Radon, water and abandoned metalliferous mines in the UK: Environmental and Human Health implications

Gavin K. Gillmore[1], John Grattan[2], F. Brian Pyatt[3], Paul S. Phillips[4], Gillian Pearce[5].

[1] Department of Environmental Science, University of Bradford, West Yorkshire, BD7 1DP, UK.
[2] Institute of Geography and Earth Sciences, University of Wales, Aberytswyth, SY23 3DB, UK.
[3] Department of Life Sciences, Nottingham Trent University, Clifton Lane, Nottingham, NG11 8NS, UK.
[4] University College Northampton, Boughton Green Road, Northampton, NN2 7AL, UK.
[5] Devon and Cornwall Prospecting Society, 44 Lancaster Drive, Paignton, Devon, TQ4 7RR, UK.

Abstract. A study has been undertaken of radon gas levels in the atmosphere in abandoned metalliferous mines that were exploited primarily for tin in South-West England, UK, and compared to levels in an old lead mine in northern England, UK. Measurements have been taken since 1992 in the South-West of radon in the air using a variety of measuring techniques. Extremely high radon gas levels have been noted in a number of these mines, one of the highest levels recorded in Europe was recorded at 3,932,920 Bq m^{-3} in a shallow adit of an ex-uranium mine. The health implications for casual users/explorers of such mines are shown to be considerable. Even outside such mines, in adit entranceways, very high atmospheric radon levels were recorded of, for example, 200,000 Bq m^{-3}. The heavy metal content of stream-water that flows from such mine adits together with dissolved radon content has also been measured and assessed in terms of potential health effects. A combination of heavy metal pollution and radiation can have a considerable impact on health and this research recommends that further research should be undertaken in such environments.

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 2,299 were noted. The ICRP (1993) have concluded that excessive radon levels are hazardous to health. Studies by Lubin and Boice (1997) and Darby et al. (1998) have shown that raised radon levels in the built environment (particularly in regions designated as radon Affected Areas) are a health hazard. There is a clear link between radon and lung cancer (Lorenz 1944; Field et al., 2000; Gillmore et al. 2000a; Kendall 2000), and it has been suggested that 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. Henshaw et al. (1990) has suggested that there is a link between radon levels and myeloid leukaeimia, cancer of the kidney and melanoma.

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} of radon gas (Gillmore et al. 2000b). 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}.

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 (in South-West England) 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 had been produced from mines in the South-West of England since at least 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.

Impact on groundwater from radionuclide emission

In 1978 Dunham et al. estimated that around 2,000 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 0.5 km 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 450 metres 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 2.5 km west of Buckfastleigh, South Devon, on the south-eastern side of Dartmoor. 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 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 gas 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.

Results

Results of this analysis are shown in Tables 1 and 2.

Table 1. Radon levels measured at South Terras mine, Cornwall, UK.

Date	Position	Detector	Radon level
Last week 5/92	70m from entrance	Alpha track	>41,667 Bq m-3 (saturated)
1st week 6/92	70m from entrance	Activated carbon	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	>1,900,000 Bq m-3 (saturated)
08/10/92	70m from entrance – head height	Alpha track	>3,390,000 Bq m-3 (saturated)
08/10/92	70m from entrance – ground level	Alpha track	>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

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.

Table 2. Radon levels measured at Kings Wood mine, Devon, UK.

Date	Position	Detector	Radon level
25/01/92	Ore chamber	Alpha track	25,400 Bq m^{-3}
Early 6/92	Ore chamber	Activated carbon	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}

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). A very short distance into the mine, in the entranceway, 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 1992 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 10mSV. Thus one hours visit would be equivalent to 18 years dose for a member of the public.

Radioactivity in Water

According to Durrance (1986) the natural radioactivity of water is highly variable. Generally, groundwater sources for drinking water have a higher level of radioactivity than water derived from surface flow (Durrance 1986). Obviously the range of radioactivity in groundwater will depend heavily on the geology and groundwater residence time.

Lewis (2001) examined radon levels in groundwaters in Pennsylvania, USA to assess the variability of levels. Average levels varied in springs from 100 to 2,000 pCi l^{-1} (3,700-74,000 Bq m^{-3}) over a number of years. However, the average for 28 groundwater sources was 465 pCi l^{-1} (17,205 Bq m^{-3}). It is interesting to note that even low radon in groundwater can lead to raised indoor air levels if there is a large enough volume of water involved (Lewis 2001).

Allen-Price (1960) undertook a study on the distribution of cancer in west Devon, UK and suggested a link with radioactivity in drinking water in the region. The activity of drinking water in the study area was up to 500 Bq l^{-1} which was primarily attributed to ^{222}Rn (Abbot et al. 1960). The result of this study was that the most active water supplies were not exploited. The US Environmental Protection Agency (EPA) estimates that 168 cancer deaths per year are caused by radon in drinking water; 89% is lung cancer as a result of de-gassed radon and 11% stomach cancer (Jasensky 2001).

Turner et al. (1961) demonstrated that there were particularly high ^{222}Rn concentrations in drinking water from Cornwall. At St. Ives the level was 400 Bq l^{-1}. Durrance (1986) has pointed out that ^{226}Ra and other ^{238}U daughter products also contribute to radioactivity in groundwaters. Kenny et al. (1966) suggests that activities in areas underlain by granite can be up to 800 Bq 1^{-1}, although activity in the order of 1,000 Bq l^{-1} has been noted in one spring (Durrance 1986).

In Devon, on the Dartmoor granite, a substantial public water supply was established extracting groundwater from an alluvial deposit. A survey of ^{222}Rn showed activities of around 550 Bq l^{-1}. A degassing plant was erected to remove ^{222}Rn and CO_2. The plant was constructed underground so some care had to be taken to avoid high ^{222}Rn levels in the plant (Durrance 1986).

According to Durrance (1986) the effect of Rn in drinking water is regarded by many authors as unclear. The effect however consists of two aspects – ingestion and inhalation of radioactivity. Anderson and Nilson (1964) suggested that the half life of ^{222}Rn in the body following consumption via water is only 30 minutes, based on an activity of 2,500 Bq l^{-1}. However, if there is an activity of 3,300 Bq l^{-1} and the tap water intake is around 2.2 l per day the dose equivalent per year is 5,000 mSv (Durrance 1986). Some authors have pointed out that the half-life is so short the radiation dose would not be significant. It is important to recognise that most drinking water comes from surface water in granite areas in the UK where activity is much less (Durrance 1986).

Lindel (1968) suggested that a maximum permitted activity in tap water (assuming an intake of 1 l) should be 3,700 Bq l^{-1}. The UK's National Radiological Protection Board suggests a maximum permitted activity of around 30,000 Bq l^{-1}, based on an annual oral intake for the general public of 2 x 10^8 Bq with a daily intake of 2 l of tap water. If we assume that the whole body is the critical organ an average dose equivalent would be approximately 50,000 mSv per year (Durrance 1986). According to Lewis (2001) and Jasenksy (2001) the EPA has yet to publish a final standard for radon in drinking water. The current proposed standards are 300 pCi l^{-1} MCL (Maximum Contaminate Level) or 4,000 pCi l^{-1} AMCL (Alternate Maximum Contaminate Level) (11,100-148,000 Bq m^{-3}).

The source for much of the radioactivity in the South Terras mine region is the uranium ore, pitchblende. It is interesting to note that elements such as Mo, Rb, Sr, Cd, Ag, Pd, Sb, Sn, Cs, I, Ba may be removed from pitchblende by solution, depending on the chemistry of that solution (Durrance 1986).

Dissolved radon was measured in a number of mines in the study area. The levels of dissolved radon were in the order of 10,000 Bq l^{-1}. It should be stressed here that it was dissolved radon that was measured rather than radon as gas bubbles in the water, which yielded much higher results. The method employed here was that developed by Alan Worley of Track Analysis Systems Ltd and field tested by the DCPS.

Gamma spectrometry was also undertaken for mine water from South Terras mine and the adjacent Tolgarrick mine. Gamma spectrometry only enables certain sections of the uranium and thorium decay chains to be measured, these were notably of ^{226}Ra (plus daughters) and ^{228}Acc (plus daughters). For South Terras one water sample yielded a result of 300 Bq kg^{-1} of ^{226}Ra, while 5 Bq kg^{-1} of ^{228}Acc was measured. This analysis was undertaken by Harwell Radiation Spectrometry Unit, AEA Environment and Energy in July 1992. Harwell also analysed the uranium levels in mine water from S. Terras. Their results indicated that there was 360 +/- 20 Bq l^{-1} of ^{238}U, with 14 +/- 2 Bq 1^{-1} ^{235}U and 370 +/- 20 Bq l^{-1} ^{234}U.

Equilibrium Factors and Dose

The ration of radon to progeny (the Equilibrium factor, F) is relatively constant in homes. 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 F of 0.5, calculate dose rates 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 considerably higher than the 1 mSv per year recommended as a maximum dose for a member of the public.

Acid Mine Water Drainage

Water that drains from mine workings may be termed acidic as a result of natural oxidation of sulphide mineral when waste is exposed to air and water (Bell 1998). Iron pyrites (FeS_2) often occurs as a gangue mineral in the mines in South-West England in this study. The pH of mine water from these mines was generally between 4 and 5, However, Kingswood mine water was measured with a pH of 3. Such acid mine drainage is responsible for water pollution in metal mining areas around the world. Acid generation can lead to elevated levels of heavy metals such as copper and zinc together with sulphate in water. The acid Kingswood mine water sample had raised levels of copper. However, the rate and nature of acid mine drainage is essentially controlled by chemical and biological reactions (Bell 1998). The correct conditions for the generation of such waters depends on the combination of mineralogy, as well as pH value, temperature, oxygen, surface area of exposed metal sulphide etcetera. The presence of the acidophilic autotrophic bacteria in the form of *Thiobacillus ferrooxidans* may accelerate oxidation of sulphides of minerals such as arsenic, cadmium, copper, lead and zinc. When mine water discharge reaches watercourses it is rapidly oxidised, and the majority of dissolved metals may be precipitated onto the bed sediment (Hill 1999). This precipitate may give an orange or yellow ochre colour to the bed of the watercourse. There are very distinctive biological effects of such discharge. These might include; a depletion of the numbers of sensitive, and diversity of all, aquatic organisms; a loss of spawning gravel for fish; direct fish mortalities; and lastly a variety of other sub-lethal effects (Hill 1999).
sonable.

Hill (1999) noted that, using the Bureau Communite de Reference method (BCR), results from heavy metal analysis of a number of stream beds in the Yorkshire region showed that Cononley Becks contained high levels of zinc, lead and cadmium. Hill (1999) recorded a zinc BCR mean in the less than 63 micron fraction bed sediment in 1998 of around 2,000 mg kg^{-1} dry weight. A lead BCR mean of 5,000 mg kg^{-1} dry weight was also noted, together with a cadmium BCR mean of over 17 mg kg^{-1} dry weight. Hill (1999) suggests that at Cononley there has been co-mineralisation of cadmium ore with galena and sphalerite. Levels of nickel, iron, manganese, chromium, calcium, copper (copper BCR mean of approximately 42 mg kg^{-1} dry weight) and aluminium (BCR mean of 1250 mg kg^{-1} dry weight) were also noted by Hill (1999) in Cononley Beck, but were generally less significant in comparison to the other stream beds examined.

Hill (1999) suggests that a cocktail of metals present in the sediment act antagonistically upon benthic macroinvertebrates, more than one metal producing toxic effects either working individually or in combination.

Impact on groundwater from radionuclide emission

Heavy metal analysis (Ni, Pb, Cd, Zn, Ba, Cu) of water from South Terras suggests that many of these metals occur in the water, sometimes in high concentrations. Zinc was found in all samples from both mines in this study, ranging from 0.123 to 0.217 ppm in S. Terras. This was above the normal range for freshwater (5-50 ppb). It is very interesting to note that similar analyses of mine water from Kingswood mine showed significantly raised levels of nickel (1.69 ppm) in winze water where the pitchblende and arsenopyrite ores are exposed. Nickel is toxic to aquatic life at 0.15 ppm. Copper (0.606 ppm) was also higher in this water than water collected from elsewhere in Kingswood mine. The ecotoxicity of copper to aquatic life in freshwater is 0.01 ppm. Lead was higher here than elsewhere in the mines in this study at 0.346 ppm.

Analysis of the sediment samples collected shows that high levels of heavy metals exist in some of the fine sediments in streams from the mine entranceways. In samples from Brookwood mine, close to Kingswood, a maximum of 6,700 mg kg^{-1} of copper was noted. A level that would be toxic to life. In the samples from Kingswood mine copper in the sediment was much lower at less than 300 mg kg^{-1}, but levels of nickel were raised. Heavy metals in South Terras mine sediments were generally not of environmental concern.

Conclusions

The analyses undertaken for the abandoned mines in this study suggest that raised radon levels within the mines poses a significant health risk. The amount of dissolved radon in the mine water is also significant and may pose a real risk to health if ingested for any length of time (e.g. via private spring-fed water supplies). The levels of some heavy metals in the water were significant where ore veins were exposed in the water courses. Analysis of heavy metals within the sediments seems to indicate that metals transported by mine water and deposited into streamways should be investigated further.

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