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Performance of basic radon protection in new homes

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Performance of basic radon protection in new homes

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Abstract

New homes in areas of high radon risk should include radon protection, typically comprising a gas-tight barrier (known as ‘basic protection’) with provision for additional measures (known as ’full protection’) that can be activated if the indoor radon concentration is above the Action Level. A radon test should be completed once the home is occupied.

Radon measurements in homes expected to have radon prevention have been compared with measurements in homes without radon protection to determine the effectiveness of that protection. All homes were in the same radon risk areas. Radon concentrations in homes with barriers were reduced by over 40% compared with those without radon barriers installed.

Basic protection reduces the occurrence of radon concentrations above the Action Level (200 Bq m^{-3}) from around 30% in unprotected homes to under 12%.

The barrier does not completely prevent radon ingress. About 10% of the properties that were assessed in this study, and were considered to have a barrier, had radon concentrations above the UK Action Level of 200 becquerels per cubic metre of indoor air. This reinforces existing advice that properties built with radon barriers should be tested for radon to inform a decision to complete the additional provision.

Contents

1 Introduction

Radon gas originates from the radioactive decay of uranium in rocks and soils. If it escapes from the ground to the outdoor air it is quickly diluted to low concentrations; however it can be accumulated to higher concentrations indoors. In the UK the outdoor concentration is around 4 becquerels per cubic metre (Bq m^{-3}) of air. The average radon level in UK homes is about 20 Bq m^{-3}. The distribution of radon concentrations in homes is approximately log normal over a wide range of concentrations, with individual homes varying from less than 10 to 10,000 Bq m^{-3} or more (Rees and Miller, 2016; Miller and Rees, 2016).

Inhalation of indoor radon is the largest contributor to the average UK radiation exposure (Oatway et al, 2016). Higher radon levels have been clearly associated with an increased risk of lung cancer, with the excess risk appearing to be approximately proportional to the long-term average indoor radon concentration. A report by the Advisory Group on Ionising Radiation (AGIR) states that radon is the second largest cause of lung cancer after smoking, leading to over 1,000 deaths in the UK every year (AGIR, 2009). High concentrations of indoor radon are a significant risk to health.

The potential for high radon levels is partly determined by local geology including the concentration of uranium and the porosity and/or degree of fracturing in the near-surface geological features. Radon maps provide an indication of the radon potential and identify areas where high levels are more likely (Miles et al, 2007, 2011; Daraktchieva et al, 2015). Definitive datasets are used to assess the likelihood that an individual property will have a high radon level. The UK has a radon action level of 200 Bq m^{-3} and areas where the risk of exceeding this is 1% or more are termed radon 'Affected Areas'. Public Health England (PHE) advises that all homes in radon Affected Areas should have their radon levels assessed (HPA, 2010)*.

1.1 Protecting new homes against high indoor radon levels

Requirement C1 (CLG, 2010) of the Building Regulations 2010 states that: 'Reasonable precautions shall be taken to avoid danger to health and safety caused by contaminants on or in the ground covered by the building, and any land associated with the building'. The Approved Document Part C (CLG, 2013) refers to guidance produced by the Building Research Establishment (Scivyer, 2015). Both identify areas where such protection is necessary and the latter gives guidance on construction. This study was limited to England and Wales because legislation covering newly built homes is different in other parts of the UK. However, since the range of building styles in other parts of the UK is similar to that in England and Wales, it is considered valid to assume that the observations are applicable across the whole of the UK.

For areas of England and Wales where the potential for homes to exceed the action level is 3% or above, the guidance recommends the inclusion of 'basic' radon protection in new buildings. Basic radon protection consists of a well-installed damp-proof membrane, modified and extended to form a gas-tight radon-proof barrier between the ground and the building.

* On 1 April 2013 the Health Protection Agency was abolished and its functions transferred to Public Health England.

Experience shows that radon membranes reduce but do not completely prevent the ingress of radon into the property. Consequently, basic protection alone is sometimes insufficient.

In areas where the radon potential is higher, with 10% or more homes predicted to be above the action level, the guidance states that new buildings should include provision for 'full' radon protective measures (Scivyer, 2015; CLG, 2013). In England and Wales, full protection consists of basic measures plus either an inactive and capped 'standby' radon sump or a ventilated sub-floor void.

Since the membrane does not entirely prevent radon ingress, some new homes with this provision may have radon concentrations above the action level. A radon measurement is necessary to determine whether the property has a sufficiently low radon level, or whether the additional provision should be utilised. A representative radon measurement cannot be made until a property is occupied because indoor radon levels are significantly affected by ventilation, heating, etc, of the property. A radon measurement is advised in the first year of occupation (HPA, 2010). This informs the decision about whether the full measures should be activated by adding a fan to the sump system or to the sub-floor void. In many cases, it is expected that radon levels will be low and activation of the full measures will not be required.

A review of radon and public health risk in 2009 (AGIR, 2009) highlighted a concern that the investment in full radon protective measures in newly built homes is unlikely to be cost-effective unless the occupant of a new property is aware that the property should be tested and the additional protection activated if measurement shows that the radon levels are high. PHE has implemented an earlier recommendation (Hodgson et al, 2016) to adopt a rolling programme advising relevant householders that radon testing is important for new homes built with the higher level of radon protection. The most recent targeted programme in January 2018 included around 18,000 homes built from the beginning of 2012 to September 2017.

1.2 Aim of the study

The aim of this study was to explore the effectiveness of 'basic protection' installed in areas where full radon protection is expected, namely where 10% or more of properties in an area are expected to be above the Action Level.

The underlying approach was to compare the distribution of radon concentrations in homes with basic radon protection with unprotected homes in areas of similar radon risk.

2 Methods

2.1 Data collection

Radon measurement data for this study was selected from the UK National Radon Database (NRD). The study used radon measurements made in occupied homes. It was assumed that the full radon protection measure was not activated and that householders had not acted to reduce the radon levels. This is supported by an earlier survey that showed half of the home-owners completing the survey were unaware of radon in their homes (Hodgson et al, 2016). For homes built with radon protection, the measurement would reflect the effectiveness of the basic membrane and in some cases under-floor ventilation, depending upon construction.

The measurements were made in the period from 1990 to 2017. Over this period, building regulations and supporting guidance have evolved to reflect the development of radon risk maps and the availability of measures that can be implemented at the time of construction to protect against future radon ingress. No radon specific requirements were in place prior 1993. The details of requirements for new properties can be found in building regulations and supporting guidance and are summarised in Table 1 below.

A subset of results was selected that included measurements in homes that were built during 2011 and 2012. In this subset, owners confirmed through a survey that radon protection was installed (Hodgson et al, 2016).

Data subsets were also created for houses built before 1993 and between 1977 and 1993 when building regulations did not require radon protection. These were compared with selected measurement data, after 1993, when building regulations were amended to include requirements for radon protection on construction.

Depending on the date of build and radon Affected Area status, measurements in homes were selected to provide separate datasets where homes were constructed with and without radon protection. All datasets were chosen from areas of the same radon potential of 10% and above according to requirements of the building regulations and BR211 guidance (CLG, 2010 and 2013; Scivyer CR, 1991, 1999, 2007 and 2015) at the time of build. That guidance has evolved and has been updated in line with radon mapping in the UK. The guidance and associated maps indicate how and where radon protection should be installed. The data was selected according to the guidance and mapping that applied when the properties were built. Table 1 shows a summary of the guidance applied at various times.

Table 1 Summary of requirements for radon protection

Measurement data in homes built:	Associated guidance	Radon protection
Before 1993	None	No
Between 1977 – 1992	None	No
Between 1993 - 2000	BR211 1991 (1992 revision)	Yes
Between 2001 – 2007	BR211 1999	Yes
Built after 2007	BR211 2007 and 2015	Yes

2.1.1 Measurement data for homes built without radon protection

First time measurements were selected for homes built before 1993 and in areas that have a radon potential of 10% and above. A subset of homes built between 1977 and 1993 was selected for comparison to eliminate older properties that would have a wider variety of construction characteristics. None of these homes would have the 'basic' radon protection installed because they were built before building regulations included requirements for radon.

2.1.2 Measurement data for homes built with radon protection

First time measurements were selected for homes built after the year 2000 in areas that have a radon potential of 10% and above. Homes were selected according to appropriate legislation and associated guidance (Table 1) to reduce uncertainties about whether they were built with 'Full' radon protection.

Measurements in homes built between 1993 and 2000 were excluded from the dataset. During this time period, the associated guidance (Scivyer, 1991) listed place names and the boundaries of the radon Affected Areas were uncertain and difficult to match with records from the NRD.

Measurements in homes built in the period 2001 – 2007 were selected according to the relevant guidance and maps (Scivyer, 1999). Results were included for properties if they were in a 1 km grid square for which 'Full' radon protection was required.

Further measurements were selected for properties that were built after 2007 reflecting updates in the maps used to determine protection requirements (Scivyer 2007 and 2015).

Measurement results from homes built during 2011-2012 were taken from a previous study (Hodgson et al, 2016) in which home owners were offered a free radon measurement and were requested to complete a questionnaire.

The annual average radon concentrations were estimated using integrating etched-track detectors (Daraktchieva et al, 2018; Howarth and Miles, 2008). One detector was placed in the main living area and 1 in a used bedroom for a 3 month period. The results were seasonally corrected using the correction factors in place at the time of measurement and an average concentration for the property was established from the 2 measurements using weighting factors to reflect typical occupancy of the different rooms.

2.2 Data Analysis

To estimate the effect of the 'basic' radon protection, datasets were compared for homes built with and without radon protection by comparing distribution data using standard statistical methods. The geometric mean was used for comparison because it is assumed that the statistical distribution of the radon concentrations will be approximately log-normal as described by others (Gunby et al, 1993; Miles, 1994; Daraktchieva et al, 2014). Such distributions are often found when a number of independent variables interact multiplicatively. The percentages of homes with and without basic protection that were above the Action Level (200 Bq m^{-3}) and Target Level (100 Bq m^{-3}) were also evaluated. The data was analysed statistically using Minitab® 17.1.0.

2.2.1 Data limitations

It is assumed that provision for radon ‘full’ protection was applied to properties built at the time following the appropriate guidance. The analysis does not take account of other factors such as building characteristics.

3 Results

3.1 General overview of data

Table 2 shows the radon protection status and the number of homes with first time radon measurements that were used in a number of date of build categories before and after the introduction of radon protection in building regulations in 1993.

Table 2 Numbers of homes in year of build ranges

Date Built	Number	%	Radon Protection?
Before 1900	14,368	29	No
1900-1919	2,810	6	
1920-1944	5,362	11	
1945-1964	8,369	17	
1965-1976	10,071	20	
1977-1992	9,017	18	
Sub Total	49,997	100	
After 2001	5,784		Expected
2010-2011*	346		Expected
2010-2011*	113		Confirmed
Sub Total	5,784		Expected
Total	55,781		
*Subsets of the 'after 2001' group			

The largest proportion of homes was built before 1900. The building characteristics of this group would be quite different to those built since 1993. For this reason, more recent data for homes built in the period 1977 to 1992 was also selected for comparison with datasets built after 1993.

3.2 Geographical distribution of homes

The geographical distributions of homes built with no protection (built 1977 to 1993) and expected protection (after 2001) are shown in Table 3. They are also plotted by postcode on a map of England and Wales in Figure 1. It should be noted that in some cases where the plots are concentrated, especially in the South West, there will be overlapping. Figure 1 also shows the South West on a larger scale. Both maps show that the 2 datasets of homes with no protection and protection are from similar areas.

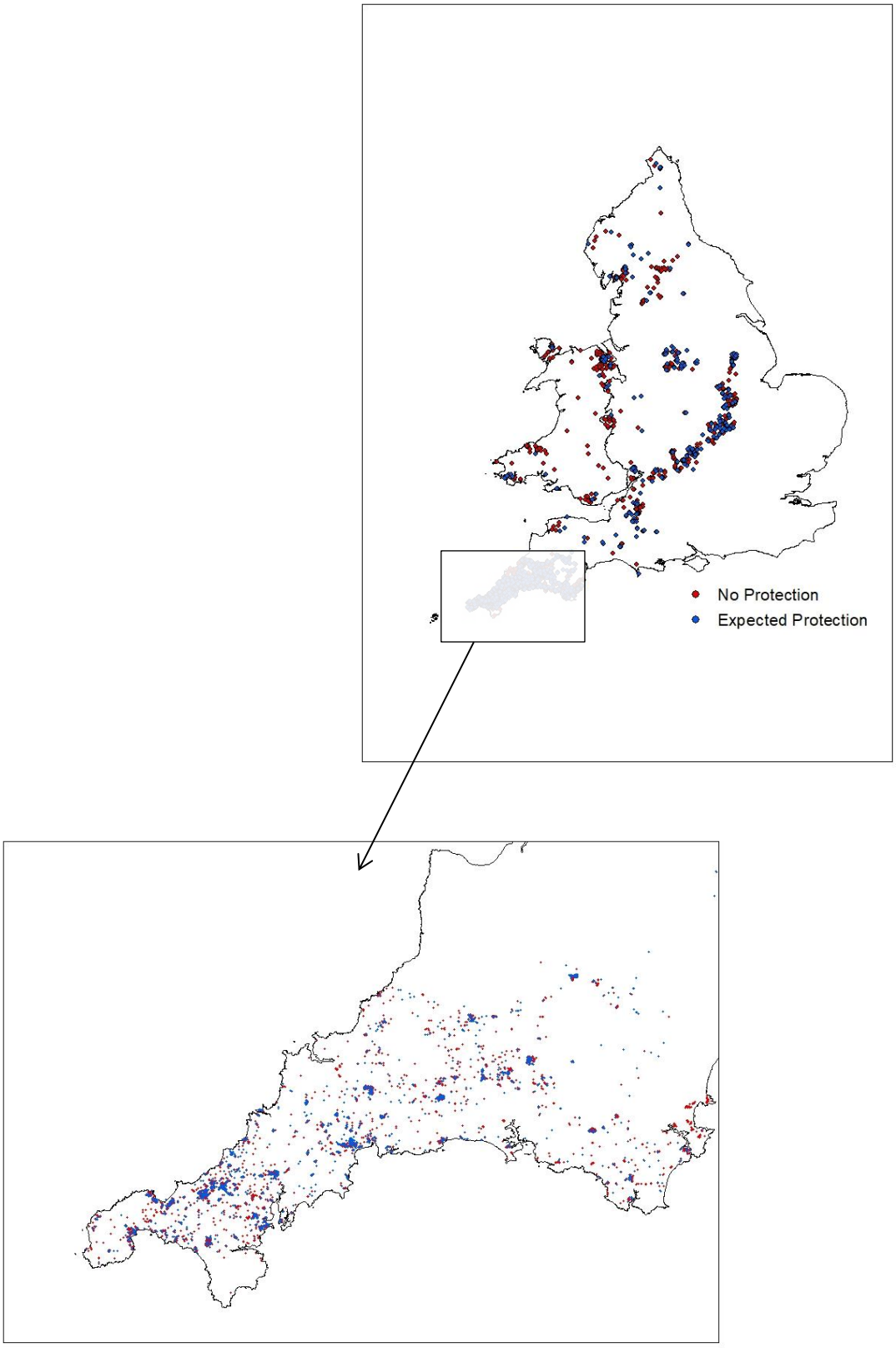

Figure 1 Geographical distribution of homes in England and Wales and expanded in South West England

Table 3 Geographical distribution of properties with and without radon protection

Postcode area	No Protection	Expected protection
TR	38.1	37.2
PL	27.2	39.9
TQ	6.2	3.1
GL	3.6	2.0
CH	3.3	1.0
OX	2.5	1.4
LL	2.1	0.4
LA	1.8	0.2
EX	2.1	5.5
BA	1.7	0.7
LE	1.8	0.4
LN	1.7	3.1
SK	0.9	0.4
BS	1.1	0.1
SY	0.9	0.1
NG	0.5	1.2
PE	0.6	0.2
DE	0.5	0.6
SA	0.5	0.1
DL	0.5	0.0
NN	0.6	1.5
NE	0.3	0.1
TA	0.1	0.1
Other areas	1.5	1.1
Total	100	100

Table 3 shows that almost 70% and 80% of homes with no radon protection and expected protection respectively, were constructed in the south west of England (Plymouth and Truro post towns). The remaining homes were scattered in radon Affected Areas across England and Wales.

3.3 Distribution of radon concentrations

Table 4 and Figure 2 show the distribution of concentrations in homes built with and without radon protection as a percentage frequency in bands of radon concentration. The distributions appear to exhibit the characteristic skewed-tail to high radon levels which are characteristic of log-normal distributions. There is a higher frequency of homes built with radon protection in the radon measurement range 0 – 100 Bq m^{-3} and a lower percentage of protected homes with high radon levels. This indicates a downward shift of the radon distribution compared to homes without radon protection. The effect of protection levels off at higher concentrations.

The percentage of homes in the higher concentration bands are reduced to around a third of those where there is no protection.

Figure 3 shows the cumulative percentage frequency of radon levels in homes built with and without radon protection. The effect of radon protection is indicated by the higher number of homes having lower radon levels.

Table 4 Distribution of radon concentrations in homes built with and without radon protection

	% Frequency (number)					
	Initial radon concentration range, Bq m^{-3}					
	0-100	101-300	301-1000	1001-3000	>3000	Total
No protection (before 1993)	43.3 (21,622)	37.1 (18,555)	16.6 (8,277)	2.7 (1,359)	0.4 (179)	100 (49,992)
No protection (1977-93)	47.2 (4,256)	34.8 (3,140)	15.2 (1,375)	2.4 (216)	0.3 (30)	100 (9,017)
Expected protection (after 2001)	70.3 (4,068)	23.2 (1,339)	5.7 (328)	0.8 (46)	0.1 (3)	100 (5,784)
Confirmed protection (2010-11)	69.0 (78)	28.3 (32)	1.8 (2)	0.9 (1)	0.0 (0)	100 (113)

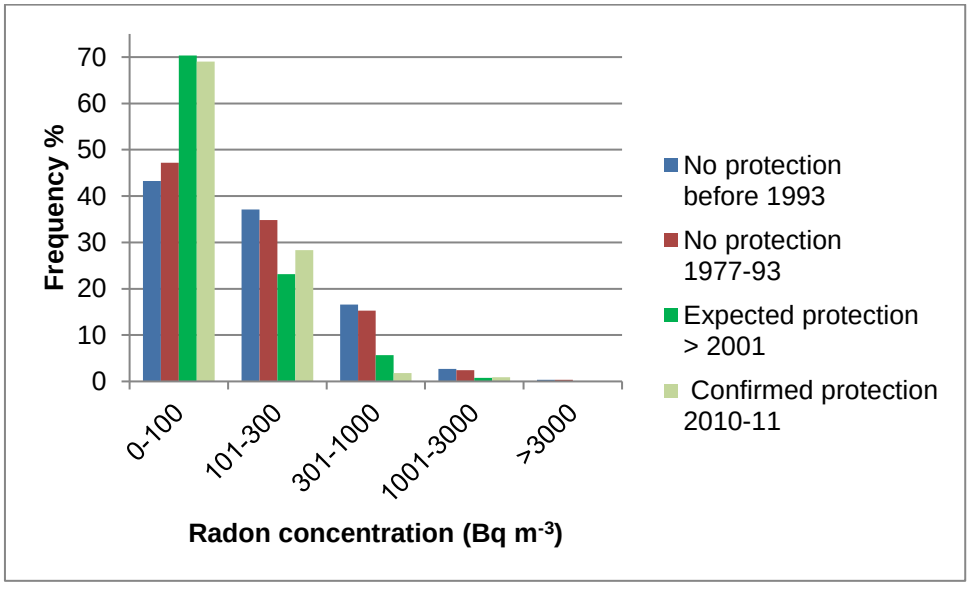

Figure 2 Distribution of radon concentration for homes built with and without radon protection

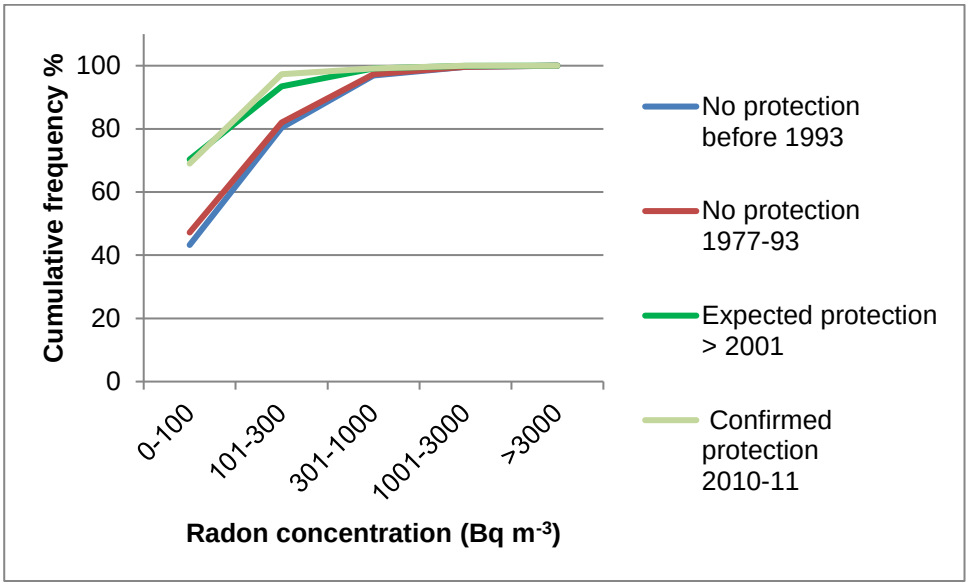

Figure 3 Cumulative frequency of concentration in homes built with and without radon protection

Table 5 and Figure 4 shows the effects of radon protection in homes compared to those without protection. The geometric mean of radon concentration in homes built since 2001 with radon protection is 48% lower than the mean concentration in homes built before 1993 without radon protection. Comparing the same group of protected homes with unprotected homes built more recently (1977 – 1993), shows a slightly lower but similar reduction (42%) in mean radon concentration.

The effect of basic protection on the occurrence of high radon concentrations in new homes can be seen by comparing the percentage of homes that exceed different high concentrations. The percentage of homes with radon protection that are above the Action Level (200 Bq m^{-3}) is 11.8% compared with 31.6% in all properties built without protection. The effect of radon protection is also seen at higher radon concentrations. Around 10% of all unprotected homes exceeded 500 Bq m^{-3} compared with around 3% of protected homes.

Table 5 Effects of radon protection in homes

	Number of properties	Geometric mean (GSD) (Bq m^{-3})	Max conc (Bq m^{-3})	Percentage of houses above Target Level (100 Bq m^{-3})	Action Level (200 Bq m^{-3})	500 Bq m^{-3}
No protection (before 1993)	49,992	121.0 (3.01)	24,392	56.7	31.6	9.7
No protection (1977-93)	9,017	108.8 (3.13)	21,939	52.8	29.3	8.9
Expected protection (> 2001)	5,784	63.4 (2.73)	4,545	29.7	11.8	2.9
Confirmed protection (2010-11)	113	64.7 (2.57)	1,523	31.0	8.8	2.7

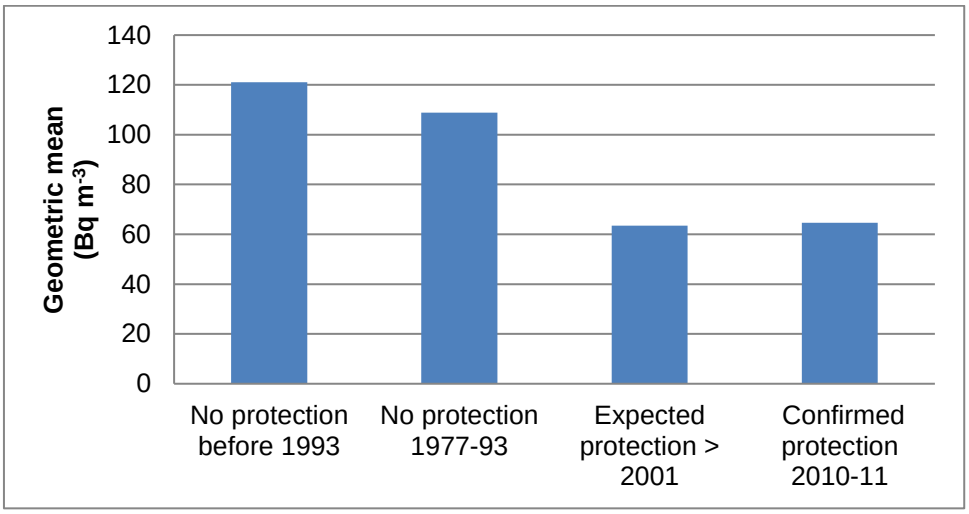

Figure 4 Effects of basic radon protection on radon concentrations in homes

4 Discussion

It is not practical to measure directly the effectiveness of radon protection measures installed during construction of homes. Ideally, a radon test would be done on the same building, in the same location, constructed with and without protection, which is not possible. In this study, homes were selected in the same radon potential areas to compare those built with and without radon protection. This study does not account for factors such as differences in construction, age, house type etc. The differences in construction have been limited by comparing the most recent measurements in homes built in the period 1977 to 1993, prior to the introduction of radon specific Building Regulation requirements.

The study evaluated a measure of the effectiveness of radon protection installed in areas where full radon protection is expected (where 10% or more of properties are likely to exceed the Action Level). The homes for each dataset were chosen according to radon risk maps and guidance available at the time of build (Scivyer 1991, 1999, 2007 and 2015). For homes built with radon protection, the measurement essentially reflects the effectiveness of the basic membrane and/or under-floor ventilation. As the radon concentration was deemed to be the first test in each property, it was assumed that full protective measures would not have been activated.

4.1 Effectiveness of radon protection

A downward shift in the distribution of radon concentrations in protected homes was observed with a reduced frequency of protected homes exceeding the radon Action Level. Around 32% of unprotected homes were above the Action Level compared with 12% in protected homes.

Measurements in homes with radon protection show that the geometric mean is reduced by 48% compared with homes that were built before 1993. A subset of homes built between 1977 and 1993 was selected for comparison to eliminate very old properties that would have quite different construction characteristics. The geometric mean of the radon concentration in homes built with protection was 42% lower than in this subset.

The percentages of unprotected homes with a radon concentration above the Target Level (TL) and Action Level (AL) were around 57% and 32% respectively. For protected homes, these percentages decreased to 30% and 12% for the TL and the AL respectively.

As anticipated, inclusion of ‘basic’ protection does not always result in radon concentrations being below the Action Level. The provision for full protection enables further reduction by activating the ‘standby radon sump’ or by increasing under-floor ventilation by using a fan.

The results of this study illustrate the effectiveness of the basic membrane that is fitted across the footprint of the building. This shows that the policy of fitting membranes is achieving its intended purpose of providing significant reductions in radon levels.

Basic radon protection is successful at reducing radon levels when compared with properties built in the same area in the period prior to the introduction of this requirement although, as expected, reduction below the Action Level is not always achieved. PHE recommends that a 3-month test should be done in radon protected new homes as soon as possible once the

property is occupied (HPA, 2010). If the Action Level is exceeded further measures can be activated to reduce radon levels further.

4.2 Other studies

In 1994, the Building Research Establishment (BRE) (Woolliscroft et al, 1994) published the results of field trials on the effectiveness of radon protection measures in new dwellings. Tables 6 and 7 show summaries of this work.

Table 6 Mean annual average radon levels in areas of different radon potential with effect of radon protection

	Mean Bq m^{-3} (number of properties)		
	Membrane	**No membrane**	**% reduction**
Radon potential 10-30%	63 (65)	212 (88)	70
Radon potential >30%	141 (49)	208 (70)	30

Table 7 Mean annual average radon levels with different construction type and effect of radon protection

	Mean Bq m^{-3}		
	Protected	**Unprotected**	**% reduction**
Block and beam	47	103	55
in situ concrete	87	194	55

The results are similar to those from this study. Woolliscroft observed a higher percentage reduction in the lower 10-30% radon potential areas and a lower percentage reduction in the 30% and above areas (Table 6).

A block and beam floor can be radon protected using ventilation provided by under-floor ventilation bricks whereas the in situ concrete is protected with a membrane. On average, both the membrane and the ventilated block and beam floor roughly halve the annual average indoor radon level compared to unprotected homes (Table 7). BRE also stated that their analysis showed evidence that the radon protection measures recommended in the Building Regulations and associated guidance actually work in practice.

An analysis (Groves-Kirkby et al, 2006) of radon concentration in 64 homes built with radon protection in the Northampton area, specifically NN6 9 postcode areas, showed that the annual average radon concentrations exhibited a log-normal distribution and they were significantly lower (80% reduction) than 7 homes in the same postcode sector that did not have protection. Around 11% (7 homes) were above the Action Level; comparable to the results in this study where around 12% measured above the Action Level.

The Radiological Protection Institute of Ireland (RPII) studied the impact of new building regulations in radon potential areas of greater than 10% that required measures to be installed during construction to prevent radon entry (Department of Environment and Local

Government, 1997). The protection comprised an inactive sump and a barrier membrane across the footprint of the building. Summary data showing the impact of Building Regulations is in Table 8. Homes constructed in Tralee after the introduction of the Building Regulations are around 50% lower than those constructed prior to the Building Regulations. In Ennis, no homes were tested that were constructed prior to the Building Regulations so were compared to the Irish National Radon Survey. In both Ennis and Tralee, protected homes had lower radon concentrations compared with the Irish National Radon Survey. Synnott et al, (2004) suggested that radon barriers are effective in reducing the average radon concentrations and the number of homes in excess of the Action Level (200 Bq m^{-3}).

Table 8 Summary data showing the impact of building regulations in Ireland

Area	Number of homes	Geometric mean Bq m^{-3}	No (%) homes above AL	Reference
Ennis, Co Clare				
Post building regulations	90	49	11 (12%)	Synnott et al, 2004
National radon survey	67	104	18 (27%)	Fennel et al, 2002
Tralee, Co Kerry				
Post building regulations 1998	44	68	9 (20%)	Synnott et al, 2004
Building regulations pre 1998	29	126	13 (45%)	Department of Environment, 1997
National radon survey	32	94	8 (25%)	Fennel et al, 2002

Further surveys in Kilkenny, Ireland (RPII, 2005) showed that a downward trend was observed in average radon levels in new homes compared to those built before 1998, when building regulations came into force (RPII, 2005 press release). Newbuild homes had average radon concentrations of 49 Bq m^{-3}, which is approximately 33% lower than the corresponding average of 73 Bq m^{-3} for homes built between 1992 and 1997.

Results of these studies are similar to and support the results of this PHE study.

4.3 Public health outcomes

The reduction in radon concentration as a result of radon protection installed in newly built homes will result in a reduced risk of lung cancer for the occupants.

A previous study (Hodgson et al, 2016) highlighted the fact that home owners in new homes with built-in radon protection should be made aware that they should do a post occupation radon test to check that radon levels are below the Action Level. Advice on further protection measures can be given to those householders whose radon levels exceed the Action Level.

5 Conclusions

In specific areas, new homes are expected to be built with radon protective measures comprising a ‘basic’ measure, typically a radon membrane and provision for further ‘full’ measures, if the property has high radon levels. To determine the effectiveness of the ‘basic’ radon protection, this study compared radon concentrations in homes with and without built-in basic radon protection.

The conclusions of this study are:

a The frequency distribution of radon concentrations in homes with basic protection showed a downward shift compared to those without protection in areas of the same radon potential.

b The geometric mean of radon concentration is reduced by over 40% in protected homes compared with unprotected homes built before 1993.

c The effect of basic protection levels off at higher radon concentrations. The percentage of homes in the higher bands of radon concentration is reduced to around a third of those where there is no protection.

d Around 10% of homes with basic protection in the study areas were above the radon Action Level. Further reduction can be achieved by activating the ‘full’ radon protection measures.

e The policy of providing basic radon protection in new properties in areas of high radon potential (at least 10%) is effective.

f PHE recommends that a 3-month radon test should be done as soon as possible in new homes with radon protection, once they are occupied. If the radon Action Level is exceeded, further measures can be activated to reduce radon levels.

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