduced at low or moderate costs along with energy efficiency and indoor air quality of buildings. Information about the combined effects of radon and smoking should be highlighted given the risk of developing lung cancer for a given exposure to radon is much higher for smokers than it is for non-smokers. The goal could be the promotion of a combined strategy to both reducing radon concentration in buildings and reviewing smoking habits. This information can be particularly useful for workers in workplaces where it is difficult or impossible to reduce radon concentration levels (e.g. caves).

When preparing the strategy for communication it might be appropriate to use communication campaigns addressing, for example, specifically employers, undertakings, property owners, building professionals or remediation services in a specific geographical area. These campaigns ought to facilitate communication and sharing of information among the groups addressed. Good communication approaches and lessons learned should be analysed and shared among stakeholders, e.g. using well-established channels for communication such as meetings of professional associations. Existing health campaigns related to smoking could be used as opportunities to enhance awareness with regard to the combined effects of exposure to radon and smoking.

A communication campaign might include training materials such as given by the IAEA at https://www.iaea.org/topics/radiation-protection/radon/training-material.

The WHO Handbook on indoor radon [WHO2009] provides a chapter on radon risk communication, which focuses, however, on communicating radon risk to members of the public. The EC publication *Technical Recommendations for Monitoring Individuals for Occupational Intake of Radionuclides* [EC2018] also contains a chapter on risks from radon and communication of risks.

Various stakeholders may need to be considered, including the following:

- Employers;
- Occupational health services; dosimetry services;
- Conventional health and safety officers;
- Labour unions, worker's or professional societies, associations, employees;
- Owners of buildings in general, and owners of office buildings in particular;
- State officials, e.g. mayors, authorities for spatial planning, authorities establishing building codes;

- Services providing radon measurements;
- Services providing building remediation;
- Professional societies (architects, engineers, builders) and construction companies;
- Real-estate agents.

A communication strategy may need to also address the retrospective assessment of radon exposure. This issue is further discussed in Annex 5.

Considerations when setting up the national action plan

When setting up the national action plan, the following items should be considered (common for both workplaces and dwellings):

- Identification of the role of different ministries and competent authorities in the implementation of the national action plan;
- Role and composition of the steering committee; elaborate the actions, monitor periodically the progress achieved and co-ordinate these actions; the steering committee may be composed of representatives of the respective ministries or competent authorities, governmental or non-governmental experts and relevant professionals;
- Interaction with stakeholders; it is important to recall the respective roles of the various stakeholders that may be involved in the prevention of radon risk, i.e. public decision makers, householders, employers and employees, public experts, measurement services, building professionals and architects;
- Current situation as regards radon in the country; available results of surveys in different areas and situations (dwellings, workplaces, building with public access) should be summarized;
- Main actions already taken for managing radon risk in the country (for both existing and new buildings), including the regulatory requirements;
- Interfaces to other related national actions and action plans, e.g. those regarding energy efficiency and indoor air quality of buildings, smoking prevention, supply of drinking water (if ground water is used), hazardous emissions from construction products, general work safety;
- Review of the national action plan; it is important to assess the effectiveness of the plan, to review and, if appropriate, revise the plan accordingly; such a review and revision could take place typically every 5 to 10 years.

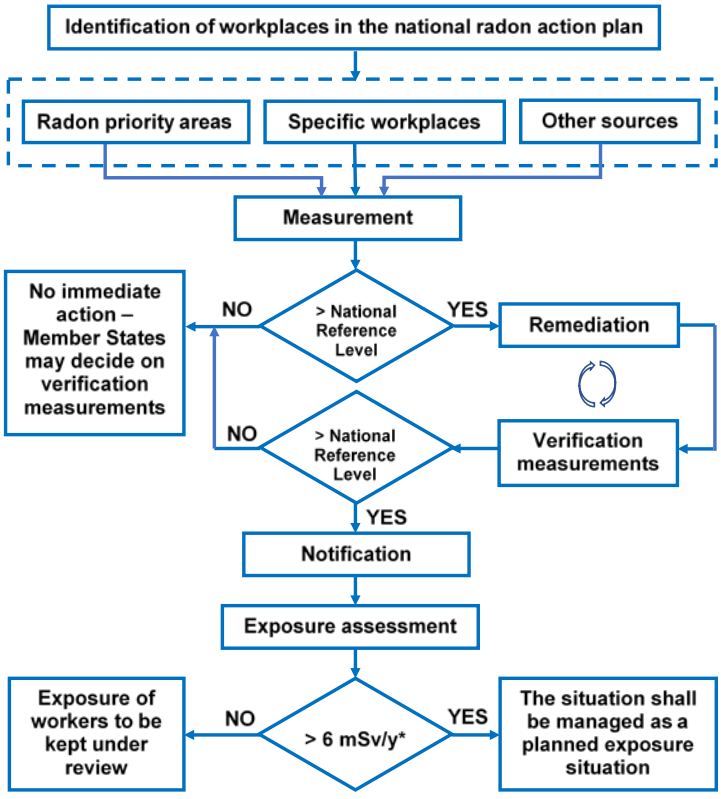
Annex 3 offers an example of a structure of a national radon action plan.

5 Regulatory control of radon in workplaces

5.1 Introduction

Council Directive 2013/59/Euratom offers a graded approach to regulatory control of radon in workplaces. Figure 1 visualises, in an illustrative and generalised way, the various steps in the decision taking process on the necessary level of regulatory control. The related decisions on justification of remedial actions and optimisation of protection as an integral part of radiation protection cannot be represented in the figure, but will be discussed in the text of this chapter[10]. It is also worth noting that changes in the workplace conditions or the conditions of the building may lead to changes in the radon exposure and may therefore require additional measurements[11].

Figure 1: *Decision making process on the necessary level of regulatory control based on Council Directive 2013/59/Euratom*



* or a corresponding time-integrated radon exposure value

The scheme for regulatory control of radon in workplaces as set out in the Articles 35(2) and 54 of the Directive includes the following steps:

[10] Considering that *optimisation of protection shall give priority to exposures above the reference level and shall continue to be implemented below the reference level* (Article 7(1)), this chapter will focus on optimisation of exposures above reference levels, although some consideration on optimisation below reference level will also be carried out.

[11] Documentation on measurements and workplace conditions is important to be able to track any changes at workplaces, which might lead to changes in radon exposure, e.g. routine renovations works that take place over the lifetime of a building might increase indoor radon concentrations; including change in structure, heating, cooling or mechanical systems of the building that may open up new entry routes for radon or introduction of other works that disrupt ventilation patterns or change air pressure differentials.

- Radon measurements shall be carried out in workplaces identified in the national radon action plan;
- Where measurements show that the reference level is exceeded, remedial action shall be taken in accordance with the optimisation principle given in Article 5(b);
- Notification to the competent authority is required if the radon concentration continues to exceed the reference level despite the remedial action taken in accordance with the principle of optimisation as set out in Chapter III of the Directive;
- An exposure assessment needs to be carried out;
- The exposures shall be kept under review in notified workplaces where exposure of the workers is less than or equal to 6 mSv per year or less than the corresponding time-integrated exposure value;
- Where the exposure of workers is liable to exceed an effective dose of 6 mSv per year or a corresponding time-integrated radon exposure value determined by the Member State, the situation shall be managed as a planned exposure situation and Member States shall determine which requirements on occupational exposure set out in Chapter VI are appropriate.

Annex 4 provides some national examples of how these steps are implemented.

5.2 Radon measurements in identified workplaces

Provisions and guidance for radon measurements

The wording of the Article 54(2) *Member State shall require that radon measurements are carried out:* implies that measurements are to be made compulsory in the identified workplaces. To this effect, national provisions should be established defining:

- The competent authority empowered to enforce the conduction of measurements;
- The responsible party for initiating the measurements;
- Workplaces in which radon measurements are to be measured;
- Requirements for measurement protocols to be applied.

Although not required by the Directive, it may be practicable to communicate the results of the radon measurements to the competent authority before any notification takes place.

Typically, the employer would be the responsible party for initiating the measurements. For practical reasons, the measurements could also be initiated by the owner of the property, especially if there are several different companies or entities operating in the same property. However, also in this case the employer would be ultimately the responsible party, and would carry its responsibility by ensuring that appropriate measurements are being conducted and by ensuring that it has access to the results. The measurements are usually performed by an appropriate measurement service, because most employers or property owners would not have the needed technical capabilities to conduct radon measurements.

The workplaces in which radon measurements would be made compulsory typically include:

- Ground floor or basement level workplaces in defined radon priority areas;
- Underground workplaces;
- Workplaces involving a specific source for radon such as indoor workplaces involving treatment of ground water, or handling or storing of bulk amounts of materials containing natural uranium or radium (Ra-226);

- Workplaces in buildings using building materials with significant radon exhalation.

Other workplaces may also be identified (see also Figure 1). The identification of workplaces subject to compulsory measurements is discussed in more detail in Chapter 4.

Provisions defining the workplaces where measurements are required should be unambiguous in the sense that any employer can easily identify itself without the need for further interpretation or guidance of the competent authority.

It is worth noting at this point that indoor radon concentrations are inherently variable, including a significant stochastic element as well as systematic, cyclic variations. It is therefore important that radon measurements should be of sufficient duration to support comparison with the reference level as an annual average.

Member States should ensure that guidance is available to employers on how to obtain appropriate radon measurements.

Measurement protocols

The competent authority should establish appropriate measurement protocols, which can be used for concluding whether or not the reference level is exceeded. These protocols should take appropriate consideration of the prevailing national conditions, for example, regarding possible expected seasonal or diurnal variations in indoor radon concentrations. The protocols should also consider specific conditions in different types of workplaces, such as those in workplaces with mechanical ventilation operating only at certain times, or those in underground mines and excavation works.

Measurement protocols should be based on the ISO standard ISO 11665-4:2012 [ISO2012].

The measurement protocols could also include provisions for verification measurements to be performed after a given period, in case the concentrations are near the reference level or in case the structure or the use of the building has substantially changed.

Measurement protocols for monitoring radon exposures of workers for the purpose of recording individual doses are discussed separately in section 5.7.

Recognition, approval or accreditation of measurement services is discussed in Chapter 6.

5.3 Remediation and follow-up

Need for remedial action

If measurements show that the radon concentration exceeds the reference level then remedial action to reduce the radon level should be taken.

If in a workplace or in some areas of a given workplace radon levels are found to be above the reference level but occupancy in this workplace is low, it may be sufficient to monitor and control access to the area. It is emphasized that this is not intended as a substitute for remedial measures when occupancy is a significant fraction of a normal working year. A specific time-integrated radon exposure value is likely to be needed in such cases. This might apply, for example, to areas visited infrequently that is less than about 100 hours per year.

Justification and optimization of remediation

The principles of justification and optimization apply to remedial action for reducing radon concentration in a workplace like any other action to reduce exposures. Some remedial action is very likely to be justified in almost all cases where the reference level is exceeded, especially in case of above ground workplaces where remedial action is likely to be successful.

However, in some rare cases, it could be difficult to implement remedial action due to technical reasons, for example in an underground mine with significant flow of radon bearing water. In such cases, remedial action might not be justified, but then other actions to reduce the exposure of workers, for example by limiting working time, could be necessary especially if the dose limit of workers is liable to be exceeded.

On the other hand, remediation may also be justified in cases where the reference level is not exceeded if simple measures can result in reducing the radon concentrations to even a lower level.

Once the decision is taken to remediate, the action should be planned and conducted with a view to optimise the protection of workers in line with Article 5(b). It is expected that the radon concentration level can be reduced well below the reference level. In some cases, the level just below the reference level might represent the optimized level of protection of workers but, in general, remediating only to just below the reference level is not an indication of successful optimization.

Provisions for remediation

The Directive does not provide any details regarding the implementation of actions to be taken to reduce radon concentration although reference to this action is made in Article 54(3) … *where radon concentration continues to exceed the national reference level, despite the action taken in accordance with the principle of optimization as set out in Chapter III, …..*.

To this effect, national provisions should be established defining:

- The competent authority empowered to enforce remediation;
- The party responsible for remediation;
- Requirements for demonstrating the success of remediation.

The competent authority should be allocated with sufficient powers and resources to enforce remediation.

The employer is ultimately always responsible for the safety of its workers and is also responsible to ensure that remedial action takes place when needed. However, unless the property is owned by the employer, the employer does not necessarily have rights nor practical means to make any technical remediation in the property. In this case, the employer would carry its responsibility by ensuring that appropriate remediation is undertaken by the property owner. The means by which a property owner could be enforced to take action depends on the national legal provisions. Ultimately, if the property owner would not agree to remediate the property appropriately, the employer would have to reconsider the use of this property, as a workplace. The Directive stresses in Article 31(3)c that the allocation of responsibilities need to be clear.

If, before remediation has started, the radon concentration in a particular workplace is at levels which may result in workers receiving doses of the order of the occupational annual dose limit (20 mSv), it would be appropriate to require immediate measures to reduce the exposure, as well as, monitoring and recording of worker doses.

Remediation measures are often performed by specialised remediation services. Recognition, approval or accreditation of such companies is discussed in Chapter 6.

Remedial action

A time frame should be set, by which a remediation should take place after the measurements have shown that the reference level is exceeded, taking also into account occupancy considerations. The time frame will depend on the radon concentration detected, and should, for example, allow to ensure that a certain dose level, such as the annual dose limit for workers, would not be exceeded before remediation is completed. Consideration could also be given to introducing simple (but temporary) remedial measures pending a more permanent remediation solution. For example, it may be possible to improve natural ventilation. Typically, technical remediation in buildings could take about 6 months but are very unlikely to take more than 12 months. However, it is worth noting that setting a period for completing remediation, based on the given radon level, may also encourage complacency and reduced remediation rates.

Choosing an appropriate method for reducing radon concentration depends on the initial radon concentration, the construction of the building and the nature of the radon source, especially the characteristics of the underlying soil. A site-specific assessment made by a specialist is often needed for finding an optimum solution.

Not all remediation techniques may be applicable for all types of workplaces. In particular, for specific workplaces, remediation techniques need to be carefully chosen to be applicable and planned to achieve the desired decrease in indoor radon level. The first step to ensure a successful remediation is to understand:

- Source of indoor radon, e.g. soil, borehole water supply source, or building materials;
- Ventilation systems;
- Construction of the building (foundation, openings, communication pathways);
- Pathways of radon gas.

Member States should ensure that advice and assistance is available on remedial measures appropriate to different types of workplaces. More information on remediation methods can be found in [WHO2009].

Remediation follow-up

The successful completion of the remedial action should always be verified with post remediation radon measurements. To ensure comparable results, initial and post remediation measurements should be performed following the same measurement protocol.

If the remedial action was successful and reduced the indoor radon concentrations below the reference level, no immediate further action is needed. However, Member States may wish to require periodic re-testing of remediated workplaces, to ensure that radon concentrations remain well below the reference level. Re-testing may be useful if, for example, construction or use of the building or parts of a building has been substantially changed. In case the remedial action is based on active measures, such as ventilation, regular re-verification of indoor radon concentrations, as well as, frequent visual and electrical checks of the system need to be carried out to ensure that this measure is still effective and efficient.

5.4 Notification to the competent authority

The wording of Article 54(3) *… where the radon concentration (as an annual average) continues to exceed the national reference level, despite the action taken …. , … Member States shall require this situation to be notified in accordance with Article 25(2) ….* and that of Article 25(2) *Member States shall ensure that notification is required for workplaces specified in Article 54(3), and…* imply that provisions requiring notification should be established.

These national provisions should define:

- The competent authority to be notified;
- The organisation responsible for notifying the competent authority (e.g. the employer);
- The information and documents to be included in the notification;
- The timeframe for the notification.

In deciding a timeframe, Member States should be mindful that remediation may be unsuccessful at the first attempt and that further remedial work is needed. Member States may decide that notification in accordance with Article 25(2) is warranted at this time even though the workplace may ultimately be remediated. Member States should provide guidance with regard to the timeframe for notification.

The competent authority will need to be able to draw conclusions and decide on further action based on the information and documents received in the notification. The notification could include the following information:

- Reports on measurement results prepared by a measurement service provider;
- Identification and description of the workplaces and the points of measurements and types of ventilations;
- Identification of worker groups concerned and the number of workers within them;
- Estimates of maximum annual working hours for affected worker groups;
- Description of remedial actions taken to reduce radon concentration and its effectiveness.

The notification is an important step to assure appropriate and timely communication between the competent authority and persons with legal responsibilities, e.g. employers, to ensure appropriate protection of the workers. Timely notification also facilitates appropriate supervision conducted by the competent authority.

The competent authority could establish a database recording these notifications for a systematic follow-up, which would also allow analysing all activities related to radon exposure subject to notification.

5.5 Exposure assessment

Based on the notification and documentation received, the competent authority should be able to:

- Decide if the results achieved in reducing radon concentrations are acceptable or if further reduction is needed;

- Request the notifying party to evaluate the exposure of workers and where it is liable to exceed an effective dose of 6 mSv per year or a corresponding time-integrated radon exposure value (Article 35(2)).

In accordance with the provisions established in national legislation by the Member State, the exposure assessment shall be performed by recognised dosimetry services or radiation protection experts. It would be useful if the Member State could offer an agreed methodology for the assessment of exposure.

Depending on the outcome of the exposure assessment, two different levels of regulatory control are required (see Sections 5.6 and 5.7)

5.6 Effective doses remain below 6 mSv per year – exposures need to be kept under review

If the exposure assessment confirms that the effective dose to workers is less than or equal to 6 mSv per year or the exposure less than the corresponding time-integrated radon exposure value, the competent authority shall require that exposures are kept under review.

The competent authority should consider providing guidelines on the level of regulatory control in these situations, which could cover, for example, the possibility to perform inspections, the assessment and review of exposures, the requirements on documentation related to measurements and exposure assessment, the control of working conditions, including working time in the radon area, to keep protection optimised. The competent authority may also require a periodic re-measurement of the radon concentrations in the workplace or re-assessment of doses as appropriate, in order to confirm the exposure assessment, in particular in cases where workplace conditions have changed.

In any case, the competent authority should promote the development of an appropriate radiation protection culture in order to optimise the protection of workers.

5.7 Application of the requirements of Chapter VI of the Directive on Occupational Exposures

Based on experiences in some Member States, most above ground workplaces can be remediated in practice, so that the requirements of Chapter VI of the Directive need not be applied. However, in underground workplaces, such as mines and tourist show-caves, remediation may not be feasible or successful, so that the radon risk will need to be managed appropriately.

According to Article 35(2), for workplaces where the effective doses are liable to exceed 6 mSv per year or the corresponding time-integrated radon exposure value determined by the Member State, the situation shall be managed as a planned exposure situation and the Member States shall determine which requirements set out in Chapter VI of the Directive on occupational exposure are appropriate.

Table 1 gives an overview of the requirements in Chapter VI of the Directive and indicates the relevance of each article for radon in workplaces.

Table 1: Requirements on occupational exposure given in Chapter VI of Council Directive 2013/59/Euratom.

Article in Chapter VI	Requirements	Relevant for radon in workplaces?
31	Allocation of responsibilities for protection of workers, outside workers and individuals who work on a voluntary basis	Yes
32, 33	Operational protection of exposed workers, apprentices and students	Yes
34	Consultations with a radiation protection expert	Yes, depending on national requirements
35, 36, 37, 38	Arrangements in and classification of workplaces	Delineation of radon workplaces and other arrangements
39	Radiological surveillance	Yes
40	Categorisation of workers	Yes
41, 42	Individual monitoring and dose assessment in the case of accidental exposure	Yes
42, 43, 44	Recording and reporting results of individual monitoring and dose assessment as well as access to the results of the individual monitoring	Yes
45, 46, 47	Medical surveillance and classification of workers as well as prohibition to employ or classify unfit worker	Yes
48, 49	Medical records and special medical surveillance	No
50	Appeals	Yes
51	Protection of outside workers	Yes
52	Specially authorised exposures	No
53	Emergency occupational exposure	No
54	Radon in workplaces	Yes

In the following sections, several occupational protection requirements are discussed with a view to their applicability and practical implementation in cases where exposure of workers to radon is liable to exceed an effective dose of 6 mSv per year or the corresponding time-integrated radon exposure value determined by the Member State.

Responsibilities

Article 31 of The Directive requires Member States to ensure a clear allocation of responsibilities for assessing and implementing arrangements for radiation protection of exposed workers.

More specifically, Article 31(3)c requires Member States to arrange for a clear allocation of responsibilities regarding protection of workers who are exposed to radon at work, in the situation specified in Article 54(3). In most cases, the employer of the worker would have to assume these responsibilities. In a few cases, it may be necessary to define the respective responsibilities shared between an undertaking responsible for the workplace (or the owner of the property) and the employer of the worker.

Radiation protection expert and radiation protection officer

The Directive requires, as a general principle, that a radiation protection expert (RPE) would be consulted in matters on protection of workers. In addition, a radiation protection officer (RPO) can be required to perform radiation related tasks of the undertaking.

In case of radon related matters, the RPE or RPO consulted need to have appropriate competence and experience in this field.

Classification of workplaces

Radon concentrations in a building or an underground establishment may vary significantly between different working areas. Therefore, it would be appropriate to identify areas with the highest radon concentrations and to provide the workers with information on the difference. The distinction between controlled area, supervised area and areas, which are not classified according to the Directive could be based on the radon concentrations and/or possible doses (or integrated exposures) received when working in the area. In addition, for controlled areas a key point is whether special operating procedures are required, for example, limitation of working time or the need to use respiratory protective equipment.

For practical purposes also other names for the areas could be used. For example, some Member States are using a label “radon area” in the meaning of controlled area due to radon exposure. Labelling of such areas would be appropriate, especially areas which are accessible only for workers. Case specific consideration might be needed regarding labelling areas, which are also accessible to the public.

Radiological surveillance of the workplace and individual monitoring

Article 41 of the Directive requires that category A workers shall be systematically monitored based on individual measurements, for example, using passive or active personal dosemeters. In cases where individual measurements are not possible or inadequate, individual monitoring shall be based on an estimate based on individual monitoring of other exposed workers or on the results of the surveillance of the workplace (for example, regularly repeated measurements or continuous recording with an electronic equipment).

Recording and reporting of results

As specified in Article 43 of the Directive, records containing the results of individual monitoring including those of radon exposures of workers and the effective dose caused by radon should be established and kept for each worker. The dose record of an individual exposed worker shall contain separate estimates of exposure from radon as well as the sum of doses from radon and from other occupational exposures. This would allow combining the estimates of doses from radon and from other radiation sources in case the workplace is part of a practice, and ensuring compliance with the dose limit for occupational exposure. Preferably, these records should be part of a national dose register, where such a register exists.

The records should include, in addition to the estimate of the effective dose, also the time-integrated gas exposures (Bq h m^{-3}) or, where appropriate, radon daughter exposure (mJ h m^{-3}), as well as the relevant parameter values used for estimating the dose such as the

equilibrium factor[12], i.e. estimated or measured value. Keeping this information would allow to reassess the effective dose in case criteria and coefficients would change.

Annex 2 provides additional information on the exposure assessment and the related dose conversion factors and dose coefficients.

Medical surveillance of exposed workers

Medical surveillance of exposed workers shall be based on the principles that govern occupational medicine in general. The medical surveillance shall allow for the state of health of workers under surveillance to be ascertained as regards their fitness for the tasks assigned to them.

Protection of pregnant or breast-feeding worker (as required in Article 10 of the Directive)

As health risks due to radon exposure are essentially related to the alpha exposure to the lungs originating from radon progeny attached to the surfaces of the lung, it is likely that an unborn child or a child subject to breast-feeding remains well protected if the mother is well protected. Specific measures on the protection of pregnant or breast-feeding workers are therefore usually not deemed necessary.

Categorisation of exposed workers

In accordance with Article 35(2), the regime for the application of provisions of Chapter VI on occupational exposures include only workers who are liable to receive an effective dose of 6 mSv per year. According to Article 40, these workers would all be categorised category A and no workers would be categorised category B.

Outside workers

Article 51 provides for the protection of outside workers. Outside workers should be afforded equivalent protection to that for workers employed on a permanent basis by the undertaking. This should be applied also in case of radon exposure. The responsibilities of the undertaking and the employer regarding the protection of workers, e.g. for providing individual monitoring and recording, reporting results and providing information to workers, need to be defined.

There may be situations where the dose due to radon exposure of an individual worker would exceed 6 mSv per year while working at several different undertakings' premises with high radon concentrations. The ultimate responsibility for the protection of the worker, in these cases, is always with the employer.

5.8 Workplaces combining a practice and exposure to radon

In some particular cases, workers are exposed in a practice/planned exposure situation to other sources of ionising radiation and to radon. In this case, the planned exposure situation is already under regulatory control, meaning the workers are already considered exposed workers and the requirements of Chapter VI of the Directive apply to them, before their exposure to radon is taken into account.

[12] The equilibrium factor is the ratio between the concentration of radon progeny and Rn-222.

In these specific cases, special attention shall be given to the implementation of the occupational dose limits. Article 9 of the Directive stipulates that the dose limits for occupational exposures apply to the sum of annual occupational exposures from all authorised practices, occupational exposure to radon in workplaces requiring notification, and other occupational exposure from existing exposure situations. For a workplace exceeding the national reference level for radon and thus requiring notification, the annual dose from radon needs to be added to the annual dose from other radiation exposures at work.

6 Recognition, approval or accreditation of measurement services, dosimetry services and remediation services

6.1 Measurement services

The requirements on radon in workplaces involve measurements to assess the annual average activity concentrations of radon in air at different stages: initial measurements, post remediation measurements, and verification measurements. The Directive proposes in Annex XVIII(11) that Member States shall consider including in the national action plan: *Guidance on methods and tools for measurements and remedial measures. Criteria for accreditation of measurement and remediation services shall also be considered*. It would be the role of the competent authority to establish such guidance.

Measurements of radon require an understanding of the workplace conditions and of the available measurement techniques for radon and radon progeny. The EC publication RP188 *Technical Recommendations for Monitoring Individuals for Occupational Intake of Radionuclides* [EU2018] contains a chapter on radon measurements and dosimetry for workers offering recommendations on: measurement devices, quality assurance and uncertainties of radon measurements, as well as on measurement strategies.

RP 188 proposes *A quality assurance programme should be established and maintained by all those providing radon measurement services. It is preferable but not mandatory that radon measurement services, testing and calibration laboratories are accredited in accordance with ISO/IEC 17025:2005.* Further to this, measurements may be performed in accordance with ISO standards of the ISO 11665 series, e.g. ISO 11665-4:2012 [ISO2012].

6.2 Dosimetry services

In cases, where the annual average activity concentrations of radon in air exceed the national reference level, Article 35(2) implies that an exposure assessment has to be performed. While the Directive does not specify explicitly who shall perform this exposure assessment, it would preferably be a recognised dosimetry service or a recognised radiation protection expert competent in radon exposure assessment. Member States need to specify the recognition requirements for services and experts and communicate them to the European Commission (see Article 79(3) of the Directive).

In cases, where the exposure of workers is liable to exceed an effective dose of 6 mSv per year, the exposure of workers needs to be assessed individually, for example through individual monitoring. Only recognised dosimetry services or recognised radiation protection experts shall carry out this individual dose assessment.

6.3 Remediation services

The Directive proposes in Annex XVIII(11) that Member States shall consider including in the national radon action plan: *Guidance on methods and tools for measurements and remedial measures. Criteria for accreditation of measurement and remediation services shall also be considered*. It would be the role of the competent authority to prepare such guidance, in collaboration with experts in remediation.

Success in remediation requires broad knowledge and expertise in the behaviour of radon in different types of workplaces and buildings, as well as, in building engineering. Member States may wish to set qualification or other criteria for those services planning and/or conducting remediation.

Member States should promote training in radon remediation techniques and could consider publishing guidelines on good engineering practice regarding remediation techniques applicable in the state.

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Annex 1: Relevant provisions in Council Directive 2013/59/Euratom

The articles of Council Directive 2013/59/Euratom directly linked to radon in workplaces are: *Article 2(2)d, Article 4(35, 82, 83, 84, 97), Article 7, Article 5 Article 9, Article 25(2), Article 31, Article 35(2), Article 43, Article 54, Article 100, Article 103, Annex XVII* and Annex *XVIII.* Further to this, recitals (9), (10), (11), (17), (22), (23), (24) and (25) address radon in workplaces. Recital (25) sets out the reasoning behind the decision to introduce requirements on exposure to indoor radon in workplaces.

Article 2 Scope

…
2. This Directive applies in particular to:
…
(d) the exposure of workers or members of the public to indoor radon, ….
…

Article 4 Definitions

…
(35) "existing exposure situation" means an exposure situation that already exists when a decision on its control has to be taken and which does not call or no longer calls for urgent measures to be taken;
…
(82) "radon" means the radionuclide Rn-222 and its progeny, as appropriate;
(83) "exposure to radon" means exposure to radon progeny;
(84) "reference level" means in an emergency exposure situation or in an existing exposure situation, the level of effective dose or equivalent dose or activity concentration above which it is judged inappropriate to allow exposures to occur as a result of that exposure situation, even though it is not a limit that may not be exceeded
…
(97) "thoron" means the radionuclide Rn-220 and its progeny, as appropriate;
…

Article 5 General principles of radiation protection

...
b) Optimisation: Radiation protection of individuals subject to public or occupational exposure shall be optimised with the aim of keeping the magnitude of individual doses, the likelihood of exposure and the number of individuals exposed as low as reasonably achievable taking into account the current state of technical knowledge and economic and societal factors.
...

Article 7 Reference levels

1. Member States shall ensure that reference levels are established for emergency and existing exposure situations. Optimisation of protection shall give priority to exposures above the reference level and shall continue to be implemented below the reference level.
2. The values chosen for reference levels shall depend upon the type of exposure situation. The choices of reference levels shall take into account both radiological protection requirements and societal criteria. For public exposure the establishment of reference levels shall take into account the range of reference levels set out in Annex I.
3. For existing exposure situations involving exposure to radon, the reference levels shall be set in terms of radon activity concentration in air as specified in Article 74 for members of the public and Article 54 for workers.

Article 9 Dose limits for occupational exposure

1. Member States shall ensure that dose limits for occupational exposure apply to the sum of annual occupational exposures of a worker from all authorised practices, occupational exposure to radon in workplaces requiring notification in accordance with Article 54(3), and other occupational exposure from existing exposure situations in accordance with Article 100(3). For emergency occupational exposure Article 53 shall apply.

2. The limit on the effective dose for occupational exposure shall be 20 mSv in any single year. However, in special circumstances or for certain exposure situations specified in national legislation, a higher effective dose of up to 50 mSv may be authorised by the competent authority in a single year, provided that the average annual dose over any five consecutive years, including the years for which the limit has been exceeded, does not exceed 20 mSv.

3. In addition to the limits on effective dose laid down in paragraph 2, the following limits on equivalent dose shall apply:

(a) the limit on the equivalent dose for the lens of the eye shall be 20 mSv in a single year or 100 mSv in any five consecutive years subject to a maximum dose of 50 mSv in a single year, as specified in national legislation.

(b) the limit on the equivalent dose for the skin shall be 500 mSv in a year, this limit shall apply to the dose averaged over any area of 1 cm 2 , regardless of the area exposed;

(c) the limit on the equivalent dose for the extremities shall be 500 mSv in a year.

Article 25 Notification

…

2. Member States shall ensure that notification is required for workplaces specified in Article 54(3), and for existing exposure situations that are managed as a planned exposure situation, as specified in Article 100(3).

…

Article 31 Responsibilities

1. Member States shall ensure that the undertaking is responsible for assessing and implementing arrangements for the radiation protection of exposed workers.

2. In the case of outside workers, the responsibilities of the undertaking and the employer of outside workers are stipulated in Article 51.

3. Without prejudice to paragraphs 1 and 2, Member States shall arrange for a clear allocation of responsibilities for the protection of workers in any exposure situation, to an undertaking, an employer or any other organisation, in particular for the protection of:

…

(c) workers who are exposed to radon at work, in the situation specified in Article 54(3).

This shall also apply to the protection of self-employed individuals and individuals who work on a voluntary basis.

4. Member States shall ensure that employers have access to information on the possible exposure of their employees under the responsibility of another employer or undertaking.

Article 35 Arrangements in workplaces

[…]

2. For workplaces specified in Article 54(3), and where the exposure of workers is liable to exceed an effective dose of 6 mSv per year or a corresponding time-integrated radon exposure value determined by the Member State, these shall be managed as a planned exposure situation and the Member States shall determine which requirements set out in this Chapter are appropriate. For workplaces specified in Article 54(3), and where the effective dose to workers is less than or equal to 6 mSv per year or the exposure less than the corresponding time-integrated radon exposure value, the competent authority shall require that exposures are kept under review.

[…]

Article 43 Recording and reporting of results

1. Member States shall ensure that a record containing the results of individual monitoring is made for each category A worker and for each category B worker where such monitoring is required by the Member State.
2. For the purposes of paragraph 1, the following information on exposed workers shall be retained:
(a) a record of the exposures measured or estimated, as the case may be, of individual doses pursuant to Articles 41, 42, 51, 52, 53 and, if decided by the Member State pursuant to Article 35(2), 54(3);
(b) in the case of exposures as referred to in Articles 42, 52 and 53, the reports relating to the circumstances and the action taken;
(c) the results of workplace monitoring used to assess individual doses where necessary.
3. The information referred to in paragraph 1 shall be retained during the period of their working life involving exposure to ionising radiation and afterwards until they have or would have attained the age of 75 years, but in any case not less than 30 years after termination of the work involving exposure.
4. Exposures as referred to in Articles 42, 52 53 and, if decided by the Member State pursuant to Article 35(2), 54(3) shall be recorded separately in the dose record referred to in paragraph 1.
5. The dose record referred to in paragraph 1 shall be submitted to the data system for individual radiological monitoring established by the Member State in accordance with the provisions of Annex X.

Article 54 Radon in workplaces

1. Member States shall establish national reference levels for indoor radon concentrations in workplaces. The reference level for the annual average activity concentration in air shall not be higher than 300 Bq m^{-3}, unless it is warranted by national prevailing circumstances.
2. Member States shall require that radon measurements are carried out:
(a) in workplaces within the areas identified in accordance with Article 103(3), that are located on the ground floor or basement level, taking into account parameters contained in the national action plan as under point 2 of Annex XVIII, as well as
(b) in specific types of workplaces identified in the national action plan taking into account point 3 of Annex XVIII.
3. In areas within workplaces, where the radon concentration (as an annual average), continues to exceed the national reference level, despite the action taken in accordance with the principle of optimisation as set out in Chapter III, Member States shall require this situation to be notified in accordance with Article 25(2) and Article 35(2) shall apply.

Article 100 Programmes on existing exposure situations

1. Member States shall ensure that measures are taken, upon indication or evidence of exposures that cannot be disregarded from a radiation protection point of view, to identify and evaluate existing exposure situations taking into account the types of existing exposure situations listed in Annex XVII, and to determine the corresponding occupational and public exposures.
2. Member States may decide, having regard to the general principle of justification, that an existing exposure situation warrants no consideration of protective or remedial measures.
3. Existing exposure situations which are of concern from a radiation protection point of view and for which legal responsibility can be assigned shall be subject to the relevant requirements for planned exposure situations and accordingly such exposure situations shall be required to be notified as specified in Article 25(2).

Article 103 Radon action plan

1. In application of Article 100(1), Member States shall establish a national action plan addressing long-term risks from radon exposures in dwellings, buildings with public access and workplaces for any source of radon ingress, whether from soil, building materials or water. The action plan shall take into account the issues set out in Annex XVIII and be updated on a regular basis.
2. Member States shall ensure that appropriate measures are in place to prevent radon ingress into new buildings. These measures may include specific requirements in national building codes.
3. Member States shall identify areas where the radon concentration (as an annual average) in a significant number of buildings is expected to exceed the relevant national reference level.

ANNEX XVII Indicative list of types of existing exposure situations as referred to in Article 100

(a) Exposure due to contamination of areas by residual radioactive material from:

(i) past activities that were never subject to regulatory control or were not regulated in accordance with the requirements laid down by this Directive;

(ii) an emergency, after the emergency exposure situation has been declared ended, as provided for in the emergency management system;

(iii) residues from past activities for which the undertaking is no longer legally accountable;

(b) Exposure to natural radiation sources, including:

(i) indoor exposure to radon and thoron, in workplaces, dwellings and other buildings;

(ii) indoor external exposure from building materials;

(c) Exposure to commodities excluding food, animal feeding stuffs and drinking water incorporating

(i) radionuclides from contaminated areas specified in point (a), or

(ii) naturally-occurring radionuclides.

ANNEX XVIII List of items to be considered in preparing the national action plan to address long-term risks from radon exposures as referred to in Articles 54, 74 and 103

(1) Strategy for conducting surveys of indoor radon concentrations or soil gas concentrations for the purpose of estimating the distribution of indoor radon concentrations, for the management of measurement data and for the establishment of other relevant parameters (such as soil and rock types, permeability and radium-226 content of rock or soil).

(2) Approach, data and criteria used for the delineation of areas or for the definition of other parameters that can be used as specific indicators of situations with potentially high exposure to radon.

(3) Identification of types of workplaces and buildings with public access, such as schools, underground workplaces, and those in certain areas, where measurements are required, on the basis of a risk assessment, considering for instance occupancy hours.

(4) The basis for the establishment of reference levels for dwellings and workplaces. If applicable, the basis for the establishment of different reference levels for different uses of buildings (dwellings, buildings with public access, workplaces) as well as for existing and for new buildings.

(5) Assignment of responsibilities (governmental and non-governmental), coordination mechanisms and available resources for implementation of the action plan.

(6) Strategy for reducing radon exposure in dwellings and for giving priority to addressing the situations identified under point 2.

(7) Strategies for facilitating post construction remedial action.

(8) Strategy, including methods and tools, for preventing radon ingress in new buildings, including identification of building materials with significant radon exhalation.

(9) Schedules for reviews of the action plan.

(10) Strategy for communication to increase public awareness and inform local decision makers, employers and employees of the risks of radon, including in relation to smoking.

(11) Guidance on methods and tools for measurements and remedial measures. Criteria for the accreditation of measurement and remediation services shall also be considered.

(12) Where appropriate, provision of financial support for radon surveys and for remedial measures, in particular for private dwellings with very high radon concentrations.

(13) Long-term goals in terms of reducing lung cancer risk attributable to radon exposure (for smokers and non- smokers).

(14) Where appropriate, consideration of other related issues and corresponding programmes such as programmes on energy saving and indoor air quality.

Recitals

(9) Calculation of doses from measureable quantities should rely on scientifically established values and relationships. Recommendations for such dose coefficients have been published and updated by ICRP, taking scientific progress into account. A collection of dose coefficients based on its earlier recommendations in ICRP Publication 60 (3), is available as ICRP Publication 119 (4). However, in ICRP Publication 103, a new

methodology was introduced by ICRP to calculate doses based on the latest knowledge on radiation risks, and this should, where possible, be taken into account in this Directive.
(10) For external exposure, values and relationships have been published following the new methodology in ICRP Publication 116 (5). These data, as well as the well-established operational quantities, should be used for the purpose of this Directive.
(11) For internal exposure, while ICRP has consolidated in ICRP Publication 119 all earlier publications (on the basis of ICRP Publication 60) on dose coefficients, updates of this publication will be provided and the coefficients that are tabulated in it will be superseded by values based on the radiation and tissue weighting factors and phantoms laid down in ICRP Publication 103. The Commission will invite the group of experts referred to in Article 31 of the Euratom Treaty to continue to monitor scientific developments and the Commission will make recommendations on any updated values, relationships and coefficients, including those for exposure to radon, taking relevant opinions of the group of experts into account.
(17) It is appropriate for this Directive to establish reference levels for indoor radon concentrations and for indoor gamma radiation emitted from building materials, and to introduce requirements on the recycling of residues from industries processing naturally-occurring radioactive materials into building materials.
(22) Recent epidemiological findings from residential studies demonstrate a statistically significant increase of lung cancer risk from prolonged exposure to indoor radon at levels of the order of 100 Bq m^{-3}. The new concept of exposure situations allows the provisions of Commission Recommendation 90/143/Euratom (1) to be incorporated into the binding requirements of the Basic Safety Standards while leaving enough flexibility for implementation.
(23) National action plans are needed for addressing long- term risks from radon exposure. It is recognized that the combination of smoking and high radon exposure presents a substantially higher individual lung cancer risk than either factor individually and that smoking amplifies the risk from radon exposure at the population level. It is important that Member States address both of these health hazards.
(24) Where, due to national prevailing circumstances, a Member State establishes a reference level for indoor radon concentrations in workplaces that is higher than 300 Bq m–3 , the Member State should submit the information to the Commission.
(25) Where radon enters from the ground into indoor workplaces, this should be considered to be an existing exposure situation since the presence of radon is largely independent of the human activities carried out within the workplace. Such exposures may be significant in certain areas or specific types of workplaces to be identified by Member States, and appropriate radon and exposure reduction measures should be taken if the national reference level is exceeded. Where levels continue to remain above the national reference level, these human activities carried out within the workplace should not be regarded as practices. However, Member States should ensure that these workplaces are notified and that, in cases where the exposure of workers is liable to exceed an effective dose of 6 mSv per year or a corresponding time-integrated radon exposure value, they are managed as a planned exposure situation and that dose limits apply, and determine which operational protection requirements need be applied.

Annex 2: Radon exposure assessment and related conversion coefficients and factors

Articles 35(2) of the Directive requires the assessment of the exposure of workers to radon in certain workplaces.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has published a radon dose conversion factor and the International Commission on Radiological Protection (ICRP) has published radon dose coefficients for occupational exposure.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)

UNSCEAR defined in its 1988 report [UN1988] a radon dose conversion factor of 9 nSv $(Bq\ h\ m^{-3})^{-1}$ EEC[13]. With this factor, a radon concentration of 400 Bq m^{-3} would correspond to approximately a dose of 10 mSv a^{-1} assuming an equilibrium factor of 0.4 and an annual exposure of 7000 hours (for homes).

It is worth noting that UNSCEAR developed this dose conversion factor for comparison purposes with other sources of ionising radiation contributing to the exposure levels to a population. The UNSCEAR dose conversion factor is not meant to be used for radiation protection purposes.

Recently, UNSCEAR reassessed lung cancer from exposure to radon. In the report to the General Assembly of the United Nations, the Committee recommends the continued use of the dose conversion factor of 9 nSv $(Bq\ h\ m^{-3})^{-1}$ EEC of Rn-222, which corresponds to 1.6 mSv $(mJ\ h\ m^{-3})^{-1}$ for estimating radon exposure levels to a population [UN2019].

International Commission on Radiological Protection (ICRP)

In January 2018, ICRP published ICRP Publication 137 Occupational Intakes of Radionuclides: Part 3 [ICRP2017], which provides, inter alia, dose coefficients for exposure to indoor radon.

In this publication, ICRP recommends the following rounded dose coefficients:

For buildings and underground mines, in most circumstances the recommended dose coefficient is 3 mSv $(mJ\ h\ m^{-3})^{-1}$ (approximately 10 mSv per Working Level Month (WLM)[14]). The corresponding dose coefficient expressed in terms of Rn-222 gas exposure depends on the equilibrium factor, F, between radon gas and its progeny. Using the standard assumption of F = 0.4 for most indoor situations, this dose coefficient corresponds to 6.7 10^{-6} mSv $(Bq\ h\ m^{-3})^{-1}$.

ICRP notes that while ICRP Publication 137 does not specifically address public exposures, it is intended that the same dose coefficient applies to exposures in homes. Dose coefficients for radionuclide intakes by members of the public will be published in due course and will include radon.

For the specific situations of indoor work involving substantial physical activity, and exposures in tourist caves, the recommended dose coefficient is 6 mSv $(mJ\ h\ m^{-3})^{-1}$ (approximately 20 mSv per WLM).

[13] EEC: Equilibrium equivalent concentration

[14] Working level month: 1 WLM = 160 WLH = 3.5 mJ h m^{-3}

To calculate effective dose, the radon (or radon progeny) activity concentration should be multiplied by the time exposed and by the appropriate radon dose coefficient:

Effective dose = radon activity concentration × time exposed × dose coefficient

For example:
300 Bq m^{-3} × 2000 h × 6.7 10^{-6} mSv (Bq h m^{-3})$^{-1}$ = 4 mSv

Using a standard occupancy time of 2000 hours per year for a worker and a dose coefficient of 6.7 10^{-6} mSv (Bq h m^{-3})$^{-1}$, exposure to radon at the upper value of the national reference level of 300 Bq m^{-3} corresponds to an annual effective dose of 4 mSv at work. The decision criterion of 6 mSv per year, defined in Article 35(2) of the Directive, corresponds to a radon concentration of 450 Bq m^{-3}.

In specific situations of indoor work involving substantial physical activity, and for exposures in tourist caves, 300 Bq m^{-3} corresponds to an annual effective dose of 8 mSv at work; 6 mSv corresponds to a radon concentration of 225 Bq m^{-3} (for a standard worker occupancy time of 2000 hours per year) [ICRP2014a].

Finally, ICRP also stresses *In cases where aerosol characteristics are significantly different from typical conditions, where sufficient, reliable aerosol data are available, and estimated doses warrant more detailed consideration, it is possible to calculate site-specific dose coefficients using data provided in ICRP Publication 137* [ICRP2017].

Annex 3: Example of a structure of a national radon action plan

1. Identification of situations with potentially high exposure to radon;
   - 1.1. Conducting surveys of radon concentration in the country including dwellings, workplaces, buildings with public access;
   - 1.2. Development of methods for the delineation of areas with potentially high exposure to radon;
   - 1.3. Identification of types of workplaces and buildings with public access which require measurements;
   - 1.4. Establishment of database(s) collecting radon measurement results;
   - 1.5. Establishment of protocols for measuring radon in the different contexts (including types of dosemeters, recognition, approval or accreditation of measurement services…);

2. Information/communication/public awareness;
   - 2.1. Establishment of a general strategy for promoting stakeholder's awareness and involvement (e.g. leaflets, web, "radon day"…);
   - 2.2. Development of tools for collecting and sharing information;

3. Strategy for reducing exposure to radon (remediation and prevention);
   - 3.1. Development of general guidance on remedial actions;
   - 3.2. List of remediation companies / experts;
   - 3.3. Establishment of a (regional, national or European) database collecting results of remediation;
   - 3.4. Introduction of specific requirements in national building codes (for new buildings and for remediation);
   - 3.5. Financial support;
   - 3.6. Establishment of links with related issues and programmes on energy saving and indoor air quality;
   - 3.7. Establishment of links with programmes on smoking prevention.

Annex 4: Member States specific information on the control of radon in workplaces

Czech Republic

Council Directive 2013/59/Euratom has been transposed to the Czech legislation by Atomic Act No. 263/2016 Coll. and Radiation Protection Regulation No. 422/2016 Coll.

Reference levels for radon in workplaces (Article 54(1), 103(2), Annex XVIII (4))

A reference level of 300 Bq m^{-3} has been established for radon in workplaces.

To comply with this reference level, the result of measurement of the radon average activity volume concentration at the workplace should not exceed this reference level in case of a worker occupancy at the workplace of 2 000 hours over 12 months. In case of a different worker occupancy at the workplace, the integral of the radon concentration over the occupancy time shall be compared with the respective reference level for worker exposure of 600 000 Bq h m^{-3}.

Identification of workplaces where measurements shall be carried out and related responsibilities (Article 31(3)c, 54(2), 103(2) and (3), Annex XVIII (1), (2) and (3))

Workplace where measurements shall be carried out are identified in legislation as the workplaces with potentially increased exposure to radon and these are:

a. Underground workplaces;

b. Workplaces in which water from an underground source is pumped, collected or otherwise handled, in particular pumping stations, spa facilities, bottling facilities, water treatment facilities or water towers;

c. Workplaces (not operated by a self-employed) located on the ground floor or in the basement of a building that is located in a radon priority area. A radon priority area is defined as a municipality where the likelihood of exceeding the reference level is greater than 30 %. The concerned municipalities are listed in the respective national regulation;

   This does not apply to workplaces:

   - In a building constructed in a way that all its perimeter structures are separated from the subsoil by an air gap wherein air can circulate freely;
   - In a parking lot or garage;
   - In buildings with a sub-cellar under its entire floor plan and without direct contact with a basement floor;
   - In buildings in which anti-radon measures have been implemented, and their sufficient efficacy has been confirmed by measurement;
   - In a building with construction permit issued after 28 February 1991 (from this date on the construction of any new building has to respect the radon prevention action);

d. Workplaces at any floor of a building for which the indoor radon concentration has already exceeded the value of 300 Bq m-3 (regardless the conditions set in previous points).

Radon priority areas

Radon priority areas – currently defined as the municipalities where the likelihood of exceeding the reference is greater than 30 % – were derived from a database containing the results of long-term (annual average) indoor radon measurements performed in more than 200 000 family houses, in all schools and kindergartens, and in other public buildings on the territory of the Czech Republic.

For the estimation of the radon risk in poorly monitored areas, eight different statistical prediction models were developed and tested on the learning data set (i.e. municipalities with enough measurement data) [Fojtíková et al. 2017, Timková et al. 2017]. Data from detailed geological maps (scale 1:50 000) of radon risk from the subsoil were used (see https://mapy.geology.cz/radon/)

The prediction model parameters, representing the chosen characteristics of the municipalities, i.e. predictors, were the following:

- Average value of radon activity in soil air in the subsoil of the municipality;
- Type of rock in the subsoil;
- Level of subsoil permeability;
- Presence of a geological fault;
- Dose rate (gamma);
- Average age of houses in the municipality (data obtained from the Statistical Office).

For the models, the level of risk of increased radon concentrations was defined by means of the "Radon Index of the municipality" (RIA):

$RIA = \log_{10}(p\ (Rn > 300\ Bq\ m^{-3}) * 100\ \%)$,

where p (Rn > 300 Bq m^{-3}) indicates the probability that the concentration of radon in selected buildings in the given municipality exceeds the reference level of 300 Bq m^{-3}.

After statistical testing on "learning data", *The bootstrap model of the aggregated neural network with the logarithm of the geometric mean of OAR values in the community (log (GM)) as a dependent variable* was derived as the best model [Fojtíková et al. 2017, Timková et al. 2017].

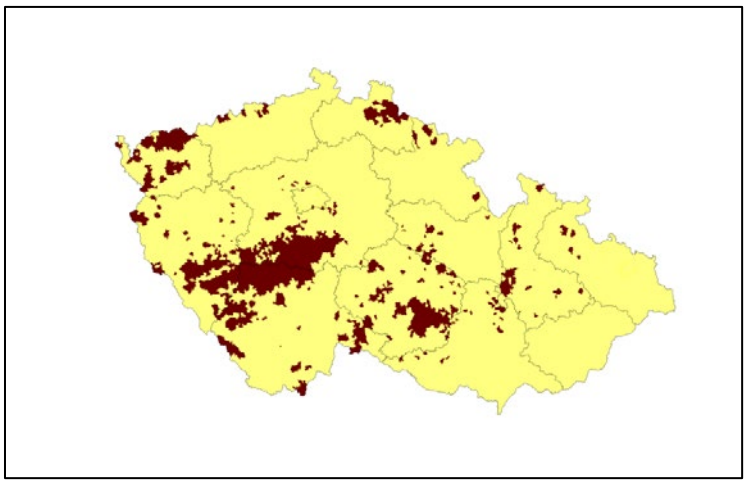

Figure A1: Radon priority areas (municipalities); probability of exceeding the reference level of 300 Bq m^{-3} at workplaces in the municipality (in percentage) > 30%.

Related responsibilities

The employer must determine the radon concentration in workplaces with potentially increased exposure to radon.

In a workplace where the reference level is exceeded, it shall be assessed whether the annual effective dose of a worker could exceed the value of 6 mSv. The assessment shall be based on repeated measurements of indoor radon concentration and calculation of the effective dose.

If the annual effective dose is likely to exceed the value of 6 mSv, the measurement and exposure assessment need to be repeated every calendar year. If the annual effective dose remains below 6 mSv, the measurement and exposure assessment need to be repeated only in case of a change in working conditions, such as the organisation or regime of work or the arrangement of the workplace, including a change in the ventilation system.

Conduct of measurements and optimization of radiation protection (Article 54(2), and (3), Annex XVIII (5), (11) and (14))

Companies performing measurements in identified workplaces need to be licenced by the State Office for Nuclear Safety (SONS). The measurement methodology used by the licensee is subject to assessment during the licencing process. SONS has issued a recommended measurement methodology, which is followed by the majority of licensees.

If the reference level is exceeded, the measures taken towards optimisation of radiation protection include change in the organisation, method or regime of work; modification of the workplace; or modification of the ventilation system.

Remediation (Article 54(3), Annex XVIII (7), (11) and 14)

It is the employer's responsibility to decide on the remediation measures to be taken, to conduct the remediation, and to decide on the need for expert consultation. To assist the employers, SONS offers on their website a variety of information, recommendations and related documents.

Notification after unsuccessful remedial action to the Competent authority (Article 25(2), 35(2), 54(3))

All workplaces that may be subject to increased exposure to radon as described in previous articles should be notified to SONS (independent of whether the reference level is exceeded). The notification needs to include the results of measurements, the assessment of the effective dose (if applicable), the description of the optimisation of radiation protection in the workplace, the measures taken to ensure radiation protection, and the results of repeated measurements after remedial action.

Applying the system of protection of workers (Article 9, 35(2) and Chapter VI)

If the remedial action is not successful and the annual effective dose value remains above 6 mSv, the following requirements apply:

a. Apply the dose limits for occupational exposure for the exposed workers;

b. Delineate the workplace or part thereof where the effective dose to a worker is liable to exceed 6 mSv per year;

c. Instruct the workers annually on the radiation risk at the workplace;

d. Draw up instructions for work in the workplace, including instructions for the safe conduct of the work;

e. Ensure that a monitoring procedure is drawn up, and ensure that documentation is maintained about the scope and method of radiation protection application.

Applying the system of protection of workers when radon is not the only source of exposure (Article 35 (2) and Chapter VI)

Anyone conducting a practice shall ensure the monitoring of doses of their exposed workers from all work activities and ensure that the sum of the doses comply with the dose limits for occupational exposure.

Further information/publications

Legislation:

https://www.sujb.cz/en/legal-framework/

National Radon Programme (in Czech)

https://www.radonovyprogram.cz/uvodni-strana/

Natural public exposure and Radon Program

https://www.suro.cz/en/prirodnioz

Radon Maps (geogenic radon risk)

https://mapy.geology.cz/radon/

References:

FOJTÍKOVÁ, I., I. Ženatá a J. TIMKOVÁ. Radon in workplaces - Czech approach to EU BSS implementation. *Radiation Protection Dosimetry*. 2017, 177(1-2), p. 104-111

TIMKOVÁ, J., I. FOJTÍKOVÁ a P. Pacherová. Bagged neural network model for prediction of the mean indoor radon concentration in the municipalities in Czech Republic. *Journal of Environmental Radioactivity*. 2017, 166, p. 398-402

Finland

Reference levels for radon in workplaces (Article 54(1), 103(2), Annex XVIII (4))

Two different reference levels related to radon in workplaces have been established in course of the transposition of the Directive:

1. Reference level for workplaces: 300 Bq m^{-3};
2. Reference level for worker exposure: 500 000 Bq h m^{-3}.

The reference level for workplaces is applied to all workplaces where the working time may exceed 600 hours per year. In case the annual working hours in a workplace is less than 600 hours per year, the reference level for worker exposure is applied instead of the reference level for workplaces.

In addition, a separate reference level of 200 Bq m^{-3} has been established for the purpose of designing and constructing new buildings. It is applicable to any type of new buildings including those used as workplaces.

Identification of workplaces where measurements shall be carried out and related responsibilities (Article 31(3)c, 54(2), 103(2) and (3), Annex XVIII (1), (2) and (3))

The identification of workplaces where measurements shall be carried out is based on the information gained from conducting various surveys and continuous updating of radon maps since the 1980s, as well as experience gained in regulating radon in underground mines and excavation works since the 1970s and in all types of workplaces since the early 1990s.

The Radiation Act defines the employer as the responsible party for conducting the radon measurement. The employer must determine the radon concentration of the workplace if the premises are located:

1. Within an area identified by the Radiation and Nuclear Safety Authority (STUK) where over 10 % of representative indoor radon measurement results exceed the reference level;
2. On an esker or other permeable gravel or sand;
3. Totally or partially below ground level;
4. A water work or a facility for food production where water used is not derived exclusively from surface water and comes into contact with the indoor air.

However, this determination need not be done if:

1. The annual working hours of any employee in the workplace does not exceed 20 hours; or
2. If the workplace prescribed in paragraph 1, points 1 or 2 above, is located on the next floor from the surface of the earth's crust or higher, or;
3. If no floor or wall of the building is in direct contact with earth's crust and there is a remaining space in between with apparent good air exchange.

Further to this, in operating underground mines and excavation works radon concentration must be measured on a regular basis.

In addition, the Radiation Act empowers STUK to issue orders to conduct radon measurements also in other workplaces if there is reason to suspect that the reference level may be exceeded. This is applied in cases where some other potential source of radon is

identified to be associated with the workplace. This could be, for example, an indoor facility processing or storing NORM or a building where NORM has been used as building material.

Conduct of measurements and optimization of radiation protection (Article54 (2), and (3), Annex XVIII (5), (11) and (14))

The conduct of measurements in the identified workplaces is enforced by STUK in cooperation with the local level Occupational Safety Authorities. The cooperation is based on voluntary cooperation arrangements covering the areas where measurements shall be carried out.

The methods and devices used for measuring radon for the purpose of showing whether or not the reference level is exceeded is subject to STUK's approval. A condition of the approval is that appropriate quality assurance is in place but there are no specific requirements related to formal accreditation.

Radon concentrations in workplaces shall be determined with long-term measurements (at least two months) during September – May. The employer shall notify the result to STUK. Based on the result, STUK enforces the employer to proceed with the following actions:

1. If the result is less than the reference level, it can be concluded that the annual average during work hours is below reference level;
2. If the result is more than 334 Bq m^{-3}, remediate or perform an at least one-week long continuous monitoring to see the daily variations and the effect of weekends in cases where there is forced ventilation with a timer; if the ratio between average during working hours versus the week average, multiplied with the long term average is less than the reference level, it can be concluded that the reference level is not exceeded.

Remediation (Article 54(3), Annex XVIII (7), (11) and 14)

If measurements show that the reference level is exceeded, STUK will issue an order to the employer to remediate. A time frame for remediation will be set and it varies from three to nine months depending on the measurement result and working time.

It is up to the employer to decide how to conduct the remediation, which method to use and whether to consult some experts. There is no formal mechanism to recognize the competence of remediation services, i.e. there are no specific provisions on the qualifications or recognition of those designing or conducting remediation. However, STUK maintains on its web site a list of companies who have declared providing such services.

Remedial action in workplaces is considered from radiation protection needs and there are no provision in place to link it to other remediation requirements or initiatives such as those related to energy saving or general air quality.

The successful completion of the remedial action shall be verified with radon measurements which shall be notified to STUK by the employer.

Notification after unsuccessful remedial action to the Competent authority (Article 25(2), 35(2), 54(3))

If remedial action is not successful in reducing the radon concentration or radon exposure below the reference level, the situation will be regulated as a practice and the undertaking

shall apply for a license for a practice causing exposure to natural radiation[15]. The license application serves as the notification referred to in Article 25(2).

In case of radon the requirement to obtain a license starts from exceeding the reference level and not from exceeding 6 mSv per year as foreseen in Article 35(2), so there is no separate regime for cases where *exposure are being under review* as provided for in Article 35(2).

Applying the system of protection of workers (Article 9, 35(2) and Chapter VI)

Once licensed as a practice, all the provision of Chapter VI apply with the following exceptions, if the workers are exposed only to radon:

1. Classification of workers to groups A and B;
2. Requirement of individual monitoring with a personal dosimeter;
3. Medical surveillance.

However, measurement arrangements shall be in place, which allow the determination of individual doses. These results shall be recorded and maintained in a similar manner as any another individual doses. Dose limits for workers apply.

Applying the system of protection of workers when radon is not the only source of exposure (Article 35(2) and Chapter VI)

By default, exposure to radon is always treated by its own right totally separately from any practice. However, in case where the remediation is not successful and a license for practice causing exposure to natural radiation is required then, if the practice is simultaneously another practice, all radiation protection arrangements will be looked at in a fully integrated manner. For example, the dose limit is applied based on the sum of doses received from both practices.

Further information/publications

Radon maps:

http://www.stuk.fi/web/en/topics/radon/radon-in-finland/radon-maps-of-finland

Remediation methods:

https://www.julkari.fi/bitstream/handle/10024/124855/stuk-a251.pdf?sequence=1

[15] In the Finnish system authorisation takes always the form of a license, i.e. registration is not used at all.

Sweden

Reference levels for radon in workplaces (Article 54(1), 103(2), Annex XVIII (4))

A reference level of 200 Bq m^{-3} is established for workplaces, dwellings and public buildings as part of the transposition of the Directive in the Swedish Radiation Protection Ordinance (SFS 2018:506).

At workplaces where the reference level is exceeded (after optimization of protective measures), specific regulations issued by the Swedish Work Environment Authority (AFS 2018:1) apply.

In these regulations three hygiene limits on annual radon exposure at workplaces have been established since many years. Please note that these hygiene limits are used within the framework of the work environment legislation, and are applied in parallel with optimization of protection and dose limitation:

- 0.36 MBq h m^{-3} for workplaces above ground, which corresponds to a radon level of 200 Bq m^{-3} for normal full time working hours (1 800 h/year);
- 0.72 MBq h m^{-3} for underground workplaces in furnished underground facilities (such as archives, furnished parts of mines etc.), which corresponds to a radon level of 400 Bq m^{-3} for normal full time working hours;
- 2.1 MBq h m^{-3} for other underground workplaces (e.g. mines and tunnel construction), which corresponds to a radon level of 1 300 Bq m^{-3} for 1 600 yearly working hours.

These hygiene limits for workplaces will continue to apply.

Regulations of The National Board of Housing, Building and Planning in Sweden (BFS 2016:6), include provisions on maximum radon concentrations in the construction of new buildings:

- The annual average of the activity concentration of radon in the indoor air must not exceed 200 Bq m^{-3}.

Regulations of the Public Health Agency of Sweden (FoHMFS 2014:16) include recommendations on radon concentration levels for dwellings and buildings with public access:

- 200 Bq m^{-3} (annual average), and if exceeded to be considered to have a negative impact on humans health.

Identification of workplaces where measurements shall be carried out and related responsibilities (Article 31(3)c, 54(2), 103(2) and (3), Annex XVIII (1), (2) and (3))

All of Sweden is considered radon prone, and therefore no specific radon prone areas have been identified. Therefore, radon measurements are required at all workplaces. However, the supervision of radon in workplaces will focus on specific types of workplaces such as underground activities, and the extent and format of the supervision will be adjusted according to a graded approach.

The Swedish Work Environment Authority carries out the general supervision of radon at workplaces. In cases, where the radon level continues to exceed the reference level after remediation actions have been conducted, the Swedish Radiation Safety Authority (SSM) will perform the supervision.

The employer is responsible for conducting radon measurements, and these shall be carried out in accordance with methods specified by the SSM. If the radon level exceeds 200 Bq m^{-3}, a remediation action plan has to be produced by the employer and approved by the Swedish Work Environment Authority.

In case several employers share the same workplace, the current draft regulations from SSM (on radon at workplaces) include requirements on the coordination of responsibilities.

Conduct of measurements and optimization of radiation protection (Article 54(2), and (3), Annex XVIII (5), (11) and (14))

The Swedish Work Environment Authority initially enforces the conduct of measurements in the prioritised workplaces. The measurements shall be carried out in accordance with methods specified by the SSM which includes requirements on the duration of the measurements (minimum two months), number of measurement points, uncertainty of the measurements etc. and it defines the appropriate season for measuring radon.

In cases, where the radon level continues to exceed the reference level after remediation actions have been conducted, additional requirements on measurements apply including:

- Radon exposure should be taken into account when determining the total annual effective dose to exposed workers in planned exposure situations;
- Assessment of radon exposure to workers by measurements or calculations. Documentation of the radon exposure, which must be kept for a minimum of 5 years;
- Methods used for measurements shall give a representative value and any instruments used shall be appropriately calibrated;
- The uncertainty of the measurements must be less than 30% at 200 Bq m^{-3}.

The conduct of measurements is then enforced by the SSM.

For workplaces where the radon levels will remain at a high level, such as mining and tunnel construction, the radon level shall be monitored continuously.

Workers at risk of receiving an annual radon exposure exceeding 0.72 MBq h m^{-3} shall be identified. At these workplaces, documented routines to determine the radon exposure and to optimize radiation protection shall be established, and additional measurement requirements apply including:

- The annual radon exposure to the identified workers shall be individually determined, by measurements or by calculations, and the results shall be documented and kept for a minimum of 40 years;
- Individual measurement devices shall be used;
- Individual measurements shall be conducted by an organization with accreditation for the task.

Radon exposure exceeding 0.72 MBq h m^{-3} is not allowed for persons under 18 years of age.

Remediation (Article 54(3), Annex XVIII (7), (11) and 14)

If measurements show that radon concentration exceeds the reference level, the employer is required to draw up an action plan, including remedial measures. A time frame for remediation will be set by the Swedish Work Environment Authority.

It is the responsibility of the employer to decide on how to conduct the remediation, on the method to be used, and the need to consult with experts. There is no formal mechanism to

recognize the competence for remediation services, i.e. there are no specific provisions on the qualifications or recognition of those designing or conducting remediation.

Notification after unsuccessful remedial action to the Competent authority (Article 25(2), 35 (2), 54 (3))

If the radon concentration continues to exceed the reference level, after remedial actions have been conducted according to the action plan agreed with the Swedish Work Environment Authority, an application for registration shall be sent to SSM, preferably using a web based system, currently under development. This is also the case for workplaces where remedial actions are not relevant, e.g. mines or tunnels.

There are two types of situations, where an application for registration shall be sent to the authority:

- Workplaces where radon concentration exceed the reference level. The notification shall be renewed every ten years (if the radon concentration continues to exceed reference level);
- Workplaces, where workers, own employees or others, are exposed to radon exceeding 0.72 MBq h m^{-3}. This notification shall be renewed every fifth year.

Applying the system of protection of workers (Article 9, 35 (2) and Chapter VI)

The following radiation protection requirements applies to practices where workers are annually exposed to radon exceeding 0.72 MBq m^{-3}

- If a worker is exposed to radon exceeding 2.1 MBq h Bq m^{-3} in one year, this should be notified to SSM, and the worker shall undergo a medical examination;
- Any worker who has been identified as being at risk of receiving a radon exposure exceeding 0.72 MBq h m^{-3} shall, on demand, have access to any documentation about their radon exposure;
- When a worker at risk of receiving a radon exposure above 0.72 MBq h m^{-3} starts a new employment, where there is also a risk of receiving a radon exposure above 0.72 MBq h m^{-3}, the employer must collect information about the worker's previous radon exposure that year.

Applying the system of protection of workers when radon is not the only source of exposure (Article 35(2) and Chapter VI)

Practices in a planned exposure situation shall take the radon exposure into account when determining the total annual effective dose to workers.

Further information/publications

The major reason for using the concept of radon exposure instead of effective dose is that the concept is already in use, known and applied by most of the practises where radon levels are high. The Swedish Work Environment Authority also uses it. This makes the regulatory system for radon in workplaces more predictable and easier to adapt for the practices.

Switzerland[16]

Reference levels for radon in workplaces (Article 54(1), 103(2), Annex XVIII (4))

The Swiss legislation on radiation protection was recently revised and adapted according to the new international recommendations and standards – namely the ICRP 103 recommendations as well as the Euratom and IAEA basic safety standards. The reference level for the mean annual concentration of radon has been fixed at 300 Bq m^{-3} for dwellings. With regard to radon exposure at the workplace, the Swiss legislation distinguishes in practice two situations. For this purpose, two different complementary levels related to the radon concentration at workplaces have been defined:

- Reference level for ordinary workplaces: 300 Bq m^{-3} ;
- Threshold value for workplaces exposed to radon: 1000 Bq m^{-3} (for immediate measures).

“Ordinary workplaces” are those, located in buildings and without significant underground activity.

“Workplaces exposed to radon” are workplaces, for which the threshold value of 1000 Bq m^{-3} is certainly or presumably exceeded.

Identification of workplaces where measurements shall be carried out and related responsibilities (Article 31(3)c, 54(2), 103(2) and (3), Annex XVIII (1), (2) and (3))

Companies with workplaces exposed to radon shall ensure that radon measurements be performed by an approved radon measurement provider. Workplaces exposed to radon include underground installations, mines, caverns and water supply installations as well as those, which the national supervisory authority for radiation protection classifies as such. The national authorities responsible for the supervision of workplaces exposed to radon may carry out sample measurements.

The majority of workplaces, notably offices, factories, hospitals, etc. are ordinary workplaces. Radon measurements are optional and in the responsibility of the building owner. However, the cantonal authority may require the building owner to have radon measurements conducted. In addition, the cantonal authority shall ensure that radon measurements are carried out in schools and kindergartens.

Conduct of measurements and optimization of radiation protection (Article 54(2), and (3), Annex XVIII (5), (11) and (14))

The approved radon measurement providers are required to use devices accredited by the Federal institute of metrology (METAS), which meet minimum requirements and participate regularly in intercomparison tests. They are also required to comply with the prescribed measurement protocols specified for ordinary workplaces or for workplaces exposed to radon. The radon measurement providers are also responsible to enter all measurement data in the national radon database.

If the threshold value of 1000 Bq m^{-3} is exceeded at the workplace, the company must estimate with the support of the approved radon measurement provider the annual effective dose due to radon received by the exposed workers. This estimate takes into account the time spent by the persons each year at the workplace. If the effective dose of a person at the

[16] This part is a joint contribution provided by the Swiss Federal Office of Public Health (FOPH) and the Swiss Accident Insurance Fund (Suva).

workplace exceeds 10 mSv per calendar year[17], the company shall immediately take organizational measures (reduction of occupancy time) or technical measures (radon remediation) to reduce the effective dose.

If, in spite of measures undertaken, the effective dose to a person at the workplace remains above 10 mSv per calendar year, this person is considered to be occupationally exposed to radiation and the company is subject to authorization. Personal radon dosimetry monitoring by a licensed individual dosimetry service is then mandatory.

The method for determining the dose received by a worker exposed to radon is based on the dose coefficient derived from the declaration on radon from ICRP Publication 115, which sets the risk factor at $8 \cdot 10^{-10}$ per Bq h m^{-3} for an exposure to radon in equilibrium in air with its progeny, and the radiological risk coefficient stated in ICRP Publication 103. For an equilibrium factor of the progeny of 1, the dose coefficient of radon is $1.87 \cdot 10^{-5}$ mSv per Bq h m^{-3} for the workers. The equilibrium factor is by default fixed at 0.4, but it can also be measured upon request at each workplace separately.

Remediation (Article 54(3), Annex XVIII (7), (11) and 14)

If the reference level of 300 Bq m^{-3} is exceeded in an ordinary workplace, the building owner shall take the necessary remedial measures according to the guidelines issued by the Federal Office of Public Health (FOPH) concerning the urgency of remedial measures based on the mean concentration of radon and the actual time spent at the workplace in question. If the building owner fails to take action, the cantonal authorities may order a radon remediation. The costs of remediation shall be borne by the building owner. It is up to the building owner to decide how to conduct the remediation, which method to use and whether to involve recognised radon consultants.

Concerning the workplace exposed to radon, the national supervisory authorities in radiation protection are required to evaluate, if companies took all reasonable measures (organizational or technical) in order to reduce the effective dose of workers below 10 mSv per year.

Notification after unsuccessful remedial action to the Competent authority (Article 25(2), 35(2), 54 (3))

The successful completion of the remedial action shall be verified by an approved radon measurement, which is registered in the national radon database. Both national and cantonal supervisory authorities have access to those data.

Applying the system of protection of workers (Article 9, 35(2) and Chapter VI)

For both ordinary workplaces and workplaces exposed to radon, the optimisation principle must be applied.

Applying the system of protection of workers when radon is not the only source of exposure (Article 35(2) and Chapter VI)

By default, exposure to radon is always treated by its own right totally separately from any practice.

[17] The dose reference level of 10 mSv per calendar was set according to the ICRP Publication 126 Radiological Protection against Radon Exposure [ICRP2014b].

Further information/publications

First application of the strategy to water supply installations. Measurements have been carried out in 192 water supply installations by the Suva, the supervisory authority in the field of crafts and industry. Mean annual radon concentrations amounted to 2153 Bq m^{-3} for pumping stations, 2597 Bq m^{-3} for water reservoirs and 12 919 Bq m^{-3} for water catchments. Measurements of the equilibrium factor showed values close to 0.4. The estimation of individual doses, established for 314 workers in 238 companies, indicated mean doses of the order of 6 mSv/year.

Links of interest:

- Radon action plan: Radon action plan 2012-2020
- Radon maps: www.radonkarte.ch
- Remediation methods: www.ch-radon.ch (Constructional measures against radon)

The Netherlands

Council Directive 2013/59/Euratom has been transposed into Dutch regulation on 6 February 2018. This transposition included the implementation of a regulatory framework for the protection against radon exposure in The Netherlands. The requirements for the control of radon in workplaces are laid down in the "Besluit basisveiligheidsnormen stralingsbescherming" (Basic Safety Standards Radiation Protection Decree; hereafter: Decree). Some of these requirements are regulated in more detail in one of the underlying regulations, i.e. "Regeling stralingsbescherming beroepsmatige blootstelling 2018" (Radiation Protection Occupational Exposure 2018 Regulation; hereafter: Regulation).

Reference levels for radon in workplaces The Netherlands (Council Directive, Article 54(1))

- The national reference level for the annual average radon activity concentration in workplaces is 100 Bq m^{-3}. (Decree, Article 7.38 (1));
- For workplaces in areas or specific types of workplaces identified in the national radon action plan, the Minister of Social Affairs and Employment may decide to deviate from the national reference level. A reference level for the annual average radon activity concentration of not higher than 300 Bq m^{-3} may be established. (Decree Article 7.38 (8)).

Workplaces include buildings with public access. For buildings with public access, the same reference levels have been established for members of the public by the Minister of Infrastructure and Water Management (Decree art 9.10 (6) and (7)).

Identification of workplaces where measurements shall be carried out and related responsibilities (Article 31(3c), 54(2), 103(2) and (3), Annex XVIII (1), (2) and (3))

Several national surveys on radon in dwellings have been conducted since the 1980's. The first national survey on radon concentrations in workplaces, including buildings with public access, has been published recently. The National Institute of Public Health and the Environment (RIVM) conducted this national survey in 2016 – 2017. One of the items named in the national radon action plan (Decree, Article 6.20) is the identification of areas and specific types of workplaces where the average annual radon concentration in a significant number of buildings is expected to exceed the national reference level (Decree, Article 6.20 (4)).

The employer is responsible for measuring the radon concentration at workplaces on the ground floor or basement level in areas or at specific types of workplaces that have been identified in the national radon action plan (Decree, Article 7.38 (2)).

Conduct of measurements and optimization of radiation protection (Article 54(2), and (3), Annex XVIII (5), (11) and (14))

The employer is responsible for measuring the radon concentration at workplaces on the ground floor or basement level in identified areas or at specific types of workplaces (Decree, Article 7.38 (2)). If the radon concentration at the workplace exceeds the national reference level, the employer is responsible for taking measures with the aim to reduce the radon concentration below the national reference level (Decree, art 7.38 (3)).

Remediation (Article54(3), Annex XVIII (7), (11) and 14)

If the radon concentration at the workplace exceeds the national reference level, the employer is responsible for taking measures with the aim to reduce the radon concentration below the national reference level.

Proposed measures to reduce radon concentrations in workplaces in identified areas or specific types of workplaces will be taken up in the national radon action plan (Decree art 6.20 and Decree Annex 8). These measures include the communication of information about radon with the aim to increase awareness of radon exposure, risks associated with radon exposure, the importance of measuring radon and how to reduce the radon concentration at the workplace. Where needed, guidance will be provided on how to reduce radon with remedial measures. (At this moment, no areas or specific types of workplaces have been identified in the national radon action plan).

Notification after unsuccessful remedial action to the Competent authority (Article 25(2), 35(2), 54(3))

If the radon concentration at the workplace continues to exceed the national reference level, despite the action taken, the employer must notify this situation within 4 weeks to the Authority for Nuclear Safety and Radiation Protection (ANVS). (Decree, Article 7.38 (4), Regulation Article 7.1). The information that needs to be provided in conjunction with the notification includes the location and description of the workplace, type of work, typical number of workers and their typical working hours in the workplace, the measured radon concentration before and after remediation and a description of the measures taken to reduce the radon concentration.

Applying the system of protection of workers (Article 9, 35(2) and Chapter VI)

The employer must take measures to protect its workers against radon exposure at workplaces where the radon concentration remains to exceed the national reference level (Decree, art 7.38 (6)). The dose limits for occupational exposure apply to these radon exposure situations (Decree, art 7.34).

For such situations the employer must

- Determine and record the exposure of its employees to radon. Monitoring of the radon exposure situation shall take place with a suitable frequency. The recording obligations are similar to those for exposed workers. The required record information includes the particulars of the employee, the workplace, type of work and working hours at the workplace, the measured radon concentration and the derived exposure of the individual employee (Decree, Article 7.38 (6.a));
- The employer must take measures to reduce the exposure of its employees to radon to a minimum (Decree Article 7.38 (6.b));
- Place warning signs for ionising radiation. Below this sign, the text “Radon” must be displayed (Decree, art 7.38 (6.c) and Regulation, Article 7.3) .

Applying the system of protection of workers when radon is not the only source of exposure (Article 35(2) and Chapter VI)

The system of protection of workers is also warranted if radon is not the only source of exposure. The dose limits for occupational exposure apply to the sum of annual occupational

exposures of a worker from all authorised practices, occupational exposure to radon in workplaces requiring notification and other occupational exposures from existing exposure situations (Decree, Article 7.34)

Further information/publications

Publication and information of Dutch regulation of indoor radon exposure (in Dutch)

https://www.autoriteitnvs.nl/onderwerpen/radon-en-thoron

Public information on Radon published by the National Institute of Public Health and the Environment (RIVM) https://www.rivm.nl/Onderwerpen/R/Radon_en_thoron

Scientific publication by RIVM

“Ingredients for a Dutch radon action plan, based on a national survey in more than 2500 dwellings”, Smetsers, R.G.C.M., Blaauboer, R.O., Dekkers, S.A.J., Journal of Environmental Radioactivity, 165 (2016) 93 – 102, https://doi.org/10.1016/j.jenvrad.2016.09.008

Annex 5: Communication regarding retrospective assessments

Surveys of indoor radon concentrations may eventually reveal very high levels of radon, several times higher than the reference level established by the Member State, e.g. 10 000 Bq m^{-3}. In some situations, it is foreseeable that people who have worked for a long time in these places become worried when they are informed and that they will not only ask for guidance on what should be done for remediating the situation but also for information on the health risk related to their prolonged exposure to radon.

National competent authorities must be prepared to deal with those situations. The Directive does not address management of retrospective assessment due to radon exposure, i.e. its requirements address radon exposure as a planned or existing exposure situation to be managed once it is identified. The competent authority might need some guidance on retrospective assessment of radon exposure.

It is important that the competent authorities be informed rapidly once such a situation has been discovered. In this respect, it may be useful to establish an “action” level above which measures are necessary. The radiation protection measures, e.g. remediation and limitation of working hours, shall be in place without unnecessary delay in order to protect present workers or members of the public as appropriate. The employer and the occupational health service must also be informed without unnecessary delay.

Regarding retrospective dose assessment, the following actions might be considered:

- identification of all individuals who have been exposed, i.e. not only those who are working or living today in the place but also those who did in the past;
- provision of information to these individuals with priority given to current occupants;
- assessment of past exposures based on available data considering associated uncertainties.

When addressing retrospective dose assessment, the competent authority should take into account that such a methodology may not be well developed and that parameters used for dose assessment such as the occupancy factor might be associated with large uncertainties. The underlying records regarding individuals exposed might also be associated with large uncertainties. An example of risk assessment performed following the discovery of a house in France with very high concentrations of radon can be found in the publication of Cléro et al. [CL2016].

It is worth noting that there is no direct means of determining the cumulated dose received by individuals exposed to radon. There is no specific short-term medical examination recommended for asymptomatic persons exposed to radon. Given the increased risk of lung cancer in persons with significant exposure to radon, it may be advisable to foresee a long-term follow-up for incipient lung diseases.

References

[CL2016] Cléro E., Marie L., Challeton de Vathaire C., Laurier D., Rannou A. Assessment of radon-induced health risk for occupants of a house built on uranium ore residues. Rev Epidemiol Sante Publique (2016), http://dx.doi.org/10.1016/j.respe.2016.03.163

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MJ-XA-20-001-EN-N

Publications Office
of the European Union

ISBN 978-92-76-10531-2