Building Research Establishment Report

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Radon: guidance on protective measures for new dwellings

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INTRODUCTION

This report gives guidance for reducing the presence of radon in new dwellings, and hence reducing the risk to occupants of exposure to radon. Interim guidance was first issued by the Department of the Environment in June 1988[1]. Since that time much experience has been gained of its application in practice. This report has been prepared to build on the experience gained and to provide a more comprehensive explanation of the principles involved. It provides practical details on methods of protecting new dwellings. Further research is however still needed and is continuing, and the results will be incorporated into revisions of this report as they become available.

Radon is a colourless, odourless gas which is radioactive. It is formed where uranium and radium are present and can move through cracks and fissures in the subsoil, and so into the atmosphere or into spaces under and in dwellings (Figure 1). Where it occurs in high concentrations it can pose a risk to health.

Whilst it is recognised that every house contains radon, some built in certain defined areas of the country might have unacceptably high concentrations unless precautions are taken. In the UK, the granite areas of south-west England are of principal concern, but high concentrations of radon are also found in some other parts of the country.

Requirement C2 of Schedule 1 of the Building Regulations 1991[2] for England and Wales states that 'precautions shall be taken to avoid danger to health and safety caused by substances found on or in the ground to be covered by the building' and the Approved Document[3] includes radon in the contaminants described. It states that 'where a house or extension is to be erected in Cornwall or Devon, or parts of Somerset, Northamptonshire or Derbyshire there may be radon contamination of the site and precautions against radon may be necessary'. The Approved Document refers to the present report for detailed guidance on where such protection is necessary and for practical construction details.

PROTECTIVE MEASURES

Radon enters a building primarily by airflow from the underlying ground. There are two main methods of achieving radon protection in new dwellings: passive and active.

- The **passive** system consists of an airtight and therefore substantially radon-proof barrier across the whole of the building including the floor and walls (Figure 2).
- The **active** system consists of a powered radon-extract system as an integral part of the services of the house. It will incur running and maintenance costs for the life of the building.

Passive systems are to be preferred in new houses, although they may need to be supplemented by secondary protection, involving for example underfloor ventilation or subfloor depressurisation.

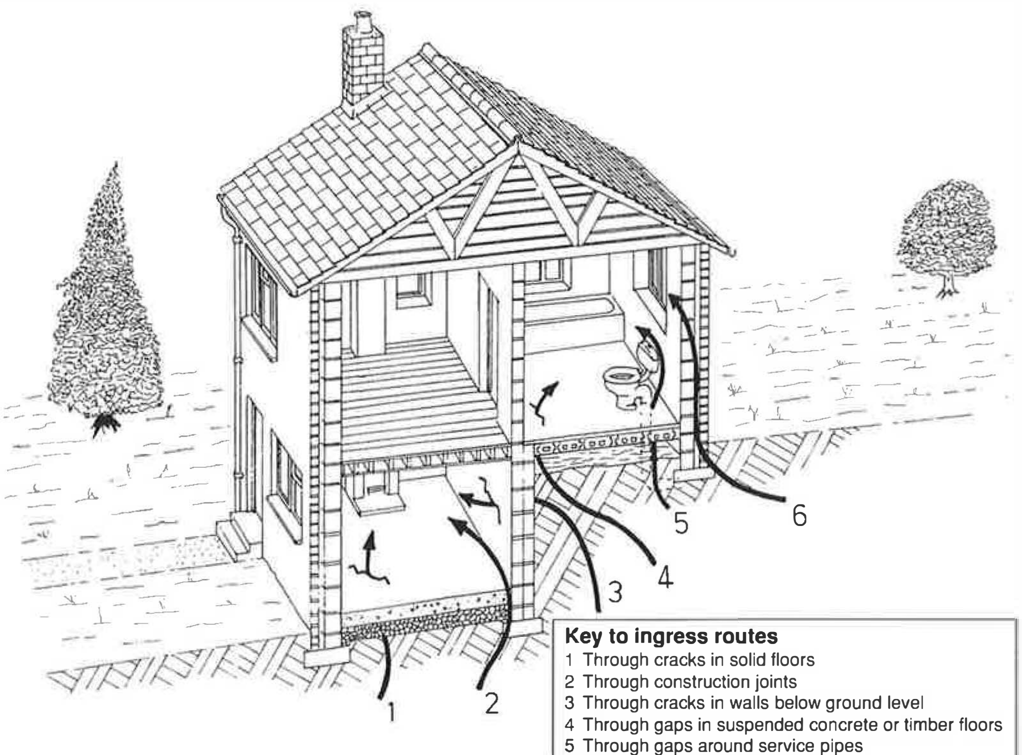

Figure 1 Routes by which radon enters a dwelling

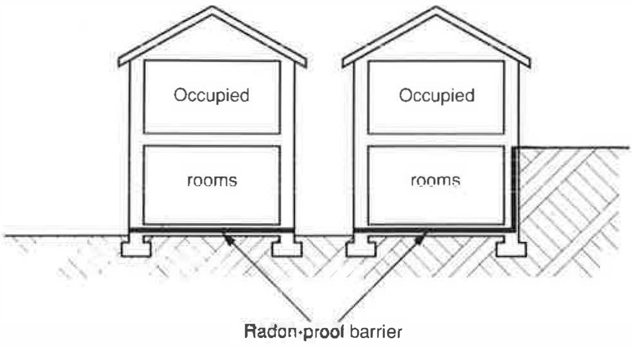

Figure 2
Passive measures to prevent radon entry

It is impractical to assess the severity of a radon problem on a particular site accurately until the building has been constructed and occupied, and therefore precautions should be taken where problems are most likely to occur. Radiological surveys of existing houses have been undertaken to establish the extent of the problem. From these surveys it is considered that precautionary measures should be taken as follows.

1. New dwellings in Cornwall, Devon, Somerset, Northamptonshire and Derbyshire within the dark-shaded areas on the accompanying maps (Figures 3(a), (b) and (c)) and listed in Table 1 should incorporate full radon precautions, ie both primary (radon-proof barrier, see section on primary protection) and secondary measures (radon sump and extract pipe or ventilated subfloor void, see section on secondary protection).
2. New dwellings in Cornwall, Devon, Somerset, Northamptonshire and Derbyshire within the light-shaded areas on the accompanying maps (Figures 3(a), (b) and (c)) and listed in Table 2 should have provision for future subfloor extraction, ie secondary measures (radon sump and extract pipe or ventilated subfloor void, see section on secondary protection).
3. Within the areas listed in Tables 1 and 2, any site on which there is little or no possibility of an enhanced level of radon will obviously need no precautionary measures; for instance the subsoil may be such as to prevent the passage of radon or may be permanently saturated.

These areas will need to be revised as more information becomes available. This report will be amended accordingly. The local authority for the district in which you are proposing to build will be able to confirm whether the Department of the Environment has amended the defined areas.

Table 1 Areas where full radon precautions are required for new dwellings

Districts and Boroughs	Parishes and Towns		
Cornwall			
Caradon	Boconnoc	Liskeard	St Keyne
	Broadoak	Looe	St Martin
	Callington	Menheniot	St Mellion
	Calstock	Morval	St Neot
	Dobwalls and Trewidland	Pelynt	St Pinnock
	Duloe	Pillaton	St Veep
	Landrake with St Erney	Quethiock	St Winnow
	Lanreath	St Cleer	Sheviock
	Lansallos	St Dominick	South Hill
	Lanteglos	St Germans	Warleggan
	Linkinhorne	St Ive	
Carrick		All	
Kerrier	Breage	Gweek	Portreath
	Budock	Helston	Redruth
	Camborne	Illogan	St Anthony in Meneage
	Carharrack	Lanner	St Day
	Carn Brea	Mabe	St Gluvias
	Constantine	Manaccan	St Martin in Meneage
	Crowan	Mawgan in Meneage	Stithians
	Cury	Mawnan	Sithney
	Germoe	Porthleven	Wendron
	Gunwalloe		

(continued)

Table 1 (continued)

Districts and Boroughs	Parishes and Towns		
Cornwall (continued)			
North Cornwall	Altarnun	Lawhitton Rural	St Teath
	Advent	Lesnewth	St Thomas the Apostle Rural
	Blisland	Lewannick	St Tudy
	Bodmin	Lezant	South Petherwin
	Camelford	Michaelstow	Stokeclimsland
	Cardinham	North Hill	Tintagel
	Davidstow	St Breock	Tremaine
	Egloshayle	St Breward	Treneglos
	Egloskerry	St Clether	Tresmeer
	Forrabury and Minster	St Endellion	Trevalga
	Helland	St Kew	Trewen
	Laneast	St Mabyn	Wadebridge
	Lanhydrock	St Minver Highlands	Werrington
	Lanivet	St Stephens by Launceston Rural	Withiel
	Launceston		
Penwith		All	
Restormel		All	
Devon			
Mid Devon	Bampton	Morebath	Oakford
North Devon	Arlington	Countisbury	Loxhore
	Bittadon	East Down	Lynton and Lynmouth
	Bratton Fleming	Kentisbury	West Down
	Brendon		
South Hams	Aveton Gifford	Holbeton	Slapton
	Bigbury	Holne	South Brent
	Blackawton	Ivybridge	South Huish
	Buckland-tout-Saints	Kingsbridge	South Milton
	Churchstow	Kingston	Sparkwell
	Cornwood	Kingswear	Stoke Fleming
	Dartmouth	Loddiswell	Strete
	Dean Prior	Modbury	Thurlestone
	Diptford	Newton and Noss	Ugborough
	Dittisham	North Huish	West Alvington
	East Allington	Rattery	West Buckfastleigh
	Ermington	Ringmore	Woodleigh
	Halwell	Shaugh Prior	Yealmpton
	Harford		
Teignbridge	Ashburton	Buckland-in-the-moor	Lustleigh
	Bickington	Christow	Manaton
	Bovey Tracy	Dunsford	Moretonhampstead
	Bridford	Hennock	North Bovey
	Buckfastleigh	Ilsington	Widecombe-in-the-moor
Torbay	Brixham		
	Churston		
West Devon	Belstone	Kelly	Sheepstore
	Bere Ferrers	Lamerton	Sourton
	Bradstone	Lewtrenchard	South Tawton
	Brentor	Lifton	Spreyton
	Bridestowe	Lydford	Sticklepath
	Buckland Monachorum	Mary Tavy	Stowford
	Chagford	Marystow	Sydenham Damerel
	Coryton	Meavy	Tavistock
	Dartmoor Forest	Milton Abbot	Thrushelton
	Drewsteignton	Okehampton	Throwleigh
	Dunterton	Okehampton Hamlets	Walkhampton
	Gidleigh	Peter Tavy	Whitchurch
	Gulworthy	Sampford Courtenay	
	Horrabridge	Sampford Spiney	

(continued)

Table 1 (continued)

Districts and Boroughs	Parishes and Towns		
Somerset			
Mendip	Cranmore		
	Doulting		
	Evercreech		
West Somerset	Skilgate		
	Upton		
Northamptonshire			
Kettering	Broughton	Grafton Underwood	Pytchley
	Burton Latimer	Kettering	Thorpe Malsor
	Cranford	Loddington	Warkton
	Cransley	Orton	Weekley
Wellingborough	Finedon	Isham	Orlingbury
	Great Harrowden	Little Harrowden	Sywell
	Hardwick	Mears Ashby	
Daventry	Boughton	Harlestone	Overstone
	Brixworth	Holcot	Pitsford
	Chapel Brampton	Lamport	Scaldwell
	Church Brampton	Moulton	Spratton
	Hannington	Old	Walgrave
Northampton		All	
Derbyshire			
Derbyshire Dales	Abney and Abney Grange	Great Hucklow	Offerton
	Aldwark	Great Longstone	Over Haddon
	Ashford in the Water	Grindlow	Parwich
	Bakewell	Harthill	Pilsley
	Ballidon	Hartington Middle Quarter	Rowland
	Birchover	Hartington Nether Quarter	Sheldon
	Blackwell in the Peak	Hartington Tow Quarter	Stanton
	Bradwell	Hassop	Stoney Middleton
	Brushfield	Hazelbadge	Taddington
	Calver	Highlow	Thorpe
	Chelmorton	Lea Hall	Tideswell
	Eaton and Alsop	Little Hucklow	Tissington
	Edensor	Little Longstone	Wardlow
	Elton	Litton	Wheston
	Eyam	Middleton and Smerrill	Winster
	Flagg	Monyash	Youlgreave
	Foolow	Nether Haddon	
	Gratton	Newton Grange	
High Peak	Aston	Green Fairfield	Peak Forest
	Brough and Shatton	Hartington Upper Quarter	Thornhill
	Buxton	Hope	Wormhill
	Castleton	King Sterndale	

Table 2 Areas where secondary radon precautions are required for new dwellings

Districts and Boroughs	Parishes and Towns		
Cornwall			
Caradon	Antony	Maker with Rame	Saltash
	Botusfleming	Millbrook	Torpoint
	Landulph	St John	
Kerrier	Grade Ruan	Mullion	
	Landewednack	St Keverne	
North Cornwall	Boyton	St Ervan	St Merryn
	Jacobstow	St Eval	St Minver Lowlands
	North Petherwin	St Gennys	Warbstow
	North Tamerton	St Issey	Week St Mary
	Otterham	St Juliot	Whitstone
	Padstow		
Devon			
Mid Devon	Bickleigh	Cruwys Morchard	Shobrooke
	Bow	Down St Mary	Stockleigh English
	Brushford	Eggesford	Stockleigh Pomeroy
	Cadbury	Hittisleigh	Stoodleigh
	Cadeleigh	Hockworthy	Templeton
	Chawleigh	Huntsham	Thelbridge
	Cheriton Bishop	Kennerleigh	Thorverton
	Cheriton Fitzpaine	Lapford	Tiverton
	Clannaborough	Loxbeare	Upton Hellions
	Clayhanger	Morchard Bishop	Washfield
	Coldridge	Newton St Cyres	Washford Pyne
	Colebrooke	Nymet Rowland	Wembworthy
	Copplestone	Poughill	Woolfardisworthy
	Crediton	Puddington	Zeal Monachorum
	Crediton Hamlets	Sandford	
North Devon	Ashford	Filleigh	North Molton
	Atherington	Fremington	Parracombe
	Barnstaple	Georgeham	Pilton West
	Berrynarbor	Georgenympton	Queensnympton
	Bishops Nympton	Goodleigh	Rackenford
	Bishops Tawton	Heanton Punchardon	Romansleigh
	Braunton	Ilfracombe	Rose Ash
	Brayford	Kingsnympton	Satterleigh and Warkleigh
	Burrington	Knowstone	Shirwell
	Challacombe	Landkey	South Molton
	Chittlehamholt	Mariansleigh	Stoke Rivers
	Chittlehampton	Martinhoe	Swimbridge
	Chulmleigh	Marwood	Tawstock
	Combe Martin	Meshaw	Trentishoe
	East Anstey	Molland	Twitchen
	East and West Buckland	Mortehoe	West Anstey
	East Worlington	Newton Tracey	Witheridge
South Hams	Ashprington	Dartington	Salcombe
	Berry Pomeroy	East Portlemouth	South Pool
	Bickleigh	Frogmore and Sherford	Staverton
	Brixton	Harberton	Stoke Gabriel
	Charleton	Littlehempston	Stokenham
	Chivelstone	Malborough	Totnes
	Cornworthy	Marldon	Wembury
Teignbridge	Abbotskerswell	Holcombe Burnell	Stokinteignhead
	Ashton	Ide	Tedburn St Mary
	Bishopsteignton	Ideford	Teigngrace
	Broadhempston	Ipplepen	Teignmouth
	Chudleigh	Kingkerswell	Torbryan
	Coffinswell	Kingsteignton	Trusham
	Doddiscombsleigh	Newton Abbot	Whitestone
	Dunchideock	Ogwell	Woodland
	Haccombe-with-Combe	Shaldon	

(continued)

Table 2 (continued)

Districts and Boroughs	Parishes and Towns		
Devon (continued)			
Torridge	Abbots Bickington Alverdiscott Alwington Ashreigney Beaford Black Torrington Bradford Bradworthy Bridgerule Broadwoodwidger Buckland Brewer Buckland Filleigh Bulkworthy Clawton Clovelly Cookbury Dolton Dowland East and West Putford Frithelstock	Great Torrington Halwill Hartland High Bickington Hollacombe Holsworthy Holsworthy Hamlets Huish Huntshaw Landcross Langtree Littleham Little Torrington Luffincott Merton Milton Damerel Monkleigh Newton St Petrock Northcott	Pancrasweek Parkham Peters Marland Petrockstowe Pyworthy Roborough St Giles in the Wood St Giles in the Heath Shebbear Sheepwash Sutcombe Tetcott Thornbury Virginstowe Weare Gifford Welcombe Winkleigh Woolfardisworthy Yarnscombe
West Devon	Beaworthy Bondleigh Bratton Clovelly Broadwoodkelly Exbourne	Germansweek Hatherleigh Highampton Iddesleigh Inwardleigh	Jacobstowe Meeth Monkokehampton Northlew North Tawton
Torbay	Paignton Torquay		
Plymouth		All	
Somerset			
South Somerset	Alford Aller Ansford Ash Babcary Barrington Barton St David Bruton Castle Cary Charton Mackerell Chilton Cantelo Compton Dundon Corton Denham Crewkerne Curry Mallett Curry Rivel Dinnington Drayton Fivehead Hambridge & Westport High Ham Hinton St George	Huish Episcopi Ilchester Isle Abbots Isle Brewers Iton Keinton Mandeville Kingsbory Episcopi Kingsdon Kingstone King Weston Langport Limington Long Load Long Sutton Lopen Marston Magna Martock Merriott Misterton Muchelney North Barrow North Cadbury	North Perrott Pitcombe Pitney Puckington Queen Camel Rimpton Seavington St Mary Seavington St Michael Shepton Beauchamp Shepton Montigue Somerton South Barrow South Petherton South Cadbury Sparkford Stocklinch Tintinhull Wayford West Camel West Crewkerne White Lackington Yeovilton
West Somerset	Brompton Ralph Brompton Regis Brushford Clatworthy Cutcombe	Dulverton Exford Exmoor Exton Huish Champflower	Luxborough Oare Treborough Winsford Withypoole
Taunton Deane	Ashbrittle Bathealton Burrowbridge	Chipstable North Curry	Stock St Gregory Wiveliscombe

(continued)

Table 2 (continued)

Districts and Boroughs	Parishes and Towns		
Somerset (continued)			
Mendip	Ashwick	Ditcheat	Priddy
	Batcombe	Downhead	Pylle
	Binegar	Emborough	Shepton Mallet
	Butleigh	Holcombe	Stoke St Michael
	Chewton Mendip	Lamyat	Ston Easton
	Chilcompton	Leigh on Mendip	Stratton on the Fosse
	Coleford	Litton	Street
	Croscombe	Milton Clevedon	Walton
Sedgemoor	Lyng	Middlezoy	Othery
Northamptonshire			
Daventry	Althorp	Draughton	Naseby
	Arthingworth	East Haddon	Newnham
	Badby	Everdon	Norton
	Brington	Farthingstone	Preston Capes
	Brockhall	Fawsley	Ravensthorpe
	Byfield	Flore	Staverton
	Canons Ashby	Great Oxendon	Stowe Nine Churches
	Catesby	Guilsborough	Thornby
	Charwelton	Haselbech	Watford
	Clipston	Hellidon	Weedon Bec
	Cold Ashby	Holdenby	Welton
	Cottesbrooke	Hollowell	West Haddon
	Creaton	Kelmarsh	Whilton
	Daventry	Long Buckby	Winwick
	Dodford	Maidwell	Woodford Cum Membris
South Northamptonshire	Abthorpe	Eydon	Potterspury
	Adstone	Farthinghoe	Quinton
	Ashton	Gayton	Radstone
	Aston le Walls	Greatworth	Roade
	Aynho	Grafton Regis	Rothersthorpe
	Blakesley	Greens Norton	Shutlanger
	Blisworth	Hackleton	Silverstone
	Boddington	Harpole	Slapton
	Brackley	Hartwell	Stoke Bruerne
	Bradden	Helmdon	Sulgrave
	Brafield on the Green	Hinton in the Hedges	Syresham
	Bugbrooke	Kings Sutton	Thenford
	Castle Ashby	Kislingbury	Thorpe Mandeville
	Chacombe	Litchborough	Tiffield
	Chipping Warden	Little Houghton	Towcester
	Cogenhoe and Whiston	Maidford	Upper Heyford
	Cold Higham	Marston St Lawrence	Wappenham
	Courteenhall	Middleton Cheney	Warkworth
	Croughton	Milton Malsor	Weston and Weedon
	Culworth	Moreton Pinkney	Whitfield
	Denton	Nether Heyford	Whittlebury
	Easton Neston	Newbottle	Woodend
	Edgcote	Pattishall	Yardley Gobion
	Evenley	Paulerspury	Yardley Hastings
East Northamptonshire	Apethorpe	Higham Ferrers	Ringstead
	Blatherwycke	Irthlingborough	Rushden
	Chelveston Cum Caldecott	Islip	Stanwick
	Collyweston	Kings Cliffe	Thrapston
	Denford	Laxton	Twywell
	Duddington-with-Fineshade	Little Addington	Wakerley
	Easton on the Hill	Lowick	Warmington
	Fotheringhay	Nassington	Woodford
	Great Addington	Newton Bromswold	Woodnewton
	Hargrave	Raunds	Yarwell
Wellingborough	Bozeat	Great Doddington	Wellingborough
	Earls Barton	Grendon	Wilby
	Easton Maudit	Irchester	Wollaston
	Ecton	Strixton	

(continued)

Table 2 (continued)

Districts and Boroughs	Parishes and Towns		
Northamptonshire (continued)			
Corby	Corby Cottingham	East Carlton Middleton	
Kettering	Braybrooke Desborough Geddington	Harrington Newton	Rothwell Rushton
Northampton	Billing Collingtree	Great Houghton Hardingstone	Wootton Upton
Derbyshire			
Derbyshire Dales	Atlow Baslow and Bubnell Beeley Bonsall Bradbourne Brassington Callow Carsington Chatsworth Cromford Curbar	Darley Dale Edensor Fenny Bentley Froggatt Grindleford Hathersage Hognaston Hopton Ible Ivonbrook Grange Kirk Ireton	Kniveton Mappleton Matlock Bath Matlock Town Northwood and Tinkersley Offcote and Underwood Outseats Rowsley South Darley Tansley Wirksworth
High Peak	Bamford Chapel en le Frith Chinley, Buxworth and Brownside	Derwent Edale Hayfield	New Mills Whaley Bridge
North-East Derbyshire	Calow Eckington	Killamarsh Sutton Cum Duckmanton	Unstone
Bolsover	Ault Hucknall Barlborough Clowne Elmton	Glapwell Old Bolsover Pleasley	Scarcliffe Shirebrook Whitwell
Chesterfield	Staveley		
Amber Valley	Ashlyhay Dethick Lea and Holloway		

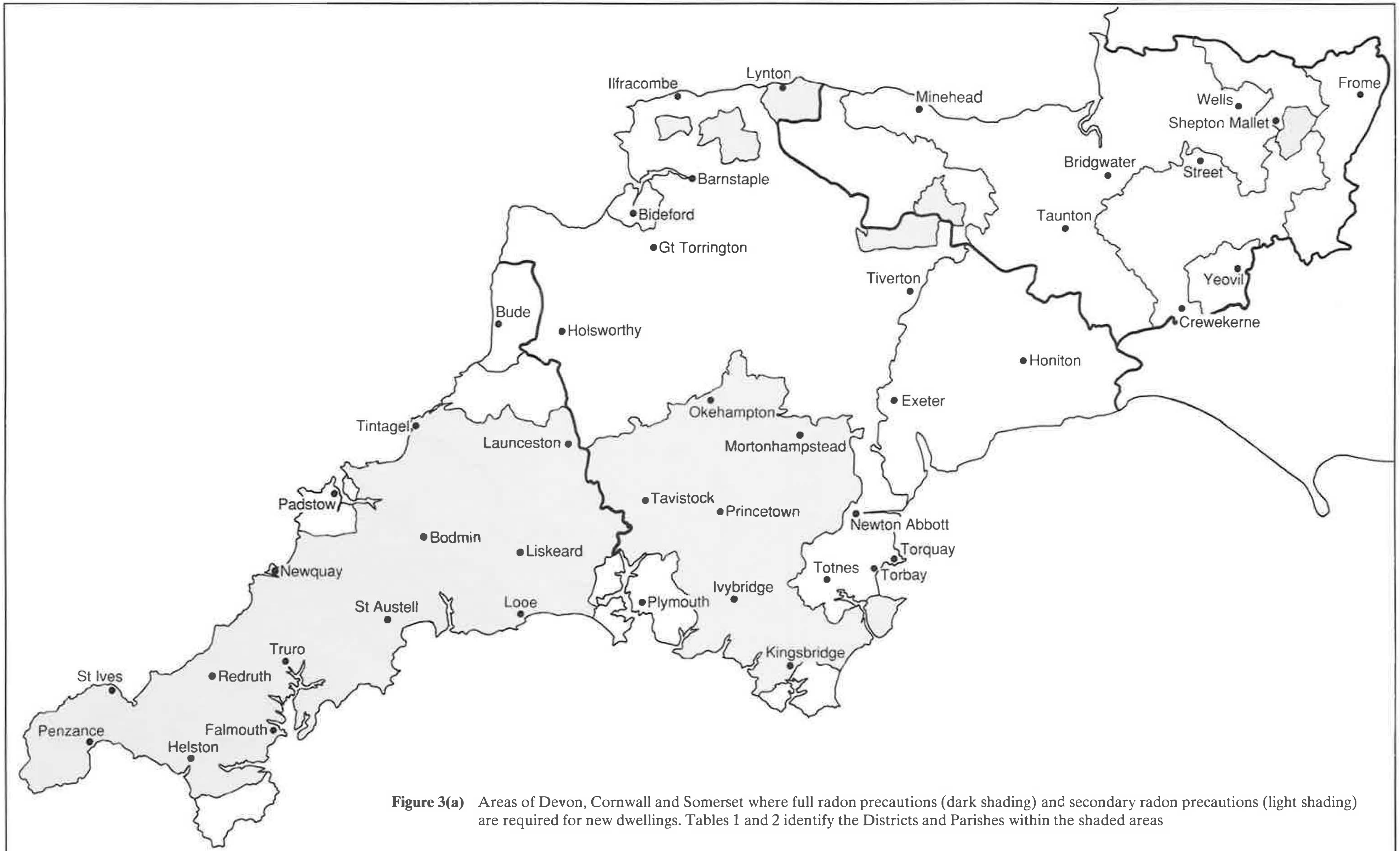

Figure 3(a) Areas of Devon, Cornwall and Somerset where full radon precautions (dark shading) and secondary radon precautions (light shading) are required for new dwellings. Tables 1 and 2 identify the Districts and Parishes within the shaded areas

Figure 3(b) Areas of Northamptonshire where full radon precautions (dark shading) and secondary radon precautions (light shading) are required for new dwellings. Tables 1 and 2 identify the Districts and Parishes within the shaded areas

Figure 3(c) Areas of Derbyshire where full radon precautions (dark shading) and secondary radon precautions (light shading) are required for new dwellings. Tables 1 and 2 identify the Districts and Parishes within the shaded areas

PRIMARY PROTECTION

The design objective is to construct an airtight, and therefore substantially radon-proof, barrier across the whole of the building including the floor and walls. This objective may be achieved by incorporating measures within conventional types of floor construction. Examples of such floor construction are shown schematically in Figures 4 and 5.

Suspended concrete floor

In the example illustrated in Figure 4 the radon-proof barrier is positioned over the floor structure and linked to cavity trays at the edges.

In-situ or ground-supported concrete floor

In the example illustrated in Figure 5 the radon-proof barrier is laid beneath the oversite concrete and continues across the cavity wall. The slab needs to be fully reinforced and is supported on the inner leaf of the cavity wall, since a traditional ground-bearing slab could settle on completion and rupture the radon-proof barrier at the point where the slab meets the external wall.

These examples are not the only design options available; alternative solutions may be adopted, such as raft foundations, fully tanked basement (eg fully waterproofed using asphalt), etc.

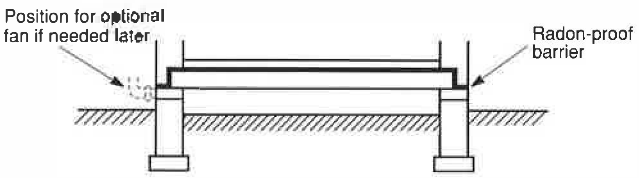

Figure 4 Radon-proof barrier in suspended concrete floor

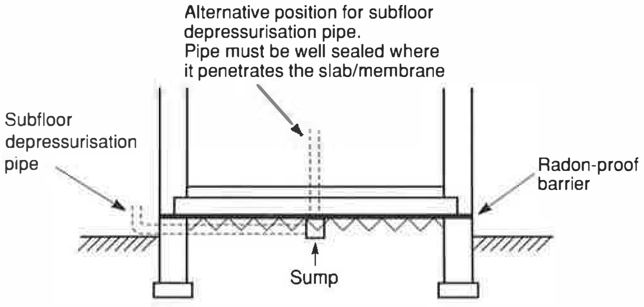

Figure 5 Radon-proof barrier in in-situ or ground-supported concrete floor

SECONDARY PROTECTION

In practice, it is recognised that the principal aim of providing a radon-proof barrier across the whole building including the floor and walls may not always be achieved. Doubts here are centred upon the reliability with which joins in membranes can be made under site conditions, and therefore the designer should also provide secondary protection. This might comprise one of the following solutions.

Natural ventilation

The underfloor space can be ventilated, preferably with airbricks on two or more sides of the space. For a suspended concrete floor underfloor ventilation will reduce the amount of radon that will need to be excluded by the radon-proof barrier.

Provision for mechanical ventilation

If a suspended floor is installed the house owner will have the option, if it is found necessary at a later date, of connecting an electrically powered fan in place of one of the subfloor airbricks to provide enhanced subfloor ventilation.

Provision for subfloor depressurisation

Where a ground-supported concrete floor (ie a floor without an underfloor ventilation space) has been specified, secondary protection can be provided by installing a subfloor depressurisation system (Figure 5). A complete system would comprise a radon sump located beneath the floor slab, coupled by pipework to a fan. However only the sump and underground pipework need be provided during construction. This gives the house owner the option of connecting a fan at a later date should it prove necessary.

DETAILED PROTECTIVE MEASURES

Once the method by which protection is to be provided has been decided, the following detailed guidance will need to be considered.

Radon-proof membranes

Generally a membrane of 300 micrometre (1200 gauge) polyethylene (Polythene) sheet will be adequate. (It is acknowledged that some diffusion will occur through the sheet. However, as most radon entry is through cracks, this diffusion can be ignored.) Where there is a risk of puncturing the membrane, reinforced polyethylene sheet should be considered.

The membrane can be constructed using other materials which match the airtightness and waterproofing properties offered by polyethylene. Alternative materials that can prove suitable include modern flexible sheet roofing materials, prefabricated welded barriers, liquid coatings, self-adhesive bituminous-coated sheet products, and asphalt. Prefabricated welded barriers are likely to offer a greater confidence in achieving radon-proof joints than the use of polyethylene sheet, but are more expensive. One solution which has been found to be effective is to use polyethylene sheet over the bulk area of the floor with self-adhesive bituminous-coated sheet for corner and edge details.

When selecting the membrane material consideration should be given to jointing. Some materials are difficult to seal in adverse weather. It is also important that the radon-proof membrane is not damaged during construction. This might be achieved by installing the membrane at a later stage of construction, eg over the floor immediately before laying of the screed.

If a basement is to be fully tanked to prevent damp penetration it will also provide radon protection. There is no need to provide secondary protection (eg sump) in such cases.

With careful design and selection of material, a single barrier will satisfy the requirements of both damp-proofing and radon protection.

Radon-proof cavities
One of the routes by which radon might enter a building is by way of the wall cavities (Figure 6), and therefore the radon-proof barrier should extend across the cavity to prevent radon entry. Where the barrier crosses the cavity, it will need to be constructed in the form of a cavity tray to prevent the ingress of water from the outer to the inner leaf. The barrier should be continuous and as airtight as possible; all joints, including any in the cavity tray, should be carefully and durably sealed. As with all cavity trays, weepholes will have to be provided in the outer leaf to drain the cavity.

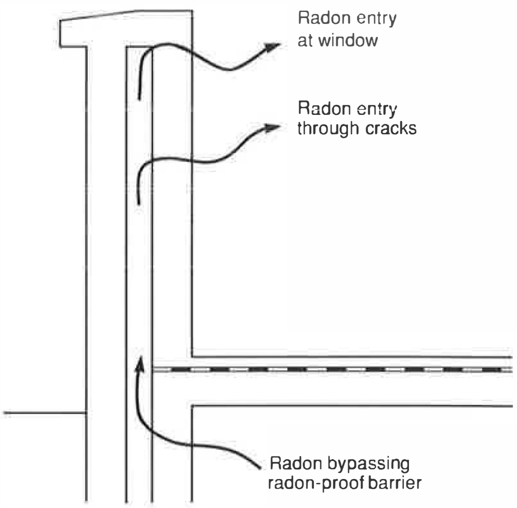

Figure 6 Radon entry through unprotected cavities

It is difficult to achieve completely airtight joints in the cavity tray. Therefore, it is desirable to provide a degree of ventilation to the cavity above the tray to help dissipate any radon that might otherwise collect there. This might be achieved by maintaining a clear cavity together with the ventilation provided by the weepholes above the cavity tray.

Where cavity fill is required, it is therefore advisable to use materials that will not prevent ventilation of the cavity. In this respect partial cavity fill is an obvious solution, although other types of cavity fill may be used provided they allow bulk air movement. If a suspended concrete floor with naturally ventilated underfloor void is used, the radon concentration beneath the floor will be reduced. This will also tend to reduce the amount of radon in the cavity below the cavity tray and the risk above the tray. Therefore, conventional mineral wool batt insulation is acceptable with this type of construction.

To reduce the risk of radon entering the cavity where periscope subfloor ventilators are used, it will be necessary to tape the joints between the upper and lower halves of the ventilators.

Slip or shear planes
It is important to ensure that the inclusion of membranes with cavity trays does not adversely affect the structural integrity of loadbearing walls. The designer should consider avoiding having a cavity tray directly on top of a membrane, or vice versa, within any loadbearing wall, as this can create a slip or shear plane. It becomes more important in cases where both of the materials being used have shiny surfaces like polyethylene. The risk is most severe if the building may be subjected to lateral loading, as might be the case in exposed locations. The risk is considered minimal for one- and two-storey dwellings, but it is more significant with taller buildings.

In view of the expense of correcting deflected walls, avoidance of slip planes in all construction is advised. One solution is to join the membrane to the cavity tray over the floor instead of within the wall (see Figure 7).

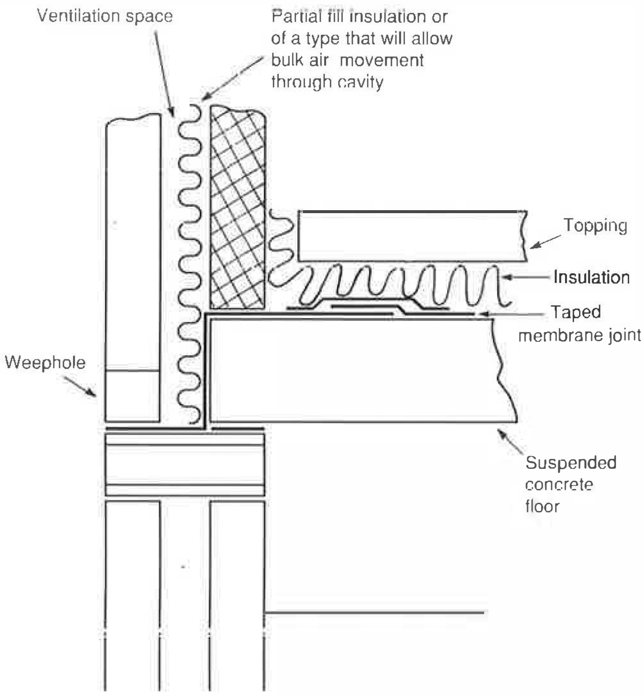

Figure 7 Avoidance of a slip plane within the wall by positioning the membrane joint over the floor

Lapping of membranes and trays
Wherever the membrane or tray needs to be lapped and sealed, care must be taken to ensure a very good standard of work. It is difficult to achieve a totally airtight seal but nevertheless this remains the objective and it is important to keep defects to a minimum.

Reinforced slabs
Where an in-situ concrete slab is laid with its edge supported on the inner leaf of an external wall, the slab must be strong enough to prevent cracking in the centre of the slab should the fill forming permanent shuttering beneath settle. This effectively means that all such slabs should be reinforced throughout.

Internal walls
Internal walls should be built off the membrane or its covering in such a way as to leave the membrane intact Figure 8). Sometimes it will be convenient to build these walls off a 600 mm wide strip of membrane material, and to lap and seal this to the main membrane before screeding. (This will reduce the risk of damage from traffic.)

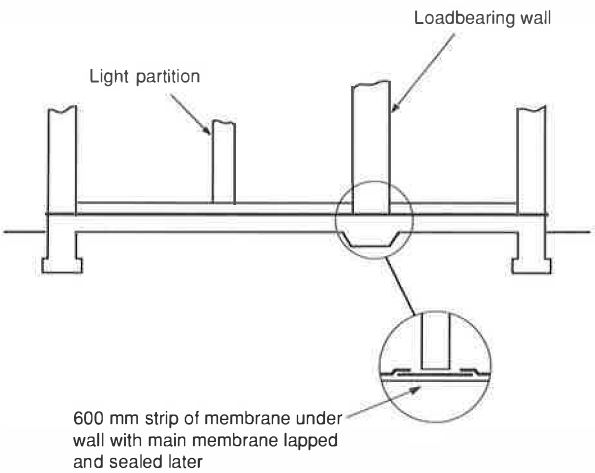

Figure 8 Avoidance of breaking the radon-proof barrier beneath internal walls

Service penetrations
Where possible service entries should avoid penetrating the radon-proof membrane. Where this is not possible it will be necessary to construct an airtight seal around each entry (Figure 9). Prefabricated 'top hat' sections are available from some membrane manufacturers for sealing around pipe entries. Penetrations should be avoided at points where the membrane is lapped, because of the greater difficulty of resealing. With careful design all supply services with the exception of mains water can be brought up the outside of the building to enter through walls. However, accommodating service entries in walls may limit where internal fixtures can be placed. Traps and other services should be located so as not to damage the radon-proof barrier within the floor slab.

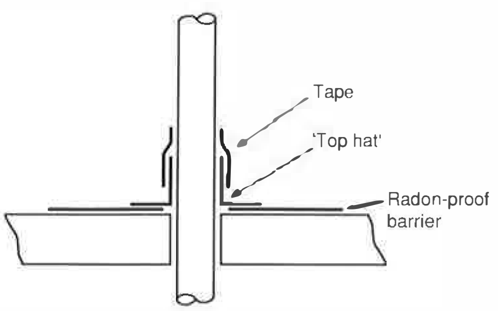

Figure 9 Achieving an airtight seal around service penetrations

Condensation and cold bridges
Condensation and cold bridging are matters to be considered. For further guidance see BRE Report *Thermal insulation: avoiding risks*[4].

Subfloor ventilation
Where airbricks are recommended they should be installed where possible on all sides of the building, and should be placed at intervals at least as frequent as would be normal for an ordinary suspended timber floor (ie openings should be large enough to give an actual opening of at least equivalent to 1500 mm^2 for each metre run of wall on two opposite sides). This may be contrary to the normal practice of some builders in south-west England, who tend to use fewer airbricks because of the high winds experienced in the region. It is also important to ensure that all airbricks are kept clear. Landscaping works such as paths and driveways must not compromise subfloor ventilation.

Where periscope subfloor ventilators are used it will be necessary to tape the joints between the upper and lower halves of the ventilators to reduce the risk of radon entering the cavity.

Subfloor depressurisation
Where a ground-supported floor is to be constructed a radon sump should be provided. This would enable subfloor depressurisation to be introduced with relative ease if desired at a later date. (Subfloor depressurisation involves sucking radon-laden air from beneath a building and discharging it harmlessly into the atmosphere.) For a typical house a single sump will probably be sufficient. (Where clean permeable fill has been used, a single sump is likely to have an influence over an area of approximately 250 m^2, or for a distance of 15 m from the sump.) The sump should preferably be positioned centrally under the house and constructed to ensure that its pipe entry is not blocked when the fill is placed (Figure 10). To allow for maximum depressurisation fill used beneath the slab should not contain excessive fines.

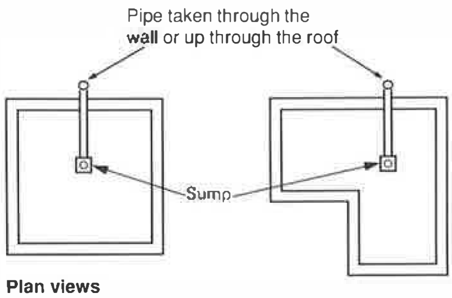

Figure 10 Central positioning of sump under dwelling

A simple sump can be constructed using bricks laid loose in a honeycomb bond so as to form a box around the end of the pipe (Figure 11). Typically the pipe needs to be 110 mm diameter uPVC with joints using standard couplings sealed and airtight. The pipe needs to leave the building so that it can be coupled to a fan mounted on the external wall. It will therefore need to terminate ideally about 100 mm from the external wall, and be located at the rear of the house or at a re-entrant corner where subsequent installation of a boxed-in fan and vertical stack will be least obtrusive. Until such time as a fan is installed, the pipe should be capped off just above ground level to prevent vermin and rain penetration. The pipe should be capped with an access plug (Figure 12); there is no advantage to be gained by capping with a vent cowl. It should be noted that the sump and pipework are only installed as a fallback measure and do not provide any radon removal until such time as a fan is installed should this prove necessary.

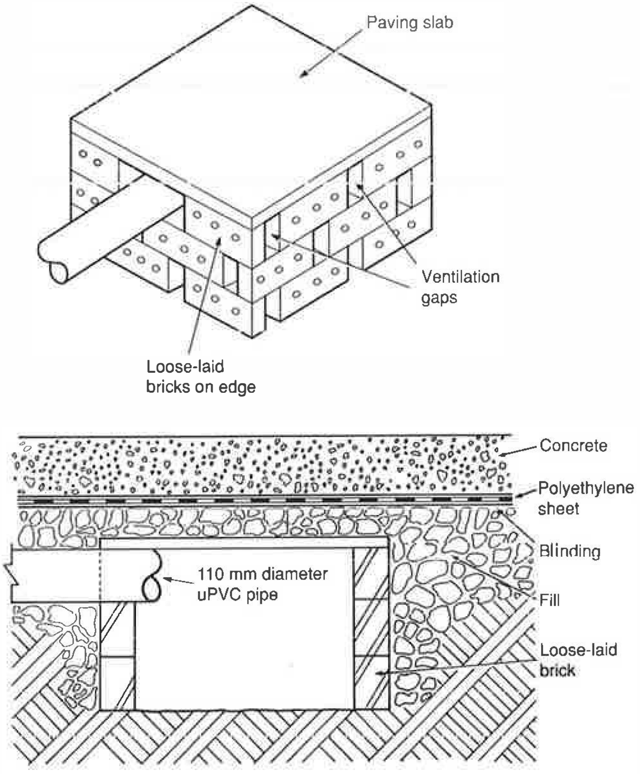

Figure 11 Radon sump details

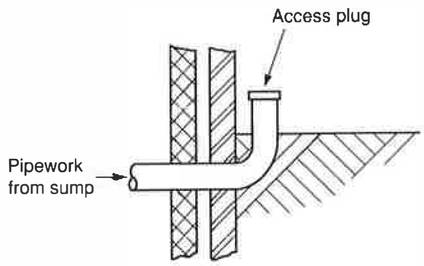

Figure 12 Pipework from sump capped-off with an access plug just above ground level

As an alternative to constructing a sump using bricks, prefabricated sumps may be used, or geotextile drainage matting can be laid beneath the slab (Figure 13) and connected to an extract pipe. The matting is likely to prove more expensive than a sump.

The fan should be positioned with the outlet well away from windows, doors and ventilation grilles, ideally discharging just above eaves level. To avoid penetrating the radon-proof membrane in the floor unnecessarily, the pipe should preferably be taken through the wall, not up through the floor. However, it may be desired for aesthetic reasons to locate pipework in ducts inside the house and to take the outlet from the fan through the roof (Figure 14). *It is not satisfactory* for the fan to ventilate into a roof space. If a fan is fitted it should always be placed as close to the outlet as practical so that the pipework is always under suction. This is of particular importance when routing pipework inside the house as even slight leaks could increase indoor radon concentrations.

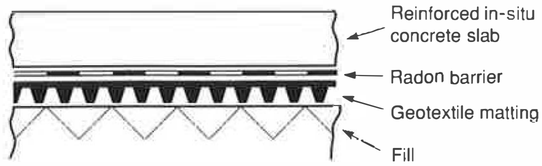

Figure 13 Geotextile matting used as an alternative to a sump

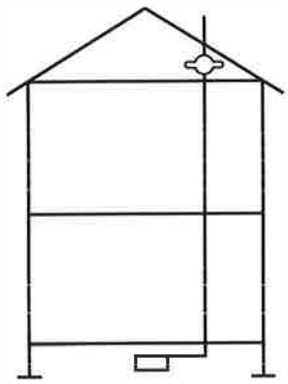

Figure 14
Pipework ducted internally, with the fan outlet through the roof and *not* ventilated *into* the roof space

If the subfloor area comprises several compartments then sumps may be required for each compartment (Figure 15). These may be connected to a manifold and a single fan (Figure 15(a) and (b)). However in most cases there is no need to establish a manifold of pipes. A single sump located alongside the separating wall, with a few bricks omitted to allow depressurisation, will suffice (Figure 15(c)). It is important for fill to contain minimal fines in order not to impair the efficiency of the depressurisation system.

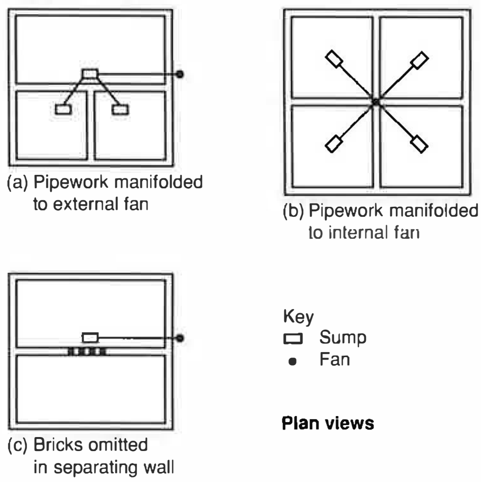

Figure 15 Location of sumps within multi-compartment subfloor areas

Passive stack subfloor depressurisation

Subfloor depressurisation is usually achieved actively using an electric fan to provide suction. It may be possible to depressurise the subfloor area sufficiently without using a fan, ie passively. A passive stack subfloor depressurisation system would comprise a vertical stack pipe run from the radon sump to discharge at a point just above eaves or at ridge level. BRE are currently investigating the effectiveness of passive stack subfloor depressurisation systems.

High water table

In areas where it is known that the water table is particularly high or the level fluctuates there is a risk that radon sumps may become waterlogged and therefore ineffective. In such cases tanking should be used to prevent water ingress and provide radon protection. There is no need to provide a radon sump. It should be noted that generally water will act as a screen to radon. However, if the water level fluctuates the ground pressure will also change which in turn may drive more radon into the building.

Blinding

Where a membrane is to be placed over fill, the fill should be blinded (ie its surface finished with a fine material) to leave a smooth surface which will not puncture the membrane. This is especially important if ordinary building polyethylene is used but care is required even with tougher reinforced membrane materials. Care must be taken to ensure that the blinding material does not block up the voids in the fill, or the efficiency of the depressurisation system will be impaired. This is particularly important if the permeable fill is of limited thickness. Foam sheeting could be used instead of blinding, but this is likely to be more expensive.

Where the radon membrane would otherwise be left exposed within a ventilated space it is advisable to blind it with a thin topping of concrete or sand to reduce the risk of damage by following trades.

Party walls

The radon-proof barrier will need to continue across party walls where they occur, and for cavity construction will need to double as a drainage channel to prevent flooding of one dwelling affecting the neighbouring dwelling (Figure 16).

Extensions

It is advisable when a house is extended that radon-protective measures be incorporated in the new work. For **a house with radon-protective measures** the extension should include protective measures equivalent to those in the existing house. Consideration should be given to linking the radon-proof barrier in the new floor to the radon-proof barrier in the existing house.

Within the areas listed in Tables 1 and 2, an extension to **an unprotected house** only requires secondary protection when the ground-floor area of the extension is greater than 30 m^2. (Experience has shown that an extension up to 30 m^2 in ground-floor area can be remedied by an externally excavated sump.)

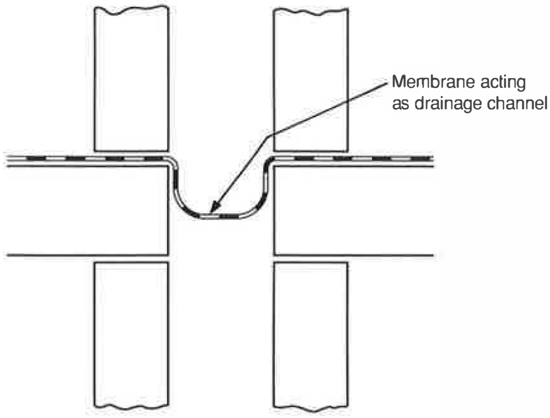

Figure 16 Radon-proof barrier continued across party wall and acting as drainage channel

Garages

Integral garages need the same provision as the rest of the dwelling. Detached domestic garages need no provision.

Monitoring of completed houses

It is not a requirement of the Building Regulations for houses to be tested for radon. If however a test is contemplated, then, in order to obtain the most reliable results, houses should be monitored for a period of several months using Tracketch (plastic) detectors. Ideally monitoring should be carried out during the winter. Indoor radon concentrations are likely to be at their highest at this time of year because of increased heating coupled with a reduction in window opening. Ideally houses should be monitored only after they have been occupied for several months so that measurements are not affected by windows being open for drying-out purposes.

STEPPED FOUNDATIONS: ADDITIONAL POINTS TO CONSIDER

Where possible stepped foundations should be avoided, as they complicate the achievement of radon protection using only sealing techniques. It may prove less expensive to excavate around the house (Figure 17) to provide a ventilated space, than try to build into the hillside and seal all the faces of the building which fall below ground level. Knowledge of

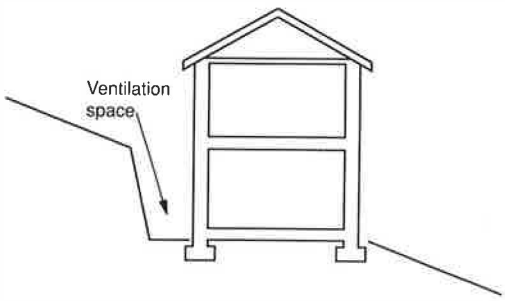

Figure 17 Avoiding stepped foundations by excavation

how to construct stepped foundations sealed against radon is limited, but the following points should be considered. It is possible that most stepped constructions in radon-prone areas of the country will need a depressurisation fan to achieve low radon concentrations. This is under investigation.

- Where a suspended concrete floor is used, any space below it should be ventilated to the outside.

- It is important that any radon-proof membrane should be incorporated in such a way as not to create a slip plane. This is of particular importance for a retaining wall. Similarly, continuity of any structural reinforcement will need to be considered at points where it would penetrate the membrane. Structural requirements remain of paramount importance.

- As with floors built on one level, it is important to try to avoid positioning service entries where they would penetrate the radon-proof membrane. Where they do penetrate the barrier they will need to be adequately sealed.

- It may be possible to use self-adhesive bitumen-coated polyethylene sheet for the vertical radon-proof membrane. However, it may require some form of additional restraint if it is not to suffer wind damage during construction. It would also be advisable to apply a render coat on nailed lathing or a masonry skin over the membrane to ensure that it remains in position once the building is complete. This is of particular importance where storey-height areas of sheet are being applied.

  An alternative to this solution is to tank the basement area fully with asphalt. This has been found to work successfully in the USA and provides a robust solution to radon ingress.

  Surface coating products available for waterproofing purposes, such as liquid bitumen, cementitious coatings, and plastic-based coatings, may be suitable for radon protection. However if they are to work they will need to be correctly applied.

- Subfloor depressurisation should be considered wherever a solid floor is proposed. Similarly, in basement construction it will be necessary to consider providing depressurisation to the areas of soil backfilled against the external walls. Geotextile drainage matting could be used in place of sumps. It could prove particularly useful for providing a vertical ventilation space behind retaining walls. It may be possible for subsoil drain pipes from these spaces to double up as radon extract pipes.

FURTHER INFORMATION

For further advice regarding building matters contact: Building Research Establishment, Garston, Watford, WD2 7JR; telephone 0923 894040.

For further advice regarding radon measurement contact: Radon Survey, National Radiological Protection Board, Chilton, Didcot, Oxon, OX11 ORQ; telephone 0235 831600.

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