Two abandoned metalliferous mines in Devon and Cornwall, UK: radon hazards and geology

Gavin K. Gillmore[1*], Paul S. Phillips[2], Gillian Pearce[3], Antony Denman[4].

*Corresponding author.

Dr Gavin K. Gillmore, Department of Environmental Science, University of Bradford, West Yorkshire, BD7 1DP, UK.

Dr Paul S. Phillips, Reader in Waste Management, School of Environmental Science, University College Northampton, Park Campus, Northampton, NN2 7AL, UK.

Gillian Pearce, Devon and Cornwall Prospecting Society, 44 Lancaster Drive, Paignton, Devon, TQ4 7RR, UK.

Dr Antony R. Denman, Head of Medical Physics, Department of Medical Physics, Cliftonville, Northampton General Hospital NHS Trust, Northampton, NN1 5BD, UK.

Abstract.
A study has been undertaken of radon levels in two abandoned metalliferous mines in South-West England, UK, one in the county of Cornwall and the other in Devon. Measurements have been taken since 1992 using a variety of measuring techniques. Extremely high radon gas levels have been noted in these mines, one of the highest levels recorded in Europe was noted, 3,932,920 Bq m^{-3}, not surprisingly, in a redundant UK uranium mine adit. The health implications for casual users/explorers of such mines are shown to be considerable.

Introduction.

Radon and safety.

Radon (^{222}Rn) is a naturally occurring gas which is formed in the decay series of ^{238}U. It is a colourless and odourless gas, which is very dense and chemically unreactive. Radon decays to highly radioactive heavy metallic daughter products (e.g. ^{218}Po) known as progeny. Some of the progeny decay by alpha particle emission. These daughter products, if retained in the lung through inhalation, will irradiate lung tissue by alpha particle emission (alpha particles are very energetic, travel short distances and cause localised damage).

There is a substantial body of evidence to show that raised radon levels in some mines can cause lung cancer in miners (Muirhead et al., 1993). Muirhead et al. (1993) have shown that, in studies of over 50,000 miners 686 lung cancer deaths might be expected, but 2299 were noted. The ICRP (1993) have concluded that excessive radon levels are hazardous to health. Studies by Lubin and Boice (1997), Darby et al. (1998) and Field et al. (2000) have shown that raised radon levels in the built environment (particularly in regions designated as radon Affected Areas) are a health hazard. Radon in homes causes some 2,500 lung cancers deaths each year in the UK (Thompson et al., 1998). The US Environmental Protection Agency (EPA) has estimated that 20,000 lung cancer deaths each year in the US can be linked to radon.

Radon has also been implicated in cancers other than those of the lung/respiratory tract (Kendall, 2000). Henshaw et al. (1990) has suggested that there is a link between radon levels and myeloid leukaeimia, cancer of the kidney and melanoma. Therefore, significance of such high radon levels on the skin should also be assessed. Kendall (2000) has pointed out that in some conditions radon decay products can deposit on the skin in sufficient quantity to give a significant dose. This is particularly important where the skin is thin, such as on the face as illustrated by Sevcova et al. (1978). They reported an elevated incidence of skin cancers linked to radon which were facial basal cell carcinomas. It is interesting to note that red bone marrow can also receive a significant dose as a result of breathing in radon and its short lived decay products (*Kendall*, 2000).

The ICRP (1981) has concluded that a dose of 10 mSv is received from an exposure to radon and its daughters of 1 Working Level Month (WLM). It is not unreasonable in the built environment and to a certain extent in enclosed spaces such as caves and mines, to assume an equilibrium factor (F) of 0.5 (Sperrin et al., 2000). This permits the derivation of the relation that 1 mSv of dose is received by exposure to 126,000 Bq m^{-3} h of radon gas (Gillmore et al., 2000a, b). This has been used by a number of authors to estimate dose received from radon to occupants in built overground environments (Denman and Parkinson, 1996; Denman and Phillips, 1998; Phillips et al., 2000).

The level of radon exposure that the population experiences in the built environment involves a complex inter-relationship between geology, meteorology, micro-meteorology, social habit and building type. There have therefore been extensive studies on radon levels in homes, hospitals, schools and other workplaces in areas of increased risk. In the UK various studies led the NRPB in 1990 to suggest an Action Level of 200 Bq m^{-3} in homes (O'Riordan, 1990; Miles et al., 1992) and 400 Bq m^{-3} in the workplace. Above these levels action should be undertaken to remediate. Under the Ionising Radiation Regulations (IRR, 1999) employers are required to remediate if radon levels are greater than 400 Bq m^{-3}.

The NRPB have shown that a number of areas in the UK have elevated radon levels (O'Riordan, 1990; Green et al., 1992; see Figure 1). Certain areas in the counties of Cornwall and Devon have much greater radon levels in homes and workplaces than the national average (O'Riordan, 1990; Miles et al., 1992; Ball and Miles, 1993; Woodcock, 1994; BRE, 1999). There are for example significant areas where greater than 30% of homes that are above the Action Level (which is 200 Bq m^{-3} in the UK). These high areas appear to be associated with large granite intrusions, their metamorphic aureoles (Varley and Flowers, 1998) and associated polymetallic mineralisation. There is a high percentage of uranium rich rocks in Devon and Cornwall with granites having an average uranium content of 4.8 ppm (Faulkner and Gillmore, 1995). These areas, and other regions in the UK such as Northamptonshire, Derbyshire and Somerset, have been designated as Affected Areas by the NRPB (Miles et al., 1992). In such areas, greater than 15% of dwellings have radon concentrations above the Action Level (Papworth, 1997).

Gillmore et al. (2000a) have shown that elevated radon levels in caves in the UK can increase radon risk for cave explorers. Gillmore et al. (2001a, b) have further shown that exposure to high levels in abandoned mine workings is also a significant risk. This work further highlights this, pointing out some record radon gas levels in the old metallic ore workings in Devon and Cornwall. A number of mines were surveyed for radon levels in 1992-1994 by the Devon and

Cornwall Prospecting Society (DCPS). These have been resurveyed by the authors in 2000 for comparative purposes and the results presented here.

There is a not insignificant community of dedicated explorers that visit abandoned mines in Cornwall and Devon. The DCPS estimate that there are around 4000 regular visitors to such mines as the ones examined in this study (Pearce, pers comm.). Therefore, there is a small section of the population that may be putting themselves into areas of considerable radon risk.

Geological background.
Tin mining has been undertaken in Britain from the time of the Pheonicians (1500-1000 BC) according to Hoover and Hoover (1986). Reliable records of tin mining in Cornwall date from the 12th Century (Hoover and Hoover, 1986).

The vast quantities of copper produced in Cornwall have come from high-temperature veins with which were associated cassiterite, wolframite, arsenopyrite, sphalerite, pyrite and small amounts of pitchblende (U_3O_8), cobalite, argentite, stibnite and galena (Dunham et al., 1978; Jackson et al., 1989). The uranium minerals pitchblende and coffinite often occur in north-south structures with polymetallic mineralization, that is, nickel, cobalt, bismuth and silver (Darnley et al., 1965). In the Land's End area pitchblende occurs with chalcopyrite in tin lodes (e.g. Geevor Mine). Small amounts were produced at several mines (e.g. Wheal Owles, East Pool, St. Austell, New Crow Hill and Trenwith: Burt et al., 1987), but only South Terras mine (national grid reference SW 935 524; see Figure 2), south-west of the St. Austell granite pluton, was at one time worked solely for uranium, according to Dunham et al. (1978) and Smale (1993). Both Smale (1993) and Burt et al. (1987) suggest that tin and iron were produced from this mine in the late 19th Century. It is interesting to note that South Terras was owned by the Societe Industrielle du Radium Ltd. in 1913, although Burt et al. (1987) also noted that it was not worked in that year. Uranium Mines (national grid reference also SW 935 524) is recorded by Burt et al. (1987) as a producer of uranium as well as lead (plumbago) and arsenic pyrite (no detailed production returns are available on the latter two). Smale (1993) suggests that the active life of S. Terras mine was from 1870-1930, and uranium and radium were produced.

The highest production year for uranium in the late 19th to early 20th Centuries is 1905 when 103 tons of ore was extracted from Uranium Mines worth approximately £10,000 (Smale, 1993). The fact that the Uranium Mines and S. Terras mines are given the same national grid reference by Burt et al. (1987) suggests that either these mines are right next to each other, or this is in fact the same mine sett. Indeed, according to Smale (1993), Uranium Mines Ltd. was formed in 1889 to acquire mining rights and work certain deposits in St. Stephen in Brannel parish. Uranium Mines were noted by A.J. Leese, the Secretary of Uranium Mines Ltd. (see Smale, 1993), as being formerly known as South Terras.

In 1978 Dunham et al. estimated that around 2000 tonnes of uranium ore had been produced from the Devon and Cornwall region. Dines (1956), Dunham et al. (1978), and Jackson et al. (1989) suggested that 750 metric tons was produced from the South Terras mine from a 60m deep vein. South Terras is 1 mile SW of St. Stephen-in-Brannel, Cornwall around Tolgarrick Mill. The workings have been flooded since 1928 (Darnley et al., 1965). In the area of this mine the uraniferous mineralization is of pitchblende in siderite. There is also pitchblende-coffinite in quartz. Smale (1993) suggests that the primary ore worked at S. Terras was uraninite and pitchblende, with a secondary zone of enrichment in the upper levels of the mine in the form of torbernite and autunite (hydrated phosphates of copper and uranium and calcium and uranium). The uranium ore lode at South Terras was over 250 fathoms long with almost unbroken uranium mineralisation (Smale, 1993). Some parts of the lode assayed 31 percent uranium. Very high radon levels were recorded in South Terras.

The country rock consists of grey and brown Lower Devonian slate of the Meadfoot Group with greenstone and elvan dyke intrusions (Smale, 1993).

Kings Wood mine (SX 713 665) is 1.5 miles west of Buckfastleigh, South Devon, on the south-eastern side of Dartmoor (Figure 2). This mine was explored for copper (Harris, 1992) but also contained argentiferous galena, sphalerite, cobalt, nickel, fluorspar and barytes together with pitchblende-coffinite (Darnley et al., 1965; Beer and Scrivener, 1982; Harris, 1992). The mineral vein in this mine is in Devonian slate and was probably derived from waning hydrothermal emissions from the granite according to Beer and Scrivener (1982). These mineralised cross-courses are younger than the east-west sulphide veins seen in mines in the Dartmoor and Gunnislake areas (Beer and Scrivener, 1982; see also Gillmore et al. 2001a). The vein containing uranium ore in Kings Wood is only a centimetre to tens of centimetres in thickness and sometimes splits into two or three branches (Darnley et al., 1965). Uranium concentration is highest where the mineral lode is particularly brecciated. Pitchblende fills the fractures in the vein quartz with coffinite forming much of the matrix. Darnley et al. (1965) noted that mineral concentrates from these veins had intense point sources of alpha activity attributable to radium.

Methods.

The mines chosen for this study were ones that were well known by the Devon and Cornwall Prospecting Society for their uranium ore content. They have also been frequently visited in the past, although one cave (South Terras) was gated in 2000 to prevent cattle wandering into the adit entrance. While South Terras workings were once quite extensive a number of levels have collapsed, so it was only possible to visit the adit entrance section. Kings Wood is a much smaller mine being a simple adit cut into the hillside by a stream.

Radon levels were measured during the months of January to December in 1992 to 1994 and in July 2000 for comparative purposes, using a variety of measuring methods. Mostly passive alpha track etch detectors were employed, following the method laid out by Green et al. (1992), from an NRPB approved source. In addition to the time-averaged track etch and activated carbon detectors electronic real time devices were used, such as a Pylon WLx and Radhome P. A Rad7 was also used but radon levels proved to be outside of the measuring range of that device.

Due to the high levels of radon gas in the S. Terras mine detectors were placed and the authors retreated outside the mine entranceway to minimise exposure times.

The radon detectors were placed on ledges within the mines where possible. They were left for only a short period of time in place due to the very high levels that were thought to exist in South Terras mine.

Results.

Results of this analysis are shown in Tables 1 and 2. Radon levels in South Terras mine can be extremely high in the mines inaccessible inner workings. The furthest point into the S. Terras adit that could be easily reached was 70m in. Measurements were taken at both head height and at floor level in order to see if there was any significant difference in radon levels. As can be seen from Table 1 there was no significant difference when measured in October 1992, both being over 3 MBq m^{-3}. However, the 2000 year measurements demonstrate that at ground level 3,932,920 Bq m^{-3} of gas was measured, while 1m above ground level the radon gas was measured as 2,154,560 Bq m^{-3}. The lowest radon gas level measured was in May while the highest level at the same point was measured in October of the same year. In other words, levels were lowest in the spring and highest during the winter months. The radon gas levels in this mine are all consistently extremely high.

It is also clear from Table 1 that there is a distinct gradation of radon gas concentration in S. Terras from the entranceway at 194,000 Bq m^{-3} to 17m in (748,000 Bq m^{-3}) to 52m in (3,000,000 Bq m^{-3}). It is interesting to note that radon levels then fell to 1,080,000 Bq m^{-3} at the 70m point. This is probably because it is at 52m that the pitchblende ore is exposed in the adit.

It is interesting to note that even standing 2 metres outside the mine entrance at South Terras will still expose an observer to radon gas levels of 7,600 Bq m^{-3} (Table 1). 2.4 m into the mine from the entrance levels were measured of 194,000 Bq m^{-3}.

Working Levels were also measured. In April 1993 52m into the mine a TN-IR-31 working level meter gave a reading of 0.37 WL. By July 1993 this level had risen to 29.9 WL.

The Volalpha personal dosemeter was left down the S. Terras mine for an hour and then retrieved. This gave a dose level of 18 mSV. It is recommended by the IRR (1999) that a member of the publics dose should not be greater than 1 mSv in a year, while a radiation workers maximum yearly dose is 6 mSv and a Classified Workers limit being 20mSv. Thus one hours visit would be equivalent to 18 years dose for a member of the public.

In Kings Wood mine radon levels are much lower, but still very high compared with most caves and mines encountered by the authors and reported in the published literature. The lowest radon gas level recorded was 25,400 Bq m^{-3} in January while the highest level measured was in July of 37,000 Bq m^{-3}. The highest Working Level was measured in July in the Ore chamber (2.71 WL).

Equilibrium Factors and Dose.

The ration of radon to progeny (the Equilibrium factor, F) is relatively constant in homes (the range of F in homes is typically between 0.4 and 0.6). So radon concentration is often used to determine dose (Phillips et al., 2000). If we assume that the radon levels and their progeny did not waver significantly in July from year to year, then the Equilibrium Factor (F) in S. Terras may be in the order of 0.2 to 0.5. Snihs and Ehdwall (1976) measured F in working Swedish mines. In most of these Swedish mines, F was 0.4 to 1, with an average F (from 37 mines) of 0.7. This suggests that our assumption of F of 0.5 is not unreasonable.

We can, using an equilibrium factor of 0.5, calculate the effective dose to occupants following Denman and Parkinson (1996) and Gillmore et al., (2000b).

$$\text{Effective Dose (mSv)} = \frac{(\text{Radon Concentration, Bq m}^{-3}) \times (\text{duration, hours})}{126{,}000}$$

Assuming that F is 0.5 in such mines as these, and each visit lasted approximately 2 hours (following Gillmore *et al.*, 2000b), exposure to the levels in South Terras mine (at a maximum of 3,932,920 Bq m^{-3}) would give an the effective dose of approximately 62 mSv per visit. This is substantially over the 1 mSv maximum suggested dose for a member of the public for a year (IRR, 1999).

In Kings Wood the radon gas levels are much lower (maximum of 37,000 Bq m^{-3}). Applying a similar formula, a 2 hour visit would give a dose of 0.6 mSv. It can be seen that it would only take two visits to exceed the UK annual dose limit for the general public.

Discussion and Conclusions.

The mines in this study, and similar ones in the South-West of England, are areas that are frequently visited by amateur industrial archaeologists, cave/mine explorers, cave divers and mineral collectors.

It has been suggested that Marie Curie used radium extracted from South Terras mine for her experiments on radiation (Pearce, pers comm.). This is supported by the mine ownership in 1913. Smale (1993) notes that the share prospectus for Societe Industrielle Du Radium Ltd. contained reports on sampling at S. Terras, including one from the Madame Curie laboratory on the radioactivity of the water in the mine, dump material and specimens from the deep levels before they were submerged. Smale (1993) also noted that the superintendent of the extraction work of radium from the mine was Dr Marcel Leon Pochon, who is known to have worked with Madame Curie.

Radon levels are lower in Kings Wood mine than one might expect (Table 2). This is because the area in which the uranium ore lode can be seen the mine is relatively well ventilated.

As can be seen from the above results and discussion, these radon levels would have posed a significant health risk to 19th Century miners, and continue to pose a risk to mine explorers today.

This study has clearly shown that very high radon levels can be found in old metalliferous mines in Devon and Cornwall in the UK. The risk to mine explorers can be reduced by time limiting visits to areas of known high radon gas levels, but the exploration of those mines by radon scientists is necessary in order to ascertain the levels and hence quantify risk. However, as illustrated by Gillmore et al. (2001b), even short exposures to radon gas levels greater than 100,000 Bq m^{-3}, can lead to a significant effective dose.

References.

Ball, T.K., and Miles, J.C.H. 1993. Geological and geochemical factors affecting radon concentration in homes in Cornwall and Devon, UK. *Environmental Geochemistry and Health*, 15, 27-36.

Beer, K.E. and Scrivener, R.C. 1982. Metalliferous Mineralisation. In: Durrance, E.M. and Laming, D.J.C. (Eds.), *The Geology of Devon*, University of Exeter Press, UK, 346pp.

Building Research Establishment, 1999. Radon: guidance on protective measures for new dwellings. BR211, London

Burt, R., Waite, P. and Burnley, R. 1987. *Cornish Mines. Metalliferous and Associated Minerals 1845-1913.* The University of Exeter, UK, 562pp.

Darby, S., Whitley, E., Silcocks, P., Thakrar, B., Green, M., Lomas, P., Miles, J.C.H., Reeves, G., Fearn, T. and Doll. R. 1998. Risk of lung cancer associated with residential radon exposure in south-west England: a case-control study. *Br. J. Cancer*, 78(3), 394-408.

Darnley, A.G., English, T.H., Sprake, O., Preece, T.H. and Avery, D. 1965. Ages of uraninite and coffinite from south-west England. *Mineralogical Magazine*, **34**, 159-176.

Denman, A.R. and Parkinson, S. 1996. Estimates of radiation dose to National Health Service workers in Northamptonshire from raised radon levels. Short communication. *The British Journal of Radiology*, 69, 72-75.

Denman, A.R. and Phillips, P.S. 1998. A review of the cost effectiveness of radon mitigation in domestic properties in Northamptonshire. *J. Radiol. Prot.*, **18**(2), 119-124.

Dines, H.G. 1956. The metalliferous mining region of south-west England. *Mem. geol. Surv. Gt Br.*, 2 vols, 795pp.

Dunham, K., Beer, K.E., Ellis, R.A., Gallagher, M.J., Nutt, M.J.C. and Webb, B.C. 1978. United Kingdom. In Bowie, S.H.U., Kvalheim, A., and Haslam, H.W. (Eds.) *Mineral deposits of Europe Volume 1: Northwest Europe*, The Institution of Mining and Metallurgy, The Mineralogical Society, London, 263-317.

Faulkner, K. and Gillmore, G.K. 1995. Geology and Radon entry into buildings. In *The Radon Manual, Second Edition: A Guide to the Requirements for the Detection and Measurement of Natural Radon Levels, Associated Remedial Measures and Subsequent Monitoring of Results*, pp.2.2.1-2.2.9. The Radon Council Ltd., Shepperton, Middlesex.

Field, R.W., Steck, D.J., Smith, B.J., Brus, C.P., Neuberger, J.S., Fisher, E.F., Platz, C.E., Robinson, R.A., Woolson, R.F. and Lynch, C.F. 2000. Residential Radon Gas Exposure and Lung Cancer: The Iowa Radon Lung Cancer Study. *American Journal of Epidemiology*, **151**(11), 1091-1102.

Gillmore, G.K., Sperrin, M., Phillips, P. and Denman A. 2000a. Radon Hazards, Geology, and Exposure of Cave Users: A Case Study and Some Theoretical Perspectives. *Ecotoxicology and Environmental Safety*, **46**(3), 279-288.

Gillmore, G.K., Sperrin, M., Phillips, P. and Denman A. 2000b. Radon-prone geological formations and implications for cave users. *Technology*, **7**(6), 645-655.

Gillmore, G.K., Sperrin, M. and Pearce, G. 2001a. Radon in a disused mine in Cornwall, UK. *Journal of Environmental Management and Health*, **12**(5), (in press).

Gillmore, G.K., Phillips, P., Denman, A., Sperrin, M., Pearce, G. 2001b. Radon levels in abandoned Metalliferous Mines, Devon, South-West England. *Ecotoxicology and Environmental Safety*, **49**(1), 281-292.

Green, B.M.R., Lomas, P.R. and O'Riordan, M.C. 1992. Radon in dwellings in England. National Radiological Protection Board Report R254, 1-72.

Harris, H. 1992. *The Industrial Archaeology of Dartmoor*. Peninsular Press, UK.

Henshaw, D.L., Eatough, J.P. and Richardson, R.B. 1990. Radon as a causative factor in induction of myeloid leukaemia and other cancers. *The Lancet*, **335**, 1008-1012.

Hoover, H.C. and Hoover, L.H. (translators) 1986. *Georgius Agricola. De Re Metallica, 1556.* Dover Publications republication of 1912 addition, 638pp.

Ionising Radiations Regulations 1999. Health and Safety Executive, Statutory Instrument 3232, HMSO.

International Commission on Radiological Protection 1981. Limits for inhalation of radon daughters by workers. ICRP Publication 32. Ann. ICRP, 6(1).

International Commission on Radiological Protection 1993. Protection against radon-222 at home and at work. ICRP Publication 65. Ann. ICRP, 23(2).

Jackson, N.J., Willis-Richards, J., Manning, D. A.C., Sams, M.S. 1989. Evolution of the Cornubian Ore Fields, Southwest England: Part II. Mineral Deposits and Ore-Forming Processes. *Economic Geology*, **84**, 1101-1133.

Kendall, G. 2000. Doses from radon to organs other than lung. *Environmental Radon Newsletter*, **23**, 4.

Lubin, J.H. and Boice, J.D. 1997. Lung cancer risk from residential radon: Meta-analsis of eight epodiomiological studies. *J. Natl. Cancer Inst.*, **89**(1), 49-57.

Miles, J.C.H., Green, B.M.R., and Lomas, P.R. 1992. Radon affected areas: Derbyshire, Northamptonshire, and Somerset. *Documents of the National Radiological Protection Board,* **3**(4), 19-28.

Muirhead, C.R., Cox, R., Sather, J.W., MacGibbon, B.H., Edwards, A.A. and Haylock, R.G.E. 1993. Estimates of late radiation risks in the UK population. *Doc. Natl. Radiol. Prot. Board*, **4**(4), 15-157.

O'Riordan, M.C. 1990. Recommendations on Radon in Homes. *Documents of the National Radiological Protection Board,* **1**(1), 17-32.

Papworth, D. 1997. "A need to reduce the radon gas hazard in the UK", *Journal, Royal Society of Health*, 117(2), 75-80.

Phillips, P., Denman, A. and Gillmore, G.K. 2000. Radon, Schools and Health: Implications for policy and practice of a comparative study of programmes in Poland and the UK. *Fresenius Environmental Bulletin*, 9, 711-718.

Sevcova, M., Sevc, J. and Thomas, J. 1978. Alpha irradiation of the skin and the possibility of late effects. *Health Physics*, **35**, 803-806.

Smale, C.V. 1993. South Terras. Cornwall's Premier Uranium and Radium Mine. *Journal of the Royal Institution of Cornwall. New Series*, 1(3), 304-321.

Thompson, A., Hine, P.D., Poole, J.S. and Greig, J.R. 1998. *Environmental geology in land use planning: A guide to good practice*. Report to the Department of the Environment, Transport and the Regions (DETR), Symonds Travers Morgan, East Grinstead, UK.

Varley, N.R., and Flowers, A.G. 1998. The influence of Geology on radon levels in S.W. England. *Radiat. Protect. Dosimetry*, 77(3), 171-176.

Woodcock, N. 1994. *Geology and Environment in Britain and Ireland*. UCL Press Ltd., London, UK, 22-32.

Table 1. Radon levels measured at South Terras mine (national grid reference SW 935 523), Cornwall, UK.

DATE	POSITION and COMMENTS	DETECTOR	RADON LEVEL
Last week 5/92	70m from entrance	Alpha track (NRPB)	>41,667 Bq m^{-3} (saturated)
1st week 6/92	70m from entrance	Activated carbon (SURRC)	1,300,000 Bq m^{-3}
Last week 8/92	2.4m from entrance	Alpha track	194,000 Bq m^{-3}
Last week 8/92	17m from entrance	Alpha track	748,000 Bq m^{-3}
Last week 8/92	52m from entrance	Alpha track	1,490,000 Bq m^{-3}
Last week 8/92	52m from entrance	Pico rad	3,000,000 Bq m^{-3}
Last week 8/92	70m from entrance	Alpha track	1,080,000 Bq m^{-3}

Last week 8/92	70m from entrance	Pico rad	1,800,000 Bq m^{-3}
08/10/92	Inaccessible inner workings	Alpha track (NRPB)	>1,900,000 Bq m^{-3} (saturated)
08/10/92	70m from entrance – head height	Alpha track (NRPB)	>3,390,000 Bq m^{-3} (saturated)
08/10/92	70m from entrance – ground level	Alpha track (NRPB)	>3,400,000 Bq m^{-3} (saturated)
Late 12/92	52m from entrance	Alpha track	200,000 Bq m^{-3}
10/04/93	52m from entrance	TN-IR-31	0.37 WL
03/06/93	52m from entrance	Alpha track	379,000 Bq m^{-3}
16/07/93	52m from entrance	Pylon WLx	29.9 WL
31/07/94	52m from entrance	Alpha track	3,200,000 Bq m^{-3}
22/07/00	Outside mine entrance, 2m away	Radhome P	7,600 Bq m^{-3}
22/07/00	52m from entrance	Radhome P	2,983,600 Bq m^{-3}
22/07/00	52m from entrance – ground level	Alpha track	3,932,920 Bq m^{-3}
22/07/00	52m from entrance – 1 metre from ground level	Alpha track	2,154,560 Bq m^{-3}
22/07/00	One mine visit (1 hour)	Volalpha Personal Dosemeter	18 mSv

Table 2. Radon levels measured at Kings Wood mine (national grid reference SX 713 665), Devon, UK.

DATE	POSITION and COMMENTS	DETECTOR	RADON LEVEL
25/01/92	Ore chamber	Alpha track (NRPB)	25,400 Bq m^{-3}

Early 6/92	Ore chamber	Activated carbon (SURRC)	30,000 Bq m^{-3}
31/07/93	Furthest point in	Pylon WLx	2.354 WL
31/07/93	Ore chamber	Pylon WLx	2.66 WL
31/07/93	Ore chamber	Pylon WLx	2.71 WL
22/07/00	Outside mine entrance, 2m away	Radhome P	13,400 Bq m^{-3}
22/07/00	40m from entrance	Radhome P	37,000 Bq m^{-3}
22/07/00	40m from entrance – ground level	Alpha track	32,257 Bq m^{-3}

Figure 1. Percentage of homes with concentrations of radon above 200 Bq m-3 in the UK.

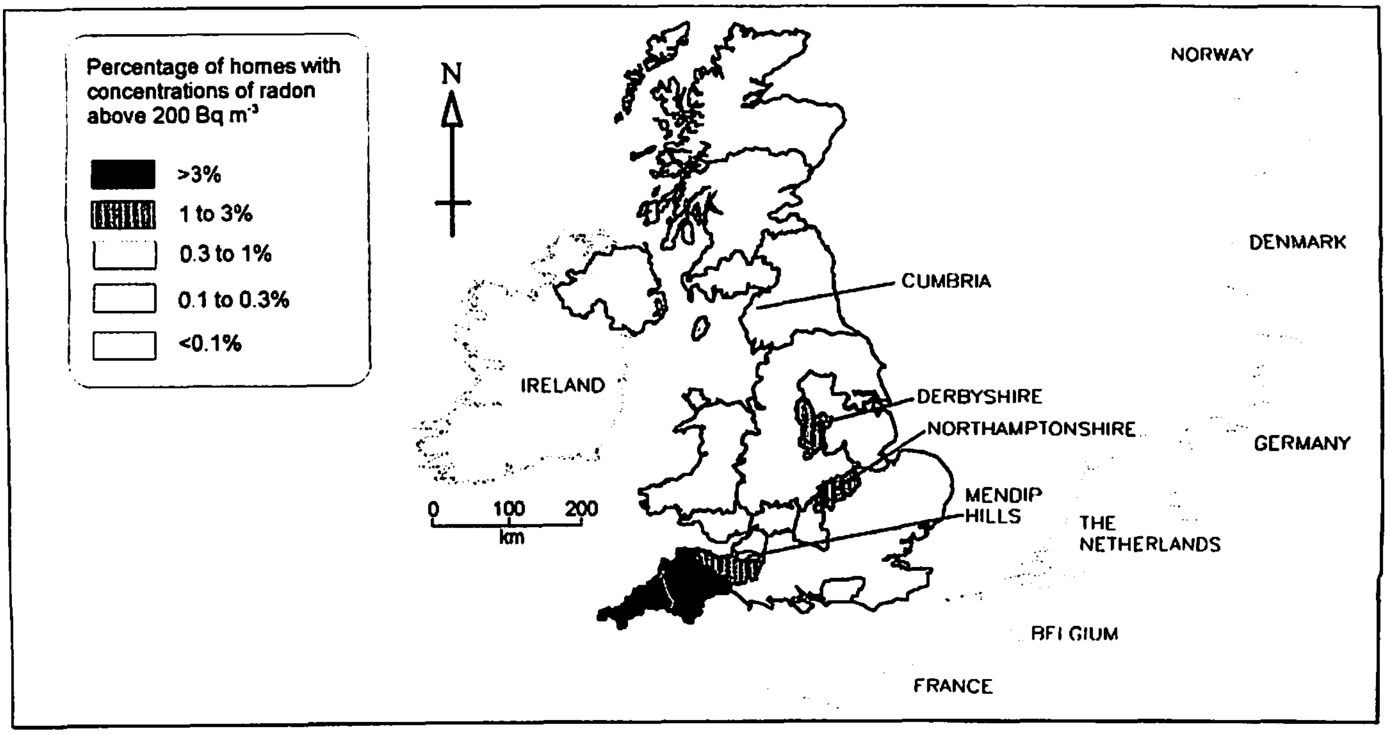

Figure 2. Granite intrusions, associated metallic mineralisation and

localities of selected mines.