

Guidance for Radon in Basements

Client: Royal Borough of
Kensington and Chelsea

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Executive summary

This guidance describes the requirements of the Royal Borough of Kensington and Chelsea (RBKC) for radon assessment and mitigation for planning applications for buildings with new or existing basements. Over 1000 new or repurposed basements were approved in RBKC between 2008 and 2017. This emphasises the need for guidance on how to manage radon risk in basements.

It provides a simple and pragmatic approach to deal with basement sites in low risk radon areas and following it should minimise the burden on developers. The approach also manages the requirements of different guidance and legislation. Much of the guidance on methods for radon protection provided in this document will also apply where the same systems are used to manage ground gas and volatile organic compounds (VOCs).

Radon is a radioactive gas that is colourless and cannot be smelt, tasted or seen. Exposure to radon increases the risk of lung cancer, the vast majority of deaths being attributable to the combined effect of smoking and radon exposure.

The source of radon in soils and rocks is uranium which is present at varying amounts in all soils and rocks. Geology is therefore the most important factor controlling radon risk. The key geology below RBKC is the London Clay Formation and the River Terrace Deposits, which are not known to have a high uranium content and are not considered high risk radon deposits. Despite this, monitoring within basements in RBKC has found concentrations of radon above the target level and residential and commercial action levels.

The London Clay will also limit the movement of any radon that is present in the ground because of its low permeability. Radon will move more quickly through permeable soils such as clean, coarse sand and gravel (some parts of the River Terrace Gravel in RBKC). Groundwater is also an effective barrier to radon migration.

Radon risk maps in the UK are not strictly applicable to basements and they also show that the whole of RBKC has the lowest possible radon potential. The maps show that radon protection is not required for ground level buildings anywhere in RBKC. It also means that most basements are likely to be at low risk of radon ingress when considered alongside the geology and basement construction.

Whether or not a basement is at increased risk of radon ingress depends on the construction and surrounding soils. In some cases, the risk of radon ingress into old basements or cellars with stone /brick construction can be greater than for ground level buildings. Conversely, there is often a very low risk, especially for new build deep basements with waterproof concrete construction in London Clay.

Any risk assessment for radon in basements should consider what type of basement that is being proposed, ie is it a new build basement, a basement extension below an existing building or the refurbishment of existing basement or cellar. A further consideration is whether a basement is used for residential or commercial purposes, and whether it is a workplace. The specific circumstances of each basement should be considered on a case-by-case during the planning application process.

There are several legal requirements that may apply to basements, depending on the use and ownership and whether it is an existing or new basement. These include national and local planning policy. As a result, RBKC must consider radon risk and protection measures in planning applications.

Radon is also a consideration with respect to the Building Regulations Part C1 (2), the Health and Safety at Work, etc. Act 1974, the Management of Health and Safety at Work Regulations 1999, the Ionising Radiation Regulations 1999, the Landlord and Tenant Act 1985 and the Housing Regulations 2004. All of these require radon to be managed and thus a risk assessment to be completed.

The guidance states that radon risk should be considered in detail for basements but there are no statutory requirements for how to complete the required assessments, testing, and mitigation. This is all provided in guidance documents, which are not mandatory, but provide generally applicable established approaches which might be suitable. There is a focus in UK guidance on use of the generic risk maps and periodic internal post-construction testing. However, other methods such as soil gas testing prior to construction may be used in RBKC and in some scenarios have certain advantages such as removing the need for long term indoor monitoring (and also demonstrate whether or not the basement requires any radon protection).

Radon maps are of little, if any, use when assessing basement radon risk in RBKC. Radon risk assessment should be based on a source-pathway-receptor (contaminant linkage) model and a simple flow chart is provided to determine whether radon mitigation and/or long-term internal monitoring will be necessary. It also describes the risk assessment and design process for radon using soil gas monitoring data. This is an established procedure used in other countries. In summary many basements will be identified as low risk and not requiring radon protection (but do require internal monitoring). Some basements will be medium risk and require radon protection and internal monitoring. If soil gas monitoring is undertaken and the radon Index is low this will remove the need for both protection and internal monitoring.

The report describes the most common methods of monitoring for radon both inside basements and in the soil below. It also provides guidance on the number of monitoring points required and the frequency of monitoring. If internal monitoring is carried out as a planning requirement in RBKC then some limited additional information over and above that required by UKHSA should be supplied with the results. This is important to understand the data quality associated with the results and the information should already be available for sites where planning permission is being applied for.

There are several ways of providing radon protection to basements. The radon protection should be considered alongside the waterproofing strategy. Passive protection is recommended by RBKC over active systems, such as ventilation systems with fans, because it requires ongoing maintenance by owners/occupiers which could become less effective in the future. The following options are available for providing radon protection to basements. These are listed in order of preference based on risk of long-term damage or deterioration, ongoing maintenance requirements and ongoing power costs:

1. Waterproof concrete,
2. Insulation as radon protection.
3. Radon/waterproofing membranes,
4. Cavity drains as radon protection.
5. Positive internal ventilation (PIV) of basement space,
6. Sub-slab depressurization (radon sumps). Will not work below groundwater table, typically not suitable below basements.

In all cases it is vital that service entries into the basement are adequately sealed, especially the internal annulus of ducts. This is the most common pathway for ingress of all types of ground gas into buildings.

This report provides the detailed requirements for the information and details that must be provided to RBKC to obtain approval of any radon mitigation proposal.

It is important that if radon protection is deemed to be required then the installation of all elements is independently verified by appropriately qualified professionals. This is likely to require a range of different professions depending on the system that is used.

Examples of poor installation are provided in Annex B and these are key areas to concentrate on during construction and verification.

1 Introduction

This guidance describes the requirements of the Royal Borough of Kensington and Chelsea (RBKC) for radon assessment and mitigation for planning applications and building control for buildings with new or existing basements.

The extent of the Borough is shown in Figure 1. Exposure to radon increases the risk of lung cancer. The risk increases as radon concentrations and duration of exposure increases. In some cases, the risk of radon ingress into basements and accumulation to unacceptable levels can be greater than for ground level buildings. Conversely, there is often a very low risk, especially for new build deep basements with waterproof concrete construction in London Clay. Therefore, basements require special consideration during the planning application process.

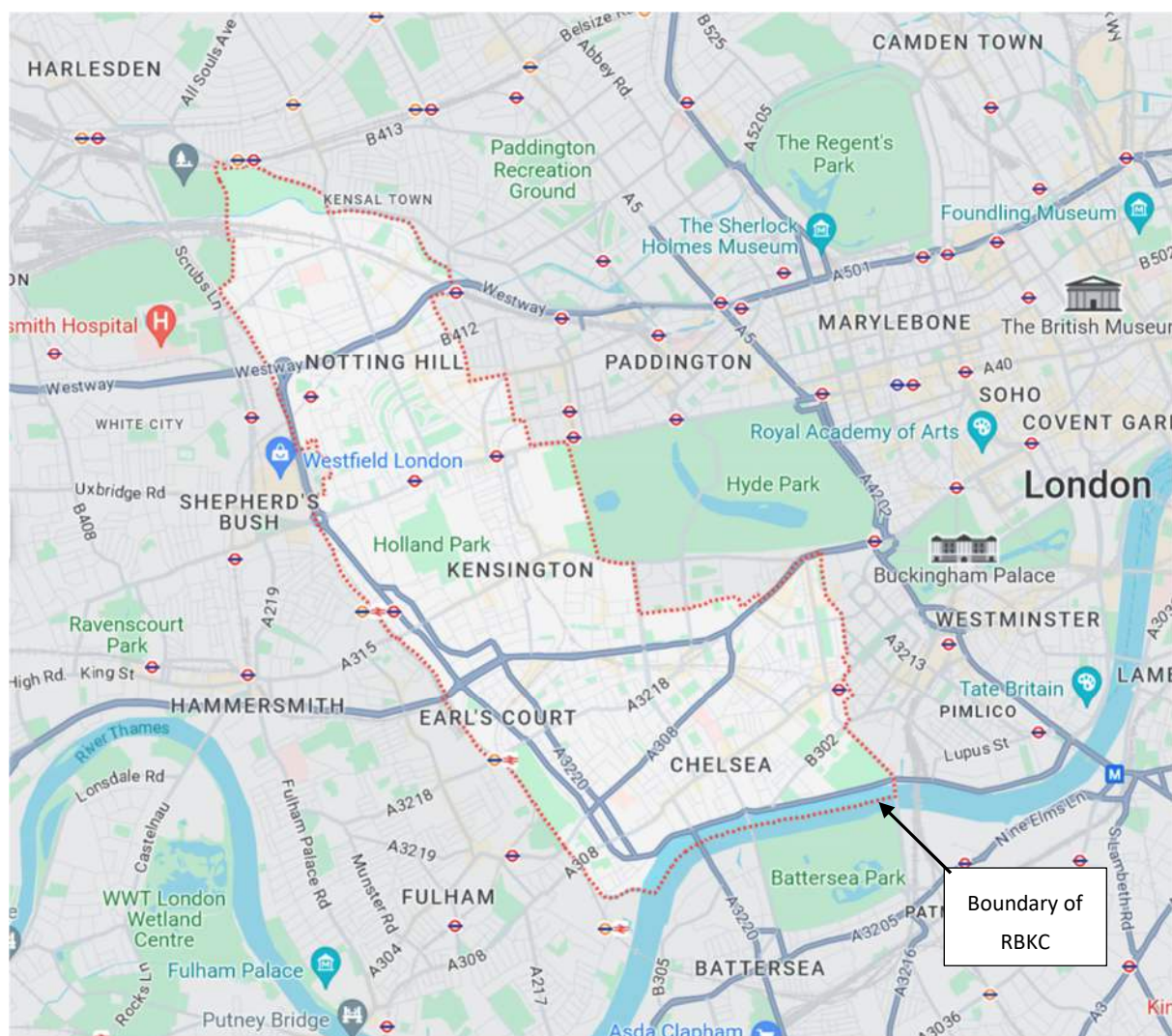


Figure 1 Extent of RBKC

2 Radon

2.1 Radon gas

Radon is a radioactive gas that is colourless. It cannot be smelt, tasted or seen. It is formed by the natural radioactive decay of radium, an element that occurs in small amounts in most rocks and soils. The radium occurs as a result of the radioactive decay of uranium and thorium in the environment. Radon is radioactive because it decays by losing an alpha particle and forming polonium. A simplified chain of radioactive decay is as follows:

$^{238}\text{Uranium} \rightarrow ^{234}\text{Thorium} \rightarrow ^{234}\text{Protactinium} \rightarrow ^{234}\text{Uranium} \rightarrow ^{230}\text{Thorium} \rightarrow ^{226}\text{Radium} \rightarrow ^{222}\text{Radon} \rightarrow ^{218}\text{Polonium} \rightarrow (\text{continues ultimately to stable } ^{206}\text{Lead})$

Radon is chemically inert and does not react with other elements. However, it does naturally decay, with a half-life of about 4 days. It is the decay products of radon that actually damage lung tissue and cause lung cancer. Radon is measured in becquerels (Bq), which is the number of atomic disintegrations per second. Radon gas concentrations are therefore reported in becquerels per meter cubed of air (Bq/m^3). The average radon concentration in houses in the UK is 20 Bq/m^3 , which is 20 radon atoms disintegrating every second in every cubic meter of air.

Radon is heavier than air (and is the heaviest known gas). However, this does not mean that it is more likely to accumulate in basements. For the radon to sink it must be present as a discrete cloud of gas rather than diffuse throughout an air space. It is emitted from the ground in such small quantities that a large cloud of gas cannot develop. This is because as the gas enters a building it diffuses into the fresh air and will remain that way. It does not reaccumulate in the bottom of the basement. It is frequently found at the lowest floor level because it accumulates there if the rate of ingress through the floor is greater than the rate it diffuses away from the point of ingress.

2.2 Radon health effects

Radon is recognised by the International Agency for Research into Cancer as a Class 1 carcinogen, resulting in lung cancer. European basic safety standards Council Directive 2013/59/Euratom, Annex 18 explains, in very broad terms, basic safety standards for radon. As a result, As Low as Reasonably Practicable (ALARP) applies where there are increased risks from radon¹. Research suggests that an individual's baseline lung cancer risk rises by 16% for each 100 Bq/m^3 of additional exposure and that being a smoker further increases the risk of lung cancer. Radon represents the greatest proportion of exposure to radiation in the UK population (about 48%), with indoor exposure estimated to result in 1,100 lung cancer deaths each year.

¹ Note that internationally and in EU Directives the term As Low As Reasonably Achievable (ALARA) is used. ALARA and ALARP are considered to be equivalent in meaning and purpose.

The vast majority (86%) of lung cancer deaths attributable to radon were caused by the combined effect of smoking and radon exposure, i.e. that avoiding either smoking or reducing levels of radon could have prevented the deaths.

It should also be noted that because there is no “safe level” for radon exposure and most people are exposed to low concentrations, most of the lung cancer deaths attributable to radon are at very low-level radon exposures with 70% occurring in homes with low radon levels ($<50\text{Bq/m}^3$) and only 3% related to radon concentrations above 200Bq/m^3 .

Further information about the health effects of radon, including benchmarking it with other public health risks, is provided in Annex A.

2.3 Radon thresholds

Different radon thresholds exist in the UK:

- 100Bq/m^3 is the **target level** for radon inside residential buildings;
- 200Bq/m^3 is the **action level** at which the UKHSA recommends that action is taken to reduce radon levels in residential settings;
- 300Bq/m^3 (annual average) is the **defined level** above which the Ionising Radiation Regulations 2017 require that employers take action to reduce levels in workplaces.

The aim of any radon risk assessment or mitigation design submitted as part of a planning or building control application should be to achieve 100Bq/m^3 or less inside residential developments. This is precautionary and takes into account different lifestyles. This should also apply to commercial buildings unless justification can be provided for a higher level based on its use and occupation (considering the likelihood of the potential for future significant changes in use).

3 Radon sources and pathways

3.1 Geology of RBKC

Geology is the key risk driver for radon. The geology of RBKC is well understood and the British Geological Survey (BGS) has developed a 3D model of the geology of the Borough (Figure 2). The geology can be described in the following general terms²:

- In the southern part of the Borough the surface geology is River Terrace Deposits (Kempton Park Gravel Member and Taplow Gravel Member) that increase in thickness towards the Thames where they reach a maximum of about 10m depth. London Clay Formation underlies the River Terrace Deposits.
- Along a strip adjacent to the River Thames, and up the former valley of the River Westbourne, Alluvium is present over the River Terrace Deposits.
- In the centre the superficial deposits are thinner and not always present over the London Clay. The superficial deposits in the centre comprise Langley Silt Member (which also extends over the Kempton Park Gravel in places), Lynch Hill Gravel or Boyn Hill Gravel.
- In the northern part of the Borough there are generally no superficial deposits with London Clay Formation present below the Made Ground.

There is also likely to be a layer of Made Ground generally present, typical of urban areas.

The London Clay extends to depths of around 90m below the western part of the London Basin³. In the Borough it is quite often thinner than this at depths of around 50m to 60m. The London Clay Formation is underlain by Lambeth Group and then Thanet Sand Formation and Chalk at depth.

² Bidarmaghz A et al, (2019) – see above

³ Jone LD and Terrington R (2011) Modelling volume change potential in the London Clay. Quarterly Journal of Engineering Geology and Hydrogeology 44(1) February 2011

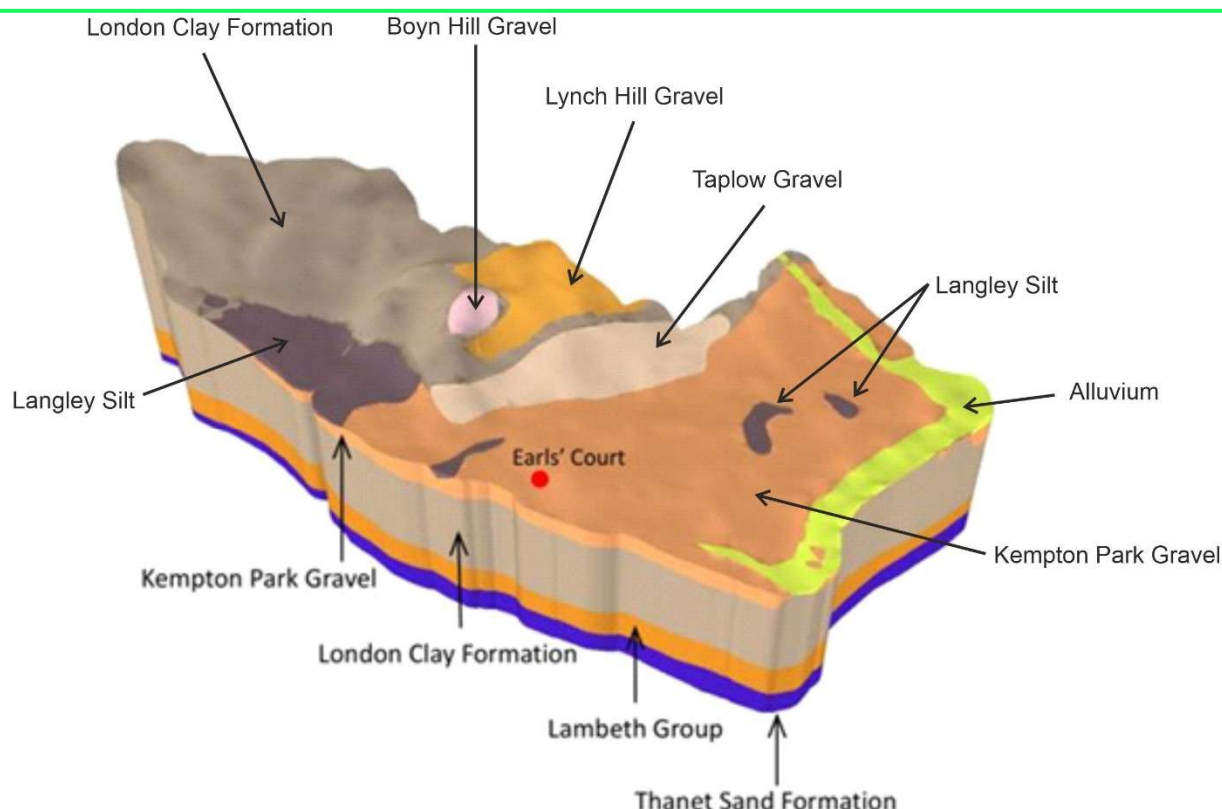


Figure 2 Geology of RBKC (Bidarmaghz A et al, 2019)

Descriptions and depths of the major River Terrace Deposits can be summarised as follows⁴:

- **Lynch Hill Gravel Member** – Average 7m thick locally up to 12m comprises sand and gravel with lenses of silt, clay or peat. Typical descriptions are medium dense, brown clayey, fine to medium sand and fine to medium to coarse gravel overlies soft brown, fine sandy, silty clay with a little fine gravel. Some grey patches. Becoming very silty and sandy near base then passing down into firm, dark grey, shaly silty clay with shells; brown fine to medium sand and fine to medium to coarse gravel with some red patches passing down into firm to stiff mottled grey-green and rusty brown silty sandy clay and clayey coarse sand and gravel. Some silty pockets; firm, brown, fine, sandy silt, clayey in places with some fine gravel overlies brown, silty, fine sand with some dark specks.
- **Boyn Hill Gravel Member** – Average 5m thick, locally up to 9m comprises sand and gravel with lenses of silt, clay or peat. Typical descriptions are medium dense orange brown silty sand with angular to rounded fine and medium gravel. With coarse gravel below; dense to very dense brown silty fine and medium sand with angular to rounded gravel and occasional small cobbles; passing down into very dense angular to rounded gravel and cobbles with some brown silty sand.

⁴ Aston ER and Mason PJ (2023) The distributions and variations of Quaternary Thames River Terrace deposits of Greater London, Quarterly Journal of Engineering Geology and Hydrogeology Vol. 56, 2023

- **Taplow Gravel Member** – Average 5m thick, locally up to 9m comprises sand and gravel locally with lenses of silt, clay or peat. Typical descriptions are fine to coarse sand with a little gravel becoming sandy; fine to coarse gravel and then sand and gravel; very sandy gravel; sandy very clayey silt with occasional gravel passing into fine sandy silt; slightly silty fine to coarse and gravel; gravel with some fine to coarse sand.
- **Kempton Park Gravel Member** – Average 6m thick, but much thicker if filling hollows in underlying bedrock (which is not the case in RBKC). Comprises sand and gravel locally with lenses of silt, clay or peat. Typical descriptions are silty fine sand with scattered gravel; fine gravel and coarse sand; slightly sandy slightly silty gravel; sandy gravel with occasional cobbles; silty gravel; sandy gravel; very sandy gravel.

Where the gravels contain clay, silt and fine sand it will result in reduced permeability compared to coarse sand and gravel deposits. Typically, silty sands and gravels have a permeability of around 5×10^{-5} m/s or less controlled by the silt content of the stratum. Also, the presence of silty and clayey layers in both strata will result in lower vertical permeability. This reduces the potential for high radon emissions.

The London Clay below RBKC, over the depths that basements are typically constructed, comprises firm or stiff silty clay that has a low permeability. Close to the surface the average permeability of fissured brown London Clay can be up to 1×10^{-7} m/s⁵. This is still low when considering radon migration through the ground. However, it can be higher in exceptional circumstances where fissuring is particularly prevalent⁶. As depth and stress increases the fissures become tightly closed and the effect on permeability reduces and is typically around 1×10^{-11} m/s.

3.2 Radon sources

The source of radon in soils and rocks is uranium. Uranium is present in all soils and rocks. In many areas it is very low with small amounts between 1 and 3ppm⁷. In such locations the radon does not pose a significant risk to people inside buildings. Geology is the most important factor controlling the source and distribution of radon⁸. There are certain rocks that can have high uranium contents. These include light-coloured volcanic rocks, granites, dark shales, some bituminous mudrocks, some carbonate rocks (that weather very quickly, such as Chalk), sedimentary rocks containing phosphate or ironstone and metamorphic rocks derived from these source rocks⁹. Superficial soil derived from radon source rocks such as River Terrace Deposits and Alluvium, can also have high uranium (in some cases resulting in higher soil gas radon than the source rocks because of a greater surface area over which radium can be produced as they are more eroded). Uranium can

⁵ <https://www.rbkc.gov.uk/pdf/REP-195-15%20Arup%20e%20mail%20-%20London%20Clay%20permeability%20-%2022%20Sep%202014.pdf>

⁶ Water Resources Board (1972) The Hydrogeology of the London Basin

⁷ USGS (2011) Geology of Radon, United States Geological Survey

⁸ ((Geological controls on radon potential in England, C. Scheib a, J.D. Appleton a, J.C.H. Miles b 1, E. Hodgkinson a Proceedings of the Geologists' Association Volume 124, Issue 6, December 2013).

⁹ USGS Geology of Radon

also accumulate in organic-rich soils and peat. There are recorded instances of localised high concentrations in UK peat deposits¹⁰.

BGS has identified high radon source rocks in areas of the UK outside RBKC. Some of the geological units associated with high radon potential in the UK are well known, such as the granite intrusions in southwest England, the Carboniferous limestones of Derbyshire and the Jurassic ironstones in Northamptonshire. However, the distribution of radon gas associated with these rocks and deposits is not uniform, it naturally varies over an area.

The London Clay Formation and the River Terrace Deposits in the RBKC area are not known to have a high uranium content and are not considered high risk radon deposits by the BGS, when compared to rocks and deposits with higher Uranian contents. Although there may be variations it is not likely that these will change the overall low-risk classification. If there is no source, then the risk posed by radon in the ground to development at ground level is minimal. For basements however, the UK Health Security Agency states that, *"All basement and cellar areas are considered to be at additional risk from high radon levels"*. This is irrespective of geographical location. This means that radon risk must be assessed for all basements in RBKC but, as discussed later in this report, the assessment may show that not all basements are at a higher risk of radon ingress.

3.3 Radon pathways

Where there is a radon source, pathways from the source are also needed for there to be a risk of radon ingress. Therefore, even where there is a high-risk source rock, some areas are less affected by radon ingress to buildings than others. Limestones and some sandstones are examples of rocks that frequently act as an effective radon pathway, allowing radon to travel relatively long distances from its source rock. These are rocks characterized by high porosity and permeability and open fractures through which gasses (and water containing dissolved gasses) pass quickly. Similarly, faulted rocks may act as a preferential pathway. None of these strata or features are present below the RBKC.

Radon will move more quickly through permeable soils such as clean, coarse sand and gravel (some parts of the River Terrace Gravel in RBKC) and very slowly thoroughly clayey soils (e.g. London Clay or clay and silt layers in the River Terrace Deposits in RBKC), although it is possible radon may collect in and move along fissures and sand lenses within the London Clay. If sand and gravels have a high clay and silt content or are saturated with groundwater (both of which sometimes occur in RBKC) this will reduce the rate of radon movement.

Transport mechanisms for radon through the ground include diffusion, advective flow and migration as dissolved gas in groundwater. However, due to its relatively short half-life radon will be depleted during transport. Very little radon migrates by diffusion over long distances. For example, it has been estimated that radon decays by about 90% after diffusion through about 5m of air,

¹⁰ Tye AM, Milodowski AE, and Smedley PL (2017), Distribution of natural radioactivity in the environment. British Geological Survey Internal Report, OR/17/001

0.05m of water or about 2m of soil. Transport beyond these distances involves other mechanisms¹¹ such as advective flow caused by slight negative pressure inside buildings.

Groundwater is an effective barrier to radon migration. Most of the radon will have decayed if it migrates through 25mm or so of water saturated soil or rock. Even in partially saturated soils, the higher the moisture content, the more radon flow is reduced. Therefore, basements that have the floor and much of the walls permanently below groundwater level are at low risk of radon ingress. However, groundwater can also be a source of radon if it enters buildings. Open fractures and fissures will increase the potential rate of radon movement.

The radon concentration in soils is relatively stable below about 1m depth in soils that are absent of fissures or cracks. Radon concentrations in soil gas are normally measured at around 1m depth below the proposed floor slab level^{12 13}. Soil gas measurements used to produce radon risk maps are also typically taken at around 1m depth¹⁴. The weather (rainfall, wind, temperature and barometric pressure changes) can affect the concentration of radon in soil gas at shallow depth. However, variations due to geology are often greater. This emphasises the primary importance of geology in radon emissions from the ground¹⁵.

3.4 Hydrogeology (groundwater)

There are two separate groundwater regimes below the Borough¹⁶:

- Perched water in the River Terrace Deposits that overlie the London Clay Formation.
- Groundwater within the sandy soils (Lambeth Group and Thanet Sand Formation) and Chalk that is present deep below the London Clay.

There is no significant free groundwater in the London Clay Formation, which is considered to be an aquiclude.

For basements to normal depths in the Borough, the groundwater in the Terrace Deposits is the only one that is relevant. Groundwater contours in the Terrace Deposits are shown in Figure 3.

In the northern part of the Borough there is no significant perched water because the London Clay outcrops. There may be minor and localised perched water in the Made Ground or soils above the London Clay, but this will vary widely between sites across the Borough.

¹¹ International Agency for Research on Cancer (1988) Man-made Mineral Fibres and Radon. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 43. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. Lyon.

¹² USGS (2011) as above

¹³ Papastefanou C (2007) Measuring radon in soil gas and groundwaters: a review, *Annals of Geophysics*, Vol 50, No 4, August 2007

¹⁴ Cinelli G, Tositti L, Capaccioni B, Brattich E and Mostacci D (2015) Soil gas radon assessment and development of a radon risk map in Bolsena, Central Italy, *Environ Geochem Health* (2015) 37:305–319

¹⁵ Nunes LJR, Curado A and Lopes SI (2023) The Relationship between Radon and Geology: Sources, Transport and Indoor Accumulation, *Applied Sciences*, Volume 13 Issue 13, 2023

¹⁶ Bidarmaghz A et al, (2019) – see above

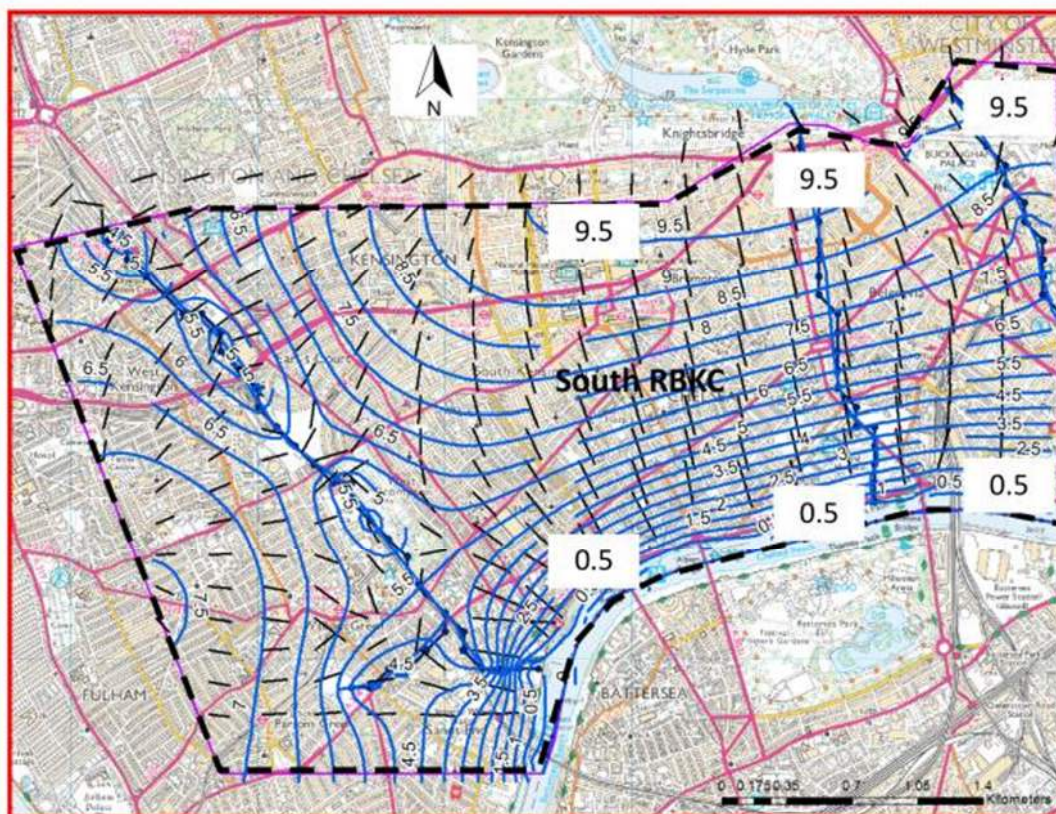


Figure 3 Groundwater contours in River Terrace Deposits (Bidarmaghz A et al, 2019)

4 Radon maps for RBKC

The radon risk maps in the UK are produced by the BGS and the UK Health Security Agency (UKHSA). They are based on a combination of indoor radon measurements from dwellings and the type of bedrock and superficial geology. Together, these data generate a radon risk map that estimates the probability of radon levels inside a house that is at ground level exceeding 200 Bq/m³ (the UK Action Level). They are not strictly applicable to basements but are useful as a screening tool as part of a wider basement radon risk assessment.¹³

The results are used to define six radon classes:

- Class 1: <1% of properties above the Action Level
- Class 2: >=1% and <3% of properties above the Action Level
- Class 3: >=3% and <5% of properties above the Action Level
- Class 4: >=5% and <10% of properties above the Action Level
- Class 5: >=10% and <30% of properties above the Action Level
- Class 6: >=30% of properties above the Action Level

The indicative radon maps (freely available at ukradon.org) show the highest radon potential within each 1km by 1km grid square across the UK. The 1km grid squares are based on the relevant Ordnance Survey National Grid squares. The definitive radon map (licensable data available from the BGS for a fee, and used in site specific radon assessments and by some environmental data providers) uses data based on 1:50,000 geological map layers with a 25m buffer applied, extending the higher radon class over the entire 25m x 25m grid square into which it overlaps, to allow for uncertainties in the resolution of the mapping.

Areas of Radon Class 2 to Class 6 are considered Radon Affected Areas as defined by the UKHSA. Building Regulations in England require radon protective measures for properties in Radon Affected Areas of Class 3 or above.

The maps show where specific radon mitigation measures may be required at ground level. If it can be shown via other methods (for example by more detailed assessment of geology below a site, risk assessment or soil gas radon measurements) that specific radon mitigation is not required, this will achieve the requirements of the Building Regulations (see section 7).

The maps are not based on any soil gas radon monitoring, nor do they consider the type of building construction. Much of the data is also from radon detectors installed by the general public and there is no publicly available information on data quality assessment. Much of the data set will be from older buildings that may be inherently more prone to radon ingress than modern buildings. The maps may therefore be considered an initial screening method to assess radon risk. In some cases, a more detailed assessment of local geology and topography below a site may show that the radon risk is less than indicated by the maps. A further level of assessment can involve site specific in ground radon and permeability assessments (see sections 8.2 and 9 below for more detail).

The UKRadon maps show that the whole of RBKC has the lowest possible radon potential at ground level and is well below the level that requires radon protection at ground level. All areas have less than 1% of homes at ground level at or above the Action Level (Figure 4), i.e. less than 1 out of every 100 houses has radon above 200 Bq/m³ at ground level. It is not a radon affected area. This applies to all the different geological strata across the Borough.

This means that above ground structures are at low risk of radon ingress and do not require radon membranes or other protection systems. It also means that many basements are likely to be at low risk of radon ingress when considered alongside the geology and basement construction. This is discussed in more detail in section 5 below.

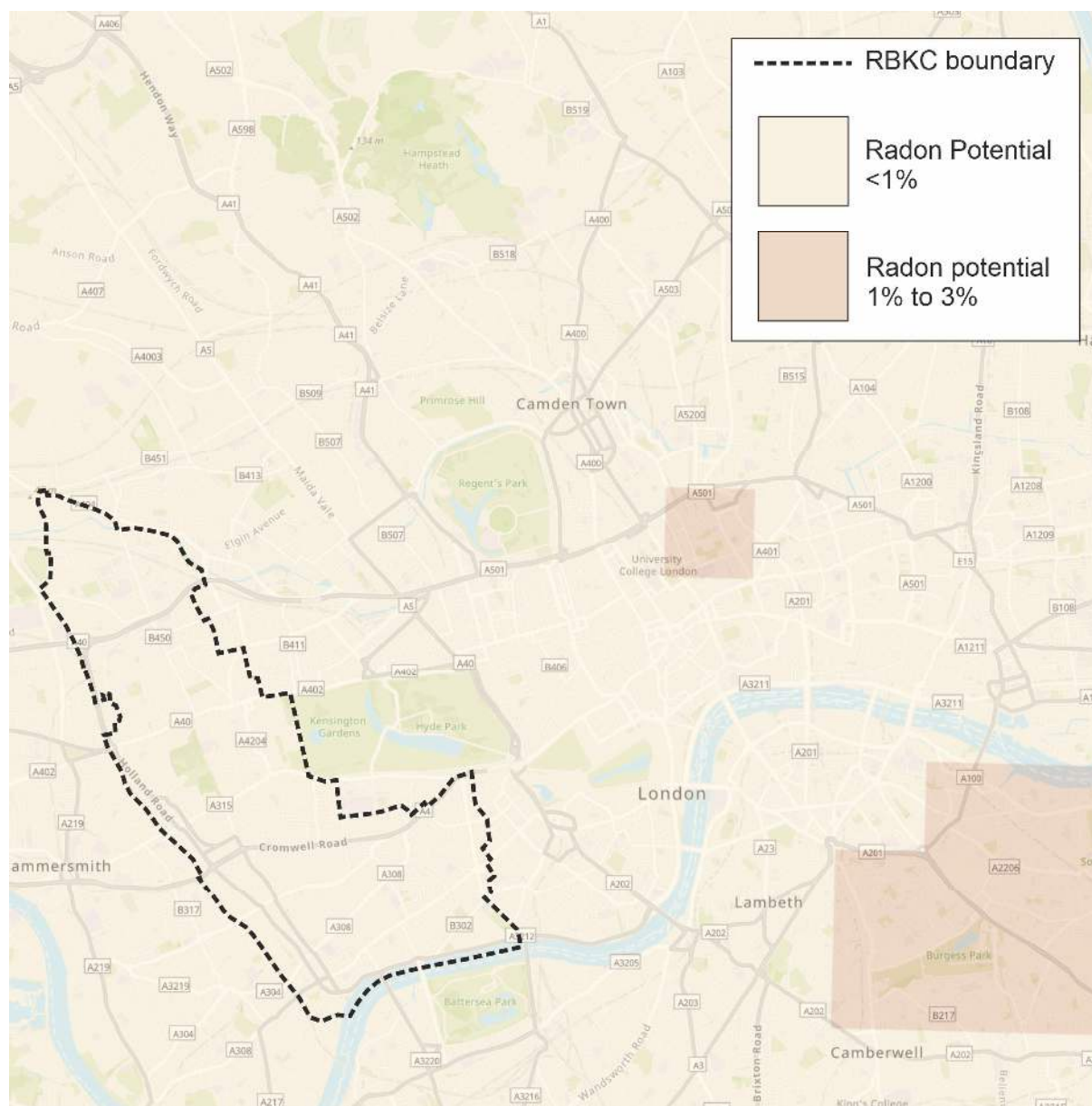


Figure 4 UKRadon maps for RKBC (1km squares)

In other countries (e.g. Germany, Sweden, Czech Republic) radon risk maps are based on soil gas radon measurements and geology¹⁷. Using soil gas radon measurements to assess radon risk in RBKC is discussed later in section 8 and 9.

¹⁷ Cinelli et al (2015) – as above

5 Basements

The term basement may occasionally be used quite loosely and applied to lower ground levels that do not have walls in contact with the ground, or are not below surrounding ground levels. These would not be considered as basements for the purposes of this guidance and would not need to be considered for the assessment of radon in RBKC.

5.1 Basements and radon risk

It is commonly perceived that basements are at increased risk from radon intrusion compared to ground level buildings. This is based on the following assumptions (BRE 2010¹⁸):

- The basement walls, as well as the floor are in contact with the ground. Therefore, the surface area through which radon can migrate is larger and the potential for radon entry is far greater when compared to just the floor slab area for a building at ground level;
- Old cellars may have stone or brick walls and stone or earth floors. These will have little resistance to radon ingress;
- Old basements and cellars are often poorly ventilated so that radon entering them is not diluted and can build up. Furthermore, in old buildings the floor between the basement/cellar and room above is often suspended timber construction. This allows radon to easily move upwards into the building.

Further, the UK Health Security Agency advise that all basement and cellar areas are considered to be at additional risk from high radon levels.

However, these assumptions and advice do not consider the differences between older cellars below houses and modern basement construction and waterproofing methods. The assumptions may not necessarily be correct for new build sites, especially modern high-rise construction.

They also do not take account of the geology. If the ground has a low permeability the practical effect of the increased surface area will be negligible. Furthermore, if a basement is permanently below groundwater there is a lower risk of radon ingress despite the surface area in contact with the ground (assuming that the basement is waterproofed to keep it dry).

Modern basements constructed with waterproof concrete and/or waterproof membranes and with high ventilation rates may be more resistant to radon build up than many older ground-level buildings. The assumption that all basements are poorly ventilated is also not correct (enhanced ventilation is a requirement to achieve a Grade 3 basement environment for residential or other uses in accordance with BS8102¹⁹).

Radon ingress to basements occurs via gaps in the walls and floors and through unsealed service ducts, with service ducts being one of the most significant ingress routes for any soil gas such as radon, methane, carbon dioxide or volatile organic compounds. Old brick and stonework have the most gaps and provides significant pathways. Modern waterproof concrete construction on the

¹⁸ BRE (2010) A BRE Guide to radon Remedial Measures in existing Dwellings, Dwellings with cellars and basements

¹⁹ BS8102: 2022 Code of Practice for Protection of Below Ground Structures Against Water Ingress.

other hand does not have significant gaps and can provide significant resistance to radon ingress²⁰. Even though concrete is a porous material, radon ingress through intact reinforced concrete is negligible²¹.

If sufficient radon is present in the ground, ingress will occur through open joints, although these can be sealed to prevent ingress.

5.2 Basements in RBKC

An assessment of planning applications in RBKC between 2008 and 2017²² indicated that 1022 basements were approved with the following split:

- 676 standard basements (single storey, mostly under terraced houses)
- 279 large basements (double storey)
- 67 deep basements (triple storey or more- up to a depth of 18m).

The applications were generally spread evenly across the whole borough (Figure 5).

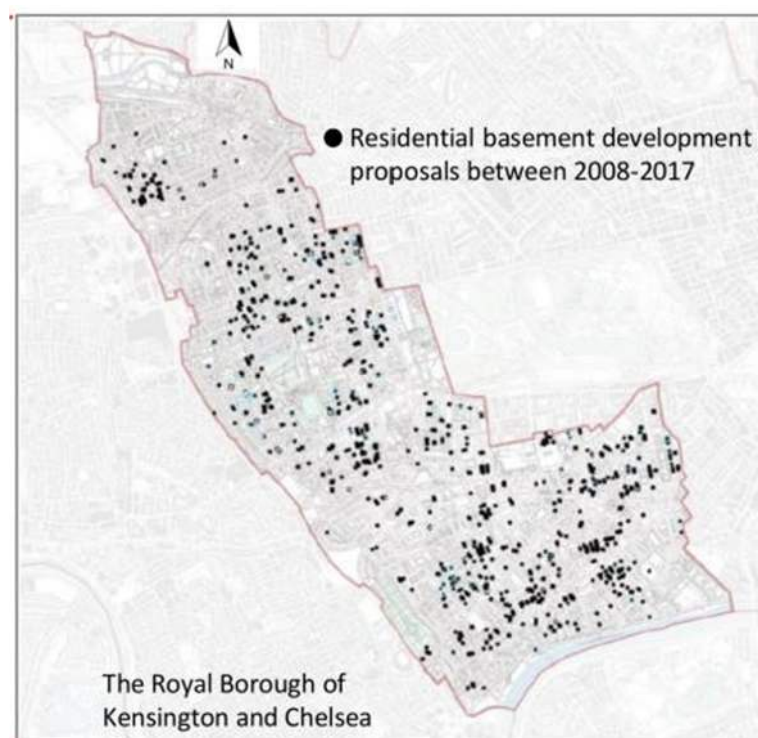


Figure 5 Distribution of planning applications for developments with basements 2008 to 2017 (Bidarmaghz et al 2019)

²⁰ CIRIA (2020) Retrofitting hazardous ground gas protection measures in existing or refurbished buildings. CIRIA Report C795

²¹ BRE Report CI/SfB (L26), 1993

²² BaldwinS, Holroyd E and Burrows R (2018), Mapping the subterranean geographies of plutocratic London: luxified troglodytism?

A review of planning applications for residential basements in London indicates that former cellars, basement storerooms and/or kitchens in older properties are now mainly repurposed as bedrooms, living spaces or leisure spaces²³.

Therefore, consideration of basements with respect to potential radon ingress is an important issue in RBKC.

5.3 Radon measurements in basements in RBKC

RBKC has been provided with the results of some limited monitoring of radon within the basements of thirteen properties in the Borough. There is currently limited or no information on the type of basement construction, in a few cases the type of monitoring that was undertaken or where in the basement it was completed and any potential indoor or building material contributors to the measured radon.

The buildings were all in the south or north east of the Borough and are likely to be underlain by River Terrace Gravel and possibly Alluvium and the London Clay, respectively.

Without information on exact location, potential indoor sources of radon, etc. it is not possible to determine the cause of the highest values. The highest values recorded (one result of 140Bq/m³ in the south and results of between 92Bq/m³ and 1500Bq/m³ and <10Bq/m³ and 250Bq/m³ at two properties in the north east of the Borough) are above one or more of the target level, the action levels and workplace defined level (the other results were below the target level of 100Bq/m³). The results are from buildings with older construction which will be inherently more leaky than modern basements, including basement extensions or cellar refurbishments.

The results of national and local monitoring by the UKHSA suggest that, even in low probability areas, radon levels in basements can exceed the target level and action level and defined level. For example, a UKHSA survey of the results of monitoring in commercial basements in the UK identified that, on average, about 10% of basements in non-affected areas were associated with radon concentrations of greater than 400Bq/m³. However, there is no information on soil permeability and basement construction, or possible preferential pathways for soil gas for these cases. In any event the number of basements affected is low when considering the overall number of properties in the lowest probability areas.

More locally, monitoring in the basements of 41 central London health care facilities found three basements above the target level (but not above the defined level for commercial property). Again, no information on basement construction, soil permeability or potential internal contributors is provided (for example an old well in a basement connected to deeper strata below the London Clay Formation or granite or limestone rocks used in the basement construction).

5.4 Types of basements and cellars

The type of basement, its use and construction all affect the risk of radon intrusion. For example, basement extensions below existing houses and cellar conversions may pose the highest risk. At

²³ Bidarmaghz A, Choudhary R, Soga K, Kessler H, Terrington RL and Thorpe S (2019), Influence of geology and hydrogeology on heat rejection from residential basements in urban areas, Tunnelling and Underground Space Technology, Volume 92 October 2019

the opposite end of the scale new build basements with waterproof construction can be extremely low risk, especially if used as car parks or service areas.

The different types of basements are:

- New build basement. These frequently have waterproof concrete and/or waterproof membranes provided. Waterproof concrete and membranes can be specified to be radon resistant and either on their own, or in combination with other measures, may provide sufficient radon resistance for a basement in RBKC;
- New basements below an existing building. These may use waterproof concrete but the method of construction (essentially underpinning) may make it difficult to achieve good quality. Drained cavities or cavity drain membranes are most frequently used as waterproofing in this situation. The basement structure is less likely to provide adequate radon protection and the cavity drain often has to be sealed and ventilated to achieve an acceptable radon resistance;
- Refurbishment of existing basement or cellar. This can cover a wide range of existing basement construction from reinforced waterproof concrete to brickwork and a site specific assessment for the risk of radon intrusion will be required.

A further consideration is whether a basement is used for residential or commercial purposes, and whether it is a workplace. For a residential property this could include long-term and live-in staff. The basement use will determine what the requirements are for assessing radon in the long term and which radon threshold is relevant (see section 2.3).

The types of basements that should be considered include:

- Full basements i.e. the ground floor slab and four walls are in contact with the soil;
- Partial basements i.e. the ground floor slab and one or more of the walls are in contact with the soil. The smaller the area of wall that is in contact with the soil the lower the risk of radon ingress;
- Properties above or next to a full or partial basement i.e. where the construction of the building would allow significant radon to migrate from the basement to properties adjoining or above via open permeable pathways.

Other factors to consider include:

- For rows of properties with lower ground levels and open access to the front and rear, very often only the end property will form a partial basement and have walls, at the lower ground level, in contact with the ground;
- The basement does not need to be regularly used or occupied to pose risks to other dwellings directly above or next to the basement (at the same level) because radon can enter the basement and move upwards or sideways to other parts of the building (subject to the specific construction and condition of a building);
- If the assessment of radon risk within a basement does not identify a risk from radon, monitoring of non-basement properties adjoining or above the basement should also not be required;

- UK Health Security Agency guidance is that monitoring should only be undertaken in occupied properties. The reason for this is that use of heating and ventilation creates a slight negative pressure inside the building that can draw radon in. Ventilation also dilutes it. These factors are not accounted for when testing is carried out in unoccupied properties. It is however possible to replicate occupied conditions, if necessary, by simply having heating and ventilation on a timer in an empty building.

The specific circumstances of each basement should be considered on a case-by-case basis.

6 Radon in building materials

Radon is emitted from some building materials, although in most cases the contribution to UK indoor radon concentrations is small compared to emissions from the ground²⁴. However, materials can contribute between 20% and 50% of the indoor radon in some cases. In areas of generally low indoor radon concentrations, the main contributor can be emanation from building materials, although in the UK high levels have never been attributed to building materials alone.

Building materials in several European countries contain radioactivity in sufficient quantities to require intervention and restrictions on their use²⁵. Although likely to be rare in the UK, it is possible therefore that some buildings do contain materials that provide a significant contribution of radon to indoor air.

Studies on radon emission from drywall, tiles and granite worktops in Canada²⁶ and concrete blocks and clay bricks in the UK²⁷ have shown that such materials do not generally make any significant contribution to indoor radon concentrations in well ventilated buildings.

Ash from coal fired power stations is used to produce concrete products or as fill material and it could potentially cause high radon emissions. US, Australian, Indian and UK coals contain up to about 4 ppm uranium²⁸. Coal from other countries can be even higher (German up to 13 ppm and Brazil and China up to 20 ppm). Thorium (another source of radon) concentrations are often about three times those of uranium.

During combustion the radionuclides are retained and concentrated in the flyash²⁹ and bottom ash, with a greater concentration to be found in the flyash. The concentration of uranium and thorium in bottom and flyash can be up to ten times greater than for the burnt coal. However building materials made with flyash (PFA) are not likely to contribute significantly to indoor radon concentrations³⁰.

It is known that some products do contribute to indoor radon, for example alum shale lightweight concrete that has been used in Sweden.

The discussion above emphasises the importance of understanding potential building material sources when carrying out internal radon monitoring in low radon potential areas such as RBKC. It is of particular note that throughout history stone for building has been imported to London from

²⁴ Appleton JD, Jones DG, Miles JCH and Scivvyer C (2020) Radon Gas Hazard, In: Giles, D.P.; Griffiths, J.S., (eds.) Geological hazards in the UK: their occurrence, monitoring and mitigation engineering group working party report. Geological Society of London, 433-456. (Engineering Geology Special Publications, 29, 29)

²⁵ Gooding TD, Smith KR and Sear LKA (2006). A radiological study of pulverised fuel ash (PFA) from UK coal-fired power stations, AshTech 2006 – Ash Technology Conference hosted by the UKQAA, 15-17 May 2006, Birmingham Hippodrome Theatre, UK

²⁶ Chen J, Rahman NM and Atiya IA (2010) Radon exhalation from building materials for decorative use, J. Environ. Radioact. (2010)

²⁷ Cliff KD, Green BM and Mile JC (1985) The levels of radioactive materials in some common UK building materials, Sci Total Environ. 1985 Oct;45:181-6

²⁸ <https://world-nuclear.org/information-library/safety-and-security/radiation-and-health/naturally-occurring-radioactive-materials-norm>

²⁹ Flyash is known as pulverised fuel ash or PFA in the UK

³⁰ Gooding et al – as above

areas affected by radon including granite from Cornwall, limestone from Derbyshire, Portland Stone (limestone) from Dorset, and Bath Stone (oolitic limestone) from Somerset. Granite was used in areas in contact with groundwater such as basements.

It is important therefore to understand the building construction when assessing indoor radon measurements in basements in RBKC.

7 Legislation

7.1 Statutory requirements

The following legal requirements may apply to basements, depending on the use and ownership and whether it is an existing or new basement.

The National Planning Policy Framework (NPPF) 2026, Following National decision-making policy P2: Ground conditions, RBKC as the planning authority must satisfy itself that planning decisions ensure

"1. Sites proposed for development should be suitable for their proposed use taking into account:

a. Ground conditions, including any risks arising from land instability or contamination (whether due to natural hazards or current and former activities such as mining or fuel storage); and

b. The extent to which any such risks can be mitigated, and the potential impacts on the natural environment arising from remediation."

This includes the effects from naturally occurring contaminants such as radon.

Therefore, RBKC must consider radon risk and protection measures in planning applications. However, responsibility for safe development ultimately lies with the developer.

The RBKC Local Plan (LP), Policy GB18A requires that a preliminary risk assessment is provided for all basement applications and thereafter requires that land contamination issues are appropriately investigated, remediated and verified. This will include the investigation or protection of basements from radon.

Article 4 Direction, In RBKC an Article 4 direction (to removed permitted development rights) and Local Plan Policy for basement developments means that land contamination needs to be addressed through planning.

The Building Regulations Part C1 (2) apply to new buildings, extensions, conversions and refurbishments in existing buildings. This requires reasonable precautions to be taken to avoid danger to health and safety caused by contaminants, including radon gas, on or in the ground to be covered by a building and any land associated with the building. This is the only legal requirement.

The Health and Safety at Work, etc. Act 1974 requires that employers must ensure workplaces are safe. Radon concentrations inside buildings are a consideration in this respect. Employers have a duty to address radon where it is relevant to the health, safety and welfare of its employees and contractors.

The Management of Health and Safety at Work Regulations 1999 require an employer to undertake appropriate health and safety assessments. The Health and Safety Executive (HSE) advise that this should include risk assessment and testing for radon for above ground workplaces in an Affected Area (Class 2 and above) and all occupied basements (those occupied for an average of an hour per week or approximately 50 hours per year).

The Ionising Radiation Regulations 1999 will come into effect where radon is present above the defined level for workplace buildings (300 Bq/m³) and employers are required to take action to restrict and address resulting exposures. This requires site specific radon risk assessment to be completed.

The Landlord and Tenant Act 1985 and **The Housing Regulations 2004** require radon risk to be assessed in occupied basements. Landlords must ensure that any dwelling is fit for human habitation. As for workplaces the risk from radon should be assessed and this may include testing.

The statutory instruments described above all require the duty holder, be that developer, employer, landlord etc. to ensure that buildings are safe and suitable for the intended use, this includes assessment and possible mitigation for radon gas. However, there are no statutory requirements for how to complete the required assessments, testing, and mitigation. This is all provided in guidance documents, which are not mandatory, but provide generally applicable established approaches which might be suitable. There is a focus in UK guidance on use of the generic risk maps (see section 4), and internal post-construction testing (see section 8.1), rather than soil gas testing and other methods. However, other methods can and should be used in some scenarios and have certain advantages (see sections 8.2 and 9 for further information).

7.2 Non-statutory guidance

Non statutory guidance (i.e. it is not a legal requirement) is provided by UKHSA on protection recommendations for new ground level buildings in England and Wales, when determined via the radon maps alone. This is summarised in Table 1.

Table 1 Summary of radon protection requirements based on radon maps

Class	Probability of properties being above the Action Level	Radon affected area	Recommended protection measures for new buildings, England and Wales*Text
Class 1	<1%	No	None
Class 2	1% to 3%	Yes	None
Class 3	3% to 5%	Yes	Basic
Class 4	5% to 10%	Yes	Basic
Class 5	10 % to 30%	Yes	Full
Class 6	>30%	Yes	Full

* Note: different guidance is provided for Scotland and Northern Ireland and radon maps relate to ground level property only

Radon risk should be considered in detail for basements in all areas.

The only legal requirement in the Building Regulations is that radon is prevented from entering buildings and accumulating at hazardous levels. Guidance on some (but not all) methods that may be used to comply with the legal requirements is provided in Approved Document C which accompanies the Building Regulations Schedule 1 Part C. Approved Document C refers in turn to radon maps and BRE 211. It is possible to prove adherence to the Building Regulations by other

methods not covered in the guidance and this is stated explicitly in the introduction to the Approved Documents (see Figure 6).

Approved Documents are intended to provide guidance for some of the more common building situations. However, there may well be alternative ways of achieving compliance with the requirements. **Thus there is no obligation to adopt any particular solution contained in an Approved Document if you prefer to meet the relevant requirement in some other way.**

Figure 6 Extract from "Site preparation and resistance to contaminants and moisture: Approved Document C"

The basic and full protection is described in BRE Report 211³¹. For basic protection measures the BRE guidance is limited and only covers radon barrier membrane solutions. However, it is possible to mitigate against the ingress of harmful gases via other types of systems as detailed further in section 10 of this guidance. It is interesting to note that in Spain, basic protection can be achieved using just a ventilated sub floor void³². Swiss guidance also indicates that a ventilated subfloor void may provide sufficient protection against radon ingress³³. For basements it is possible to provide adequate radon protection in high-risk areas using just waterproof concrete walls and floor slab construction, which is likely to be as, or even more, effective than some radon membranes sold in the UK³⁴.

³¹ BRE (2023) Guidance on protective measures for new buildings (including supplementary advice for extensions, conversions and refurbishment projects). BRE Report 211

³² Consejo Superior de Investigaciones Científicas (2020) Rehabilitación Frente al Radón, guía September 2020

³³ Swiss Federal Office of Public Health (2017) Swiss Radon Handbook.

³⁴ CIRIA (2020) Retrofitting hazardous ground gas protection measures in existing or refurbished buildings. CIRIA Report C795

8 Radon monitoring

UKHSA and HSE recommend that internal radon monitoring (i.e. monitoring inside the building) is undertaken in basements irrespective of their geographical location. If elevated radon concentrations are found at any time, then retrofitting radon protection measures will need to be considered (but is not mandatory). The recommendation is that internal monitoring is undertaken within the first year after construction.

The use of post-construction indoor monitoring imposes a long-term liability and uncertainty on developers, owners, occupiers, who will not have certainty that their building is safe until after construction. There is, however, an alternative approach that can be used to assess radon risk that is arguably more robust and can avoid or reduce the need for long term indoor monitoring (and also demonstrate whether or not the basement requires any radon protection). The alternative is on site soil gas radon monitoring. This approach is used in other countries to assess the radon risk of the site and inform the design of protection measures.

8.1 Internal monitoring

8.1.1 Passive detectors

The normal method of internal monitoring to assess radon risk in a property is to measure average concentrations over a 3 month period using passive alpha track devices.

Indoor monitoring devices can be obtained from the UKHSA³⁵ or from an independent laboratory that is validated by UKHSA³⁶ (see footnote reference for list of laboratories). It is recommended that internal monitoring devices are not obtained from companies that also install radon protection.

For small residential buildings two detectors are provided with instructions to install them in the “living area” and “bedroom”. The detectors are provided with instructions, and they are left in place for three months before being returned for analysis. Larger buildings are likely to require more detectors. It is also important to ensure that the “living room” is the room with the highest occupancy.

The recommended number of detectors required to test for radon in a workplace or residential basement in RBKC are as follows (based on UKHSA guidance³⁷):

- One detector in each separate room, section or area irrespective of size, if occupied more than 50 hours per year; and
- Minimum one per 250m² for larger areas of basement used as workshops, plant rooms, gyms, home cinemas, changing rooms, retail, etc and one per 100m² for larger areas used as residential.

³⁵ <https://www.ukradon.org/services/orderdomestic>

³⁶ PHE validation scheme for laboratories

https://www.ukradon.org/cms/assets/gfx/content/resource_3462cs9edda0fd4d.pdf

³⁷ <https://www.ukradon.org/information/workplace>

The method of measurement is a passive method (i.e. there are no pumps) using solid state nuclear track detectors³⁸. The detector contains a detector element (often referred to as a lens, film or foil). The detector element is a dosimetry grade poly allyl diglycol carbonate (PADC) known as CR-39 which is the material used to make spectacle lenses.

Radon diffuses through the detector and over the detector element. When radon atoms decay inside the detector, they release alpha particles and they travel rapidly so that when they strike the element they make microscopic tracks in the surface. It is insensitive to visible light, x and gamma rays and beta particles.

At the laboratory the element is chemically treated to enlarge the alpha tracks, which are counted on an automated image scanner. The average radon level is calculated from the number of tracks and the number of days the detector was exposed and using calibration coefficients. It is adjusted depending on the time of year the monitoring was carried out to assess the likely radon concentration in winter, when levels are normally higher.

The instructions provided with the detectors need to be followed correctly to get accurate results.

Detectors record continuously and must be placed within two days of receipt as the monitors are continuously recording radon.

The building should be in normal use during the measurement. The detectors should be placed following the guidance notes that accompany them plus the considerations noted below^{39 40}.

Tests are invalid if:

- There is building work during the test;
- Windows or doors are left open or high ventilation is in use for unusual, prolonged periods of time;
- The building is empty for more than 3 weeks of the test;
- There is a change in occupier during the test.

Problems that can occur with the passive detectors are as follows:

- They are positioned incorrectly. They should not be located in draughts (close to windows or HVAC inlets and outlets), on top of tv screens or computer monitors, above heat sources (radiators, hot pipes, direct sunlight), very close to materials that may emit radon (granite work tops, concrete or block work walls), too close to the ceiling or floor, inside cupboards, cabinets or drawers, or in contact with water. The definition of close is not given in the guidance and judgement is required;
- Too few measuring points are used;
- They are not sent for analysis immediately after measurement is complete;

³⁸ Stajic JM, Markovic VM, Milenkovic B, Stevanovic N and Nikezic D (2021) Distribution of alpha particle tracks on CR-39 detector in radon diffusion chamber Radiation Physics and Chemistry Volume 181, April 2021

³⁹ https://www.ukradon.org/cms/assets/gfx/content/resource_3452cs66121d1f78.pdf

⁴⁰ https://www.ukradon.org/cms/assets/gfx/content/resource_3988csbbbe7ef28a.pdf

- They are analysed by an unaccredited laboratory.

In RBKC, if internal monitoring is undertaken the following information should be provided with the internal monitoring in order to provide a better long-term understanding of the risk from radon in basements in the Borough:

- A detailed floor plan showing the location and number of detectors and height should be provided, where possible with a photograph that shows the location in context with the room;
- Details of basement construction and qualitative assessment of ventilation provided by a suitably qualified professional (noting, if possible, whether any granite or limestone is present in the basement walls);
- Notes of any potential indoor or building material contributors (provided by a qualified professional);
- Assessment of geology below the basement and groundwater levels (provided by a qualified ground engineering professional);
- Meteorological data over the period of monitoring (wind speed, rainfall, temp, barometric pressure).

8.1.2 Frequency of internal monitoring

For basements, where internal monitoring is completed after construction, the results should be assessed and recommendations made for a review period. As with all health and safety risk assessments, applicability should be kept under review. Where significant changes are made to the fabric of a building or to the work processes carried out within it, then the need to re-measure the radon levels internally should be considered. In any case, it is still good practice to assign a maximum period upon which remeasurement of the internal radon levels will occur. The frequency of any re-measurements is site specific. The HSE suggests the following general guidelines for workplaces⁴¹:

- i. where radon levels were found to be significantly less than 300Bq/m³ at the initial measurement, the period of remeasurement might be of the order of once every 10 years;
- ii. where radon levels were just below 300Bq/m³ at the initial measurement, the suggested period for remeasurement will be less than 10 years;
- iii. where radon levels were above 300Bq/m³ at the initial measurement and measures have been taken to reduce radon exposures (such as engineered systems or occupancy restrictions), the remeasurement periods may need to be significantly more frequent in order to verify their continuing effectiveness (possibly every year).

While this relates to health and safety in workplaces the similar advice can be applied to residential settings, including rented properties but with a reduced frequency:

⁴¹ <https://www.hse.gov.uk/radiation/ionising/radon.htm>

- i. where radon levels were found to be less than 100Bq/m^3 at the initial measurement, the period of remeasurement might be of the order of once every 10 years;
- ii. where radon levels were between 100Bq/m^3 and 200Bq/m^3 at the initial measurement, the suggested period for remeasurement will be 5 years;
- iii. where radon levels were above 200Bq/m^3 at the initial measurement and measures have been taken to reduce radon exposures, the remeasurement periods may need to be significantly more frequent to verify effectiveness (possibly every year).

An alternative to internal radon monitoring is to monitor in the ground prior to construction. This is described in section 8.2.

8.1.3 Short term “grab samples”

If radon levels are found to be elevated inside a building, then it may be necessary to provide radon mitigation or protection. In order to allow a cost-effective solution to be determined it is vital that short term testing is completed so that the pathways for radon ingress are understood. For example, if radon ingress is occurring at isolated points such as water pipe ducts sealing these may remove the problem and avoid the need for expensive active systems such as sumps and other fans that also require long term maintenance and power use.

Short term measurements can be made using various types of instruments. The person using the instruments should provide justification that it will provide representative results that are suitable for the assessment being undertaken, along with up-to-date calibration certificates. Note that short term indoor samples are not suitable for assessing long term risk, only for determining likely ingress pathways.

8.2 Soil gas radon monitoring.

The most common type of instrument used for short term soil gas measurements uses passivated implanted planar silicon detectors (PIPS). However other methods may be acceptable and the person using the instruments should provide justification that it will provide representative results that are suitable for the assessment being undertaken, along with up-to-date calibration certificates.

Monitoring of soil gas radon should be undertaken in the ground prior to construction or below existing basement floors. The following is required:

- Soil gas radon monitoring in the soils that are at least 1m below the top of the structural basement slab level;
- Soil gas monitoring in soils around the basement walls (where these are different from those beneath the basement slab) at least 1m below the top below ground level;
- Permeability of the soil should also be measured using a permeameter, or the permeability assessed based on soil descriptions and particle size distribution tests;
- Moisture content of soil should be tested;

The assessment of the radon results and of permeability should be undertaken by a suitably competent and experienced Chartered Geologist or Chartered Engineer (geotechnical).

A suitable number of test locations should be used. This should be justified by the consultant. In other countries a minimum of 15 test locations per plot is required⁴². However, that is based on undertaking a statistical analysis of the results and using the third quartile as the design value. If the maximum recorded result is to be used, then a lower number of locations may be used. It is suggested that given the low-risk radon sources present in RBKC that the following is used as a guideline, which is similar to that adopted for other soil gas investigations (e.g. VOCs):

- For small houses (individual plot detached, semi detached and terraced houses of less than 100m² basement floor area) with new basement or refurbished cellar/basement below – at least three test locations in building footprint;
- For larger houses (between 100m² and less than 2500 m² basement floor area) with new basement below – at least five test locations;
- For large new build residential/commercial high-rise blocks with large basements (greater than 2500m²) – test on a 25m grid with a minimum of five samples.

The test locations should be evenly distributed over the area of the basement. They should also cover differing soil types if geology varies below or beside the basement and also different parts of the basement if for example it is split level or there are separate areas.

The results should be assessed against the criteria in the following section, to determine the Radon Index for the site.

⁴² J. Hulka, J.Thomas, I.Fojtikova, J.Vlcek, L.Moucka, A.Fronka, K.Jilek, A.Heribanova, J.Slovak, I.Barnet, I.Burian, M.Jiranek, T.Cechak, (2018) Radon programme in Czech Republic Results, Experience and Future (pdf dated 2018)

9 Radon risk assessment

The assessment of radon risk should be based on a source-pathway-receptor (contaminant linkage) model and the complexity can range from simple screening through to detailed assessment using soil gas radon monitoring and other data. A flow chart showing the required approach in RBKC is provided in Table 2.

Table 2 Flowchart for RBKC basement radon risk assessment framework

RBKC basement developments radon risk assessment framework			Long term radon monitoring requirements ¹
Basement formation level entirely within London Clay, <3m Made Ground	Yes →	Basic radon protection required. (One of either Type A waterproofing membrane or Type B structural concrete can be designed to achieve basic radon protection)	Recommended, unless additional radon soil gas monitoring completed to determine low radon index.
No ↓			
Waterproofing to comprise both Type B waterproof concrete and Type A fully bonded waterproof membrane (not active core membrane) or steel sheet piling with welded joints	Yes →	No specifically designed radon protection required (waterproofing provides sufficient inherent protection).	Recommended, unless additional radon soil gas monitoring completed to determine low radon index.
No ↓			
Radon soil gas monitoring and permeability testing (in accordance with methodology provided in section 8.2) available and shows “Low” radon index – See Note 1 and Table 3.	Yes →	No radon protection required.	Not required.
No ↓			
Radon protection required. Specification of products to be justified in terms of radon diffusion coefficients and thicknesses of materials. Details of the design to be provided in site specific drawings and sections. See Note 2			To be specified by the designer based on assessment of risk of failure of the protection system.

1. See Section 8.1

Note 1 Site specific in ground measurement of soil gas radon concentration and soil permeability (see section 8.2). This is the most reliable method of determining whether a building is at risk of radon ingress. It should also be combined with an assessment of geology and groundwater conditions. It allows a more robust design of mitigation measures if there is an unacceptable risk of ingress. Soil permeability may be measured using a permeameter (for either air permeability or hydraulic conductivity that is converted to air permeability) or assessed from the particle size distribution (based on fraction of fine material less than 0.063mm particle size and soil descriptions). Further information on assessing permeability test results and factors that can affect them is provided by Neznal et al (2004)⁴³. The soil gas and permeability results are used to determine the Radon Index of a site using Table 3.

Note 2 It should be demonstrated that the basement construction provides sufficient mitigation against radon ingress for the development. This should take account of the basement construction, structural waterproofing and surrounding geology and groundwater conditions (for example if the floor is permanently below a continuous groundwater level as determined by a qualified ground engineering professional).

Table 3 Radon Index of the site⁴⁴

Radon index	Soil gas radon concentration, C_A (kBq/m ³)		
Low	$C_A < 30$	$C_A < 20$	$C_A < 10$
Medium	$30 < C_A < 100$	$20 < C_A < 70$	$10 < C_A < 30$
High	$C_A > 100$	$C_A > 70$	$C_A > 30$
	Low	Medium	High
	Soil permeability		

Notes

Soil permeability direct measurement:

Low $k < 4.0 \times 10^{-13} \text{m}^2$; Medium $4.0 \times 10^{-12} \text{m}^2 \geq k \geq 4.0 \times 10^{-13} \text{m}^2$; High $k > 4.0 \times 10^{-12} \text{m}^2$

Soil permeability based on particle size distribution:

Low $> 65\%$ passing 0.063mm; Medium $15\% < \text{passing } 0.063\text{mm} < 65\%$; High $< 15\%$ passing 0.063mm

Soil gas radon concentration (**C_A**) is maximum recorded from an appropriate number of sample locations

If the results show a **low** Radon Index there is no significant source and therefore radon protection is not required and future internal monitoring after construction is not required.

⁴³ Neznal M, Matolin M, Barnet I and Miksova J (2004) The new method for assessing the radon risk of building sites. In Prague C Editor, Czech Geological Survey Special Papers 2004.

⁴⁴ Neznal M, Matolin M, Barnet I and Miksova J (2004) The new method for assessing the radon risk of building sites. Czech Geological Survey

If the results indicate a **medium** Radon Index, radon mitigation will be required and internal monitoring after construction may be necessary as in section 8.1 above. For sites with medium risk a basic level of protection will be required for basements.

The geology of RBKC will not create a high radon risk. Further information on protection measures is provided in the next section.

10 Radon protection to basements

10.1 Introduction

There are several ways of providing radon protection to basements. It is important that the radon protection is considered alongside the waterproofing strategy because in many cases the proposed waterproofing will provide more than adequate protection against radon ingress. The range of methods listed in BRE211 is limited and there are other methods that are also suitable to provide adequate protection that are described later in this section.

Passive protection is preferred by RBKC over active systems, such as ventilation systems with fans as these require ongoing maintenance by owners/occupiers.

For all systems RBKC must be assured that they have a suitable design working life. Guidance on design working life is provided in BS EN1990: 2002 Basis of structural design, (Eurocode 0). Normally for Category 4 building structures and other common structures this is 50 years. However, NHBC and/or clients may require a 60 year working life or longer. Category 5, monumental building structures, bridges and other civil engineering structures require 120 years working life (UK National Annex to Eurocode 0). The designer of the radon protection must demonstrate that all parts of a radon protection system can achieve the required design life. For items such as fans the required maintenance period and likely replacement period should be stated.

Warranties must cover the system for radon protection (including any waterproofing that is part of the radon system).

Cementitious waterproof coatings are not likely to provide sufficient radon resistance to provide any meaningful protection.

The radon protection system should be designed to ensure that the radon concentration inside a basement is below the target level of 100Bq/m³. This must be demonstrated by the radon protection designer.

It is important that radon protection systems are designed and installed taking into consideration where failures are most likely to occur. Studies in the Czech Republic⁴⁵ have found that the factors responsible for most failures in radon protection systems are:

- Leakages in joints and around pipe penetration seals for radon barriers,
- Partial application of barriers – they are not applied over the entire surface,
- Perforation of barriers during construction works,
- Use of barrier materials that were not tested for radon diffusion, or use of low-quality products,
- Passive ventilation with inlet and outlet holes in external walls only (without a vertical exhaust stack).

⁴⁵ Neznal M., Neznal M., Jiránek M., Froňka A. Failure of Preventive Measures against Radon Penetration from the Ground in a New-Built Family House - a Case Study. In: Proceedings of Full Papers CD-Rom from the 2nd European IRPA Congress on Radiation Protection. Paris (2006)

It is important that if radon protection is deemed to be required then the installation of all elements is independently verified.

Examples of poor installation are provided in Annex B and these are key areas to concentrate on during construction and verification.

The following options are available for providing radon protection. These are listed in order of preference based on risk of long term damage or deterioration, ongoing maintenance requirements and ongoing power costs:

1. Waterproof concrete, this is preferred as it the most difficult to damage, requires no ongoing maintenance and is normally already required as part of the waterproofing design in many basements, especially new build.
2. Insulation as radon protection. More resistant to damage than thin membranes and requires no ongoing maintenance. It is often required as part of the floor construction or used to face of contiguous or secant piled walls so is already part of the design.
3. Radon/waterproofing membranes, require no ongoing maintenance but must be protected from damage (pre applied membranes on the outside of concrete construction are preferred). Post applied membranes and liquid membranes on the inside of the structure more prone damage. Post applied membranes inside the structure require support to maintain adhesion to walls.
4. Cavity drains as radon protection (with or without ventilation). Difficult to seal effectively over a long design life (jointing tapes only have a limited design life). Inside the structure so often more prone to damage than other methods. However, in refurbishments and basement extensions they may be the only realistic option in certain situations (depends on construction methods used for basement). Passive ventilation of the cavity drain not likely to be effective so powered fans required. Require ongoing maintenance and power supply.
5. Positive internal ventilation (PIV) of basement space, only effective in dealing with low concentration of radon in a building. Requires ongoing maintenance and power supply.
6. Sub-slab depressurization (radon sumps). Do not work if basements are below groundwater or groundwater can collect below the basement slab. Require ongoing maintenance and power supply.

In all cases it is vital that service entries into the basement are adequately sealed especially the internal annulus of ducts. This is the most common pathway for all ground gas ingress into buildings.

Further information on RBKC's requirements for each method is provided in the following sections.

10.2 Waterproof concrete

Waterproof concrete may provide adequate protection against radon ingress on its own and is used in other countries. The sealing at joints/induced cracks may need to be specified to reduce radon ingress using either metal/PVC water bars or resin injection systems rather than hydrophilic expanding strips (which only become effective when they expand in contact with water). This will depend on the nature and number of joints/cracks. Normally a minimum concrete thickness of 200mm is required.

Assessment of the radon resistance of waterproof concrete should be made by a Chartered professional (civil or structural engineer, geo-environmental engineer or similar) taking into account crack width design, geometry of basement and method of construction. This is explained in CIRIA Report C795⁴⁶.

Key information to be provided for waterproof concrete:

- Structural design calculations for waterproof concrete with crack width assessment
- Detailed structural design drawings
- Specification and details of concrete mix design (note that waterproof concrete may be achieved without proprietary waterproofing additives)
- Radon diffusion coefficient test results for concrete and water bars or resins
- Design calculations showing radon resistance is sufficient taking account of any increased diffusion at joints and the nature of joint sealing or water bars.
- Confirmation of the design working life.
- Provide a clear plan of action to be followed if defects or damage occurs

Verification requirements for waterproof concrete:

- Verification that construction is in accordance with the design and National Structural Concrete Specification for Building Construction⁴⁷.
- Verification of construction under the overall control of an appropriately qualified and experienced Chartered Civil or Structural Engineer.

10.3 Insulation as radon protection

Some insulation boards or spray applied materials also provide adequate resistance to radon ingress if detailed correctly. Spray applied materials are used to face of contiguous or secant piled walls before placing membranes and is a useful method of providing radon resistance to basement walls. If insulation is placed below a floor slab, spray applied systems can be used or boards can be sealed to provide radon protection. The insulation should meet the requirements for radon barriers in Section 11.

Key information to be provided for insulation:

- Design drawings for system (site specific showing how it fits into the basement construction, suppliers' standard details are not acceptable).
- Specify jointing methods used to connect insulation across the basement slab to insulation, membranes, etc. of the basement walls
- Radon diffusion coefficient test results for concrete and water bars or resins

⁴⁶ CIRIA (2020) Retrofitting hazardous ground gas protection measures in existing or refurbished buildings, Report C795

⁴⁷ The Concrete Centre (2010) National Structural Concrete Specification for Building Construction, Edition 4

- Design calculations showing radon resistance is sufficient taking account of any increased diffusion at joints
- Confirmation of the design working life for the materials from the supplier supported by laboratory test results.
- Provide a clear plan of action to be followed if defects or damage occurs,
- Confirmation that installer is approved by the material supplier.

Verification requirements for insulation:

- Verification construction is in accordance with the design and specification by CL:AIRE accredited specialist in gas protection verification⁴⁸
- Provision of CL:AIRE declaration for the verification report⁴⁹
- On site testing/sampling of material samples should include applied thickness of each layer, internal temperature of previous layers prior to next layer (for multi layer applications).

10.4 Radon/waterproofing membranes

Normal radon membranes are unlikely to be robust enough for use around basements. It is normally most cost effective to rely on a waterproofing membrane made of a polymeric material as the radon membrane. The membrane should meet the requirements for radon barriers in Section 11. Liquid applied membranes may also be used if appropriate and should also meet the requirements in Section 11.

Key information to be provided for membranes:

- Design drawings for system (site specific showing how it fits into the basement construction - suppliers standard details are not acceptable)
- Radon diffusion coefficient test results for the membrane, jointed membrane and any sealing components.
- Design calculations showing radon resistance is sufficient for the thickness of membrane proposed taking account of any increased diffusion at joints.
- Confirmation of the design working life for the materials from the supplier supported by laboratory test results.

⁴⁸ Note that RBKC does not require verifiers to have membership of any particular trade or other organisation, but must be CL:AIRE accredited (or provide evidence demonstrating equivalent competence, adherence to a set of professional standards and continuing professional development).

⁴⁹ The provision of a CL:AIRE Declaration is optional and the scheme is voluntary. However in the same way as the National Quality Mark Scheme for contaminated land reports the aim is to provide assurances to problem holders and regulators alike that verification has been adequately managed. This should help speed up respective regulatory permissions or decisions on regulatory compliance resulting in savings to both public and private sector participants.

- Provide a clear plan of action to be followed if defects or damage occurs.

Verification requirements for membranes:

- Verification following guidance in CIRIA Report C735 or by the CL:AIRE, associated with the Gas Protection Verification Scheme.
- QA testing/sampling of samples on site
- Thickness of membrane shall be tested in site
- Verification by CL:AIRE accredited specialist or technician in gas protection verification⁴⁸
- Provision of verification report by CL:AIRE accredited specialist in gas protection verification
- Provision of CL:AIRE declaration for the verification report⁴⁹.

10.5 Cavity drains as radon protection

Cavity drains may be used as part of a radon mitigation system, but great care is required to achieve a long-lasting installation. Some suppliers claim the drainage sheet itself can be sealed to act as a radon membrane and some claim the sheet can be used to provide ventilation. They are not allowed to be used as radon membranes in the Czech republic because of the difficulty of sealing joints between sheets. If they are used the membrane should meet the requirements for radon barriers.

Key information to be provided for cavity drain designs:

In all cases:

- Design drawings for system (site specific showing how it fits into the basement construction - suppliers standard details are not acceptable). Site specific details showing how the cavity drain sheet is sealed to be radon resistant at all edges
- Test data for radon diffusion through the cavity drain membrane including all joints and wall fixings. Independent laboratory test reports to be provided (see Section 11).
- Calculations to show radon resistance of the cavity drain is sufficient taking account of any increased diffusion at joints
- Details to show the protection of the cavity drain sheet to show how the risk of damage by occupiers (for example drilling into it) is minimised
- Details of maintenance requirements and how long-term maintenance will be assured over the working life of the building
- Where methane or other explosive gases could potentially be present either in gas phase or dissolved in groundwater – specification of intrinsically safe pumps, fans and control equipment.
- Ensure the entire system is gas tight including provision of gas tight covers to all pump chambers, rodding points, etc.
- Confirmation of the design working life for the materials, including fans and jointing tapes (supported by laboratory test results). Particular consideration of unsupported vertical tape joints will be required.

- Provide a clear plan of action to be followed if defects or damage occurs. Require permanent metal tags on fans, sumps and pipework advising that it is part of a radon protection system. Provide links to required annual maintenance.

Where the cavity wall membrane is to be relied on as a ventilation layer:

- In plane air permeability of the cavity wall membrane. Independent laboratory test reports to be provided
- Calculations to show the proposed air flow in system is sufficient to dilute radon to acceptable levels (below the target level of 100Bq/m³) by an independent consultant and not the system supplier. This will need to take into account head losses and the in-plane air permeability test data for the cavity drain (or demonstrate that ventilation is not necessary and that accumulation of radon in the system does not pose an elevated risk to the basement.
- Demonstrate that the system will provide sufficient air flow when the cavity drain sheet is operating at design capacity to manage the design groundwater flows by an independent consultant and not the system supplier.

The designer of the cavity drain system must provide confirmation of the end discharge point for the system. If discharge is ultimately to a sewer the designer must provide evidence that Thames Water will give permission for the discharge of the groundwater from the system and that it will have sufficient storage capacity for times when the sewer is surcharged and cannot accept water. Note that permits to discharge have to be renewed each year (at a cost). The impact of this on its performance as a radon system must be assessed. Discharge of groundwater from the cavity drain should be considered along with the surface water discharge from the site and when combined should not exceed greenfield runoff rates or other rates agreed with the Lead Local Flood Authority. This is important because it will determine if a cavity drain can be used in a development and will affect the radon mitigation strategy.

Verification requirements for cavity drain systems used as radon protection if the cavity membrane is being relied on for gas resistance:

- Verification of the cavity drain sheet or membrane and all sealing following guidance in CIRIA Report C735
- Verification by CL:AIRE accredited specialist or technician in gas protection verification⁴⁸
- Provision of verification report by CL:AIRE accredited specialist in gas protection verification⁴⁹
- Tracer gas testing of the installed system (this is because of the greater risk of gas leakage occurring compared to other waterproofing systems) using an appropriate method based on the advice in CIRIA Report C735⁵⁰;
- Provision of CL:AIRE declaration for the verification report⁴⁹.

⁵⁰ CIRIA (2104) Good practice on the testing and verification of protection systems for buildings against hazardous ground gases, CIRIA Report C735

Verification requirements for cavity drain systems used as radon protection if the cavity ventilation is being relied on to dilute radon or create a pressure field to prevent radon ingress to the cavity:

- Pressure field testing to show the pressure extension across the cavity drain sheet in all areas of basement in contact with the ground.
- If active fans are used the designer must demonstrate how long-term operation and maintenance will be assured.

10.6 Positive internal ventilation to increase pressure

Positive internal ventilation (PIV) is normally required within basement to ensure a Grade 3 waterproof environment. It can also be used as part of a radon protection system to maintain a positive pressure inside the basement so that air flows out into the ground rather than inwards from the ground into the basement. The PIV unit should have a radon mode so that it can be set to run continuously. PIV can only provide limited reduction to indoor radon concentrations. It is not appropriate for use on its own in medium risk locations. The designer must demonstrate how long-term operation and maintenance will be assured

Key information to be provided for internal positive pressure design:

- Confirmation of the design working life for the materials from the supplier supported by laboratory test results.
- Confirmation of maintenance requirements and fan replacement intervals and how long-term operation and maintenance will be assured
- Calculations to demonstrate that the system will provide adequate air flow and increase in internal pressure
- Require permanent metal tags advising that it is part of a radon protection system and must not be disconnected or turned off
- Confirmation of fan power requirements
- Provide a clear plan of action to be followed if defects or damage occurs

Verification requirements for positive internal ventilation:

- Confirmation unit has been installed by technically competent and qualified persons
- Confirmation of installation and commissioning of system. It is vital that a PIV unit is commissioned properly to ensure pressurization is sufficient to ensure air flow into the ground and it is achieved the required over pressure.
- Measurement of air changes and internal air pressure.

10.7 Sub slab depressurisation (radon sumps)

External sub slab depressurization methods (radon sumps) are not normally suitable below basements. If proposed the designer must demonstrate it will not become flooded and how long-term operation and maintenance will be assured.

Pipework to be marked permanently that it is radon pipework and not drainage. It should also provide a link to details of the required annual maintenance.

Key information to be provided for sub slab depressurisation:

- Design drawings for system (site specific showing how it fits into the basement construction – suppliers' standard details are not acceptable)
- Calculations to support the spacing of radon sumps and fan or passive ventilation performance requirements (considering head losses in ground and pipework).
- Confirmation of the design working life for the materials from the supplier supported by laboratory test results.
- Maintenance requirements and frequency for fans and control components.
- Power requirements for fans.
- Provide a clear plan of action to be followed if defects or damage occurs.

Verification requirements for sub slab depressurisation:

- The system must be adequately tested after installation to demonstrate that a negative pressure field is developed below and around the whole basement area that is in contact with the ground. For passive systems this must include varying barometric pressure and wind speed conditions.

10.8 Sealing services

Service penetrations and soil gas flow inside ducts for services are the most common pathway for any ground gas to enter buildings. These require particular focus to provide a radon resistant construction. The internal sealing of ducts should be completed using proprietary duct waterproofing systems. These will also provide adequate radon resistance. Key information to be submitted:

Verification requirements for duct sealing:

- Because the ducts are normally visible on completion of construction and can be inspected by others it is not necessary for the verification to be completed by a specialist verification consultant. Verification can be provided by the contractor in the form of photographs that are location referenced and have a wide enough angle to show the location within a building clearly:
- Written confirmation by the contractor that the duct seal has been installed in accordance the supplier's guidance (signed and dated on headed company paper by a named individual).

11 Specification of materials for radon barriers

Materials used as radon barriers (including the jointing and penetration sealing materials such as tapes) should be able to last for the working design life of the building. RBKC has the following requirements for materials used as radon barriers (insulation, membranes, including liquid applied membranes, or cavity drain membranes). They should meet the following with respect to radon (note that other requirements will also apply in respect of the primary function, waterproofing, insulation or drainage and also with respect to fire resistance):

- Radon diffusion - Be sufficiently impervious, both in the sheet material and in the sealing of sheets and sealing around sheet penetrations, to prevent any significant passage of radon through the membrane. Independent laboratory test reports to be submitted. RBKC will not rely on supplier data sheets or agrément certificates.
- Be capable after installation of providing a sufficient barrier to the entry of the relevant gas. Assessment to be provided by the radon protection system designer (who should not be the material supplier).
- Be sufficiently durable to remain serviceable for the anticipated life of the building and duration of gas emissions. Independent assessment to be provided along with laboratory test reports. Statements by material suppliers are not acceptable.
- Be sufficiently strong to withstand in service stresses (e.g. due to ground settlement if placed below a floor slab). Assessment to be provided by the radon protection system designer (who should not be the material supplier).
- Be sufficiently strong to withstand the installation process and following construction activities until covered (e.g. penetration from steel fibres in fibre reinforced concrete, penetration of reinforcement ties, tearing due to working above it, and dropping tools). Assessment to be provided by the radon protection system designer (who should not be the material supplier).
- Be chemically resistant to degradation by other contaminants that might be present. Independent assessment to be provided along with laboratory test reports. Statements by material suppliers are not acceptable.

Cementitious waterproof coatings and renders and active core membranes (bentonite membranes) are not normally suitable as radon barriers. Aluminium foil membranes are not suitable as radon membranes around basements. Czech experience is that the aluminium foil has a low tear resistance and elongation and it is almost impossible to avoid damage to it.

The use of cavity drain sheets or membranes as radon barriers requires careful consideration. They are not allowed to be used in the Czech Republic because of the difficulty of sealing the joints. If they are used in RBKC they will require tracer gas testing after installation. Other protection methods may be necessary in conjunction with the cavity drain.

11.1 Radon diffusion coefficient

The radon diffusion coefficient should be determined following the latest version of Method C of ISO/DIS 11665-10 *Measurement of radioactivity in the environment - Air: radon-222 - Part 10: Determination of diffusion coefficient in waterproof materials using activity concentration measurement*. Independent laboratory test reports should be provided.

11.2 Durability

Durability is the ability of a product to maintain its required performance over a given or long time, under the influence of foreseeable actions. Subject to normal maintenance, a product shall enable a properly designed and executed works to fulfil the Essential Requirements for an economically reasonable period of time (working life of the product). Durability is covered by the construction product standards (EN Standards for waterproofing membranes, damp proof membranes and insulation products).

The following requirements to demonstrate durability must be followed:

- Radon membranes will usually be in contact with moistened concrete, for example under the floor slabs or in contact with reinforced concrete walls. Membranes with aluminium foils are not normally suitable where in contact with wet cement. Furthermore, the foil has a very low strain rate. If they are used the membrane must be tested to show it has sufficient resistance to ageing in alkaline environment following BS EN 1847: 2009. The radon diffusion coefficient must not change by more than 20% as a result of the test. It must replicate an exposed edge of the membrane or a defect in the plastic protection (which is impossible to avoid on a construction site).
- Furthermore, the designer must demonstrate that strain and folding in the membrane will not tear the foil.
- All barrier materials shall have a statement on the working design life of the material provided by an independent organisation and not the material supplier. Some materials have to comply with British or European product standard (e.g. waterproofing membranes). In such cases independent laboratory test result, using the methods stated in the product standards, shall be supplied to support the durability assessment.

11.3 Resistance to damage

Membranes used around the outside of a basement to provide radon resistance should be sufficiently resistant to damage during construction.

The risk of damage to membranes in a basement construction is much higher than in ground level floor construction (where a membrane is loose laid above a floor slab). Therefore, the normal thin radon membranes (0.4mm) are not considered suitable around basements. NHBC guidance on gas resistant membranes⁵¹ recommends that in ground membranes are a minimum of 0.6mm thick and protected above and below. Pre applied bonded waterproofing membranes normally have an integral protection layer on the inner face. The outer face is applied against a prepared substrate such as faced off piles or blinding concrete. The provision of a protection layer is therefore not necessary if the membrane element is 0.6mm thick or greater (the required thickness should be based on an assessment of radon diffusion through it – See Section 10.4). For any given material the greater the thickness the greater the resistance to damage and the lower the rate of radon diffusion. Where post applied membranes are installed onto the outside of basement walls they should be provided with protection boards to minimise the risk of damage during installation. Only

⁵¹ NHBC Foundation (2023) Hazardous ground gas – an essential guide for housebuilders, Report NF94

bonded membranes should be used for radon protection around basements. This minimises the risk of radon spreading in any gap between concrete and membrane.

Waterproofing membranes should not be loose laid below basement floors. If membranes are not laid on a concrete blinding layer they will require protection below using a geotextile fleece).

Test data for the parameters identified in Table 5.2 of NHBC NF94 for a Type C membrane (location in the ground) should be supplied. The following typical minimum values are acceptable (but lower values may be suitable if adequate justification is provided by the designer of the radon protection system). In any event the choice of membrane should be justified by the designer of the radon protection based on the test results for the membrane and the specific conditions of the installation.

Table 4 Typical minimum requirements for radon barriers around basements (sheet polymeric membranes)

Parameter	Test Method	Typical minimum requirements	Comment
Thickness	EN1849 Part 2	0.6mm	Thickness of plastic sheet providing radon resistance and excluding any bonding layer or adhesive layer. Measured at thinnest part of membrane between any reinforcement scrim
Tensile strength and tensile elongation	EN12311-1 or 2	To be justified by designer, typically > 500N/50mm	Consideration of tensile stress the membrane will be subject to both during installation and in service
Shear strength of joints	EN12317-1 or 2	>100N/50mm	
Impact resistance	EN12691 (A)	>350mm	See CIRIA Report C748 ⁵² - can resist a 500g weight (similar to a 19oz hammer - one of the most common sizes used)) falling a maximum of 350mm onto it. A greater value may be required where there is a higher risk of impact from heavier objects from greater heights
Resistance to static load	EN12730 (A)	>20kg	Static load applied via 10mm ball and applied for 24h. the value is the maximum weight the membrane can support without puncture. 20kg is the maximum value achievable in the test
Resistance to tearing (nail shank)	EN12310-1	>350N	See CIRIA Report C748

Various seam jointing methods are used for radon barriers. Welding is the preferred method for radon resistance. Bonded waterproofing membranes with self-adhesive selfedge joints are acceptable because the joint is under permanent pressure and there is less risk of gas tracking behind the membrane with minimum overlap of the adhesive section of 100mm.

⁵² CIRIA (2014) Guidance on the use of plastic membrane as VOC vapour barriers, Report C748

Insulation is much thicker than sheet membranes (normally at least 75mm) it is far less prone to puncture and tearing. There are no specific tests methods to assess damage to this type of barrier. Care should however be taken to ensure it is not damaged once placed.

11.1 Long term maintenance/ensuring no damage

Passive systems such a waterproof concrete, insulation or sheet membranes do not require any maintenance. However, they do require measures to be taken to prevent long term accidental damage.

A permanent notice must be installed in a suitable location in the building advising of the presence of the radon protection system, and any membrane, waterproof concrete, insulation or cavity membrane. It must advise on depth limits for drilling holes in walls/floors (or advise not to do this) and any building alterations should take account of the presence of the radon barrier.

Active fans need regular maintenance and replacement at intervals. The designer must specify the required maintenance and replacement periods and also how this will be ensured.

The requirements for long term monitoring inside basements are provided in section 8.1 and Tables 2 and 3 in section 9.

Annex A Health risk from radon

The primary reference source for information about the health effects of radon in the UK is the UKHSA (formerly the Health Protection Agency – HPA) study from 2009⁵³. This report presents the results from a meta study which was completed in 2006 and interprets the findings in terms of health risk from radon in the UK. The most used statistic on this is that an estimated 1,100 deaths per year are attributable to radon exposure. This was true in 2006, but is likely to have reduced, given the decrease in smoking rates across the UK population during this time (smoking rates were around 20% to 22% in 2006 and had dropped to about 13% in 2022⁵⁴).

The report describes how radon is a non-threshold carcinogen that increases the risk of lung cancer. Non-threshold meaning that there is no “safe” level, and that even at very low concentrations radon will influence your cancer risk. The effect is estimated to be linear, and around a 16% increase in risk for every 100Bq/m³ exposure⁵¹.

Smokers or people who have previously smoked, have an increased risk of lung cancer than the general population. This means that an increase in their baseline risk level of 16% is much more significant than for lifetime non-smokers. This is shown in Figure A1 below.

⁵³ RCE-11 Radon and Public Health: Report of the independent Advisory Group on Ionising Radiation
https://assets.publishing.service.gov.uk/media/5a7ea84aed915d74e6225a5d/RCE-11_for_website.pdf

⁵⁴ <https://ash.org.uk/uploads/Smoking-Statistics-Fact-Sheet.pdf?v=1697728811>

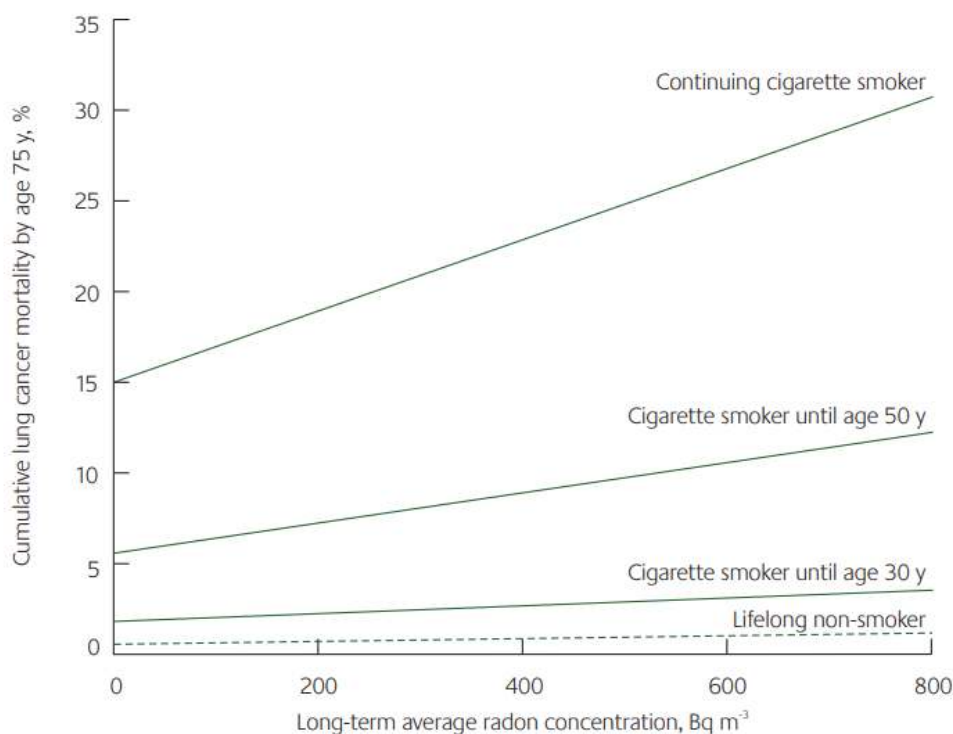


FIGURE 4.1 Cumulative absolute risk of death from lung cancer by age 75 years versus long-term average radon concentration at home for continuing cigarette smokers, ex-smokers and lifelong non-smokers in the UK (see Table 4.3 for sources of data and method of calculation)

Figure A1 Risk of death from lung cancer vs long term average radon concentration at home from *Radon and Public Health*⁵¹

For a continuing cigarette smoker, the baseline risk of death from lung cancer by age 75 is 14.7%, long term exposure to residential radon at the action level (200 Bq/m³) would increase this to 19.0%, and exposure at 800Bq/m³ to 30.5%. In contrast for a lifelong non-smoker the equivalent lifetime risk of death from lung cancer are 0.41%, 0.53% and 0.92% at 0Bq/m³, 200Bq/m³ and 800Bq/m³ respectively (0.53% is a 1 in 188 chance and 0.92 % is a 1 in 108 chance).

LUNG CANCER DEATHS IN UK 2006

- Not caused by radon or smoking (14%)
- Caused by radon but not smoking (0%)
- Caused by smoking and radon - current smokers (2%)
- Caused by smoking and radon - ex-smokers (1%)
- Caused by active smoking and not radon (83%)

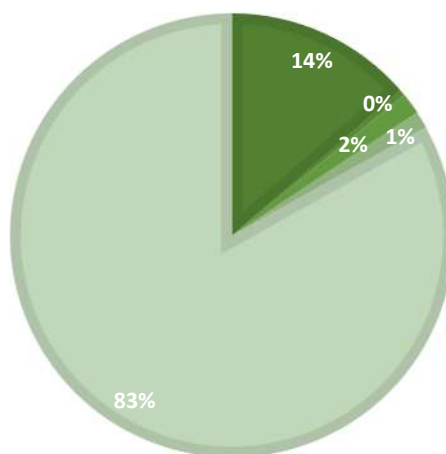


Figure A2 Lung cancer deaths in UK

For non-smokers the risk is much lower than for smokers or former smokers. The risk also increases as the length of time being exposed to radon increases. The graph assumes a lifetime of exposure at a given concentration, or that the exposure concentration is the average at home over the lifetime.

Of the 1,110 estimated radon related deaths in 2006, 157 are attributed to radon alone (14%), and 953 (86%) are attributable to radon and smoking, in that avoiding either smoking or reducing levels of radon could have prevented the deaths.

Further to this, given the non-threshold effect and the fact that most UK homes have very low levels of radon, most of these deaths are attributable to very low-level radon exposures with 70% occurring in homes with low radon levels ($<50\text{Bq/m}^3$) and only 3% related to radon concentrations above the action level (200Bq/m^3).

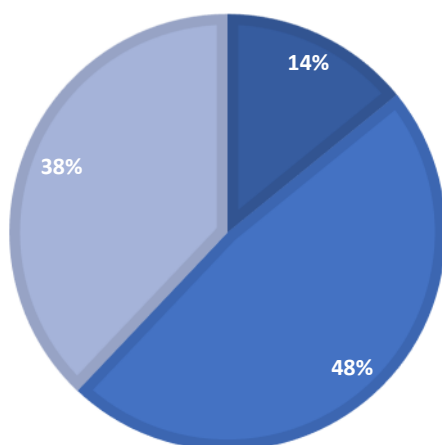
So of the 1,110 deaths only 5 people would be non-smokers living in a home with radon above the residential action level of 200Bq/m^3 .

This perhaps supports the use of the radon target level (100Bq/m^3) as a limit value as this would help reduce a proportion of the 27% of deaths (or 297 people) that occur at between $<50\text{Bq/m}^3$ and 200Bq/m^3 .

LUNG CANCER DEATHS IN UK IN 2006, CAUSED BY RADON

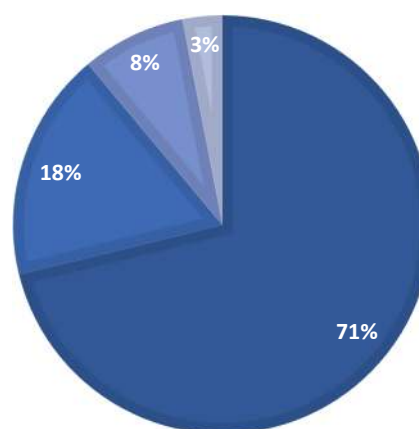
BY SMOKING STATUS

- Casued by radon but not smoking
- Caused by smoking and radon - current smokers
- Caused by smoking and radon - ex-smokers



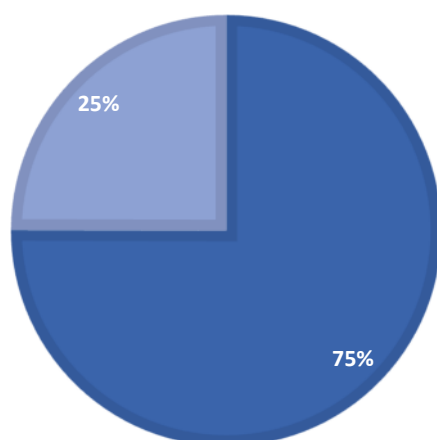
BY LONG-TERM AVERAGE RADON CONCENTRATION

- 0 to 49 Bq/m3
- 50 to 99 Bq/m3
- 100 to 199 Bq/m3
- 200+ Bq/m3



BY AREA

- Not in radon affected area
- In radon affected area



BY AREA AND RADON CONCENTRATION

- Not in radon affected area
- In radon affected area with measurement < 200Bq/m3
- In radon affected area with meassurement > 200Bq/m3

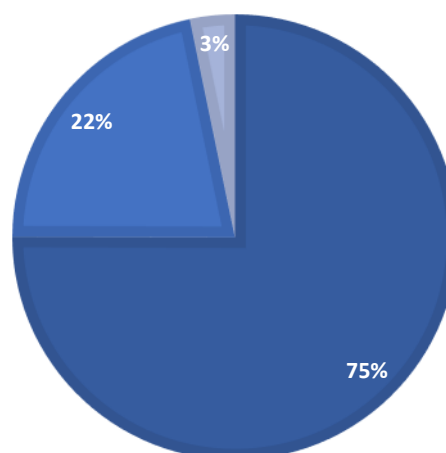


Figure A3 Factors that influence radon risk

Annex B Radon protection installation considerations

A selection of photos showing key areas where damage or poor installation may occur in radon protection systems or where particular focus is required during verification:

Leakages in joints and around pipe penetration seals for radon barriers,



Pipes too close together to allow effective sealing using membrane products (liquid pourable sealant would be required)

Pipes too close to wall and top hat bent up wall

Tape pulling away from wall at bend in top hat

Poor taping around top hat

Internal sealing of waterpipe duct not complete (expanding foam is not suitable for duct sealing in basements)

Damage to membrane on wall



Passive ventilation with inlet and outlet holes in external walls only (without a vertical exhaust stack).



Vent stack to sub floor venting system is 3m high

Ground level vents or airbricks will not provide sufficient ventilation across wider buildings (for example when venting cavity drain systems).

Ducts for services require sealing internally around the services (this is normally done on the inside of the basement so the sealing can be removed and replaced if services are replaced).



Leaking joints or honeycombing in waterproof concrete



Leaking construction
joint and honeycombing
at base of basement wall

Phased construction leads to parts of system being exposed to damage and deterioration



Part of floor slab constructed with
membrane below.

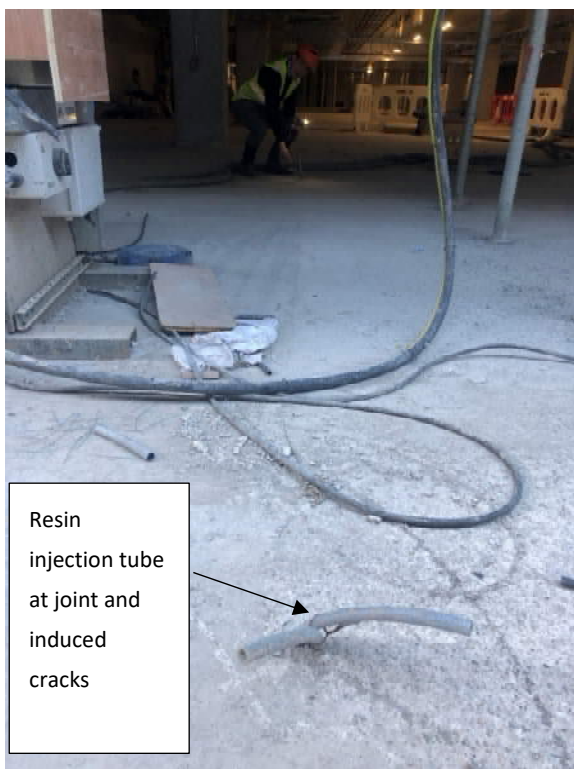
This part left of several months until
main basement slab and membrane is
installed

Care required to ensure a waterproof
joint is provided at these locations

Welded steel sheet piles as waterproof (and radon) barrier



Waterproof concrete as radon barrier



Waterproof concrete used as a radon barrier

Waterproof concrete has radon diffusion test data

Resin injection of all construction joints (resin has radon diffusion test data)

Resin injection tube at joint and induced cracks

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