Public Health England

Protecting and improving the nation's health

UK National Radon Action Plan

About Public Health England

Public Health England exists to protect and improve the nation's health and wellbeing, and reduce health inequalities. We do this through world-leading science, knowledge and intelligence, advocacy, partnerships and the delivery of specialist public health services. We are an executive agency of the Department of Health and Social Care, and a distinct delivery organisation with operational autonomy. We provide government, local government, the NHS, Parliament, industry and the public with evidence-based professional, scientific and delivery expertise and support.

Public Health England
133–155 Waterloo Road
Wellington House
London SE1 8UG
T: 020 7654 8000

www.gov.uk/phe
Twitter: @PHE_uk
Facebook: www.facebook.com/PublicHealthEngland

Any enquiries regarding this publication should be sent to:

Centre for Radiation, Chemical and Environmental Hazards
Public Health England
Chilton, Didcot, Oxfordshire OX11 0RQ
E: Radon@phe.gov.uk

Published: December 2018
PHE publications
Gateway number: 2018687

PHE supports the UN Sustainable Development Goals

UK National Radon Action Plan

N P McColl[1], E J Bradley[1], T D Gooding[1], C Ashby[11], J Astbury[1], J Atkinson[3], R Harrall[9], T Howard[6], J Hunt[3], D Kernohan[11], K James[12], R Jones[8], J Laverty[7], N McMahon[4], C McNicholas[7], L Moss[3], L Murphy[8], T Netherwood[5], P Rankin[9], M Stewart[11], J Taylor[7], V Tink[9], G Waldron[10], G Wasson[2]

[1] Public Health England, CRCE, Chilton, Didcot, Oxfordshire OX11 0RQ
[2] Department of Agriculture, Environment and Rural Affairs (Northern Ireland Environment Agency), Klondyke Building, Gasworks Business Park, Belfast BT7 2JA
[3] Department for the Environment, Food and Rural Affairs / Drinking Water Inspectorate, Area 1A, Nobel House, 17 Smith Square, London SW1P 3JR
[4] Department of Health, Northern Ireland, Castle Buildings, Stormont, Belfast BT4 3SQ
[5] Department of Health and Social Care, 39 Victoria St, London SW1H 0EU
[6] Environment Agency, Horizon House, Deanery Road, Bristol BS1 5AH
[7] Health and Safety Executive, Redgrave Court, Merton Road, Bootle, Merseyside L20 7HS
[8] Health and Safety Executive Northern Ireland, 83 Ladas Drive, Belfast BT6 9FR
[9] Ministry of Housing, Communities and Local Government, Fry Building, 2 Marsham St, Westminster, London SW1P 4DF (retired)
[10] Public Health Agency, Northern Ireland, 12-22 Linenhall St, Belfast BT2 8BS
[11] Scottish Government, St. Andrew's House, Regent Road, Edinburgh EH1 3DG
[12] Public Health Wales, 2 Capital Quarter, Tyndall Street, Cardiff CF10 4BZ

Abstract

Radon is a colourless, odourless radioactive gas that is formed by the radioactive decay of elements that occur naturally in rocks and soils. Radon is the single biggest source of radiation exposure to the UK population in both homes and workplaces. This report presents in a single document, the elements that make up the national radon strategy and the national radon action plan. It fulfils relevant requirements in the 2013 European Union Basic Safety Standards Directive on protection against ionising radiation (EURATOM, 2013).

EURATOM (2013). Council Directive 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, Official Journal of the European Union L13/1.

Centre for Radiation, Chemical and Environmental Hazards
Public Health England
Chilton, Didcot
Oxfordshire OX11 0RQ

Approval: December 2018

Executive Summary

Radon is a colourless, odourless radioactive gas that is formed by the radioactive decay of elements that occur naturally in rocks and soils, and may also be found in certain building materials and water. Radon is the single biggest source of radiation exposure to the UK population in both homes and workplaces, is present in all air indoors and outdoors, and is the second leading cause of lung cancer after tobacco smoking.

The United Kingdom has more than four decades of experience in characterising and controlling radon in homes and workplaces. Using this scientific understanding, which is informed by evidence, research, guidance and practical experience from within the UK and international bodies, the range of exposure situations of the UK population to radon has been established. In addition, effective and durable ways of reducing and preventing radon exposures have been developed.

Previously, reports covering the various aspects of radon measurement and control have been published that represent parts of a national strategy to reduce both high individual radon exposures and the overall level of radon exposure to the population. The fundamental aim is to reduce the individual and overall risks of lung cancer.

This report presents, in a single document, the existing elements of radon control that make up the national radon strategy and the national radon action plan. It fulfils radon-related requirements in the Ionising Radiations (Basic Safety Standards) (Miscellaneous Provisions) Regulations 2018 (SI 2018/482) that enact part of the 2013 European Union Basic Safety Standards Directive on protection against ionising radiation.

The report describes: the properties and health risks of radon; its distribution within the UK and routes of exposure; how radon exposure is assessed and managed in homes, workplaces, new buildings, water supplies and building materials; the approaches to communicating on radon with groups of people affected. The report identifies new topics for consideration.

This report was prepared by UK representatives of government departments and agencies and with input from stakeholders. The report was subject to open consultation.

The UK National Radon Action Plan will be updated at intervals of no more than five years.

Contents

1 Introduction

Radon is the single biggest source of radiation exposure to the UK population in both homes and workplaces. This report presents, in a single document, the existing elements of radon control that make up the national radon strategy and the national radon action plan. It fulfils a radon-specific requirement in the 2013 European Union Basic Safety Standards Directive (EU-BSS) on protection against ionising radiation (EURATOM, 2013a).

The United Kingdom has more than four decades of experience in characterising and controlling radon in homes and workplaces. Using this scientific understanding, which is informed by evidence, research, guidance and practical experience from within the UK and international bodies, the range of exposure situations of the UK population to radon has been established. In addition, effective and durable ways of reducing and preventing radon exposures have been developed.

This report was prepared by representatives of the government departments and agencies shown in Table 1 and with input from stakeholders. The report was subject to open consultation.

Table 1 Government departments and agencies contributing to the UK National Radon Action Plan

Government departments and agencies contributing to the UK National Radon Action Plan
Department of Agriculture, Environment and Rural Affairs (Northern Ireland Environment Agency)
Department for the Environment, Food and Rural Affairs / Drinking Water Inspectorate
Department of Health and Social Care
Department of Health, Northern Ireland
Environment Agency
Health and Safety Executive
Health and Safety Executive Northern Ireland
Ministry of Housing, Communities and Local Government
Public Health Agency, Northern Ireland
Public Health England
Public Health Wales
Scottish Government

1.1 Properties of radon

1.1.1 Physical properties

Radon is a colourless, odourless radioactive gas that is undetectable by the human senses and as such the level of radon can only be identified by measurement. It is formed by the radioactive decay of the small amounts of primordial elements that occur in most rocks and soils and is present in all air, both indoors and outdoors. It has a number of radioactive isotopes which have the same chemical properties but different nuclear properties. There are three naturally-occurring isotopes of radon of which two, radon-222 and radon-220, occur in significant amounts and decay by alpha emission.

Radon-222 is part of the uranium-238 radioactive decay chain. It is the immediate decay product of radium-226 which in turn is the radioactive decay product of primordial uranium-238

(half-life 4.5 billion years). Radon-222 has a half-life of 3.8 days and has a number of short-lived chemically reactive decay products that decay by alpha and beta emission. Radon-222 is commonly known as radon.

Radon-220, commonly known as thoron, is part of the decay chain of a primordial radionuclide, thorium-232. Thoron has a half-life of 55.6 seconds and has a number of short-lived decay products.

Uranium (and radium) in near-surface rocks and soil is the main source of radon. In order for radon to be a source of radiation exposure, the surrounding soil or rocks must be sufficiently porous or permeable to allow radon to migrate with soil gas and enter overlying buildings. Activity concentrations of radon in the ground range from below 2,000 becquerels per cubic metre (Bq m^{-3}) to more than 100,000 Bq m^{-3} of soil gas (Varley and Flowers 1998). Where radon is released to open ground, concentrations in air are low: the UK average is 4 Bq m^{-3} (Wrixon *et al*, 1988).

1.1.2 Health risks

Most radiation exposure from radon arises from inhaling its short-lived solid radioactive decay products including isotopes of bismuth, lead and polonium, rather than radon itself. The decay products of radon, when created in indoor air, tend to adhere to airborne particulates which can then be inhaled.

Radon is recognised by the International Agency for Research into Cancer (IARC) as a Class 1 carcinogen (IARC, 2012). Evidence has been obtained from pooled large scale epidemiological studies (Darby *et al*, 2005) that there is a linear relationship between long term radon exposure and excess relative lifetime lung cancer risk. Overall, this increases an individual's baseline lung cancer risk by 16% for each 100 Bq m^{-3} to which they are exposed over the long term. The risk relationship has been demonstrated (Darby *et al*, 2005) at concentrations at least as low the UK radon Action Level for homes (200 Bq m^{-3}). An individual's baseline lung cancer risk is strongly dependent on their smoking status. Smokers have a risk of about 15% to age 75, compared with 0.4% for lifelong non-smokers. In the UK, exposure to indoor radon is responsible for an estimated 1,100 lung cancer deaths each year with smokers and ex-smokers at the greatest individual risk. These findings were supported by an independent review of Radon and Public Health (AGIR, 2009).

There is currently no strong evidence to link radon exposure to cancers other than lung cancer or to other disease (AGIR, 2009). Calculations of radiation doses to organs other than the lung suggest a small theoretical risk of cancer to other organs but these would be much smaller than the doses, and risks, to the lung. The UK Advisory Group on Ionising Radiation (AGIR) concluded that any effects on organs other than the lung are "so weak as to be generally undetectable in the published epidemiological studies".

1.1.3 International advice

Radon is recognised as a health risk by the World Health Organisation (WHO) (WHO, 2009) and IARC (IARC, 2012). Other international bodies that have provided advice on radon include the International Atomic Energy Agency (IAEA) (IAEA, 2014), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (UNSCEAR, 2009) and the International Commission on Radiological Protection (ICRP) (ICRP 2010,2018). UK

organisations work collaboratively with many international organisations on radon and contribute as members of their committees and working groups.

1.2 Radon exposure in the UK

1.2.1 National radon survey and measurement database

The UK has completed a radon survey to establish the population weighted average and distribution of radon exposure (Wrixon *et al*, 1988). This survey, undertaken in the 1980s, which measured radon in more than 2,000 homes selected systematically, identified that the population weighted average radon concentration was around 20 Bq m^{-3}.

The results of these measurements, and many more, are stored in a national radon measurement database. The database currently holds the results from measurements made in around 600,000 homes and other premises, throughout the UK including over 170,000 homes outside radon Affected Areas (see section 3.1.2) but reflecting many programmes that targeted Affected Areas. Individual results are not published to maintain their privacy. Statistical summaries of measurements made in dwellings are published on www.gov.uk/government/collections/radon.

1.2.2 Radon in buildings

Radon can be drawn into a building from the ground below. Indoors, the radon is diluted less than if it is released to open air. A variety of processes, including indoor/outdoor temperature differential, heating, ventilation and the effect of prevailing winds, each influence the slightly lower indoor air pressure that in turn drives radon ingress.

Some building materials contain small amounts of radium and thorium, which can emit radon and thoron into room air. Private water supplies may also be a source of indoor radon.

Indoor exposure to radon is the single largest source of ionising radiation exposure for people in the UK, representing around half of the total average individual exposure, as shown in Figure 1, but in some areas of the country gives significantly higher exposures (Oatway *et al*, 2016). Indoor radon concentrations in air range from a few to over ten thousand Bq m^{-3}.

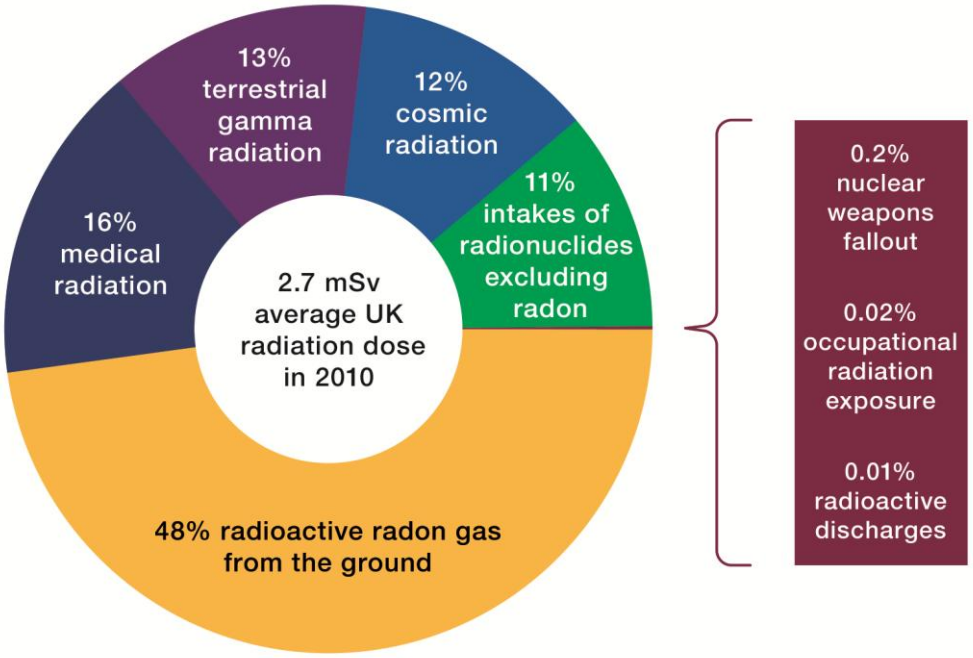

Figure 1 Sources of radiation exposure in the UK

1.2.3 Radon and thoron from building materials

The UK national radon survey found that radon emitted from building materials generally leads to low exposures. Radon concentrations in buildings from this source alone have not been observed above the UK Action Level (Wrixon *et al*, 1988).

Building materials with high thorium content may exhale thoron into buildings in which they are incorporated. This depends on the source concentration of thorium together with the physical matrix of the building material and the surface characteristics of the material. In the UK, thoron contributes about 4% of the annual average radiation exposure (Wrixon *et al*, 1988).

1.2.4 Radon in water

Water derived from underground sources with elevated uranium or radium concentrations may have high levels of dissolved radon. Water used in the public drinking water supply networks generally has sufficient dilution, storage and treatment to reduce radon to very low levels. In some private domestic ground-water derived drinking water supplies, these processes may not operate to the same extent such that the water has elevated radon concentrations at the point of entry into the consumer's home. In these cases, the consumer may be exposed both through the inhalation of radon in indoor air caused by de-gassing when water is drawn from taps, showers, etc and to a lesser extent from the ingestion of radon in water. The inhalation pathway gives rise to the great majority of radiation exposure from radon present in drinking water.

Industrial premises using large volumes of water, especially from private supplies, should consider this source during their risk assessments as it can produce radon concentrations in air high enough to be subject to regulatory control.

1.2.5 Radon from uses of radium and thorium

Radon can be generated from human activities involving radium and thorium. Radium-226 (half-life 1,600 years) is the radioactive parent of radon and has been used in the past for research, in luminised instruments and in other devices, e.g. to eliminate static electricity. A small number of premises, including factories and laboratories, have been found to have high radon levels from this source. Thorium-232 (half-life 14.05 billion years) is the source of thoron (radon-220). Thorium has also been used in research and, in the past, in manufacturing e.g. as a component in gas-mantles. The use of radioactive materials is covered by the radioactive substances regulations (DEFRA, 2016, SG, 2018) and the Ionising Radiations Regulations IRR17 (HSE, 2017 and HSENI, 2017).

1.2.6 Radon and related issues

Radon does not exist as an isolated problem independent of other factors in society. It is well established that the risk of radon exposure is amplified in those who are smokers or ex-smokers (AGIR, 2009). This is reflected in the UK approach to radon that provides enhanced advice for these groups in relation to radon at home.

It has been shown that some physical aspects of a building, such as presence of primary or secondary double glazing, can adversely affect the indoor radon level. While these observations alone are not sufficient to impact on advice about testing for, or remediating radon, they inform an emerging area of investigation into the interaction between radon concentrations and energy efficiency measures that are retro-fitted to buildings or are a design feature of new buildings, although the latter are also often associated with other features such as managed ventilation that may reduce the effect.

There is regular interaction and cross-fertilisation of ideas between organisations working on radon and those engaged in related problems such as air quality and other environmental hazards.

2 UK radon strategy

Radon is the single biggest source of radiation exposure to the UK population in both homes and workplaces as it is present in all air, both indoors and outdoors. The fundamental aim of the UK radon strategy is to reduce high individual radon exposures and the overall level of radon exposure to the population whether at home, at work or elsewhere, with a consequent reduction in individual and overall risks of lung cancer.

The UK strategy meets the radon requirements of the European Union Basic Safety Standards Directive (EURATOM, 2013), including those transposed through the Ionising Radiation (Basic Safety Standards) (Miscellaneous Provisions) Regulations 2018 (BEIS, 2018) and other regulations.

The UK radon strategy is built on the scientific understanding of radon and its presence across the UK. It is informed by evidence, research, guidance and practical experience from within the UK and from international bodies, including the WHO, the ICRP and the IAEA. The strategy has been developed within the wider context of how the UK addresses health risks in homes and workplaces, and sits alongside the public health goal of reducing health risks from smoking.

The UK radon strategy is implemented through various means including public health action; provision of advice and information; and legislation and regulation. Where appropriate, the strategy is implemented by including radon-specific elements into wider arrangements. Some legislation is UK-wide whereas others, such as building and housing regulations, are matters devolved to the home nations.

The strategy focuses mainly on the dominant radon exposure pathway, which is indoor exposure resulting from inhalation of radon that enters a building across its interface with underlying soil and rock. The strategy addresses radon exposure in new and existing premises, principally homes and workplaces. Other radon sources and exposure pathways are considered and reflected in the strategy and specific arrangements as appropriate.

For existing buildings, the main components of the strategy are risk assessment and action to reduce high exposures. The key elements are: a decision about whether the radon level in buildings should be measured; making suitable radon measurements; and choosing and implementing a suitable remediation where this is considered necessary.

The results of radon measurements are compared to the relevant reference levels to inform decisions about action to reduce radon exposures, and in relation to occupational exposures, determining whether there is work with radiation and that further regulations apply. High exposures can generally be reduced by remedial building works that lower the concentration of radon in indoor air. In some workplace circumstances, exposures may be managed by restricting the time spent in relevant rooms or spaces.

Radon Affected Areas are defined as those where at least 1% of the homes are expected to exceed the UK radon Action Level (the reference level for homes). Radon measurements are mainly recommended for buildings that are located in a radon Affected Area and for basement (below ground) rooms that are regularly occupied, irrespective of their geographical location.

For new construction, the strategy aims to prevent high exposures occurring through the targeted requirement of protection from radon in new buildings and extensions in areas where high radon levels are more likely.

The strategy also takes account of the synergistic interaction between radon exposures and smoking that leads to current smokers and ex-smokers having a higher lung cancer risk than a lifelong non-smoker for a given level of radon exposure. The longstanding UK policy to reduce smoking contributes to reducing the lung cancer risks from radon exposure.

Since the presence of radon is not perceived by the human senses and is generally not determined by the type of human activity undertaken in a building, communication is an important element of the strategy, which aims to promote awareness of radon in those individuals and organisations that have to take action. This takes a number of forms including: addressing radon in existing processes, such as property transactions and workplace health and safety activities; targeted campaigns to address specific groups; and ongoing provision of information and guidance.

Radon will always be produced in the ground and its entry into homes and workplaces cannot be prevented completely. Radon levels in remediated buildings remain low only while a remediation system continues to work effectively and subsequent building modifications do not affect the entry of radon into the property. Radon is therefore a continuing source of radiation exposure and the UK radon strategy will need to be maintained to ensure that radon awareness, action and protection progresses at the national, local and individual levels

.

3 Existing UK action on radon

Radon has been recognised for many years as a significant source of radiation exposure in UK homes and workplaces. The major elements that implement the UK radon strategy are described below. This report does not include exhaustive references to specific legislation, guidance and scientific evidence on the topics listed below.

3.1 Exposure to radon in homes

3.1.1 Radon reference level for homes

The setting of a reference level for radon in dwellings is a requirement of Article 74.1 of the EU-BSS (EURATOM, 2013a) and is covered by UK legislation (BEIS, 2018). In the UK, a radon Action Level (200 Bq m^{-3}) provides the primary reference level for informing decisions about reducing indoor radon concentrations in homes (HPA, 2010). The Action Level has been in place since 1990 (NRPB, 1990) and was reviewed and retained in 2010 (HPA, 2010).

This Action Level is within the ranges established by international standards and guidance published by the WHO (WHO, 2009), the IAEA (IAEA, 2014), ICRP (ICRP, 2010) and the European Union (EURATOM, 2013a), each of which stipulates that indoor radon concentrations should not exceed an annual average of 300 Bq m^{-3}.

In 2010, a supporting Target Level (100 Bq m^{-3}) was introduced (HPA, 2010) to serve two purposes: to represent a target, below which remediation should aim to reach, and as a point above which those at higher individual risk, such as current smokers and ex-smokers, should seriously consider radon reduction. The Target Level also corresponds to the lower value of radon reference level recommended by the WHO (WHO, 2009).

3.1.2 Radon maps to support decision making

Radon is present in all buildings. High indoor radon levels occur in a small percentage of UK buildings and in many cases can be reduced by practical remediation methods. Indoor radon concentrations depend on a number of factors, including the geological characteristics of the ground underneath the building. This is taken into account in maps of radon potential. Other factors, including the construction details and the living styles of the occupants, are responsible for a very wide variation of indoor radon concentrations found in homes built on ground with the same radon potential. This generally results in indoor radon concentrations in an area exhibiting a distribution that is characterised by most premises having relatively low concentrations but with some having considerably higher levels.

In order to identify whether a particular building has high radon levels, it is necessary to measure the radon level in the building.

Maps are produced that identify radon Affected Areas (Miles *et al*, 2007; Miles *et al*, 2011; Daraktchieva *et al*, 2015), where at least 1% of homes are expected to be above the radon Action Level (200 Bq m^{-3}). Databases of radon measurements and geological features are maintained and used to prepare these maps. At the time of writing, results from about 550,000 dwellings have been recorded in a database maintained by PHE: 380,000 in radon Affected Areas and 170,000 outside the Affected Areas. The maps (Figure 2) are used to identify areas

with a high probability of having elevated radon levels. The current advice is that all homes in Affected Areas should be tested for radon.

The maps are accessible in indicative form in published atlases on www.gov.uk and as an online interactive resource (www.ukradon.org). Online and other services provide definitive guidance for specific postal addresses and land areas.

Radon measurements should be made in regularly occupied basements of properties irrespective of their geographical location (HPA, 2010).

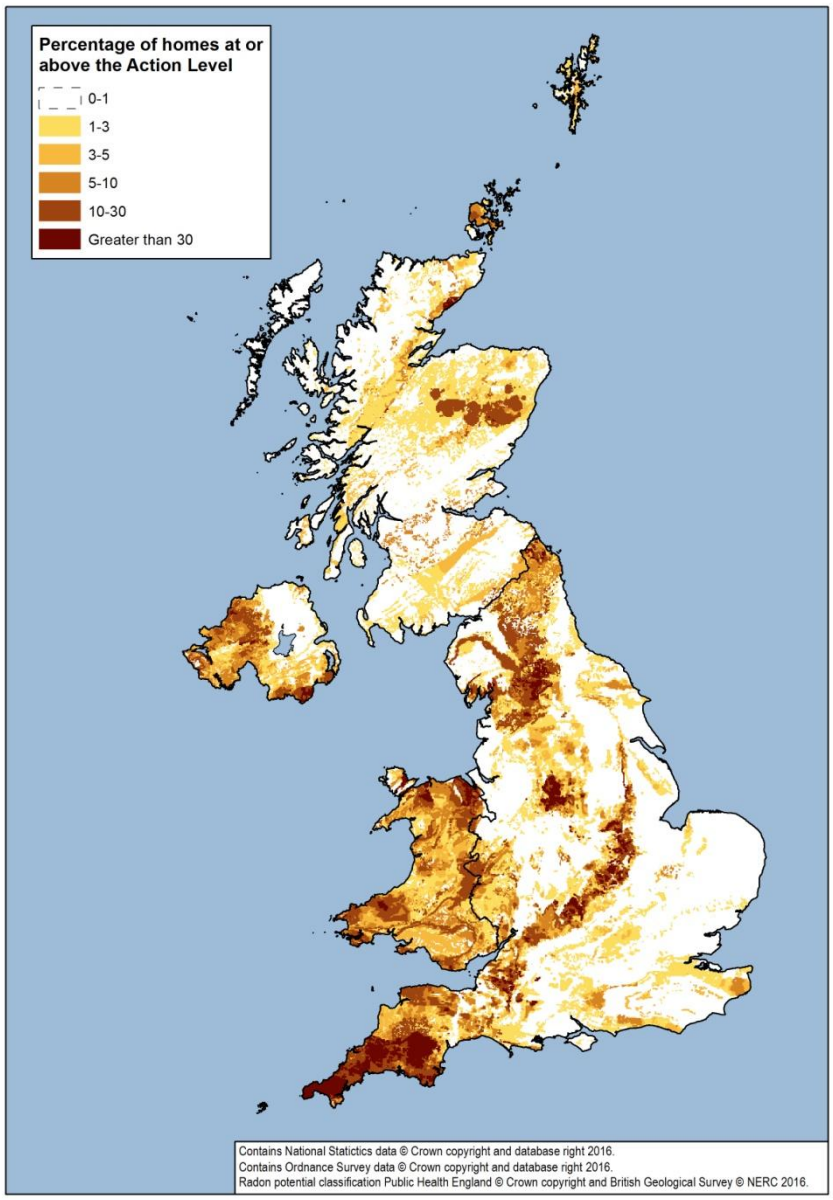

Figure 2 Indicative UK radon map

A programme is maintained, involving the British Geological Survey, PHE and other organisations, to review and update the UK radon risk maps to reflect significant new information, such as improved geological mapping, additional radon measurements and improvements to the methodology for mapping radon potential.

The identification of areas where the radon concentration in a significant number of buildings is expected to exceed the reference level is a requirement of Article 103.3 of the EU-BSS (EURATOM, 2013a) and is covered by UK legislation (BEIS, 2018).

3.1.3 Measuring radon in homes

Services are available from a number of organisations to undertake measurements of radon in homes. Most long term domestic measurements are made using two detectors, one placed in the main living room and one in an occupied bedroom for a period of at least 3 months, to smooth out short term fluctuations. This is often a postal service but individual placement services are also offered by some providers.

The results can be combined to reflect typical domestic occupancy and corrected for seasonal variations in radon levels to allow the estimation of the radon concentration (expressed as an annual average) to which occupants are exposed. The result can be compared with the Action Level and Target Level to inform decisions about installing appropriate radon remediation.

Shorter duration measurements using passive detectors are also available from some providers, as are measurements using electronic (active) monitors. These measurements can be used to provide an indication of radon levels and are often referred to as screening measurements.

In exceptional situations, it may be appropriate to make additional measurements in the home.

A validation scheme for organisations offering radon measurements in homes has been run for many years and was updated in 2018 (Daraktchieva *et al*, 2018). This ensures that householders can obtain a reliable radon measurement that can be compared with the Action Level and hence make a properly informed decision about the need for remediation. In addition, regular international intercomparison exercises are available (Howarth, 2017) that allow those offering radon measurement services to check the technical performance of their measurement capability.

3.1.4 Reducing indoor radon levels in homes

Where high radon levels are identified, practical remediation methods, and supporting technical guidance, are available to reduce radon concentrations, including from the Building Research Establishment (www.bre.co.uk). Householders are advised to reduce radon levels that are above the Action Level and to seriously consider reducing levels between the Target and Action Levels, informed by the risk to the occupants and taking account of the greater risk to current smokers and ex-smokers. Specific guidance for individual properties, such as the design and location of remediation systems, is available from specialist companies in the radon sector, informed by research and operational experience. If the source of high radon levels was identified as being from the private water supply, remediation must be focused accordingly.

Mitigation methods should start being effective immediately. However, to assess their performance it is necessary to repeat the radon measurements. Long term post-mitigation measurements are the most reliable way of comparing radon concentrations with the Action level, but short term screening measurements have a role in giving rapid feedback on whether the work has been successful. A number of companies undertake radon measurement and remediation work, some of whom are members of industry groupings including the Radon Council (www.radoncouncil.org) and the UK Radon Association (www.radonassociation.co.uk), who publish lists of services provided by their members.

Those with responsibility for a building with radon remediation installed are advised to follow the installer's maintenance instructions and to re-test the building periodically to ensure that protection is maintained.

3.1.5 Radon in housing standards

Each part of the UK has regulations, guidance and other supporting material that aim to ensure that homes are of an adequate standard. Provision for and consideration of radon varies across the UK: some parts (England and Wales) use the Housing Health and Safety Rating System (HHSRS), which identifies radon as a potential health hazard (Housing Act, 2004); in Scotland, a recent review of the housing standards has included radon as a topic that may be included in an updated standard for tolerable housing; in Northern Ireland, a consultation included adoption of HHSRS (and hence explicit consideration of radon) as an option. At the time of writing, the reviews in Scotland and Northern Ireland were still under way.

3.1.6 Promoting action on radon and encouraging remediation in homes

Numerous public health programmes, generally funded by central and local government, to identify and encourage the remediation of homes with high radon levels have been completed. These have been conducted in partnership with local authorities (which has been shown to increase public engagement), in areas with significant numbers of homes in the higher bands of radon potential, and typically where at least 5% of homes are expected to exceed the UK Action Level. However, it is internationally acknowledged by WHO (WHO, 2009) and others that engaging the public in effective radon activities remains a challenge, even when there is effective collaboration between radon stakeholders.

At the time of writing, PHE (and forerunner organisations) had undertaken more than 20 programmes of this nature. Advice on action to remediate high radon levels is provided in the form of letters, leaflets, signposting to online resources and, in many cases, press advertisements and invitations to local "drop-in" sessions to obtain individual face-to-face advice about radon risks and remediation. A number of similar programmes have been undertaken as local initiatives, generally by, or in collaboration with, local authorities. PHE maintains this ongoing programme of work, using resources from national government where these are available, and evaluating the effectiveness of programmes through a process of continual improvement.

Targeted activities are also carried out by the radon industry, for example, through letter drops in areas of high radon potential and provision of online information to raise awareness regarding measurement and remediation (see section 3.6), the instigation of 'Radon Awareness Week' and the annual UKRA Radon Symposium.

Where homes with exceptionally high radon levels are found, PHE provides additional individual practical support to the householders that can include: on site visits, individual advice, assistance in remediating, and periodic radon monitoring.

Building Regulations require that buildings in certain areas should be constructed with protective measures that aim to prevent radon ingress (see section 3.3). Work by the radon industry and others in this area has also shown that radon levels can still be elevated in homes built with protection, reinforcing the importance of testing these properties by the new occupiers.

During the house buying and selling process, radon is included in the conveyancing process through the local authority search (CON 29 document) and property information form completed by the seller (TA6 in England and Wales). PHE continues to work with the Law Society to update and improve information for solicitors and purchasers.

3.2 Radon in the workplace

3.2.1 Regulations

Under the Health and Safety at Work etc Act 1974 (HASAWA, 1974), employers must, so far as is reasonably practicable, ensure the health and safety of employees and others who have access to their work environment.

The Management of Health and Safety at Work Regulations 1999 (HSE, 1999) require the assessment of health and safety risks.

Where the radon concentration in a workplace exceeds the relevant reference level (300 Bq m^{-3} as an annual average), the Ionising Radiations Regulations 2017 (HSE, 2017; HSENI, 2017) apply to work with radiation and the employer is required to take certain actions including those to restrict exposures.

3.2.2 Radon maps to support decision making by employers

The radon Affected Area maps that have been produced from radon measurements in homes can be used to indicate whether radon is likely to be a hazard in typical workplaces and can be used to inform the risk assessment and need for radon measurements.

The identification of areas where the radon concentration in a significant number of buildings is expected to exceed the reference level is a requirement of Article 103.3 of the EU-BSS (EURATOM, 2013a) and is covered by UK legislation (BEIS, 2018).

However, in occupied workplaces below ground, which includes basement areas of buildings, and mines and caves, the risk assessment should include radon measurements irrespective of the radon Affected Area status (HSE, 2018).

3.2.3 Measuring radon in workplaces

Radon measurement in workplaces forms part of the risk assessment process and informs decisions about whether radon exposures should be controlled through remediation or other means. The services available for radon measurements in homes are often suitable for indoor workplaces. Most occupational radon measurements are made with passive monitors that are in place for three months. The number required in each building, however, depends upon its internal area and the layout, for instance cellular or open plan offices may require different measurement densities. Protocols have been published to assist employers in determining the appropriate number of monitors for a suitable and sufficient test. Where reference levels have been exceeded, additional measurements are often required in workplaces after the initial test to determine the room(s) with the highest radon concentrations and to assist with the design of mitigation work (see section 3.2.4) and comply with regulations (section 3.2.1).

The location of radon monitors in mines and caves is typically within the main working areas and transit routes. The mining industry has a culture of using active monitors for routine air

quality tests and electronic (active) monitors are used to complement the passive measurements.

In 2018, a revised validation scheme (section 3.1.3) was published (Daraktchieva *et al*, 2018) that applies to radon measurements in dwellings and, for the first time, indoor workplaces. This scheme takes into account the differences in the occupancy, physical size and layout of buildings, applies to long term measurements (3 months), updates protocols and performance standards, and includes a major review of seasonal correction factors. Laboratories being validated under this scheme from 2019 can choose whether to provide radon measurement services for dwellings, workplaces, or both.

3.2.4 Controlling radon exposure in workplaces

The first choice is usually to reduce the concentration of radon. The same techniques for radon remediation in homes are usually applicable to workplace buildings, sometimes with adaptations depending upon the size and layout of the building, radon levels, and any ventilation systems. Specialist contractors may also be needed where premises have undergone multiple extensions or changes of use. Post-mitigation radon measurements are required to determine whether the work has been successful, with regular maintenance checks thereafter to show that it remains effective.

In mines and caves, radon levels are generally controlled by air handling techniques, which may be informed by specialist advice on optimising ventilation.

In some workplaces, radon exposures may be controlled by managing local occupancy, for instance by limiting the access duration and frequency to a high radon area.

In a small minority of workplaces, where elevated concentrations are difficult to reduce in practice, some workers have their radon exposures assessed individually using personal radon dosemeters.

In all workplaces where equipment is used to reduce radon concentrations, the systems should be included in standard maintenance schedules as defined by the manufacturer's instructions.

3.3 Protecting new buildings against radon

Building regulations, supporting documents and guidance provide, in a tiered approach, for the limitation of radon ingress in new buildings and extensions. In areas of lowest radon risk, no specific measures are expected. In areas of elevated radon risk, new buildings and extensions should include a membrane that limits radon ingress from the ground. In areas of highest radon risk, the membrane should be augmented by provision for additional measures that can be completed and activated if a radon measurement shows that the building has high levels in spite of the protection afforded by the membrane. Therefore, testing is recommended within the first year of occupation in all new buildings with radon prevention measures to ensure that radon concentrations are below the levels that require action (BRE, 2015).

The areas that are subject to each level of protection are identified in relation to the UK radon map. Specific criteria for and descriptions of the expected measures are established by the individual nations within the UK (BRE, 2015). For instance in Scotland, the building standards require that "every building must be designed and constructed in such a way that there will not be a threat to the health of people in or around the building due to the emission or containment of radon gas".

The provision of appropriate measures to prevent radon ingress in new dwellings is a requirement of Article 103.2 of the EU-BSS (EURATOM, 2013a) and is covered by UK legislation (BEIS, 2018).

3.4 Radon in water

In most UK drinking water supplies radon is present at very low levels. The potential presence of radon in public and private drinking water supplies is subject to regulation within each of the UK nations to meet the requirements of the EU Directive on drinking water (EURATOM, 2013b). The requirement for testing can be different according to whether the supply is for commercial or public use, or for a single dwelling. Guidance is available about techniques to reduce high radon levels in water supplies.

3.5 Radon exhalation from building materials

The EU Construction Products Regulation 2011 (DCLG, 2011) provides uniformity in assessing the performance of construction products through harmonised product standards and technical assessments, which include radiation. Although radon emitted from building materials generally leads to low indoor exposures (Wrixon *et al*, 1988), research is under way to identify if there are any building materials with significant radon exhalation and whether regulations or other controls on their use will be required.

3.6 Communicating on radon

In most cases, the level of indoor radon does not relate to work or domestic activities in the building. The person responsible for a building, whether it is a home or workplace, may remain unaware of the presence and potential significance of radon in the building unless it is brought to their attention and they are made aware, through appropriate communications, of what actions they should take. The need for a communication strategy on radon is one of the aspects needed to be considered in the EU-BSS (EURATOM, 2013a)

The individual circumstances will determine the need for particular radon information and guidance. This is available and communicated to relevant groups and individuals through a range of processes.

3.6.1 Online information resources

Information and guidance about radon is published in a number of online locations to support radon awareness and action. The major resources are listed below:

- www.bgs.ac.uk – access to BGS technical guidance and services
- www.bre.co.uk – access to BRE technical guidance and services
- www.dwi.defra.gov.uk/stakeholders/guidance-and-codes-of-practice - guidance on radon in water supplies
- www.dwi.defra.gov.uk/research/completed-research/reports/DWI70-2-301.pdf - radon in drinking water

- www.gov.uk - links to key government information on radon
- www.hse.gov.uk – guidance on radon in the workplace
- www.hseni.gov.uk – guidance on radon in the Northern Ireland workplaces
- www.radonassociation.co.uk – an industry association
- www.radoncouncil.org - an industry association
- www.ukradon.org – a dedicated radon website managed by PHE
- www.wales.nhs.uk – information on radon from PHW

Many local authorities have information about radon on their websites relevant to their areas.

Some individual companies provide radon information on their websites.

3.6.2 Media communications

Specific programmes, publications and events provide opportunities to promote radon awareness, including both national events such as 'Radon Awareness Week' and the promotion of other European radon events. A range of media channels are used including print and broadcast news media and social networking sites. In general, the specific activity provides a context, often either sectoral or geographical, in which radon information and guidance is provided.

3.6.3 Targeted communications

In some contexts, communications are more closely targeted to those who may need to take action on radon, including those with statutory duties. The actions being promoted are generally related to the processes of risk assessment and intervention as outlined in the strategy. Examples of targeted communications include: postal invites to participate in government-funded radon surveys; invitations to householders with high domestic radon levels to attend local "drop-in" events focused on remediation; information to bodies managing schools to remind them of their existing responsibilities and offering support to assess their school property portfolio; and information about radon for buyers of new and existing properties.

PHE maintains a programme of work, in partnership with stakeholders, to identify and address relevant sectors and groups, covering exposures in homes and workplaces that have a low awareness of radon. This includes exhibiting at conferences and events aimed at key groups (including social landlords and employers) to increase awareness and action in this sector.

3.6.4 Training for professionals

A number of organisations offer short duration or online training courses in radon measurement and remediation and radon protection / prevention aimed at professionals in the building sector. Practical training in remediation techniques is provided by industry professionals, along with mentoring. Radon is also included in the training of Environmental Health Officers and provided as part of the Continuing Professional Development on indoor air quality by the Chartered Institution of Building Services Engineers (CIBSE).

3.6.5 Stakeholder engagement

A range of activities are undertaken to provide engagement between the various stakeholders with a role in delivering UK's radon strategy. In many cases, radon is dealt with as part of a wider engagement process between relevant parties. In other cases, radon is the central theme of interaction.

While far from being an exhaustive list of all relevant interactions, PHE's engagements on radon serve to illustrate this. PHE undertakes the following regular radon stakeholder interactions:

- attend meetings, by invitation, of the two UK radon industry bodies: the Radon Council and the UK Radon Association.
- hold the annual UK Radon Forum, which is attended by a wide range of stakeholders, including local government and the radon industry
- update and seek views on radon activities with parts of government including:
    - devolved administrations (Northern Ireland, Scotland and Wales)
    - the Drinking Water Inspectorate (through the PHE/DWI Water Advisory Group)
    - Committee on the Medical Aspects of Radiation in the Environment (COMARE)
    - the PHE Environmental Public Health Network

Other bodies engage with radon stakeholders as part of these and other channels but while it would not be practical to list the full range of these interactions, examples of radon activities undertaken by Public Health Wales are given below:

- managing a radon programme for schools in Wales, with supporting training, information and health advice
- providing sector-specific radon information and training to the childcare providers, public buildings working group and social landlords
- providing radon introductory training for the Chartered Institute of Environmental Health Wales

3.7 Radon in UK overseas territories and crown dependencies

There are a number of British overseas territories and crown dependencies. Responsibility for managing radon in each of the territories lies with the local territorial government. UK departments and agencies provide appropriate support to the territorial governments.

3.8 Maintaining and developing the evidence base on radon

For many years, the UK has made a significant contribution to the understanding of radon and the effectiveness of various aspects of a radon strategy. Evidence and findings are generally published in the open literature, at relevant conferences or through the www.gov.uk portal.

4 Forward plan for action on radon

The radon strategy presented in section 2 is implemented through the elements described in section 3.

Radon will continue to be released from the soils and rocks on which homes and workplaces are situated, and from private water supplies and building materials. Radon remediation systems that reduce high concentrations must continue to operate for the lifetime of a building in order to protect the building occupants. Since radon is imperceptible to the human senses, general awareness of radon and knowledge of the radon situation in particular buildings are at risk of diminishing over time, especially when the ownership or responsibility for the premises changes hands.

It is therefore important that the established arrangements and provisions for addressing radon are maintained so that, over time, more people in the UK are aware of radon, take appropriate action and are protected from high radon exposure.

This section identifies actions that will seek to maintain and enhance the UK's position on managing radon in an effective, evidence-based manner.

4.1 Maintain and review the existing processes that address radon exposure

The established UK infrastructure and provisions that support the assessment of and protection against radon exposure, outlined in section 3, will be maintained and reviewed in light of relevant evidence and experience. The main provisions are summarised below:

- a suite of radon advice including reference levels for radon exposure and the definition of radon Affected Areas
- the capability to develop and the provision of resources, including radon risk maps, that can be used by householders, landlords, employers and others to identify premises for which radon measurements are advised
- methods for increasing public engagement with and action on radon
- the capability for and provision of radon measurement services to support the assessment and management of indoor radon levels
- the provision of information, guidance and services relating to the measurement and reduction of indoor radon levels
- the capability for and delivery of activities to promote householder and landlord awareness and action on radon in homes including testing and remediation, involving local and national stakeholders
- legislation and guidance concerning radon exposures in the workplace
- Consideration of radon in health and safety arrangements for buildings, including new build, extensions and refurbishments
- the evidence base for radon exposure and associated risks, including the national radon database and the publication of area statistics

4.2 New topics for consideration

A review of Annex XVIII of the EU-BSS (EURATOM, 2013a) identified a small number of topics that the national plan should consider but which are either not currently in place in the UK or are appropriate for review. These are outlined below with specific proposals for future action.

4.2.1 Consider updating the national radon survey

The original UK national radon survey was undertaken in the mid 1980's (Wrixon *et al*, 1988) and established the population weighted average and distribution of indoor radon concentrations in homes. This provides the baseline of evidence of the magnitude of radon exposure in UK homes. Since then, a number of influences may have led to changes in these parameters, including: better insulation of some existing and new homes; changes in the population size and distribution; changes to the national housing stock; changes in lifestyle; changes in house construction; and the inclusion of radon prevention measures in new properties in areas of elevated radon risk.

ACTION: PHE to consider whether an updated national survey is needed and if so what form this should take.

4.2.2 Consider developing an accreditation scheme for remediators

The UK has at least two industry groups that provide services that fulfil some of the characteristics that might be expected of an accreditation scheme for remediation services. There may be merit in considering, potentially as an industry-led initiative, whether a national accreditation scheme would add value and it how it would relate to existing arrangements.

ACTION: PHE to engage with stakeholders to consider benefit, options and practicality of establishing an accreditation system for radon remediation.

4.2.3 Consider developing radon exhalation standards for building materials

Government is carrying out research to identify building materials of concern from a radiation protection point of view. Further action will depend on the results of this research. However, it is expected that test methods being developed for European Product Standards will form the basis of future British Standards and enable regulations to be made, should this be deemed necessary.

ACTION: PHE to support government and stakeholders on relevant standards including research on radon exhalation from building materials, as required.

4.2.4 Development of resources to aid local action on radon

PHE provides information on health related issues as part of its 'Fingertips' tool and has developed specific packages of information for use by local authorities and others who are responsible for public health in their areas and regions. Currently, there is no information related to radon exposures within these items.

ACTION: PHE will lead a programme to prepare and provide material to support local radon activities, including a radon-specific public health indicator and locally-oriented digital information and resource packs, aimed primarily at local authorities.

4.2.5 Review of special treatment for homes with very high radon concentrations

The special treatment of homes with very high radon levels is noted in the EU-BSSD Annex XVIII given in Appendix A. Householders who live in homes with very high radon levels, with annual average radon concentrations in excess of 10,000 Bq m^{-3}, are given additional advice and support to reduce their levels. Currently, fewer than 20 homes have been identified for special action.

ACTION: PHE will review the process for providing advice and support to householders with very high radon levels. The review will include the advice, actions, ongoing support and the level of radon which would trigger this special action.

4.2.6 Updating the UK National Radon Action Plan

An update of the UK National Radon Action Plan, involving input from those with relevant responsibilities, should be undertaken periodically to provide a focus for ensuring and providing feedback on action and to ensure that an up to date picture is maintained on the national position on radon. Such a process is covered by UK legislation (BEIS, 2018) and would meet the requirement of EU-BSS Article 103.1 to update the plan on a regular basis and the need to consider schedules for its regular review.

In between formal reviews, other methods such as existing forums and online blogs could provide useful channels for providing informal updates.

ACTION: Department of Health and Social Care, supported by PHE, to initiate a review and update of the subject and contents of the National Radon Action Plan initially within 5 years of its first publication and on a similar frequency thereafter.

5 Acknowledgements

The authors wish to thank all those who helped with the drafting of this document and the preparations for the public consultation. We also wish to acknowledge the contributions of former members of the cross-government core group and those who joined latterly, including: Ian Chell (formerly DHSC, retired), Phillippa Hunnisett (DHSC), Laurie Mousah (DHSC), Roger Yearsley (formerly EA, retired) and Nick Price (formerly MHCLG, retired).

6 Glossary

6.1 Terms and expressions

Becquerel (symbol Bq) The unit of the amount or activity of a radionuclide. Describes the rate at which transformations occur. 1 Bq = 1 transformation per second.

Becquerel per cubic metre of air (symbol Bq m^{-3}) The amount of a radionuclide in each cubic metre of air. Often referred to as the activity concentration.

Mitigation The reduction in the radon level by mechanical or other means. Mitigation does not imply the complete removal of radon.

Radon The radionuclide Rn-222 and its progeny, as appropriate.

Radon Action Level The reference level for the activity concentration of radon in UK homes. Its value, expressed as the annual average radon gas concentration in the homes, is 200 Bq m^{-3}.

Radon Affected Areas Parts of the country with a 1% or more probability of present or future homes being above the Action Level.

Reference level The level of 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.

Remediation See mitigation.

Thoron The radionuclide Rn-220 and its progeny, as appropriate.

6.2 Acronyms and organisations

AGIR Advisory Group on Ionising Radiation

BEIS Department for Business, Energy and Industrial Strategy

CIBSE Chartered Institution of Building Services Engineers

DAERA Department of Agriculture, Environment and Rural Affairs (NI)

DEFRA Department for Environment, Food and Rural Affairs

DoH NI Department of Health Northern Ireland

DHSC Department of Health and Social Care

EA Environment Agency

EU-BSS European Union Basic Safety Standards, Council Directive 2013/59/EURATOM

HHSRS Housing Health and Safety Rating System

HSE Health and Safety Executive

HSENI Health and Safety Executive Northern Ireland

IAEA International Atomic Energy Agency

IARC International Agency for Research on Cancer

ICRP International Commission on Radiological Protection

MHCLG Ministry of Housing, Communities and Local Government

PHA NI Public Health Agency Northern Ireland

PHE Public Health England

PHW Public Health Wales

SG Scottish Government

UNSCEAR United Nations Scientific Committee on the Effects of Atomic Radiation

WHO World Health Organisation

7 References

AGIR (2009). Radon and Public Health. Report of the independent Advisory Group on Ionising Radiation. Documents of the Health Protection Agency. Radiation, Chemical and Environmental Hazards, RCE-11, June 2009. ISBN 978-0-85951-644-0. [https://www.gov.uk/government/publications/radon-and-public-health]

BEIS (2018). The Ionising Radiation (Basic Safety Standards) (Miscellaneous Provisions) Regulations 2018. SI 2018/482. [http://www.legislation.gov.uk/uksi/2018/482/made]

BRE (2105). Radon. Guidance on protective measures for new buildings. BRE-211. Building Research Establishment. ISBN 978-1-84806-434-8.

DCLG (2011). EU Construction Products Regulation 2011. SI305/2011. [Available at https://www.gov.uk/guidance/eu-construction-products-regulation-and-ce-marking-including-uk-product-contact-point-for-construction-products]

DEFRA (2016). Environmental Permitting (England and Wales) Regulations 2016. SI1154/2016 [Available at http://www.legislation.gov.uk/uksi/2016/1154/contents/made]

Daraktchieva *et al* (2015). Daraktchieva Z, Appleton JD, Rees DM, Adlam KAM, Myers AH, Hodgson SA, McColl NP, Wasson GR and Peake LJ (2015). Indicative Atlas of Radon in Northern Ireland. PHE-CRCE-017. [Available at https://www.gov.uk/government/publications/radon-indicative-atlas-for-northern-ireland]

Daraktchieva *et al* (2018). Daraktchieva Z, Howarth CB, Gooding TD, Bradley EJ and Hutt N. Validation Scheme for Organisations Making Measurements of Radon in UK Buildings: 2018 Revision. PHE-CRCE-040. [Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/742223/validation_scheme_for_organisations_making_measurements_of_radon_in_UK_buildings_2018.pdf]

Darby *et al* (2005). Darby S, Hill D, Auvinen A, Barros-Dios JM, Baysson H, Bochicchio F, Deo H, Falk R, Forastiere F, Hakama M, Heid I, Kreienbrock L, Kreuzer M, Lagarde F, Mäkeläinen I, Muirhead C, Oberaigner W, Pershagen G, Ruano-Ravina A, Ruosteenoja E, Schaffrath Rosario AS, Tirmarche M, Tomásek L, Whitley E, Wichmann H-E, Doll R (2005). Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies BMJ 2005; 330 doi: http://dx.doi.org/10.1136/bmj.38308.477650.63

EURATOM (2013a). Council Directive 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, Official Journal of the European Union L13/1. [https://ec.europa.eu/energy/sites/ener/files/documents/CELEX-32013L0059-EN-TXT.pdf]

EURATOM (2013b). Council Directive 2013/51/EURATOM of 22 October 2013 laying down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption. [Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013L0051&from=en]

HASAWA (1974). Health and Safety at Work etc Act, 1974. [https://www.legislation.gov.uk/ukpga/1974/37]

HPA (2010). McColl NP, Miles JCH, Green BMR, Dixon DW, Fey R, Meara JR, Harrison JD and Cooper JR. Limitation of Human Exposure to Radon. HPA-RCE-15. [Available at https://www.gov.uk/government/publications/radon-limitation-of-human-exposure]

HSE (1999). The Management of Health and Safety at Work Regulations 1999 SI 3242/1999. [http://www.legislation.gov.uk/uksi/1999/3242/contents/made]

HSE (2017). The Ionising Radiations Regulations 2017 SI1075/2017. [http://www.legislation.gov.uk/uksi/2017/1075/contents/made]

HSE (2018). http://www.hse.gov.uk/radiation/ionising/radon.htm (accessed 30th May 2018)

HSENI (2017). The Ionising Radiations Regulations (Northern Ireland) 2017 SR No 229. [http://www.legislation.gov.uk/nisr/2017/229/made]

Housing Act 2004. Chapter 34. [https://www.legislation.gov.uk/ukpga/2004/34/contents]

Howarth, CB (2017). Results of the 2015 PHE Intercomparison of Passive Radon Detectors. PHE-CRCE-036. [Available at https://www.gov.uk/government/publications/phe-2015-intercomparison-of-passive-radon-detectors]

IAEA (2014). Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. General Safety Requirements Part 3. [Available at https://www-pub.iaea.org/books/iaeabooks/8930/radiation-protection-and-safety-of-radiation-sources-international-basic-safety-standards]

IARC (2012). International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans ; Vol. 100D. A review of human carcinogens. Part D: Radiation / IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. [http://monographs.iarc.fr/ENG/Monographs/vol100D/mono100D.pdf]

ICRP (2010). Lung Cancer Risk from Radon and Progeny and Statement on Radon. ICRP Publication 115. Ann ICRP 40(1), 2010.

ICRP (2018). Summary of ICRP Recommendations on Radon. (2018). [Available at: http://www.icrpaedia.org/images/f/fd/ICRPRadonSummary.pdf]

IAEA (2014). Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. General Safety Requirements. No. GSR Part 3 STI/PUB/1578. [Available at https://www.iaea.org/publications/8930/radiation-protection-and-safety-of-radiation-sources-international-basic-safety-standards]

Miles *et al* (2007). Miles JCH, Appleton JD, Rees DM, Green BMR, Adlam KAM and Myers AH (2007). Indicative Atlas of Radon in England and Wales. HPA-RPD-033. [Available at https://www.gov.uk/government/publications/radon-indicative-atlas-in-england-and-wales]

Miles *et al* (2011). Miles JCH, Appleton JD, Rees DM, Adlam KAM, Scheib C, Myers AH, Green BMR, McColl NP (2011). Indicative Atlas of Radon in Scotland. HPA-CRCE-023. [Available at https://www.gov.uk/government/publications/radon-indicative-atlas-in-scotland]

NRPB (1990). Board Statement on Radon in Homes. Documents of the NRPB Docs 1 No 1.

Oatway *et al* (2016). Oatway WB, Jones AL, Holmes S, Watson S and Cabianca T (2016). Ionising Radiation Exposure of the UK Population: 2010 Review. PHE-CRCE-026. [Available at https://www.gov.uk/government/publications/ionising-radiation-exposure-of-the-uk-population-2010-review]

SG (2018). Environmental Authorisations (Scotland) Regulations 2018. SSI219/2018. [Available at http://www.legislation.gov.uk/ssi/2018/219/made]

UNSCEAR (2009). United Nations Scientific Committee on the Effects of Atomic Radiation (2009) Effects of Exposure to Radon Gas. [Available at: http://www.unscear.org/docs/Radon-distrib.pdf]WHO (2009). WHO Handbook on Indoor Radon. A Public Health Perspective. WHO Press, Geneva. [Available at http://www.who.int/ionizing_radiation/env/9789241547673/en/]

Varley and Flowers (1998). Varley NR and Flowers AG. Indoor radon prediction from soil gas measurements. Health Phys. 1998; 74(6): 714-718.

WHO (2009). WHO Handbook on Indoor Radon. A Public Health Perspective. WHO Press, Geneva, 2009.

Wrixon *et al* (1988). Wrixon AD, Green BMR, Lomas PR, Miles JCH, Cliff KD, Francis EA, Driscoll CMH, James AC and O'Riordan MC (1988). Natural Radiation Exposure in UK Dwellings. NRPB-R190.

UKradon.org (2018). www.ukradon.org (accessed 23rd November 2018)

Appendix A EU Basic Safety Standards - 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.