Radon

Research Paper 97/37

18 March 1997

It has been recognised during the past decade that radon poses a significant risk to health in the UK. It is thought that radon is responsible for about 5% of lung cancer deaths which is approximately 2,000 deaths in the UK annually.

This paper explains why radon it is a problem; the history of the link with lung cancer; how smoking affects the risk; recommended maximum concentrations in buildings; statutory control of radon in the workplace; the Government programme on radon; UK policy for assessing and controlling radon in dwellings; remedial measures which may be undertaken, and public perception of risk from radon.

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I Why is Radon a Problem?

Radon is a naturally occurring, odourless, colourless gas which is radioactive. It is formed during the radioactive decay of uranium, an element found in small quantities in all soils and rocks. Radon travels through fissures in the subsoil until it reaches the surface where it usually disperses in the atmosphere, but can accumulate in buildings. In areas where the underlying rock contains concentrations of uranium which are greater than the average and the ground is permeable the concentration of radon in buildings can reach high levels.

The radioactive decay of radon leads to other radioactive species called radon daughters which are themselves radioactive. These resulting products attach themselves to particles in the air which can be inhaled and deposited in the lungs. The radon daughters emit α-particles[1] in the course of further decay. Their radioactivity is measured in becquerels (Bq) where a becquerel is one nuclear disintegration per second. Some α-particles deposit their energy within the cells of the conducting airways called bronchi and bronchioles. If this occurs in the nucleus of a cell the energy may disrupt the function of the genetic material known as DNA. Amongst other effects this may cause a mutation which could initiate the cancerous process.

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[1] Alpha (α) particles consist of two protons and two neutrons which is the form of the nucleus, or heavy central part, of the helium atom

II History of a Link Between Radon and Cancer

In the sixteenth century a notable physician, Paracelsus, who lived in Saxony noted that local silver miners from the Schneeburg mines were severely affected by a pulmonary disease[2]. His most significant contribution was the recognition that the disease was caused by an agent in the air. In 1879 the disease was recognised as lung cancer and at the turn of the century measurements in the Schneeburg mines indicated high concentrations of radon. Early in the twentieth century the hypothesis was put forward that there was a causal relationship between the two. Weight was added to this hypothesis by the elevated lung cancer incidence in workers from other similar mines including those in Jachymov in Bohemia.

Animal studies begun in the 1950s demonstrated a causal relationship between radon and lung cancer. Subsequently, epidemiological investigation amongst uranium miners which were started in the mid 1960s confirmed the link for man[3]. A summary of the twelve principal studies is set out in the table[4]:

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2 *Radon* WHO 1996

3 *Committee on the Biological Effects of Ionizing Radiation (BEIR IV)* Washington DC National Academy Press 1988

4 NRPB-R272 p4

TABLE 1 Mortality from lung cancer among miners exposed to radon

Mine(s) (follow-up period)	Number	Mean WLM	Man-years	Number of lung cancer deaths	
				Observed	Expected
Colorado Plateau, USA (1951–82)[17]	3,346	821	73,642	256	59.1
Ontario, Canada (1955–81)[18]	13,469	30	–	152	67.6
Beaverlodge, Canada (1950–80)[19]	8,487	13	114,170	65	34.2
Port Radium, Canada (1950–80)[20]	2,103	144	52,930	57	24.7
West Bohemia, Czech Republic (1953–90)[21]	4,320	219	–	702	138
Malmberget, Sweden (1951–76)[22]	1,294	94	27,397	51	14.9
New Mexico, USA (1977–85)[23]	3,469	111	59,000	68	17.0
Newfoundland, Canada (1950–84)[24]	1,772	383	38,500	113	21.5
Yunnan Province, China (1976–87)[25]	17,143	217	175,406	981	267
Cornwall, UK (1941–86)[26]	3,010	~100	–	105	66.6
Radium Hill, Australia (1952–87)[27]	1,429	7	–	32	23.1
France (1946–85)[28]	1,785	70	44,995	45	21.1

WLM Working Level Month (WLM) is defined as exposure to 1 Working Level (WL) for a working month of 170 hr. This is approximately equivalent to 144 becquerels per cubic metre (Bq m^{-3}) for a year.

In all, the studies followed about 60,000 miners who developed 2,600 lung cancers. This is statistically far in excess of the expected number of about 750. It is generally accepted that the data from mines show a dose-related association between radon exposure and carcinogenic effect. There are, however, problems in extrapolating the risks quantified for miners to those for the general population in the indoor environment. These include the fact that miners are all adult males and their lung cancer incidence is confounded by other factors such as smoking and the dust and fumes to which they are exposed in the mines. Another consideration is whether it is valid to assume a linear extrapolation from the high concentrations of radon experienced in mines to the relatively lower concentrations in some

homes[5]. There are radiobiological grounds for expecting a linear dose response relationship at low doses[6]. On the basis of this it is estimated that 5% of all lung cancer deaths in the general population of the UK could be caused by radon[7]. This is a total number of about 2,000 deaths annually and places radon as the second most important cause of the disease after smoking.

Further epidemiological surveys designed to study the risk in dwellings are under way in many countries[8,9]. Due to the low level of risk to be detected and the range and variety of confounding factors such as smoking history, age, sex, etc, the results are sometimes contradictory. In an attempt to overcome the lack of statistical power in individual studies in which low levels of risk are being detected, researchers are considering pooling data from various indoor studies. It is predicted that within the next few years there will be a crop of results which should help answer the questions still open.

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5 *Radiological Protection Bulletin* No 185 January 1997 p10-13

6 ICRP IV *Health-risks of radon and other internally deposited alpha-emitters* Washington DC National Academy Press 1988.

7 *Department of the Environment* News Release 5 February 1996 No 45

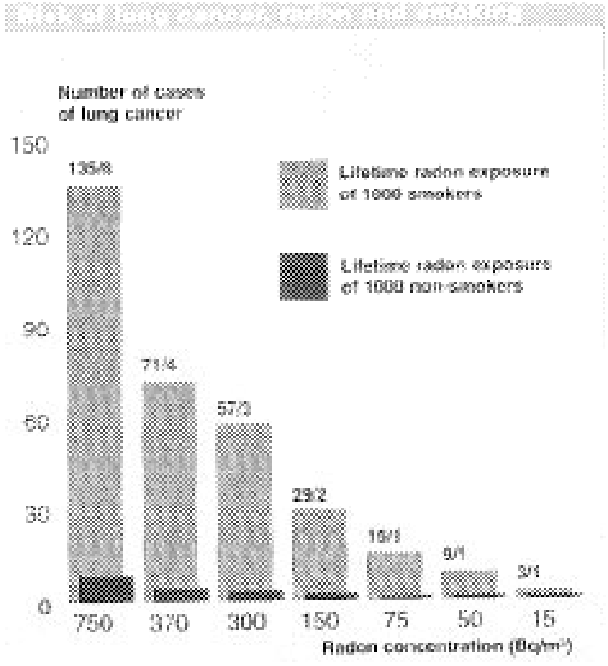
8 *Radon* WHO 1996

9 *Radiological Protection Bulletin* No 181 September 1886 p8-11

III Radon and Smoking

As has already been mentioned certain aspects of the effect of radon upon human health are well established. It is recognised from studies of miners, animal experiments and radiobiological considerations that there is a dose-related association between radon exposure and lung cancer. In addition exposure of the general population to radon by itself is recognised as the second most frequent cause of death from lung cancer after smoking. There is, however, less certainty about the combined effect of exposure to tobacco-smoke and radon. It is possible that the risk of smoking is simply added to the radon risk. Alternatively the risk of one could multiply the risk of the other. Exercises have been carried out to try to fit additive, multiplicative and intermediate models to the data. The truth appears to lie with an intermediate fit, but there is increasing evidence that the best fit is closer to the multiplicative model and that the additive model should be rejected[10]. Thus smoking greatly increases the risk of lung cancer to radon and vice versa. The extent of the increase is effectively illustrated in the following figure[11]:

Figure 1 - Risk of lung cancer from radon for smokers and non-smokers



NB The numbers that surmount each column (X/Y) show the number of cases of lung cancer expected after a lifetime of radon exposure at the concentrations indicated for 1,000 smokers (X) and 1,000 non-smokers (Y).

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10 *Radioactive Protection Bulletin* No 181 September 1996 p8-11

11 *Radon* WHO 1996

IV Recommendations about the Concentration of Radon in Buildings

Taking all the evidence into account the Internal Commission on Radiological Protection (ICRP) recommends an Action Level for radon in homes of 200-600 becquerels per cubic metre (Bq m^{-3}), where 1 becquerel is one nuclear disintegration per second. At this concentration, and above, remedial measures should be taken to reduce it. ICRP has recently emphasised the scale of the public health problem caused by radon by formulating specific recommendations[12].

In the UK the National Radiological Protection Board (NRPB), an independent statutory body, makes recommendations to the Government about maximum radon levels in homes. This is on the strength of its own and other research, and after close liaison with ICRP. Following a recommendation from the NRPB an Action Level of 200 Bq m^{-3} was adopted by the UK government for new and existing dwellings in 1990[13].

In other countries the attitudes of governments vary widely. Some countries do not have any guidance. Within the EU there are six member states which are still considering what action to take within their own jurisdictions. Some other countries have advisory levels commonly called "reference levels", "guidance levels" or "action levels" which differ widely from one country to another. There are two countries, Sweden and Switzerland, which have both an advisory level and a compulsory upper limit. The Netherlands is alone in setting a very low advisory level of 20 Bq m^{-3}. In the Netherlands there are generally very low radon concentrations in houses, but in most countries this would not be a practicable limit. The following table compiled from two sources lists these levels for existing and future housing[14,15].

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12 *Protection against radon 222 at home and work* ICRP publication 65 New York Pergamon 1993

13 *Department of Environment* News Release 32/90 January 1990

14 *Radon* WHO 1996

15 *Radiological Protection Bulletin* No 181 September 1996

Table 2 - Guideline Values (Action Levels) for Average Annual Radon Concentrations in Dwellings (Bq m^{-3})

Country	Year Set (if known)	Existing Dwelling	Future dwelling
Australia	1990	200	200
Austria	1992	400	200
Belgium	1995	400	400
Canada	1988	800	800
Czech Republic	-	200	200
EU	-	400	200
Finland	1992	400	200
Germany	1988	250	250
Ireland	1991	200	200
Israel	-	200	-
Lithuania	-	100	50
Netherlands	1994	20	20
Norway	1988	200	200
Poland	-	400	200
Sweden	1994	400[+] 200[*]	200[+]
Switzerland	1994	1000[+] 400[*]	400[+]
UK	1990	200	200
USA	1988	150	Same as outdoors

[+] Regulatory limit

[*] Recommended upper limited for remediation

The assessment of radon concentrations in dwellings for comparison with reference levels are normally based on long-term measurements, but Sweden and the USA allow short-term measurements for this purpose. There are grants towards the remediation costs in Sweden, Finland, Belgium, Luxembourg and the UK, although these are means-tested in the last three.

In Canada, Finland, Ireland, Sweden and the UK where it is known that there are areas with high radon levels in dwellings, building practices for new dwellings have been specified. In the UK these are contained in guidance to the Building Regulations.

The WHO recommends that in buildings which are not permanently inhabited such as schools and workplaces, equivalent levels should apply by weighting the action levels to take account of the maximum exposure times.

V Radon in the Workplace

In the workplace[16,17] the Health and Safety at Work etc. Act 1974 places the principal duty on the employer to ensure the health and safety of employees and others who have access to the work environment. The *Ionising Radiations Regulations* (SI 1333 of 1985) made under the Act require employers to carry out remediation where radon concentrations are above a defined level. If elevated radon levels seem likely, for example due to the location, the employer should have the premises tested. Research[18] has shown that radon concentrations in large premises such as factories and warehouses are usually too low to be a problem, and measurement programmes should be focused on smaller premises not unlike houses in size and construction. Where measurements averaged over a prolonged period indicate levels below 400 Bq m^{-3} and the workplace is occupied for a normal working day, further action is unlikely to be required. This figure is comparable with the action level of 200 Bq m^{-3} in homes taking into account the time most people spend at home and at work. Where measurements indicate average concentrations above 400 Bq m^{-3} the employer should seek advice from the local Health and Safety Executive Area Office or Local Council's Environmental Health Department, as appropriate. There are successful and relatively inexpensive remedial techniques to reduce radon concentrations applicable to both workplaces and homes (see later). In workplaces where remedial measures are necessary it is strongly recommended that employees have their homes tested as well.

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16 *Radon in the Workplace* Health and Safety Executive, 20 July 1992

17 *Radiological Protection Bulletin* No181 September 1996 p18-20

18 *ibid*

VI The Government Programme on Radon

In the early 1980s the NRPB began a survey of radon concentrations in representative samples of all UK dwellings and more detailed surveys in areas where high concentrations might be expected to occur. Results indicated mean radon concentration of about 20 Bq m^{-3}, but that there was large variation and a significant number of dwellings had concentrations of 1,000 Bq m^{-3} or more.

Government action on radon in dwellings dates back to 1987[19] when it accepted the advice of the NRPB and that of COMARE (Committee on the Medical Aspects of Radiation in the Environment). The advice was that there was a causal relationship between radon gas and lung cancer and that action should be taken to reduce radon levels in existing buildings with high concentrations and to limit exposure in those to be built in the future. This followed earlier recommendations from the ICRP[20] and the Royal Commission on Environmental Pollution[21]. The Government funded further surveys by NRPB to identify dwellings with high radon levels.

In 1990, the NRPB updated and simplified its advice on radon in dwelling[22]. It recommended an Action Level of 200 Bq m^{-3} in existing and future homes. This was an amendment of the initial 1987 Action Levels of 100 Bq m^{-3} for new and 400 Bq m^{-3} for existing dwellings. NRPB also suggested a comprehensive control strategy based upon the concept of Affected Areas. An Affected Area is defined as a part of the country with 1% or greater probability of dwellings being above the Action Level. NRPB recommended that radon concentrations should be reduced in dwellings where it was found to be above the Action Level, and that in Affected Areas preventive measures should be taken against radon in new dwellings. The Government accepted its advice which was consistent with the recommendations of the House of Commons Environment Committee review of radon in its report on indoor pollution[23]. This recommended that by the year 2000 the Government should aim to identify the majority of dwellings above the Action Level. The Government supported this goal and anticipated that surveys already initiated would achieve this[24].

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19 HC Deb 27 January 1987 c189-197
20 ICRP Publication 39 Ann ICRP 14 No1 1984
21 Royal Commission on Environmental Pollution. Tenth Report. Cmnd 9149 1984
22 Board Statement on Radon In Homes Doc NRPB 1 No 1 1990
23 HC Select Committee on the Environment. Sixth Report. HC-61 1990-91
24 Governments Response to HC-61, 1990-1991, Cmnd 1623 1991

The Government initiated campaigns to encourage householders to take up offers of free radon measurements (see later for details). The main objectives of these measurement programmes are to complete radon maps for the UK and identify most of the estimated 100,000 dwellings with radon concentrations above the Action Level so that householders can be advised how to take remedial action.

A. Domestic Radon Concentrations in the UK: Maps

Progress is being made on the objective of producing a radon map of the whole of the UK[25]:

> The aim is to draw a definitive radon map of the whole country and identify any other areas with raised radon levels that might qualify for Affected Areas status. The plan, wherever possible, is to measure at least 12 homes evenly spread throughout each 10 km square of the Ordnance Survey grid. Where mean radon concentrations are close to the Action Level, approaches are made to other householders to obtain five measurements in each 5 km grid square. This survey involves a total of about 18,000 measurements.

1. England and Wales

The completion of the mapping exercise for England and the most recently for parts of Wales was announced on 16 May 1996[26,27,28]. The map, reproduced from the report[29], indicates the estimated proportion of homes exceeding the Action Level in each 5 km grid square in England.

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25 NRPB-R272

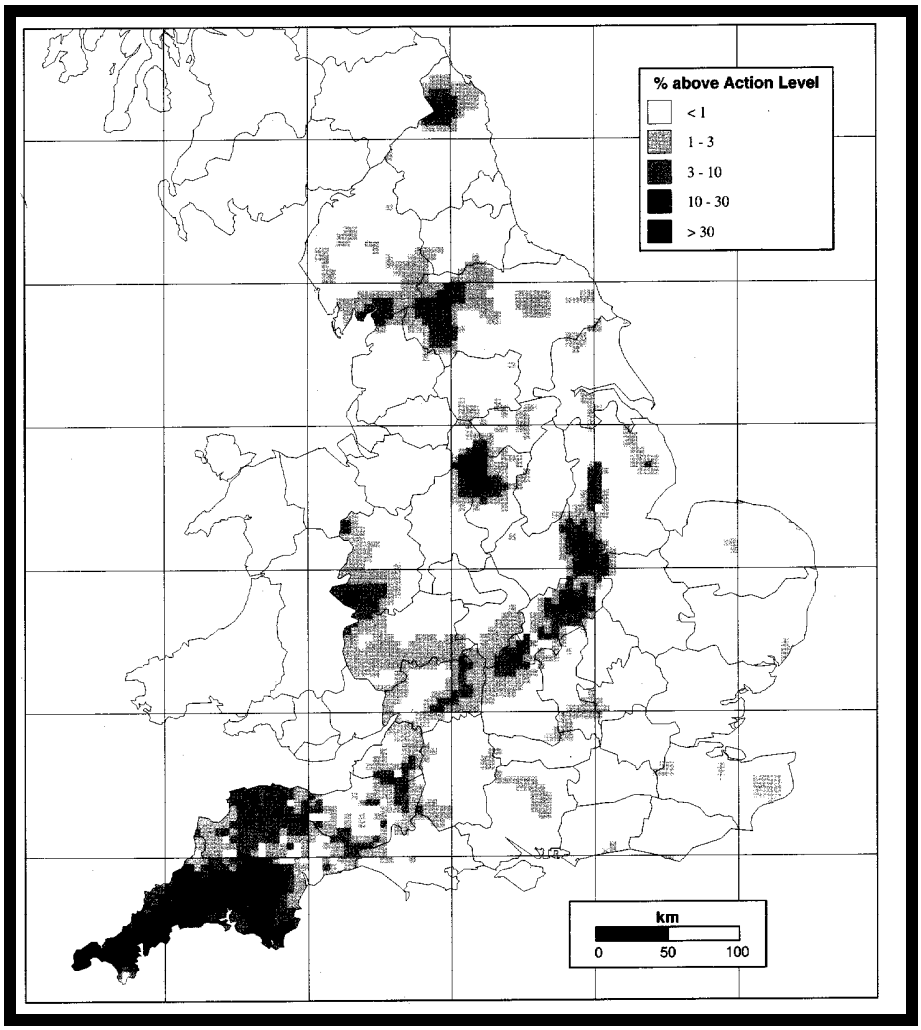
26 Department of Environment News Release No 206, 16 May 1996

27 *Radon Affected Areas: England and Wales* Doc NRPB 7 No 2 1996

28 Doc NRPB 7 No2 1996 also as Deposit \3 3376

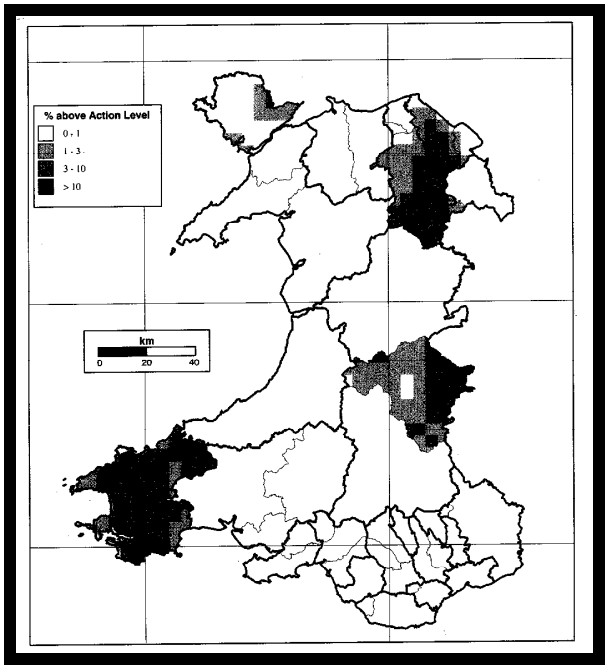
29 Doc NRPB 7 No2 1996

Figure 2 - Areas in England exceeding the Action Level



A similar interim map for parts of Wales is reproduced from the same report in the figure below. The map shows results only from the previous Welsh districts of Alyn and Deeside and Delyn (now in the Unitary Authority of Flintshire), of Glyndwr (now in Denbighshire), of Radnorshire (in Powys), of Ynys Mon (now called Anglesey), and of Preseli Pembrokeshire (now Pembrokeshire).

Figure 3 - Some areas in Wales exceeding the Action Level



In both maps all shaded areas indicate parts of the country in which there is a 1% or greater chance of the radon concentration in dwellings exceeding the Action Level, and are therefore designated or recommended to be delimited as Affected Areas.

In September 1996 NRPB published the *Radon Atlas of England*[30] which contained larger scale maps of England.

A further interim report for Wales was published in 1996[31], but the mapping exercise for Wales is still incomplete. Measurements are continuing at its possible that further areas will be found to qualify for Affected Area status.

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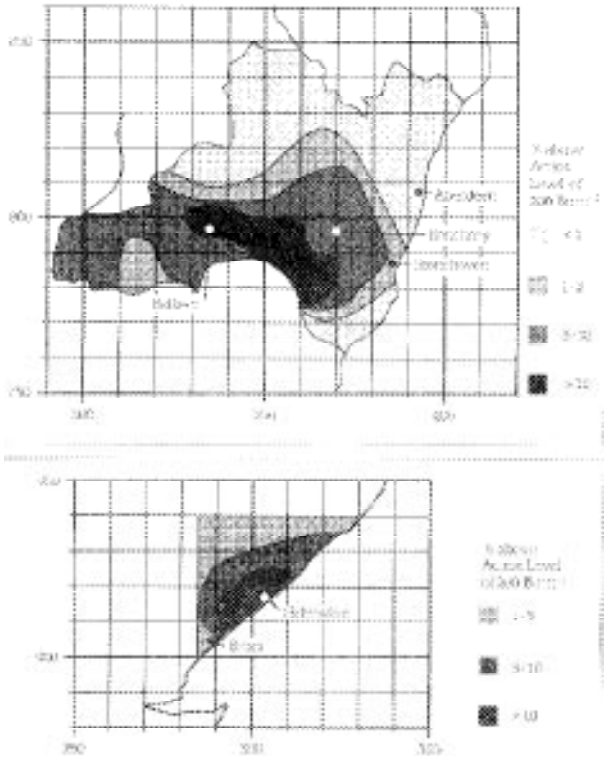
30 *Radon Atlas of England* NRPB-R290

31 NRPB - M673

2. Scotland

In 1993[32] the NRPB published advice to the Scottish Office. It recommended that the parts of Scotland, shown in the following figure reproduced here from the report, with 1% probability or more of homes being above the Action Level should be regarded as Affected Areas:

Figure 4 - Some areas in Scotland exceeding the Action Level



Estimated proportion of homes exceeding the Action Level in parts of Grampian.

Estimated proportion of homes exceeding the Action Level in parts of Highland Region.

An interim report updating the survey for Scotland was published in 1996[33,34] which confirmed the previous findings. The mapping exercise for Scotland is still incomplete. Measurements are continuing and the map is expected to be completed in 1997. It is possible that further areas may qualify for Affected Area status.

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32 Doc NRPB 4 No 6 1993

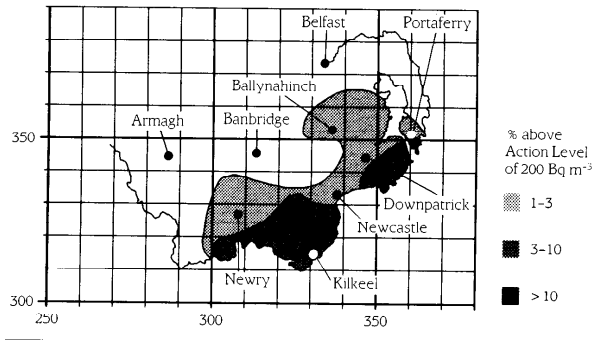
33 NRPB-M569

34 Scottish Office News Release 1804 31 October 96

3. Northern Ireland

In 1993[35] the NRPB recommended that parts of Northern Ireland, shown in the following figure reproduced here from the report, with 1% probability or more of homes being above the Action Level should be regarded as Affected Areas:

Figure 5 - Some areas in Northern Ireland exceeding the Action Level



Estimated proportion of homes exceeding the Action Level in the southeastern part of parts of Northern Ireland. Areas not shaded have less than 1% of homes above the Action Level.

The study continues. It is possible that further areas may qualify for Affected Area status.

B. Domestic Radon Concentrations in the UK: By Region

As a result of Government surveys certain counties or areas have been designated, or recommended for designation, as Affected Areas since 1990.

1. England and Wales

The counties of Cornwall and Devon were designated as Affected Area in 1990[36]. These were followed by Northamptonshire and parts of Derbyshire and Somerset in 1992[37]. The mapping exercise for England and Wales, mentioned above, indicated more precisely than before areas with high radon levels in England and Wales, and led to other Affected Areas being declared early in 1996 [38]:

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35 Doc NRPB 4 No 6 1993

36 *Radon Affected Areas: Cornwall and Devon* Doc NRPB 1 No 4 1990

37 *Radon Affected Areas: Derbyshire, Northamptonshire and Somerset* Doc NRPB 3 No 4 1992

38 *Radon Affected Areas: England and Wales* Doc NRPB 7 No 2 1996

> The NRPB report, *"Radon Affected Areas: England and Wales"*, published today by HMSO, shows a number of new areas where more than one per cent of homes are expected to be above the Government's "Action Level" for radon. None of these areas is as affected by high levels of radon as the areas previously identified.
>
> The NRPB study confirmed that throughout the country, 80 per cent of the homes most likely to be affected by high levels of radon, will be situated in the areas originally identified ie Cornwall, Devon, Somerset, Northamptonshire and Derbyshire, and only 20 per cent in the new areas.

A further interim report for Wales published in 1996[39] concluded:

> The main conclusion of the work reported here is that parts of the unitary authorities of Anglesey, Denbighshire, Flintshire, Pembrokeshire and Powys qualify as radon Affected Areas in the formal sense. This was foreshadowed in the previous report and is the subject of separate formal advice to the Welsh Office[40].
>
> The increased coverage of Wales has indicated other areas with elevated levels. These areas are in Merthyr Tydfil, Monmouthshire, Powys and Vale of Galmorgan and further systematic surveys are required to determine the need for Affected Areas and delimit their extent.

The survey is continuing.

2. Scotland

An interim report for Scotland[41,42] was published in 1996. Preliminary results show that most people in Scotland are unlikely to be affected by radon and confirmed formal advice to the Government in 1993 when parts of Grampian and Highland were designated as Affected Areas[43]. The first of these comprises most of the old local authority district of Kincardine and Deeside and part of Gordon. The second is found along part of the east coast between Caithness and Sutherland[44]. The survey is continuing.

3. Northern Ireland

Measurements in Northern Ireland have led to areas of Down and Armagh being designated as Affected Areas[45]. The survey is continuing.

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39 NRPB-M673
40 *Radon Affected Areas: England and Wales* Doc NRPB 7 No 2 1996
41 NRPB-M569
42 *Scottish Office* News Release 1804 31 October 96
43 Doc NRPB 4 No 6 1993
44 NRPB-M569
45 Doc NRPB 4 No 6 1993

C. The Continuation of the Government's Programme

Although the concept of Affected Areas is useful in identifying areas of the country most at risk it is important to be aware that[46]:

> Two neighbouring and apparently identical houses can, however, have radon levels differing by a factor of a hundred: the only satisfactory method of determining the radon level in a house is to measure it. Furthermore, measurements need to be made over an extended period since radon levels indoors change rapidly and markedly because of pressure differentials between the indoor and outdoor atmospheres.

With this in mind the Government's free radon measurement programme in individual dwellings is now targeted on homes at risk which have not yet been tested. On 16 January 1996 such a programme was announced for parts of Devon, Cornwall, Somerset, Northamptonshre and Derbyshire[47,48]:

> The next phase of the radon programme will take place in early February, when 200,000 invitations to have a free radon measurement will be sent to those householders in Devon, Cornwall, Somerset, Northamptonshire and Derbyshire most likely to have high radon levels in their homes. All householders in these counties have, over the past eight years, been offered free measurements. The results obtained so far have enabled the National Radiological Protection Board (NRPB) to identify with far greater precision the areas within those countries where homes are most likely to have high radon levels. This allows measurement invitations to be targeted more accurately and efficiently. The offer of free measurements will therefore now be based on invitations to individual householders, and the current arrangements for free measurements will be discontinued from 29 February.

On 28 January 1997 the programme was extended further[49]:

> Following two successful campaigns conducted last year, we intend to offer a further quarter of a million invitations to have a free radon measurements this year. Invitations will be sent to all homes in England where there is a greater than five per cent chance of being above the Government's radon "Action Level", and which have not already received an invitation. Maps have been placed in the libraries of both Houses showing these areas.
>
> Counties due for invitations over the coming year are Cambridgeshire, Derbyshire, Leicestershire, Northamptonshire, Shropshire, Staffordshire, Warwickshire, Bristol, Bath, Cornwall, Devon, Dorset, Gloucestershire, Hampshire, Hereford and Worcester, Oxfordshire, Somerset, Wiltshire; and Cumbria, Lancashire, Northumberland, and North Yorkshire.

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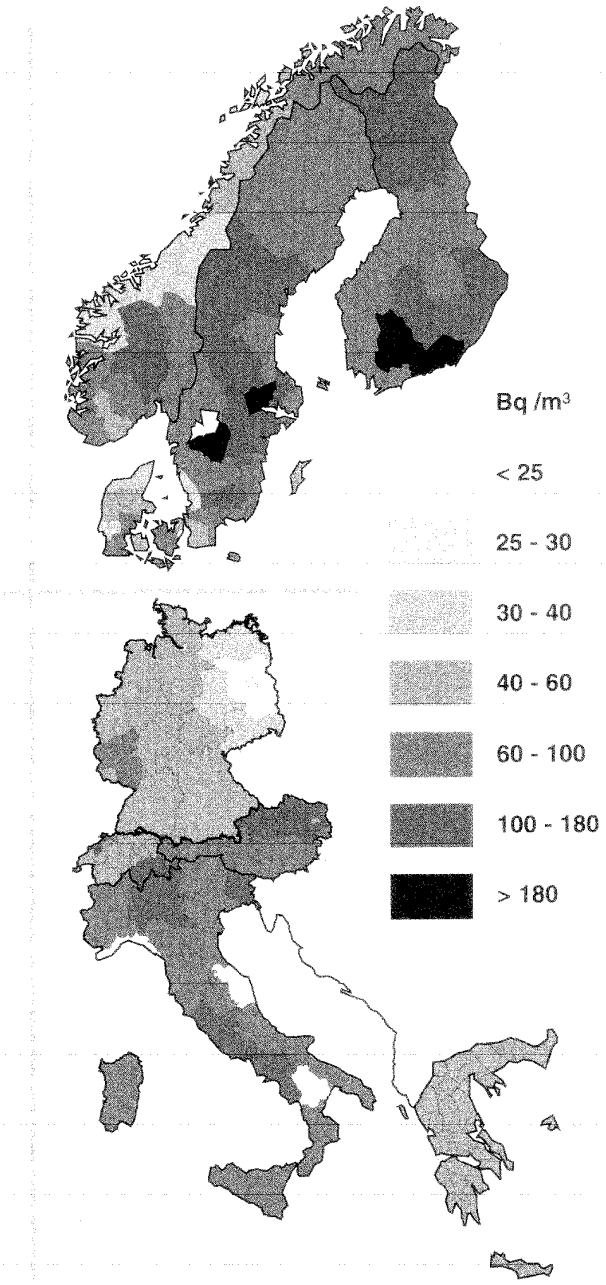
46 Radiological Protection Bulletin No181 September 1996
47 *Department of Environment* New Release No 15, 16 January 1996
48 *Department of Environment* New Release No 45, 5 February 1996
49 *Department of Environment* New Release No 37, 28 January 1997

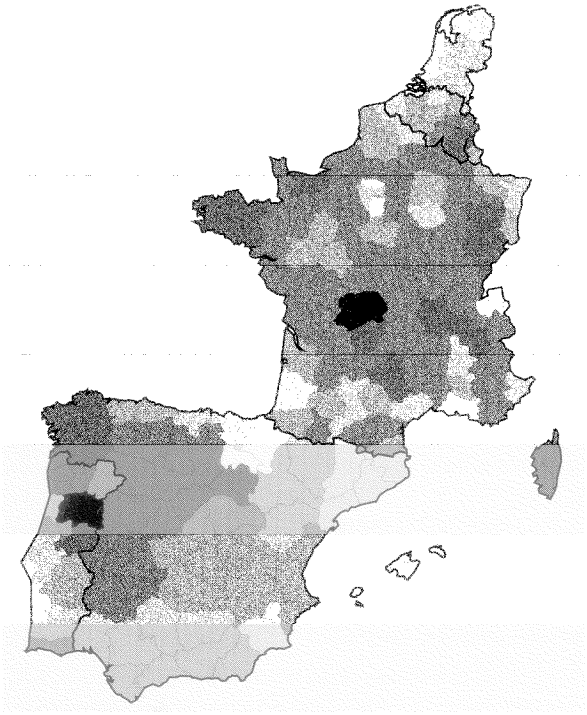
VII Domestic Radon Concentrations in Europe

During the past decade programmes to assess radon concentrations in homes have been launched in almost all European countries. Some of the maps available are reproduced here for comparison with the UK. These indicate regions where the radon in homes approaches the UK Action level of 200 Bq m^{-3} [50]:

Figure 6 - Radon concentrations in Europe



[50] *Radon* WHO 1996



The following table provides additional information[51].

[51] *Radon* WHO 1996

Table 3 - Domestic radon concentrations in Europe (*Studies under way)

Country (population millions)	Number of houses sampled	Average (Bq/M^{-3})	Percentage of 200 Bq/M^3	houses above: 400 Bq/M^3
Austria (8.0)	3499	75	19	7.4
Belgium (10.0)	300	48	1.7	0.3
Bulgaria (8.5)	841	28	2.4	0
Czech Republic (15.6)	75,000	140	32	11.4
Denmark (5.2)	496	47	2.2	<0.4
Germany (85)	7,500	50	1.5-2.5*	0.5-1.0*
Finland (5.0)	50,000	123	12.3	3.6
France (56.9)	6,878*	68*	5.8*	1.8*
Greece (10.2)	571	92	3.3	1.4
Hungary (10.6)	1,000	55	17	4
Ireland (3.5)	6,211	60	17.5	7.7
Israel (4)	17,000*	-	<5	-
Italy (56.8)	4,800	77	5	1
Lithuania (3.7)	120*	37*	4*	1.7*
Luxembourg (0.4)	2,500	*	-	-
Norway (4.2)	7,525	51-60	7	2.5
Netherlands (15.1)	1,000	29	0.1	0.01
Poland (38.2)	<5	0	-	-
Portugal (10.3)	4,200	81	8.6	2.6
Romania (23.2)	-	-	0.9	0.4
Spain (39)	239	-	6.46	2.48
Sweden (8.4)	350,000	108	25*	4-5
Switzerland (6.6)	9,000	70	15	7
United Kingdom (57)	270,000	20	8	2.5

It shows the average domestic radon concentration in different countries which masks regional highs and lows apparent from the maps. In addition it indicates the proportion of dwellings above two concentration levels, one of which (200 Bq m^{-3}) is the UK Action Level. The table identifies several countries which have a greater problem than the UK, notably Austria, the Czech Republic, Finland, Hungary, Ireland, Sweden and Switzerland.

VIII Assessing and Controlling Radon in Dwellings

A. The Radon Test

The test to determine the concentration of radon in a building is safe and extremely simple. A small plastic container about the size of a door knob is used. Within it is a piece of a special plastic which is sensitive to the α-particles emitted by radon and its daughters. In homes one is placed in the main living room and another in the main bedroom. These are left in place for three months and then analysed by the NRPB who send the confidential result to the householder, usually within a month.

Before 29 February 1996[52] the Government offered free tests for all, but since that date offers of free measurements have been issued by invitation to individual householders in areas of high risk. For those no longer eligible for a free test details of how to order a test, which cost about £35, may be obtained from NRPB Radon Freephone 0800 614529 or by post from NRPB, Chilton, Didcot, Oxon, OX11 0RQ.

If measurements show that the average indoor radon concentration exceeds 200 Bq m^{-3}, remedial action is recommended. In the case of a dwelling this is only advisory. The responsibility for deciding whether remedial measures should be undertaken rests with the owner or landlord in rented accommodation. This is to be contrasted with the position in the workplace where the employer is legally required to reduce the concentration (see Radon in the Workplace).

B. Remedial Measures

The effects of temperature and wind result in the air pressure in dwellings unusually being slightly below the air pressure in the soil beneath them. To equalise the pressure air passes from the soil through cracks and gaps in the floor into the dwelling. If the air contains radon from the soil it can accumulate in the building and the concentration may rise above the Action Level. Obviously it is best to prevent radon from entering a dwelling in the first place, but if this is not practicable and the concentration is near or above the Action Level it should be reduced by active measures. It must be stressed that the Action Level is not a boundary between and safe and unsafe radon concentrations, and householders should aim to reduce levels by as large a factor as possible, not simply to reduce it to just below 200 Bq m^{-3}. Remedial measures work by changing the pressure difference, by sealing the floor, or

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[52] *Department of Environment* New Release No 15, 16 January 1996

by removing radon that has entered the building. Similar measures are suitable for both dwellings and workplaces. There are five methods of achieving reductions; which one is applicable depends upon the particular dwelling and the extent of the reduction required. The measures, which are presented in detail elsewhere[53,54,55] are:

1. Ordinary Ventilation

This is the simplest and least effective measure. It works by increasing the ventilation in the dwelling with the aim of diluting the radon-laden air. Examples include the installation of trickle vents in window frames. The average reduction factor (= initial average radon concentration divided by average radon concentration after carrying our remedial work) is 2 to 3. This method should only be used with other measures or if the indoor radon level is close to the Action Level.

2. Floor Sealing

This method reduces the radon that passes into the dwelling from below by sealing gaps and cracks in the floor. A flexible filter is placed into large gaps and cracks and then a flexible watertight compound is used to paint over these and small cracks. The aim is to form an airtight seal to prevent radon from entering the dwelling. It is essential to seal all cracks: sealing 90% is unlikely to have any effect on radon concentration. This method is suitable for solid concrete floors, but should not be used on suspended timber floors which might rot following treatment. The average reduction factor is 2 to 3, but it is generally difficult to reduce the radon concentrations to half. This method may be adequate if the radon concentration is not far above the Action Level, but usually needs to be used in combination with other methods. It may be possible to seal a floor as a DIY job for as little as £25, but the exact cost will depend upon a number of factors.

3. Positive Ventilation

A specially installed fan draws air from the loft or from outside into the dwelling to dilute the radon-laden air. It also reduces radon entry by reducing the amount of air which enters the dwelling from the ground. It is difficult to reduce radon concentrations by this means by much more than a third. The average reduction factor is 3 to 4. For the average dwelling

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53 *Radon: A guide to reducing levels in your home* Department of Environment. May 1996

54 NRPB-R272

55 Radiological Protection Bulletin No181 September 1996

it is suitable when the initial radon concentration is up to two or three times the Action Level. The average cost is approximately £450.

4. Underfloor Ventilation

This method is designed to improve ventilation by natural or forced means under suspended floors and to dilute the radon concentration both there and in the dwelling. In its simplest form, air bricks are installed at a cost of as little as £20-£50 per brick. More sophisticated methods employ a fan which adds about £120 to the cost. The average reduction factor is 2 to 3. It is suitable up to about 700 Bq m^{-3} using natural ventilation, but above this using fan assisted methods.

5. Radon Sump

This is the most effective and expensive method. If a large reduction in radon concentration is required or the dwelling has a concrete floor this is the method of choice. The average reduction factor is 19 making it the most suitable method for radon concentrations above 1200 Bq m^{-3}. It can also be used with a suspended floor if there is a membrane or concrete layer beneath it. The average cost of installing this system is £750 and the work can take as little as 1-2 days. Maintenance costs will be about £50 annually to run the pump, with a cost of around £120 about every five years to replace it.

A sump (or small cavity) is dug under the concrete floor. A pipe connected to the sump is routed to a pump which is vented to the outside air. This arrangement reduces the under-pressure slightly which in turn reduces the amount of radon entering the dwelling. A passive sump, in which the fan is omitted, is possible but this is less effective. The following diagram illustrates the arrangement[56]:

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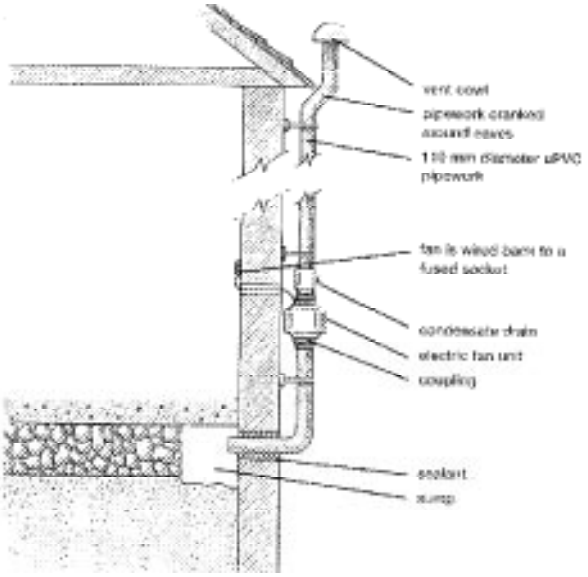
[56] *Radon: a guide to reducing levels in your home* Department of Environment May 1996

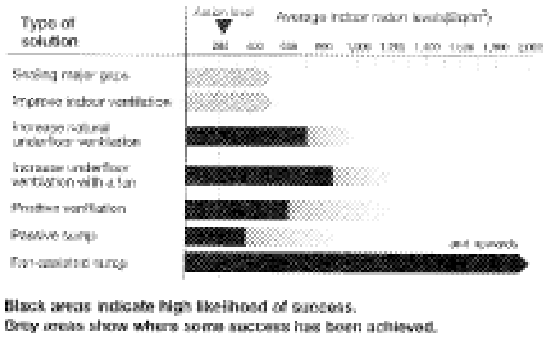
Figure 7 - A typical external sump



C. Which Measure?

This chart is a guide to the choice of the appropriate method of radon reduction based upon the average radon concentration in a dwelling[57]:

Figure 8 - Radon: a guide to reducing levels in your home



57 *Radon: a guide to reducing levels in your home* Department of Environment May 1996

D. Financial Assistance

Means-tested financial assistance is available[58]:

> Local Councils have power to award discretionary house renovation grants to help with the cost of radon remedial work. The Government considers that the house renovation grant system provides the right framework for providing financial assistance to those least able to afford the cost of remedial work. The DOE has given the Local Authorities advice on the way in which grant applications might be considered in DOE Circular 12/90 (paragraph 64). All grants are means-tested, but grants of up to 100% may be given to those householders least able to pay for radon remedial work themselves. The Government's proposals for moving to a fully discretionary renovation grant system will enable authorities in areas affected by radon more effectively to prioritise available grant resources for such works.

E. New Buildings

Building practices for new dwellings have been specified in areas where it is recognised that there are likely to be high radon concentrations in buildings[59]:

> The Building Regulations contain a requirement that precautions shall be taken to avoid danger to health caused by substances found on or in the ground to be covered by the building. In June 1988, after discussions with Local Authorities and others, the DOE issued interim guidance for new house construction to support this regulation and this is currently in use by builders and designers. The Revised Approved Document and Support Document BR211 were published and updated in 1991 and updated 1992 to include additional areas.
>
> In February 1996 Building Regulations Advisory Committee (BRAC) members were forewarned that the Department will be considering new evidence from the NRPB and reviewing the areas designated for the purposes of Building Regulations. As many of the new areas are beyond the counties which are currently subject to the radon protective measures of the Building Regulations, the method of designating these areas has to be determined. At the May 1996 BRAC meeting, a working party was set up to discuss and make recommendation on how the new areas should be designated and if the technical guidance should be reviewed.

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58 *Radon Briefing: Question Most Often Asked About Radon*, NRPB

59 ibid

IX Public Perception of Risk from Radon

It is notable that there is great public concern about radiation arising from the nuclear fuel cycle even though radiation doses to the population are extremely small. By contrast there is little concern about exposure to radon even though it delivers doses very much higher to many more people. One of the reasons for this difference in public perception is that radiation from radon is from a natural source and is therefore considered (albeit erroneously) to be less hazardous than that from man-made sources such as nuclear power. This difference in perception has been explored in terms of the familiarity of the hazard, its controllability, and the degree that exposure is voluntary[60,61].

A survey of householders response to the risk from radon was published in 1994[62]. A research report, published in 1996, included information about public attitudes to risk from radon and suggested how this should shape policy for conveying a clear message about the hazard[63]:

> A genuine psychological study in Britain reveals that members of the public have conflicting attitudes to radon.
>
> *Public Attitudes*
> ---
> Risk disbelief
> Health concern
> Policy scepticism
> Property pragmatism
> ---
>
> Some do not believe that there is a risk in the home whereas others are quite concerned about family health. Among those interviewed, some had doubts about the official policy on radon and wondered if it were a deliberate distraction from the hazards of nuclear discharges. But another powerful feeling was pragmatic concern about the value of the homes. Finding a way to counter the negative attitudes and foster the positive is quite a challenge.

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60 NRPB-R272

61 *Radiation Protection Dosimetry* 42 No 3 257-62 1992

62 *Householders' Response to the Radon Risk: Summary Report* Department of the Environment February 1994

63 *Journal of Radiation Protection* 16 No 4 269-272 December 1996

The message must be clear and firm.

Radon persuasion

Face the facts
Realise the risks
Take the test
Simple solutions
Help is at hand

All the facts about radon must be given and the risks spelt out bluntly. To persuade people to test their homes, they must know that if the results are high there are simple ways to solve matters. And they must be told where they can turn for help and advice. Only in this way can we overcome the harmful effects of professional ambivalence and give the public the protection it requires.

Environmental Issues
Science and Technology

Recent Research Papers on related subjects include:

92/280	Radon Gas	16.01.92