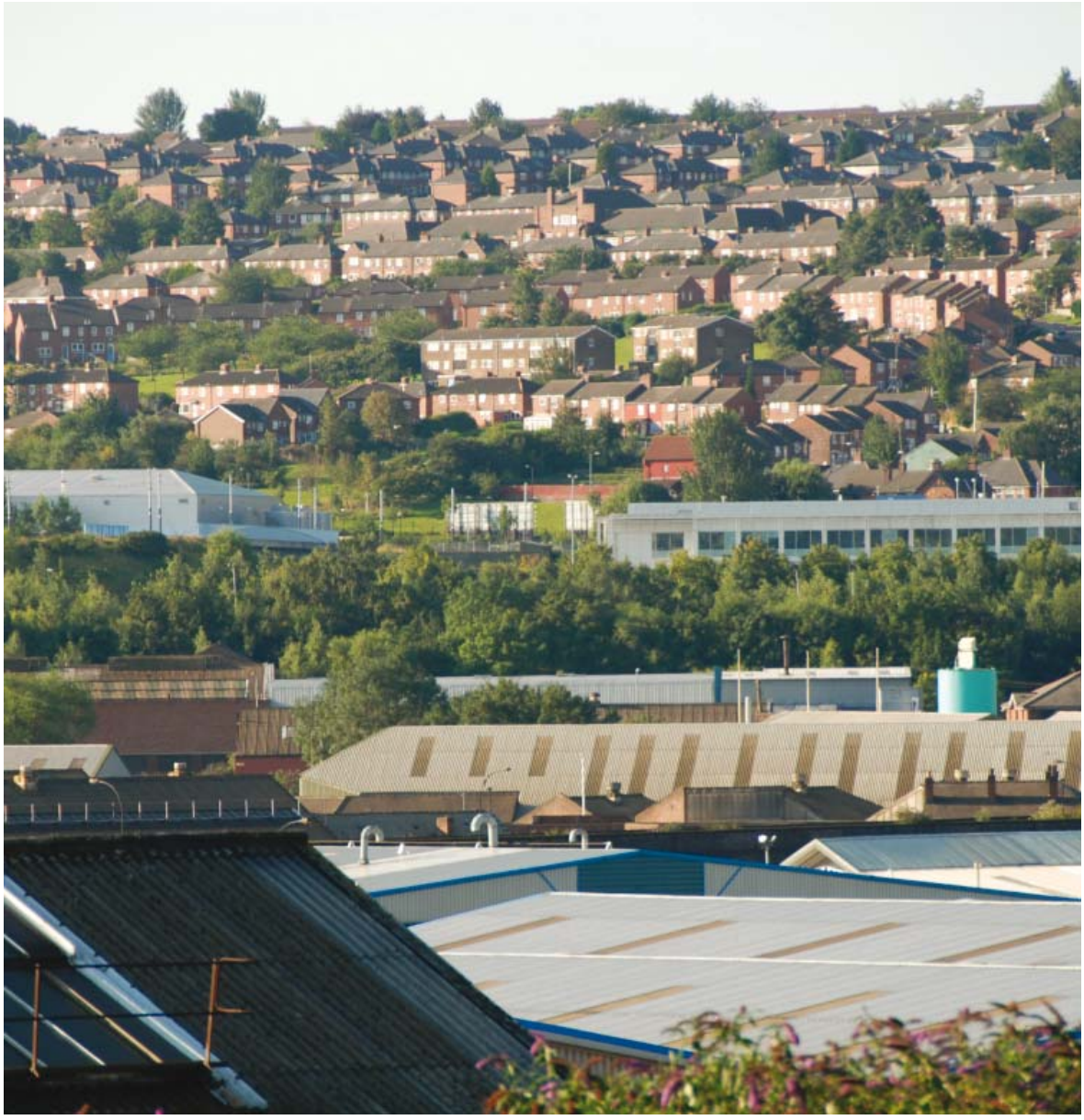
Health Protection Agency

Limitation of Human Exposure to Radon

Advice from the Health Protection Agency



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Limitation of Human Exposure to Radon

Advice from the Health Protection Agency

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This paper from the Health Protection Agency reflects understanding and evaluation of the current scientific evidence as presented and referenced in this document.

Summary

This document provides advice on the limitation of exposure of the population to radon and its short-lived decay products in buildings. It replaces the advice published in 1990 by the National Radiological Protection Board (NRPB), which joined the Health Protection Agency (HPA) in April 2005. There are five main reasons for updating the advice on radon now. First, radon remains the single biggest source of public radiation exposure in the UK. A significant proportion of the homes with elevated radon concentrations have been found but many remain to be identified and large numbers of homes with elevated concentrations have yet to be remediated. Second, the International Commission on Radiological Protection (ICRP) and the World Health Organization (WHO) have recently issued revised advice on protection against radon, including recommendations for revised reference levels, supported by improved evidence about risks from radon exposure. Third, the independent Advisory Group on Ionising Radiation (AGIR) of the HPA has issued recommendations about radon and public health. Fourth, the HPA (NRPB prior to 2005) has published radon probability maps of all parts of the UK. Fifth, the HPA issued advice to government on protection relating to new buildings in 2008.

The advice concerns exposure of the public wherever they are and is intended to reduce the radiation exposure of those most at risk from high concentrations of radon and to lead over time to a reduction in the average exposure of the whole population to radon. The latter aim follows from the recognition that most radon-induced lung cancers occur among the main body of the population exposed to low or moderate concentrations of radon rather than the small proportion exposed to high concentrations. Advice on the desirability of installing basic radon preventive measures in all new buildings, extensions, conversions and refurbishments, and on testing the effectiveness of full preventive measures within one year of occupation, has already been provided to government by the HPA, and is reiterated here.

The HPA recommends that the current radon Action Level for homes should be retained. A new Target Level for radon in homes should be introduced. The values of the Action Level and Target Level, expressed as the annual average radon concentration in the home, should be 200 Bq m^{-3} and 100 Bq m^{-3}, respectively. The role of the Target Level is to provide an objective for remedial action in existing homes and preventive action in new homes.

Areas where less than 1% of homes are estimated to be above the Action Level should be regarded as lower probability radon areas. Areas where 1% or more but less than 10% of homes are estimated to be above the Action Level should be regarded as intermediate probability radon areas. Areas where 10% or more of homes are estimated to be above the Action Level should be regarded as higher probability radon areas. The term 'radon Affected Area' is retained, for consistency with current administrative measures to control radon, and is defined as those parts of the country with 1% or more of homes estimated to be above the Action Level. Taken together, the intermediate and higher probability radon areas constitute radon Affected Areas. The HPA recommends that householders in intermediate and

higher probability radon areas should make measurements of indoor radon concentrations in their homes. Householders with radon concentrations above the Action Level should reduce the radon concentration to as low as reasonably practicable, if possible to below the Target Level. The Action and Target Levels should be applied to non-domestic buildings with public occupancy exceeding 2000 hours per year and to all schools. Building regulations and supporting documents should be amended to ensure that all new buildings in the UK include basic radon protective measures. There should be further study of the effectiveness of methods for radon prevention in new buildings.

1 Introduction

Radon is a natural radioactive gas. Isotopes of radon, different forms of the same element, occur in the three naturally occurring decay chains headed by uranium-238, uranium-235 and thorium-232. These radionuclides are found naturally in trace amounts in most rocks and soils. Radon-222, which occurs in the uranium-238 decay chain, has a half-life of 3.8 days, sufficiently long to allow it to escape from the ground and accumulate in the air within buildings. The other two isotopes, radon-219 and radon-220, have half-lives of 3.9 seconds and 54 seconds, respectively, and are less able to escape from the ground before undergoing further radioactive decay into solid elements. Attention is therefore focused on radon-222 which will be referred to as radon in this document. Radon is measured in becquerels per cubic metre of air (Bq m^{-3}), where one becquerel is one atomic disintegration per second.

Radon is one of a group of elements, called the noble gases, that also includes helium and neon. These elements do not readily react to form chemical compounds and are simple gases under most conditions. However, radon undergoes radioactive decay by alpha-particle emission to form a short-lived isotope of polonium. Several further short-lived decay products are formed in a series of decays by alpha- and beta-particle emission before a long-lived isotope, lead-210 (half-life 22 years), is reached. The risk of lung cancer following inhalation of radon is largely attributable to alpha-particle emissions from the short-lived decay products.

More information about radon can be found on websites operated by the Health Protection Agency, www.hpa.org.uk and www.ukradon.org, and in several of the references listed – in particular, AGIR (2009), BEIR VI Committee (1999), ICRP (2007, 2009), UNSCEAR (2009) and WHO (2009).

Radon inside buildings is the main source of human exposure to radiation in the UK. The concentration of radon in air in homes is about 20 Bq m^{-3}, on average, with a range of 5 to 10,000 Bq m^{-3} and more; the comparable value outdoors is about 4 Bq m^{-3}. In 2009, the independent Advisory Group on Ionising Radiation (AGIR) of the HPA published a review entitled *Radon and Public Health* (AGIR, 2009). That report included a review and analysis of epidemiological data and a health economics evaluation of radon interventions. The main findings are given below.

a Epidemiological data have provided direct evidence linking exposure to radon in the home and increased risk of lung cancer. The dose–response relationship appears linear with no evidence of any threshold radon concentration below which there is no risk.

b The majority of radon-related lung cancer deaths occur amongst the large percentage of the population exposed to modest radon concentrations. Most radon deaths occur in smokers or ex-smokers.

c Health economics modelling suggests that basic radon preventive measures in new homes would be cost-effective for all areas of the UK.

d Health economics modelling can also be used to inform judgements on the cost-effectiveness of government-funded surveys of existing homes in areas with high radon concentrations.

Previous advice on protection from radon was issued by the National Radiological Protection Board in 1990 (NRPB, 1990a,b). The NRPB became part of the HPA in 2005. HPA advice on protection of the public against indoor radon following publication of the AGIR report (AGIR, 2009) is provided in this document, noting the following points.

a Radon remains the single biggest source of public radiation exposure in the UK. A significant proportion of the homes with elevated radon concentrations have been found but many remain to be identified and large numbers of homes with elevated concentrations have yet to be remediated.

b The International Commission on Radiological Protection (ICRP) and the World Health Organization (WHO) have recently issued revised advice on protection against radon, including recommendations for revised reference levels, supported by improved evidence about risks from radon (ICRP, 2009; WHO, 2009).

c The HPA (NRPB prior to 2005) has published radon probability maps of all parts of the UK (Miles et al, 2007; Green et al, 2009a,b). The HPA has issued advice to government on protection relating to new buildings (HPA, 2008a).

In 2009, the HPA issued a consultation document inviting responses to seven questions about possible changes in its advice on radon (HPA, 2009). Responses to the consultation, a summary of which will be published, have been taken into account in the current revision of advice.

This advice is mainly concerned with exposure of the public wherever they are and is intended to reduce the radiation exposure of those most at risk from high concentrations of radon and, over time, to reduce the average exposure of the whole population to radon. The latter aim follows from the recognition that most radon-induced lung cancers occur among the main body of the population exposed to low or moderate concentrations of radon rather than the small proportion exposed to high concentrations. While the advice is mainly concerned with radon exposure of people in their homes, it is also applicable to prolonged occupancy of other buildings.

Changes to the building regulations by government have the potential to reduce the total number of deaths in the UK caused by radon. HPA (2008a) advice on radon preventive measures in new buildings is restated in Section 4 of this document. The changes in advice introduced in this document relate to protection from radon in existing dwellings and other buildings. Such advice is aimed principally at reducing the higher individual risks from radon exposure.

2 Previous UK Advice and Guidance on Protection Against Radon

In 1990, the NRPB issued advice on protection against radon in the home (NRPB, 1990a,b). This advice was intended to reduce the radiation exposure of those most at risk from high concentrations of radon while focusing attention on radon reduction where it is most required. The NRPB advised that action should be taken to reduce radon concentrations in existing homes if the radon concentration exceeded an Action Level of 200 Bq m^{-3} in room air averaged over a year, ten times the average UK domestic radon concentration. Furthermore, parts of the country with a 1% probability or more of present or future homes being above the Action Level were regarded as radon Affected Areas. Measurements were recommended for existing homes in Affected Areas with remediation if necessary (responsibility usually falling on the owner). The government accepted this advice. The NRPB first indicated which parts of the country should be regarded as radon Affected Areas in 1990 (NRPB, 1990c). Mapping progressed subsequently such that the HPA has advised on radon Affected Areas for the whole of the UK (NRPB, 1993, 1996, 1998, 1999; Green et al, 2009a,b). A more detailed mapping method was developed by the HPA in conjunction with the British Geological Survey and was applied to mapping radon in England and Wales (Miles et al, 2007). This method allows a more accurate delineation of the probability that radon will exceed a specific threshold concentration in any locality.

The NRPB advice also informed changes in the requirements for radon protection in new buildings. Basic preventive measures are required in new buildings, extensions, conversions and refurbishments if the probability of exceeding the Action Level is 3% or more in England and Wales, and 1% or more in Scotland and Northern Ireland (BRE, 1999, 2001, 2007). Provision for further preventive measures is required in new buildings if the probability of exceeding the Action Level is 10% or more. These thresholds were set by the appropriate government departments and devolved administrations.

3 Background to Changes in Advice

3.1 Radon risks

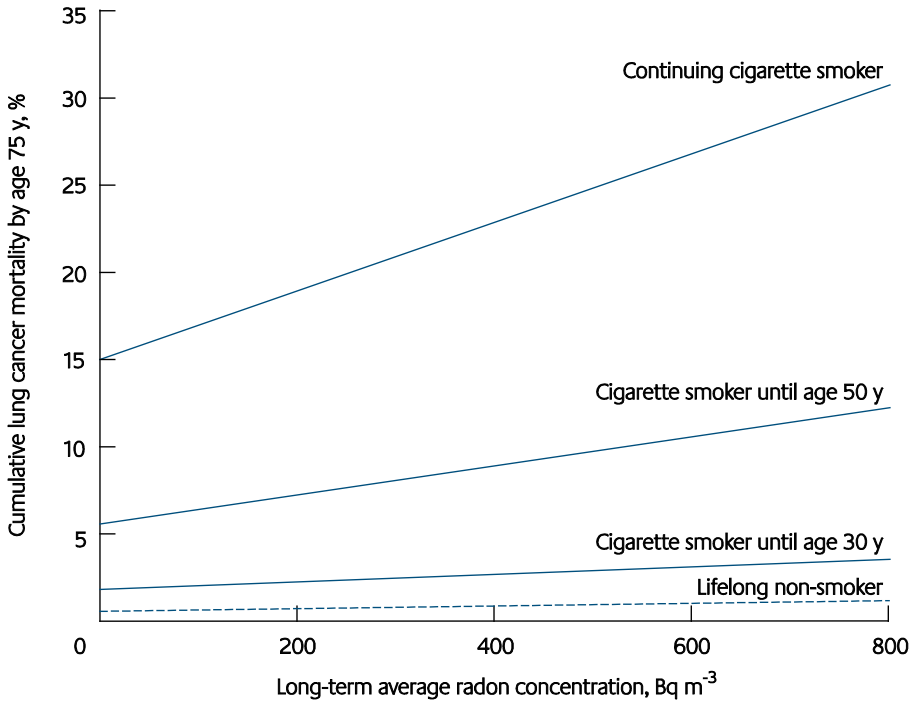
There is strong evidence from epidemiological studies of radon-exposed miners, from animal experiments, and from dosimetric calculations that exposure to radon can lead to lung cancer. Based on this information, the International Agency for Research on Cancer concluded more than 20 years ago that there was sufficient evidence of carcinogenicity in humans (IARC, 1988).

More recently, epidemiological studies have been conducted of people exposed to radon in their own homes. These studies now provide confirmation that radon is a cause of lung cancer in the general population and they provide powerful new evidence to help quantify the risk of residential radon exposure (AGIR, 2009; ICRP, 2007; UNSCEAR, 2009; WHO, 2009). In particular, the dose–response relationship appears linear, with no evidence of any threshold radon concentration below which there is no risk. There is now direct evidence of a risk below 200 Bq m^{-3}, the UK Action Level at the time the research was published (NRPB, 1990b).

Currently, the best information on the risks from radon exposure in homes is that published by Darby et al (2005, 2006), which shows the association between the long-term average residential radon concentration and the risk of lung cancer in a pooled analysis of individual data from 13 European studies. From this analysis, it was estimated that any increase in radon concentration of 100 Bq m^{-3} would increase an individual's risk of lung cancer by between 5% and 31%, with a central estimate of 16%.

A number of factors could not be taken into account in this pooled analysis of European studies. As a result, it is possible that the true percentage increase in lung cancer risk from radon exposure is somewhat higher than the central risk estimate of 16% per 100 Bq m^{-3}. A slightly higher risk estimate is also suggested by the studies of miners exposed to radon (BEIR VI Committee, 1999), although the overall conclusion from such comparisons is that the data are remarkably consistent (ICRP, 2009; UNSCEAR, 2009).

The available evidence suggests that the same percentage increase in lung cancer risk per 100 Bq m^{-3} increase in radon concentration applies for men and women, across all age groups and for current smokers, ex-smokers and lifelong non-smokers (see the figure). Since the baseline risk of lung cancer is much higher among smokers than among non-smokers, this means that – in absolute terms – the increase in lung cancer risk due to radon is much higher among smokers than it is among non-smokers. The findings of the European pooling study imply that at long-term average radon concentrations of 20, 100 and 200 Bq m^{-3}, the cumulative absolute risks of lung cancer by age 75 years in the UK would be about 0.42%, 0.47% and 0.53%, respectively, for lifelong non-smokers, and about 15%, 17% and 19%, respectively, for continuing cigarette smokers. For recent ex-smokers, the risks would be somewhat lower than those for current smokers, while for long-term ex-smokers, the risks would be close to those for lifelong non-smokers.



Cumulative absolute risk of death from lung cancer by age 75 years versus long-term average radon concentration at home for continuing cigarette smokers, ex-smokers and lifelong non-smokers in the UK (AGIR, 2009)

3.2 Distribution of high radon concentrations in the UK

The table overleaf shows the housing stock, the number of homes measured and the number identified at or above 100 Bq m^{-3} and 200 Bq m^{-3} for each part of the UK; the highest concentration found is also provided. It is estimated that the total numbers of homes with average radon concentrations at or above 100 Bq m^{-3} and 200 Bq m^{-3} are about 500,000 and 100,000, respectively, so the numbers currently identified as being above these levels are roughly one-quarter and one-half of these estimated totals. As would be expected, most of the homes with high radon levels that are yet to be identified are expected to be located in radon Affected Areas but a significant proportion (20–25%) are expected to be in areas designated as having less than 1% probability of exceeding 200 Bq m^{-3}.

Radon levels are variable within dwellings and are generally greater in ground-floor rooms than in rooms on upper floors. Radon concentrations are also likely to be greater in basements.

Summary data from the national radon database held by the HPA (January 2009)

Country	Housing stock*	Number of results†	Number of homes identified at or above 200 Bq m^{-3}	Number of homes identified at or above 100 Bq m^{-3}	Highest concentration found (Bq m^{-3})
England	22,500,000	465,000	52,900	121,400	22,000
Scotland	2,500,000	18,000	370	1,300	4,600
Wales	1,300,000	17,000	1,800	4,300	4,200
Northern Ireland	700,000	23,000	1,200	4,000	4,900
Totals	**27,000,000**	**523,000**	**56,000**	**131,000**	–

* Obtained from the residential housing stock contained within the Royal Mail address files.
† First valid measurement in the property only.

3.3 International advice and guidance

3.3.1 International Commission on Radiological Protection

The primary source of international recommendations on protection against ionising radiation, including exposure to radon, is the International Commission on Radiological Protection (ICRP). The ICRP issues general recommendations for a system of protection (ICRP, 2007) and has issued specific advice for protection against radon, in Publication 65 (ICRP, 1993) and a recent statement (ICRP, 2009).

The ICRP states that some remedial measures against radon in dwellings will almost always be justified above a continual annual effective dose of 10 mSv (millisievert) and that an Action Level should be set within the range of annual effective doses between about 3 mSv and 10 mSv. These doses were estimated by the ICRP to correspond to continuous domestic exposures at average concentrations of 200 Bq m^{-3} and 600 Bq m^{-3}, respectively. The ICRP also drew attention to the merit of defining radon-prone areas in which the concentration of radon in buildings is likely to be higher than is typical of the country as a whole. This would, in the view of the ICRP, allow attention to be focused on radon where it is most exigent and action to be concentrated where it is most likely to be effective.

In its most recent general recommendations for a system of protection against ionising radiation the ICRP retained the concepts of Action Levels (now called Reference Levels) against radon and of radon-prone areas (ICRP, 2007). The 2007 recommendations also stated that national authorities should set a reference level for radon in dwellings and that the upper value for such a reference level should be 600 Bq m^{-3}. The ICRP also recommended that the estimation of risk from domestic radon exposure should be informed by the pooled residential radon case–control studies. The HPA has endorsed the overall approach recommended by the ICRP to the control of radon in homes and workplaces (HPA, 2008b).

The ICRP (2007) stated that:

> "It is the responsibility of the appropriate national authorities to establish their own national reference levels for radon, taking into account the prevailing economic and societal circumstances and then to apply the process of optimisation of protection in their country.
>
> "All reasonable efforts should be made to reduce radon-222 exposures in homes and at workplaces to below the national reference levels to a level where protection can be considered optimised.
>
> "The actions taken should be intended to produce substantial reduction in radon exposures. It is not sufficient to adopt marginal improvements aimed only at reducing the radon concentrations to a value just below the national reference level.
>
> "National authorities should periodically review the values of the national reference levels for radon exposure to ensure that they remain appropriate.
>
> "Regulatory authorities may wish to specify levels at which protection against radon-222 can be considered optimised, ie where no further action is needed.
>
> "The implementation of the optimisation process should result in concentration activities below the national reference levels.
>
> "In general, no further action will be required apart from perhaps monitoring activity concentration periodically to ensure that levels remain low."

The HPA notes that the ICRP advice is consistent with existing UK policies with regard to setting a national reference level, defining radon-prone areas of the country, and considering radon exposure at work at levels above (but not below) the national reference level as part of occupational exposure. In November 2009 the ICRP issued a statement on radon (ICRP, 2009) updating its advice and revising the maximum value of the reference level for homes to 300 Bq m^{-3}. It also advised that doses from radon will in future be calculated using dosimetric modelling methods and that there is likely to be an increase in effective dose per unit exposure of around a factor of two.

3.3.2 European Union

The European Commission issued a non-binding recommendation for protection of the public against indoor exposure to radon in 1990 (EC, 1990). For existing buildings, the European Commission recommended that national authorities establish a reference level, corresponding to an effective dose of 20 mSv per year (estimated to be equivalent to 400 Bq m^{-3}, using the conversion factor in use by the ICRP at that time), above which consideration should be given to simple measures aimed at reducing radon concentrations.

3.3.3 World Health Organization

In 2009 the WHO published a handbook on indoor radon (WHO, 2009). The Handbook gives practical guidance on radon risks, strategies, measurement methods and dose reduction. It also recommends that countries set a reference level for the maximum accepted average annual radon concentration in a residential dwelling. On setting the value of the reference level, the Handbook says:

> "It is recommended to set a national reference level as low as reasonably achievable. In view of the latest scientific data on health effects of indoor radon a reference level of 100 Bq m^{-3} is justified from a public health perspective because an effective reduction of radon-associated health hazards for a population is herewith expected. However, if this level cannot be implemented under the prevailing country-specific conditions, the chosen reference level should not exceed 300 Bq m^{-3} which represents approximately 10 mSv per year according to recent calculations by the ICRP."

3.4 National advice and guidance

3.4.1 AGIR report and recommendations

The independent Advisory Group on Ionising Radiation of the HPA undertook a substantial review of the effects of radon and its decay products on the health of the UK population (AGIR, 2009). The AGIR considered the application to the UK population of the risk estimates derived from the pooled epidemiological studies of residential radon exposure, and also examined the application of health economics to radon policies. The AGIR report contains 16 recommendations. The HPA responses to these recommendations were appended to the consultation document on radon (HPA, 2009).

The cost-effectiveness calculations in the AGIR report focused on two principal areas: the cost-effectiveness of changes to building regulations to reduce radon concentrations in new homes, and the cost-effectiveness of government surveys to identify homes with high radon concentrations, and persuade householders to take action to reduce the concentrations below the radon Action Level.

It was concluded that changes by government to the building regulations have the potential to reduce the total number of deaths in the UK caused by radon in a cost-effective manner. In anticipation of publication of the AGIR report, the HPA (2008a) issued advice to government on radon preventive measures in new buildings, restated in Section 4 of this document.

The AGIR report included example analyses of the cost-effectiveness of strategies for reducing radon concentrations in existing homes. These examples indicated that reducing the radon concentration threshold at which remedial action was advised could result in an improvement in the cost-effectiveness of government-funded radon surveys (AGIR, 2009). This increase in estimates of cost-effectiveness occurs because the cost of a survey of a given area is the same irrespective of the Action Level, but a reduction in the threshold radon concentration at which remedial action is taken should result in more homes having radon reduction measures installed. The report showed that greater improvements in

cost-effectiveness could be achieved by increasing the proportion of householders who participate in measurement campaigns and undertake remedial action when advised to do so.

3.4.2 COMARE recommendations

In November 2007, the Department of Health's Committee on Medical Aspects of Radiation in the Environment made the following recommendations regarding radon in buildings (COMARE, 2007).

> "**1** Very high level houses should be remediated and government should check that appropriate legislation is in place to enforce this action. Financial assistance should be made from central funds.
>
> "**2** The Action Level for schools should be reduced from 400 to 200 Bq m^{-3}.
>
> "**3** Consideration should be given to using radon-proof membranes in all new build in the UK in the future. This will have benefits in preventing egress of other soil gases and pollutants and provide better damp proofing. If required we believe legislation should be amended to ensure correct and tested installation of such membranes."

The HPA has incorporated recommendation 1 into its ongoing radon measurement and reduction programme. Special procedures to support householders are followed by the HPA and the relevant local authority when homes with very high radon concentrations are identified. The support available is tailored to the particular circumstances and will normally include a detailed survey and individual report on remedial options, often the provision of specialised equipment and, in some cases, help with the cost of installation. Confirmatory measurements after remediation are always offered. The 400 Bq m^{-3} level in schools, to which COMARE referred, relates to the application of the Ionising Radiations Regulations 1999 (GB Parliament, 1999) in workplaces. HPA advice in relation to recommendation 2 is presented in Section 4.5. The Department of Health requested advice from the HPA on recommendation 3 and, in May 2008, the HPA issued the recommendations (HPA, 2008a) which are restated in Section 4.1.

3.5 Responses to the consultation document

In 2009 the HPA consulted on options to revise its advice on radon (HPA, 2009). The responses generally favoured a move to a lower Action Level for radon in the home, but concerns were expressed regarding a reduced emphasis on higher radon exposures that would result from such a change and significant uncertainty over the practicality of a lower Action Level.

There was general support for the application of the Action Level for dwellings to buildings where there was prolonged public occupancy, but there was no consensus on the definition of prolonged occupancy. There was general agreement that assessment of such buildings required adherence to an agreed measurement protocol. There was also general support for further research on the effectiveness of methods for radon prevention and remediation, including passive preventive and remedial measures.

Various types of information campaign were suggested to improve public understanding of the radon problem. It was also suggested that the key to obtaining a high remediation rate was to provide central funding for remedial actions.

One of the proposals included in the consultation document was to replace the concept of radon Affected Areas with three bands of low, medium and high probability of homes being above the Action Level. The rationale for such a change was to avoid the implication that areas outside designated Affected Areas are not affected by radon at all, and to provide a graduated scheme in which advice on the necessity of radon measurements depends on the probability of high radon concentrations being found. There was a clear majority of opinion among respondents in favour of such a graduated system, although not all respondents expressed a view on this.

A summary of the comments made during the consultation and the HPA response will be published separately.

4 Advice on Protection Against Radon

This section contains HPA advice on protection against radon, which is consistent with the recommendations of the ICRP (2007, 2009) and the WHO (2009). The advice builds on that issued by the NRPB (1990a,b). In developing revised advice, the HPA maintains the aim expressed in 1990: to reduce the radiation exposure of those most at risk from high concentrations of radon while focusing attention on radon reduction where it is most required. An additional aim is that the advice should lead to an overall reduction in radon exposure in the UK. The HPA notes that significant reductions in the mean radon exposure of the UK population can be achieved only through changes to building practices, and that the reductions will be gradual. In view of the fact that the majority of radon-related lung cancers are caused jointly by radon and smoking, the recommendations stand alongside existing programmes to reduce smoking-related lung cancers.

4.1 Radon Action Levels

The ICRP has advised on optimising protection against radon and the roles of reference levels and reduction measures (ICRP, 2007, 2009). To apply this advice in the UK, the HPA advises that a system of an Action Level and a Target Level should be used to guide decisions relating to radon reduction. The HPA advises that the Action Level should be 200 Bq m^{-3} and that the Target Level should be 100 Bq m^{-3}, expressed as the annual average radon concentration in the home.

The role of the Action Level is to assist in the designation of areas of concern for possible high radon concentrations in new and existing homes and to provide a threshold above which all householders are advised to remediate. The principal role of the Target Level is to provide an objective for remedial action in existing homes and preventive action in new homes.

Householders with radon measurement results in between the Target and Action Levels should seriously consider taking remedial action, informed by the risk to the occupants of the home, particularly their smoking status. Householders with radon concentrations below the Target Level are not advised to remediate. Use of the two Levels retains the emphasis on reducing the highest radon concentrations, while recognising that concentrations below the Action Level entail radiation exposures higher than desirable. Having two Levels avoids the false impression that there is a clear boundary between safe and unsafe radon concentrations, and the impression that remediation has failed if it does not reduce concentrations below the Action Level. Further advice is given in Section 4.4.

4.2 Areas affected by high radon concentrations

The HPA recommends that all parts of the UK should be classified according to the probability that a home in the locality will have an indoor radon concentration above the Action Level.

a Areas where less than 1% of homes are estimated to be above the Action Level should be regarded as lower probability radon areas.

b Areas where 1% or more but less than 10% of homes are estimated to be above the Action Level should be regarded as intermediate probability radon areas.

c Areas where 10% or more of homes are estimated to be above the Action Level should be regarded as higher probability radon areas.

The term radon Affected Areas is retained, for consistency with current administrative measures to control radon. A radon Affected Area is an area in which the estimated probability of an existing or future home exceeding 200 Bq m^{-3} is 1% or more. Taken together, the intermediate and higher probability radon areas constitute radon Affected Areas.

Appropriate maps are available for all parts of the UK showing the probability of homes having high radon concentrations.

4.3 Measurements of radon concentrations

The HPA recommends that householders in lower probability radon areas need not make measurements of radon concentrations in their homes unless they have a specific reason to suspect that occupants may be exposed to higher radon concentrations, such as in those homes which have underground rooms that are often occupied.

The HPA recommends that householders in intermediate and higher probability radon areas should make measurements of indoor radon concentration in their homes. Where the decision to test for radon lies with the householder, some householders in intermediate probability areas may consider not testing, depending on household circumstances and judgements on risk (eg lower risk to non-smokers). However, it should be remembered that while the prevalence of homes above the Action Level is less in intermediate probability than in higher probability radon areas, high concentrations do occur in homes in intermediate probability radon areas. The only certain way of determining the radon concentration in a home is through an appropriate measurement. In general, it should be considered prudent to test for radon rather than to rely upon a probability estimate.

At the time of publication, around half of the homes in the UK above the Action Level have been identified, mainly in surveys funded by national and local government. The HPA recommends that further surveys to identify homes with high radon concentrations should be undertaken. These should include higher and intermediate probability radon areas according to practicality and the availability of resources.

Surveys are not appropriate in lower radon probability areas. These recommendations are consistent with the findings of the AGIR (2009).

4.4 Reducing radon concentrations

The HPA recommends that householders with radon concentrations above the Action Level should reduce the radon concentration to as low as reasonably practicable, if possible to below the Target Level.

The HPA recommends that householders with radon concentrations below the Action Level but above the Target Level, should seriously consider reducing the radon concentration, informed by the risk to the occupants of the home. The risks to individuals vary markedly between continuing smokers, ex-smokers and lifelong non-smokers, as shown in the figure (see page 9).

The appropriate authorities should give priority to reducing radon concentrations in those homes with the highest concentrations. Support and assistance should be considered for those households most in need. The appropriate authorities with responsibility for housing should consider what steps can be made to encourage and to aid householders to reduce their exposure to radon.

The HPA recommends that householders who have installed remedial measures to reduce radon concentrations should carry out measurements to ensure their effectiveness, and should repeat those measurements at intervals of perhaps five to ten years, and after substantial alterations to the home such as extensions.

4.5 Application of domestic radon Action Level and Target Level in non-domestic buildings

The HPA recommends that the domestic Action and Target Levels should be applied to non-domestic buildings with public occupancy exceeding 2000 hours per year and also to all schools. Measurement programmes for non-domestic buildings should conform to a protocol to be agreed by the appropriate government departments and national agencies.

4.6 Building regulations

This section reiterates advice previously issued by the HPA concerning new buildings (HPA, 2008a), in which the HPA made the following recommendations.

> "**1** Building regulations and supporting documents should be amended to ensure that all new buildings, extensions, conversions and refurbished buildings in the UK include basic radon protective measures.

> "**2** Building regulations and supporting documents should be amended to ensure that all buildings which require full radon protective measures [as defined in BR211 (BRE, 2007), BR376 (BRE, 1999) and BR413 (BRE, 2001)] are subject to appropriate radon tests during the first year of occupation. The current cost of such a test is around £30–£40. If a test indicates that the mean radon concentration in a building is above the relevant Action Level for radon, measures should be implemented to reduce the radon concentration to below the Action Level."

The aim will now be to reduce concentrations to below the Target Level of 100 Bq m^{-3} if possible.

4.7 Further research

The HPA recommends that there should be further study of the effectiveness of methods for radon prevention in new buildings, extensions, conversions and refurbishments (including administrative methods, such as mandatory inspection of the measures installed). Further information is needed, particularly for areas where full preventive measures are required. In the interests of energy efficiency, the HPA recommends that research is undertaken to develop better passive preventive and remedial measures.

5 References

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