RADON UNDERGROUND

Radon Exposure During Underground Trips:
Guidelines for Caving and Mine Exploration

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THE BRITISH CAVING ASSOCIATION is the national body representing the interests of caving and mine exploration in the United Kingdom. The Association was formed in 2004 from an amalgamation of the functions of the National Caving Association and some of the functions of the British Cave Research Association. The Association is a national federation comprising: individuals; caving, mining and other related clubs; regional caving councils and national bodies with specialist interests, all of whom have autonomy in their own field; together with any other bodies who express an interest in caving, mining or other subterranean phenomena. The Association is recognised by the Government as the national governing body for the sport.

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1 Introduction

1.1 Background

Research has demonstrated that the air in most caves and mines contains varying concentrations of the radioactive gas radon (Rn) and its daughter products. The most common form of radon is produced by the radioactive decay of uranium (U). Because it is a gas, the concentrations of radon and daughter products are not constant at any one location and are controlled in a complex manner by, for example, the amount and direction of air flow, external air pressure and the season.

The radioactive elements formed by the decay of radon can be inhaled and enter our lungs. Inside the lungs these elements continue to decay and emit radiation, most importantly alpha particles. These are absorbed by the nearby tissues and cause localised damage. This damage can lead to lung cancer. Public Health England (PHE) quote figures of around 1,000 deaths a year from lung cancer from radon at home (1). The World Health Organisation (WHO) state that radon exposure is "the most important cause of lung cancer after smoking" (2).

The introduction in 1985 of the Ionising Radiations Regulations (IRRs) created a new definition of work to ensure that exposure to radon was regulated. As a consequence, recognition of the presence of radon in caves and mines potentially used by professional persons and outdoor centres highlighted the need to consider the application of these Regulations and also the potential health effects to cavers in general.

It was in response to this that the then National Caving Association commissioned the preparation of the first edition of this publication. A second edition, commissioned by the British Caving Association (BCA), was an update of the text in light of the 1999 revision of the IRRs, changes to relevant case law and more recently published work on the impact of radon. This third edition has been commissioned by BCA to cover the 2017 revision to the IRRs (3) known as IRR17 and to expand the coverage of the publication to include guidance material for professional persons.

This publication provides:

- a background to the problem;
- an assessment of the risk from exposure to radon in caves and mines;
- a brief review of the legislation.
- detailed guidance for professional persons on meeting legal requirements
- advice to other persons on meeting legal requirements

The material in this publication is considered sufficient to enable a professional person to meet his or her obligations under the IRRs in respect of exposure to radon provided that such persons work within the limitations of this guidance. The publication is not intended to cover operating mines nor business owners of voids but the material will give some guidance on achieving compliance with the legislation.

1.2 Radon: General Information

Radon is the heaviest naturally occurring gaseous element and is formed mainly by the radioactive decay of uranium, which is a naturally occurring radioactive substance present in some rocks in the scheme: uranium $\rightarrow$ radium $\rightarrow$ radon. Radioactive decay of radon leads to a sequence of unstable 'daughter products', each one decaying into another until finally reaching a stable product.

Radon, which is always present in minute quantities in the air, has three isotopes, all of which are unstable. Isotopes are forms of the same element that have a nucleus containing different numbers of neutrons thus giving it a different atomic weight, e.g. uranium exists as ^{234}U, ^{235}U, ^{238}U. The radon isotope ^{222}Rn, which has the longest half-life (3.82 days) and is of predominant concern, decays to isotopes of the metals lead, polonium and bismuth. These radon daughters have short half-lives of no more than 30 minutes. Radon decays by emitting an alpha particle and its radioactive daughter products decay by emitting either an alpha particle or a beta particle and associated gamma rays. These alpha and beta particles and gamma rays are types of ionising radiation which cause damage to living tissues.

The sources of radon gas in Britain are varied. Most caves in Britain are developed in the Carboniferous Limestone, which is generally rich in organic material and in places has thin, organic-rich mud layers. The organic matter may frequently contain small amounts of uranium compounds. In addition, the rocks, either beneath a cave (often Devonian) or above (other Carboniferous or younger rocks), can also be uraniferous. As the uranium decays the radon gas produced can seep out through fissures, either upwards or downwards, and may collect in voids. Similarly, in mines the source of radon are the same uraniferous compounds. Notable uranium-rich rocks and mineral veins are associated with the granites located in Devon and Cornwall. Certain parts of the Carboniferous Limestone sequence in Wales and Derbyshire are also known to be rich in uranium and thus have high radon potential. However, other rocks, such as the Old Red Sandstone of Caithness and the Northampton Sand in Northamptonshire, may have significant levels of uranium compounds.

The concentration of radon gas in the open air is very, very small, due to the dilution of the small proportion of radon by air currents. In any air system the quantity of radon present depends upon the concentration of uranium in the local rock, the atmospheric conditions and the extent of ventilation. Thus, in enclosed spaces such as house cellars, mines and caves, a lack of ventilation can permit higher concentrations of radon to build up in the contained air. In active mines this problem is alleviated by forced ventilation that keeps the concentrations down below specified legal limits. This concept has been adopted successfully in some Show Caves and Show Mines, and is in common usage in houses in high-risk areas. However, for disused mines and natural caves this is largely an unrealistic option, particularly if the cave or mine has the status of a Site of Special Scientific Interest (SSSI). Forced ventilation of a cave or mine classified as an SSSI may be a potentially damaging operation and thus prohibited. Therefore, particularly in areas of reduced airflow, caves and abandoned mines may be subject to radon accumulation.

When radon daughters are formed in air, some naturally tend to attach themselves, and remain stuck, to particles such as dust and water droplets in the air. Those which

are not so attached are known as the unattached particles. The proportion of those unattached is described by a parameter known as the unattached fraction. Some of these particles can stick on surfaces and thus be removed from the air. This loss of daughters from the air disturbs the natural ratio of the radon parent to its daughters in air and hence available to be breathed in. This feature is described by a parameter known as the equilibrium factor, denoted as F.

A person breathing will inhale both radon gas and radon daughters, either attached to particles or unattached. Most of the inhaled particles will be trapped and remain within the lungs whilst the rest, together with undecayed radon, will be exhaled. Hence the unattached fraction and the equilibrium factor are significant parameters in determining the amount of radon daughters left in the lungs.

As a result of radioactive decay, radon and its daughters emit ionising radiation that may collide with, and damage, living cells in the body. The chemical and physical properties of the particles themselves may also have a harmful effect upon the lungs. When radon and its daughters are trapped within the lungs, any radioactive decay may cause the cells of the lungs to become damaged. Damaged cells may repair themselves, die or become cancerous, hence the importance of understanding the radon risk. The chance of cancer developing as a consequence is related to the extent of exposure to radon and its daughters. Thus the potential consequence of being exposed to radon is death by lung cancer. However, Darby (4) notes that the lung cancer might only arise many years after exposure.

Field (5) produced a paper which starts with the claim that "this paper was developed to provide the National Speleological Society reader with an intensive investigation of the potential health effects posed by exposure to elevated levels of radon in caves". The paper provides a useful starting point for more detailed reading on radon in caves.

1.3 Measurement of Radiological Impact / Exposure

The quantity of radon in air is normally measured by detecting the number of alpha particles emitted by radon and its daughters in a given volume of air over a period of time. The World Health Organisation has compiled a useful review of methods to measure radon in air (6).

There is a very complex relationship between this quantity and the concentration of radon and its daughters. The formal SI unit of activity is the Becquerel denoted by Bq, a Becquerel being the disintegration of one atom in one second. More conveniently, activity concentrations per cubic metre denoted by (Bqm^{-3}) are used to describe the concentration of radioactivity in air, based on an assumption between the number of alpha particles measured and the number of atoms that have disintegrated to emit them. Examples of radon concentrations in caves, by region, are given in Table 1.1 below.

Table 1.1 Examples of radon concentrations (Bq m^{-3}) measured in caves in various parts of the UK in the period 1991–2011. Data from: a) Hyland (7), b) Friend & Gooding (8), c) Taylor (9), d) Friend (10), e) Friend (11) and f) Langridge et al. (12).

Radon Concentration Bqm^{-3}			
Region	**Min**	**Max**	**Mean**
Portland (a)	10	974	454
Mendip (a)	99	3,621	1,129
Forest of Dean (c)	654	10,070	6,167
North Pennines (a)	14	27,136	1,116
Yorkshire Dales (f)	50	3,470	985
Peak District (a)	9	46,080	8,258
South Wales (b, d, e)	60	16,290	3,858

The mining industry has a long-established and more pragmatic unit, known as the Working Level denoted by WL, for which measuring instruments have been developed. The Working Level is based on a measurement of the radon daughters. There is a relationship between Working Level and Bqm^{-3} involving the equilibrium factor F, see Annex A.

The exposure to radiation is measured in terms of time-integrated exposures being related to the length of time the air is breathed in hours denoted by h and the concentration of radon and daughters denoted by hBqm^{-3}. The mining industry use a unit of Working Level Month denoted by WLM to record exposure where a month is defined as 170 hours. Dose is measured in Sieverts denoted by Sv, but because a Sievert is a large quantity, the unit more normally used is the milli Sievert denoted by mSv. The derivation of the conversion factor to change exposure in hBqm^{-3} and WLM into dose in mSv is complex. A simplified overview is given in Annex A.

1.4 Limits on Exposure

1.4.1 Professional Persons

Annex A cites the conversion factor for professional persons at work based upon International Commission on Radiological Protection (ICRP) Publication 65 (13) (usually referred to as ICRP 65) to convert exposure in hBqm^{-3} into a dose in mSv. IRR17 (3) lays down legal limits (rather like speed limits) on the extent to which a person at work can be exposed, see Section 4.3.

1.4.2 Recreational users of caves or mines

Because of the ubiquitous nature of radon, Kendall and Dixon of the then National Radiological Protection Board (NRPB) issued advice on limits for exposure in non-work situations (14). (The Health Protection Agency (HPA) subsumed the functions of the NRPB in 2005 which has in turn been subsumed into PHE in 2013.) This included the advice that recreational users should limit their annual exposure to below 1,000,000 hBqm^{-3}. They also noted that this value is similar to the Action Level for exposure to radon in homes, above which steps should be taken to reduce radon concentration. So

if one is going into a cave with a radon concentration of say 10,000 Bqm^{-3} for a period of say 4 hours, then one would record an exposure of 40,000 $hBqm^{-3}$. Repeating that trip 25 times would then give 1,000,000 $hBqm^{-3}$ thus reaching the advisory limit.

Following further research on the health effects of radon exposure there has subsequently been debate on the Action Level for exposure to radon in homes and the then HPA have promulgated advice that a new "Target Level" be introduced and set at a factor of two the retained Action Level (15). In addition, ICRP have issued new guidance on the conversion factor, see Annex A, though it has yet to be adopted in the United Kingdom. It is anticipated that the advisory limit of 1,000,000 $hBqm^{-3}$ will be reduced.

2 Health Risks

2.1 Health Risks Associated with Radon Exposure

ICRP Publication 115 (16) recommended a relationship between detriment (being both death and hereditary effects) and dose as an estimated risk of death of 5×10^{-4} per WLM[1] and that 1 WLM is equivalent to 6.37×10^{5} / F $hBqm^{-3}$ of radon. Using an Equilibrium factor F of 0.5 (see Annex A) gives a risk of death of 3.9×10^{-10} per $hBqm^{-3}$. Given the uncertainties involved in estimating this number, it is appropriate to round the value up to 4×10^{-10} per $hBqm^{-3}$. This reflects a factor of two increase in risk from the previous estimate given in the second edition of this publication.

Darby et al. also included an analysis of the impact of smoking on the relationship between radon in homes and incidence of lung cancer (4). The results of this work indicate that on average in Europe the absolute risk of dying from lung cancer by the age of 75 is as set out in Table 2.1 below:

Table 2.1 Absolute risk of lung cancer with increasing radon in home level and smoking status

Radon Level Bqm^{-3}	**0**	**100**	**400**
Non-Smokers	0.4%	0.5%	0.7%
Smokers	10%	12%	16 %

So for a person who is a smoker and lives in a house with an average radon concentration of 100 Bqm^{-3}, the estimated risk of dying from the cause of lung cancer by the age of 75 is 12% for that person. The remaining 88% is mostly made up of other causes such as heart diseases, other cancers or accidents. There are two significant features about these results. The first is that the data takes into account lung cancers arising from causes other than radon, hence the value of 0.4 % for a zero concentration of radon. The second is that smoking multiplies the risk of getting lung cancer by a factor of about 25 both in the presence of radon and in its absence.

2.2 Radon Risks in Context

Caving is acknowledged as a risky activity, perhaps equivalent to outdoor climbing. Persons engaged in recreational caving do so willingly and as such accept the associated hazards of their chosen sport – which are many. Such risks are considered to be outweighed by the physical and mental health benefits. Some of the risks are immediately obvious, such as falling or drowning, whilst others, such as contracting Weil's Disease, are intangible. The hazards involved in entering an underground void relate to three main sources: first, the individual's ability level e.g. poor climbing skills and/or poor use of technical equipment; second, the hazards of the void itself, such as rockfalls; and third, the cave or mine environment e.g. flooding or bad air or radon.

[1] The format of the number 5×10^{-4} as used throughout this publication follows standard scientific number convention, see https://en.wikipedia.org/wiki/Scientific_notation as at 27/1/2024

BCA recognises radon exposure as one of the potential intangible underground hazards and will endeavour to ensure members are updated on the nature and extent of the risks as new information becomes available. Deaths from radon-related causes are only likely to become apparent some years after persons have given up active caving. Although some cavers have been recorded as dying from lung cancer, the numbers do not appear to be sufficient to suggest radon is a risk on a par with other accepted risks associated with caving.

It is possible to compute the approximate increased risk of lung cancer from exposure to radon resulting from a single caving trip. Given a typical caving trip could last some four hours and taking a typical radon concentration of say 3,000 Bqm^{-3} (the mean value of those cited in Table 1.1) and using the risk relationship computed above of 4×10^{-10} per $hBqm^{-3}$, gives an increased risk of lung cancer from one trip of about 1 in 200,000.

In comparison, it is possible to make an order-of-magnitude estimate of the actual risk from caving. BCA reported (17) to their AGM that its active caving membership for 2018 was nearly 5000. Given the considerable variability in the frequency that this population actually goes caving, an average of 10 trips per year is probably optimistic. However this probably more than compensates for those cavers who do not belong to BCA.

The 2009 annual incident report of the British Cave Rescue Council (BCRC) (18) stated that between 1983 and 2007 the total number of underground incidents was 992, including 50 fatalities, 7 of whom were divers. Subsequent BCRC annual incident reports (19) for the years 2008 to 2017 indicate a further 405 incidents, including 6 fatalities, 2 of whom were divers. That gives 1397 incidents, 56 fatalities of which 9 were divers. Cave diving involves a small number of people who expose themselves to hazards quite separate from those taken by ordinary cavers. Removing these fatalities from the figures, there has been an average of 1.3 deaths per year over the last 35 years. This gives an estimated risk of death for a recreational caver from an accident in a cave during one caving trip of about 1 in 38,000. (The 2nd edition cited a value of 1 in 30,000.)

To place these figures in a broader context, the HPA (15) cite the average concentration of radon in the air in UK homes at about 20 Bqm^{-3}, with a range of 5 to 10,000 Bqm^{-3} and higher. The independent Advisory Group on Ionising Radiation (AGIR) stated (20) that at the average national long-term residential radon concentration of 21 Bqm^{-3} the cumulative risk of death from lung cancer by the age of 75 years is 0.4 %, or 4 in every 1,000 for a lifelong non-smoker. The AGIR also estimate that "3.3% of lung cancer deaths in the UK are attributable to residential radon exposure. This corresponds to around 1,100 deaths each year out of a total of around 34,000 lung cancer deaths."

Exposure to all radiation should be limited to be as low as reasonably practicable but, as with anything, there is a risk. BCA recommend that, wherever possible, individuals should:

- attempt to find out as much as possible regarding the likely exposure to radiation from radon on each trip undertaken, taking particular note of any seasonal variations;

- use known values to make rough calculations of the potential cumulative dose during a year;
- attempt to keep exposure within PHE / NRPB recommended values.

3 Definitions

For the purposes of these Guidelines the following definitions are adopted. The definitions include reference to factors that are of significance when considering legal matters relating to radon gas underground.

3.1 British Caving Association

BCA is the nationally-recognised governing body of caving and mine exploration in the UK. BCA is constituted from Regional Caving Councils and specialist groups such as the National Association of Mining History Organisations and the William Pengelly Cave Studies Trust, together with individual members. BCA has a policy of publicising knowledge concerning the underground environment and conservation, and of attempting to minimise the risks involved. Several advisory, training and assessment schemes are run through its various standing committees and working groups such as the Qualifications Management Committee which is charged with the management of the leadership schemes.

3.2 Underground Voids

Caves are defined by the International Speleological Union as "solutionally enlarged voids, within limestone strata that can be penetrated by humans". For the purposes of this publication, caves not in limestone, metalliferous or stone mines which are entirely man-made, or those mines that have encountered a natural cave and have enlarged it are also included.

3.2.1 Cave – a natural network of voids, either horizontal or vertical, with an entrance that may have been opened naturally or artificially.

3.2.2 Mine – a man-made network of voids, either horizontal, or vertical, working or abandoned, created during the extraction of a mineral.

3.2.3 Show Cave, Show Mine – that part of a cave or mine which is operated as a business enabling members of the public to enter. Attached to such a cave or mine there may also be large areas that are not open to the public, but which are sometimes made available for others to enter.

3.2.4 Other Underground Void – any underground void, whether natural or artificial, not covered by the above definitions, such as tunnels, drains and fortifications.

3.3 Persons Engaged in Underground Activities

Three broad groups of people may engage in underground activities. The first two groups relate to whether a person is not at work or is at work. It should be noted that a person may belong to more than one group and may visit both caves and mines, e.g.

a professional (see 2 below) may also be involved in mine exploration as a recreational pursuit. The third group relates to persons who own voids and land.

3.3.1 Recreational Persons

i) Cavers and Mine Explorers – persons who explore underground voids as a pastime, typically as a member of a club established for that purpose, though not necessarily affiliated to the BCA. These people have no contract of employment for the underground activity they are engaged in. This category includes people with specialist local knowledge of a cave or mine who may be requested, on a voluntary basis, to take a recreational party through that cave or mine.

ii) Voluntary Group Leader – an adult leading or instructing a group, normally on behalf of a charitable organisation such as the Scouts or youth group. The participants will normally carry out underground activities in both caves and mines and the leader will be in a position of acknowledged authority. There is no contract of employment and no financial reward.

iii) Members of Instructed or Led Parties – anyone under the charge of a Professional Instructor or Leader or a Voluntary Group Leader.

3.3.2 Professional Persons

i) Professional Instructors or Leaders – persons such as holders of the BCA Cave Instructor Certificate (CIC) or Local Cave and Mine Leader Award (LCMLA) providing a service of instructing others in underground exploration techniques and practices in any type of underground void. Such persons are normally either self-employed or are employed by, for example, an Outdoor Education Centre.

ii) Research Scientists – persons employed, engaged, commissioned or directed to carry out scientific investigations in all types of underground void. As these persons will be briefed by the Radiological Protection Advisor appointed by their employer, they are excluded from this publication.

iii) Show Cave / Show Mine Guides and Other Persons – employees of a Show Cave or Mine Owner, who either guide and assist visiting members of the public or perform other duties in the Show Cave or Mine. As these persons will be briefed by the Radiological Protection Advisor (RPA) appointed by their employer, they are excluded from this publication.

iv) Employers and Self-employed – those who employ the people listed above, or those who are self-employed.

v) Miners and Mine Operators – these are specifically excluded from this publication as they have well-understood legal obligations.

3.3.3 The Public

Members of the public are all those people not defined above and who are not a member of a body affiliated to BCA. These are specifically excluded from this publication.

3.4 Owners of Underground Voids and Land

Owners may be individuals, incorporated or unincorporated companies, public bodies, lessees, licensees or other organisations or associations within this definition.

There are two distinct types of owner. The first is concerned with the underground void, whilst the second is concerned with the land surface. Clearly they are not mutually exclusive, but often are in practice. The key feature of either type is that they have the legal right to control access either within the underground void or across the land surface up to the entrance of the underground void. The term "Owner" will be used to include all other alternatives who may hold the legal right of access. Whilst ownership of a working mine is known, ownership of a natural cave or abandoned mine is commonly not clear and could reside with the owner of either the mineral rights or the land surface. There are 5 groups:

3.4.1 Private Void Owners – owners of a natural cave or abandoned mine or other underground void or part thereof, which does not form part of the owner's business (e.g. an owner of a private estate).

3.4.2 Private Land Owners – owners who have control of access of the land surface that is not part of the owner's business, exclusive of their legal relationship to the underground void (e.g. a householder).

3.4.3 Business Owners of Voids – owners of a natural cave or mine (working or abandoned) or other underground void, or part thereof, which forms part of their business (e.g. Show Caves and Mines).

3.4.4 Business Land Owners – owners who have control of access of the land surface as part of their business, exclusive of their legal relationship to the underground void (e.g. a farmer).

3.4.5 Mine Managers – these are appointed under the Mines Regulations (2014). Mine Managers are specifically excluded from this publication as they have well-understood legal obligations.

4. Legislation

Deciding precisely where civil and/or criminal liability may lie and what duty of care is owed by one party to another in the matter of entering and exploring underground voids on private land can be a complex legal matter. Almost invariably, advice will depend on all of the facts of the case, including specific actions and knowledge together with existing case law. The Health and Safety Executive (HSE) state (21) that "health and safety law does not cover safety matters arising out of the sport or activity itself e.g. damaging a wrist during a boxing match or being injured following a bad tackle during football training". The following should be read with these points in mind. Those involved may also wish to check the extent of their public-liability insurance cover.

4.1 Duty of Care

In England and Wales the Occupiers' Liability Acts of 1957 (22) and of 1984 (23) impose a duty of care on owners/occupiers towards their visitors (who may include children) and all persons who might happen to come onto their land (whether strictly permitted, invited or trespassers). Similar legislation exists in Scotland – the Occupiers' Liability (Scotland) Act of 1960 (24) – and in Northern Ireland – the Occupiers' Liability Act (Northern Ireland) of 1957 (25) and the Occupiers' Liability (Northern Ireland) Order of 1987 (26). The duty is to ensure the land and premises are reasonably safe for all such persons. For example, farmers should take steps to protect visitors from hazards which they, the visitors, might not reasonably be expected to foresee.

Over recent years case law that has been pursued as far as the Supreme Court has considerably altered this situation where it is clear that such visitors who know and willingly accept the risks associated with going onto land and into caves and mines for their particular recreational or educational purposes are largely excepted. This is a recognition of the common-law principle *volenti non fit injuria* (a willing person cannot claim for injury). It follows that cavers injured underground are unlikely to succeed in a claim that they did not knowingly and willingly accept the risks.

Owners may feel more protected through the erection of signs such as "*Caves are dangerous places. Persons entering must accept risk of injury or harm to themselves or others.*" However, these are largely irrelevant and carry little or no legal effect.

4.2 The Work Situation

The Health and Safety at Work etc. Act 1974 (27) places duties on employers and the self-employed to ensure, so far as is reasonably practicable, the safety of employees and other people who may be put at risk from their work activities (see Sections 2 and 3 of the Act). The HSW Act applies in any place made available or used as a place of work and hence can include underground voids. The IRRs which are made under the HSW Act will be covered in the next subsection.

Any person controlling access to an underground void in connection with a trade, business or other work undertaking there has a duty under Section 4 of the Act to take such measures as it is reasonable for that person to take to ensure, so far as is reasonably practicable, that the work place (i.e. the underground void) is safe and without risks to health. In this context the HSW Act and thus the IRRs apply to persons controlling access to Show Caves and Mines, at least insofar as access to that part of the underground void which is defined as the Show Cave or Mine is concerned.

The extent to which the HSW Act affects Land Owners, such as farmers, who make a charge for access across land that affords visitors entry to underground voids (which the Land Owner may or may not own) will depend on how far the void forms part of the Land Owner's business. There are cases where the underground void does not form part of the Land Owner's business or, where the Land Owner cannot reasonably be expected to know all the hazards present in the void, or to be able to distinguish between visitors engaged in conducting a business within the void and those not so engaged. In such cases, control of access to meet the requirements of the HSW Act (and hence the IRRs) in reducing risks, may be deemed to lie with whoever uses the void as a place of work. In the absence of a work situation within the void, the HSW Act will not apply. However, this does not remove the usual duty of care regarding foreseeable injury to an unsuspecting party.

4.3 The Ionising Radiations Regulations

The HSE have produced an Approved Code of Practice (ACoP) in IRR17 which also contains guidance material designed give practical advice on how to comply with IRR17 (3).

It is important to emphasise that the overarching principle of the IRRs is a duty on employers to "… take all necessary steps to restrict so far as is reasonably practicable the extent to which its employees and other persons are exposed to ionising radiation …" (often referred to as ALARP: As Low As Reasonably Practicable) which is expanded on in section 5.3 of this document. This legal duty is one which is given significant attention by HSE Inspectors when inspecting for compliance with the IRRs. The biggest step any employer or self-employed person can take to reduce exposure is to choose a cave or mine with the minimum radon levels consistent with the objectives of the intended trip.

The significant change of concern with IRR17 was in redefining the threshold concentration of radon in air above which IRR17 applied. The previous threshold of 400 Bqm^{-3} averaged over one day was changed to 300 Bqm^{-3} averaged over one year. In theory based on the summer winter variations in radon levels, this should relax the impact. In practice it has meant undertaking measurements across a year to obtain reassurance about the application of the IRRs. As underground voids have been shown to contain radon above this threshold (Table 1.1), it is considered that it is reasonably practicable for employers and self-employed persons check that such caves or mines they intend to use as a work place to confirm whether or not the IRRs apply. In the event that the caves and mines being used all have radon concentrations below 300 Bqm^{-3}, then employers and self-employed persons should keep evidence of this so as to

be able to demonstrate their compliance with the HSW Act and the inapplicability of the IRRs.

If an employer or self-employed person intends to work in caves and mines with an annual average of radon concentrations above 300 Bqm^{-3}, then they must notify the HSE.

The IRRs place a limit to the exposure of employed persons to radiation in any calendar year and thus makes it a criminal offence to exceed that limit. It also places a limit to the exposure of any other person to radiation caused by an employer, such as might arise if an employer invited a member of the public to occupy a cave or mine for a long period of time. The values of these radiation dose limits for employees and any other persons are 20 and 1 mSv respectively. (There are other limits for persons aged between 16 and 18, pregnant women and for various parts of the body.) In addition, the IRRs creates a threshold on the exposure of employees of 6 mSv per year, above which the employee must be designated as a classified person for whom a different and more intense regime of monitoring and care is required. The ongoing cost of this regime is high.

The IRRs place a number of duties upon employers and the self-employed in respect of ionising radiation dependent upon the anticipated level of exposure being above or below the 6 mSv threshold. For situations where the 6 mSv threshold is likely to be exceeded, then the employer or self-employed person must:

- consult a suitable Radiation Protection Advisor (RPA) who is competent to provide advice on underground radon exposure and can advise on all of the points below;
- perform a radiation risk assessment to identify the hazard and the magnitude of the risk;
- write Local Rules, setting out the general principles and description of the means for complying with the IRRs;
- suitably train and appoint a Radiological Protection Supervisor (RPS) to ensure that Local Rules are followed;
- consider whether voids under their control should be designated as Controlled Areas;
- assess whether any staff have the potential to receive doses of radiation above 6 mSv and if so, should be declared classified persons and hence make suitable arrangements (e.g. personal dosimeters from an approved dosimetry service, medical examinations);
- keep records of staff exposures required by the IRRs;
- ensure that staff understand the risks of exposure to radon and the relevant legal requirements, including the need to minimise exposure;
- provide any necessary information, instruction and training;
- take reasonably practicable measures to obtain information on radon concentrations in the voids to be visited;
- ensure that trips are planned so as to minimise the exposure to individual employees and members of parties under their control to levels which are as low as is reasonably practicable. This may be done by selecting voids likely to have lower radon concentrations and by rotating staff duties so that particular individuals do not receive unnecessary cumulative exposures.

It is emphasised that the IRRs extend to self-employed persons, who are required to treat themselves both as employer and as employee, as well as potentially acting as their own RPS.

One of the key duties placed upon employers by the IRRs is to restrict, as far as is reasonably practicable, the exposure of employees and others. This can be done in a number of ways, for example:

- reducing the duration of exposure;
- choosing times when radon levels may be lower, such as winter;
- avoiding areas known or suspected to have high concentrations of radon, e.g. particular caves or parts of caves;
- reducing the concentration of radon in the void e.g. several Show Cave owners have installed fans to reduce concentrations as part of their measures to comply with the regulations.

As is the case in most health and safety legislation, much of the duty of compliance is on the employer or self-employed person. One point worthy of note is IRR17 considers that the employer who is responsible for exposing the employee to a dose of radiation which finally takes them over a limit or a threshold such as the 6 mSv value for classified persons, is responsible in law for the breach. It is therefore recommended that employers should take particular care when employing any person who may have been exposed to radon in other work, to check their record of exposure is up to date. Persons who work for several employers should be prepared to provide an up to date copy of their estimated radon exposure to any employer.

If the 6 mSv threshold is not likely to be exceeded, then a lesser set of duties applies. Further details and advice on compliance with these requirements will be found in section 5.

4.4 The Mines Regulations 2014

The Mines Regulations of 2014 (28) substantially revised the law applying to operating mines and replaced many of the powers of the Mines and Quarries Act of 1954 (29) and supporting regulations. This publication is not intended to cover operating mines. However, material within this publication will be of help to those mining organisations who have interests in specific mines.

4.5 Abandoned Mines

Section 151 of the Mines and Quarries Act (29) requires entrances to mines that are no longer being worked, especially ones close to a highway or place of public resort, to be fitted with an efficient and properly maintained barrier to prevent accidental entry. This requirement applies regardless of any measured radon levels or the use of the mine for any other type of work undertaking. Being an abandoned mine, there will not be an appointed Mine Manager and, as with other voids, control of access to meet the requirements of the HSW Act and the IRRs will lie with whoever uses the abandoned mine as a place of work.

5. Guidance for Professional Persons on Complying with the Ionising Radiations Regulations

5.1 Preamble

This section applies to those employers who employ persons to work underground or self-employed persons who work underground. It includes detail of what employees, that is professional persons, are required to do to ensure their compliance with the legal requirements of the IRRs. The section is based on the assumption that employees will NOT be exposed to radon at levels likely to exceed the 6 mSv threshold mentioned in section 4.3 above. Regulation 14(1) of IRR17 (3) requires that an employer must consult with an RPA.

BCA's Radon Working Party consulted an appropriately experienced RPA in drawing up the guidance within this document and supporting Radon Exposure Estimation tool. Provided an employer works within the guidance of this document then it is considered that the consulting of an RPA has taken place.

If the Minimal or Simple Exposure schemes described below are not usable, then the employer or self-employed person must conduct a more rigorous process for achieving compliance with IRR17 whilst remaining under the 6 mSv threshold as outlined in the subsequent subsections. If the employer or self-employed person considers that they are not likely to remain below the 6 mSv threshold, then they should consult with a RPA to obtain guidance on how to comply with IRR17.

The words 'must', 'should' and 'may' in this section are significant. 'Must' means that one shall comply with the requirement in order to comply with the law. An example is "must be written" in section 5.12 below. 'Should' means that complying with the requirement is the recommended way of complying with the law, though other ways exist. An example would be "should retain evidence" in section 5.3 below. 'May' means that alternatives exist which can also achieve compliance with the law. An example is "estimated exposure may be used" in section 5.8 below.

5.2 IRR17 Regulation 3 – Threshold for Application of IRR17

Regulation 3(1)(b) of IRR17 (3) states that the Regulations apply to "*any work … carried on in an atmosphere containing radon 222 gas at an annual average activity concentration in air exceeding 300 Bqm^{-3}*". Hence if the concentration of radon is less than 300 Bqm^{-3} then there is no need for employer or self-employed person to comply with the IRRs. The regulation is written such that it only requires one result being above an annual average activity concentration of 300 Bqm^{-3} at a given location within the cave or mine for it to apply, whether or not all the results at other locations are below 300 Bqm^{-3}. It is worth considering whether the proposed trip(s) can be modified so as to avoid exposure to radon concentrations above 300 Bqm^{-3}. Note that because the regulation uses the phrase "*annual average*" that does allow one to average the results of a given location obtained at different times of the year and indeed over different years.

Regulation 5(2) requires that the HSE must be notified of such work and this should be complied with on the basis of the results from the first set of area monitoring radon detectors. The HSE provide a web form[1] for doing so. The impact of subsequent results will be discussed below.

5.3 IRR17 Regulation 9 – As Low As Reasonably Practicable

The principle of "As Low As Reasonably Practicable" is a corner stone of working with radiation. Regulation 9(1) states (3) "*Every employer must, in relation to any work with ionising radiation that it undertakes, take all necessary steps to restrict so far as is reasonably practicable the extent to which its employees and other persons are exposed to ionising radiation*". The ACoP goes on to state at paragraph 86 (3) that "*The dose control measures should make it unlikely that such people would receive an effective dose greater than 1 mSv per year*". However, the guidance at paragraph 113 (3) focuses on ventilation as the primary means of controlling exposure to radon. Annex B presents the case as to why ventilation is not reasonably practicable even at the 6 mSv threshold.

Thus the primary means of restricting exposure is to use caves or mines with the lowest levels of radon consistent with achieving the objectives of the trip into the cave or mine. Employers and self-employed persons should retain evidence of their consideration of their choice of caves and mines to restrict exposure to radon, whatever the level of exposure.

5.4 Minimal Exposure Scheme

IRR17 does not apply if the radon concentration averaged over a whole year is under 300 Bqm^{-3}. So if an employer or self-employed persons confines their work underground to trips along routes in caves and mines evidenced as having a seasonal average below 300Bqm^{-3}, such as those identified in Table 5.1, then there is no need to comply with the IRRs or notify the HSE. (Table 5.1 is based on work by BCA, MoD, the Association of Heads of Outdoor Education Centres and others collecting radon concentration levels using PHE monitors.)

Table 5.1 List of routes and trips in caves and mines whose peak concentration is under 300 Bqm^{-3}

Cave/ Mine	LCMLA Panel Area	Trip / routes	Annual Cons. Bqm^{-3}
Gaewern	North Wales	All	14
Cathedral Quarry	Northern England	All	28
Goldscope Mine	Northern England	All	36
Seathwaite Mine	Northern England	All	47
Aberllyn Lead Mine	North Wales	All	51
Long Churn	Northern England	All	76
Jingling Pot	Northern England	All	90

[1] https://services.hse.gov.uk/bssd/ as at 27/1/2024

Thistle Cave	Northern England	All	119
Sell Gill Holes	Northern England	All	130
Wrysgan	North Wales	All	130
Calf Holes	Northern England	All	140
Heron Pot	Northern England	All	155
Rampgill Mine	Northern England	All	160
Bwlch y Plwm	North Wales	Not beyond Low Adit 5	190
Rhiwbach	North Wales	All	195
Great Douk	Northern England	All	210
Goatchurch	Southern England	All	223
Yordas Cave	Northern England	All	240
Bull Pot Kingsdale	Northern England	All	269
Wills Hole	South Wales	All	282
Mouldridge Mine	Peak	All	293
Porth Yr Ogof	South Wales	Avoiding Howells Grotto, Mud Hall and Top Sump 4	296

Table 5.1 may be updated from time to time by BCA as more data is gathered. Details can be found on the BCA web site.[1]

5.5 Simple Exposure Scheme

This subsection has been written as a means by which employers or self-employed persons who only use caves or mines with low radon concentrations can adopt a scheme which reduces the demands of compliance with IRR17 to a minimum. It is based on a conservative approach to selecting caves and mines for use whilst at work to minimise exposure to radon. This forms a vital part in working towards satisfying regulation 8 of the IRR17 by forming part of the radon risk assessment.

The employers of professional persons must produce a list of all of the caves and mines they intend their employees to work in (including those in Table 5.1). Separate entries must be made for each route / trip. Self-employed persons must likewise produce a list of all of the caves and mines, together with the trips they intend to be taken. This list must cover not only those caves and mines that they intend to work in (including those in Table 5.1) but also those they intend to undertake under contract to another employer. (If the employer or self-employed person takes on additional work during the year then the list must be updated.)

Using Table 5.2 below, the employer or self-employed person must then confirm that all of the proposed trips in all of the caves and mines are included in Table 5.2 and identify the trip with the highest annual mean radon concentration. (Table 5.2 is based on work by BCA, MoD, the Association of Heads of Outdoor Education Centres and others collecting radon concentration levels using PHE monitors. The derivation of Table 5.2 is given in Annex C.) Note that a number of caves and mines have double entries reflecting the availability of different trips resulting in different levels of exposure to radon. If a proposed trip is not included in Table 5.2, then the site should not be used until environmental sampling has taken place as outlined in Annex E with the maximum number of hours calculated as outlined below. Evidence of any

[1] https://www.british-caving.org.uk/ as at 27/1/2024

independent sampling must be retained by the employer. The sharing with other interested parties such as the BCA Qualifications Management Committee (QMC) of any further environmental sampling should be encouraged

Table 5.2 List of caves, mines and trips and peak concentrations encountered

Cave	LCMLA Panel Area	Trip	Annual Max Cons. Bqm^{-3}	Max hours per year at this site to reach:	
				4.5mSv	6mSv
Parc Lead Mine	North Wales	All	320	3516	4688
Fish Caves	North Wales	All	343	3285	4380
Penarth	North Wales	All	345	3261	4348
Cwmorthin Floor 4	North Wales	All	345	3261	4348
Cwm Pwll y Rhyd	South Wales	All	347	3242	4323
White Lady	South Wales	All	377	2984	3979
Belgrave Mine	North Wales	All	380	2961	3947
Cwmorthin	North Wales	All	415	2711	3614
Wedding Cave	North Wales	All	440	2557	3409
Talagoch	North Wales	All	485	2320	3093
Belgrave Mine	North Wales	All	500	2250	3000
Dow Cave	Northern England	All	513	2195	2927
Bull Pot of the Witches	Northern England	All	530	2124	2832
Smallcleugh Mine	Northern England	All	550	2045	2727
Birkwith Cave	Northern England	All	683	1646	2195
Sunset Hole	Northern England	All	743	1515	2020
Ofof Pasg	South Wales	All	782	1439	1918
Ogof Fechan	South Wales	All	783	1437	1916
Tynebottom Mine	Northern England	All	865	1301	1734
Ogof Pasg/Foel Fawr	South Wales	All	943	1193	1591
Bridge Cave	South Wales	All	1030	1092	1456
Ogof Nadolig	North Wales	All	1107	1017	1355
Ogof Clogwyn	South Wales	Lower series only	1182	952	1269
Valley Entrance	Northern England	All	1265	889	1186
Old Ing Cave	Northern England	All	1385	812	1083
Rod's Pot	Southern England	All	1403	802	1069
Symonds Yat	South Wales	All	1421	792	1056
Poachers Cave	North Wales	All	1425	789	1053
Pwll Dwfn	South Wales	All	1435	784	1046
Ashford Black Marble Mine	Peak	All	1600	703	938

Carlswark	Peak	Excluding Stalactite Passage	2010	560	746
Pridhamsleigh	Southern England	All	2100	536	714
Craig y Nos Quarry Cave	South Wales	All	2189	514	685
Ogof Clogwyn	South Wales	All	2563	439	585
Ibbeth Peril	Northern England	All	2800	402	536
Bakers Pit	Southern England	All	2900	388	517
Suicide Cave	Peak	All	3300	341	455
Ogof Pen Eryr	South Wales	All	3425	328	438
Ogof y Ci	South Wales	All	3461	325	433
Eglwys Faen	South Wales	All	3518	320	426
P8	Peak	Entrance series	3745	300	401
Crackpot	Northern England	All	3950	285	380
Craig y Ffynnon	South Wales	All	4196	268	358
Porth Yr Ogof	South Wales	All	4581	246	327
Swildons	Southern England	All	4780	235	314
Pant Mawr	South Wales	All	4826	233	311
Ogof Llanymynech	North Wales	All	5400	208	278
Greenbridge cave	South Wales	All	7662	147	196
P8	Peak	All	8900	126	169
Little Neath River Cave	South Wales	All	9180	123	163
Bwlch y Plwm	North Wales	All	10000	113	150
Giants Hole	Peak	Upper Series only	11875	95	126
Town Drain	South Wales	All	13112	86	114
Giants Hole	Peak	All	14850	76	101
Carlswark	Peak	All	15950	71	94
Agen Allwedd	South Wales	All	16920	66	89
Peak Cavern	Peak	All	17000	66	88
Bagshawe	Peak	All	20500	55	73
Llygad Llwchwr	South Wales	All	22023	51	68

Table 5.2 may be updated from time to time by BCA as more data is gathered. Details will be found on the BCA web site[1].

The employer or self-employed person must then divide the identified highest peak concentration from Table 5.2 into 1,500,000 $hBqm^{-3}$ to derive the maximum permissible hours which would be permitted under the 6 mSv exposure threshold within the IRRs.

The employer or self-employed person must then make a careful assessment as to the number of hours each of their employees or themselves are likely to be working

[1] https://british-caving.org.uk/about-bca/working-groups/radon/ as at 27/1/2024.

underground in all of the caves and mines listed (and not just the one used in the calculation above) during a calendar year.

If the projected total number of hours of potential exposure to radon whilst underground is less than the maximum permissible hours then it is unlikely that the employee will exceed 6 mSv during their working year. A logbook of all trips worked by each employee must be maintained by the employer or self-employed person to provide evidence of time spent underground and estimated exposure. It is emphasised that the employer or self-employed person must also notify the HSE, see section 5.1, since they will be permitting employees to be exposed to radon above the threshold at which the IRRs apply for exposure to radon.

If the employee's projected total number of working hours is above the maximum permissible hours, then the employer or self-employed person will have to reduce the number of hours to be worked underground by either:

1. Avoiding sites of high radon and re-calculate the maximum permissible hours and projected total number of hours worked, or
2. Following the process laid out in the subsequent subsections of this publication to produce a Radon Exposure Estimator, or
3. Appointing a Radiation Protection Adviser competent to advise on radon specific matters for bespoke advice.

Annex D contains a worked example of this approach.

5.6 IRR17 Regulation 12 – Estimating Exposure

In the first instance the choice of cave or mine must be justified against the objectives for the trip into the cave or mine. Having selected a cave or mine, then the approach detailed in Annex E should be undertaken to carrying out a radon survey of the cave or mine. This approach details an initial paper-based assessment to determine the location to place area monitoring radon detectors, deploying and retrieving the detectors and then processing the results to assess the potential exposure of an employee carrying out one type of trip into one cave or mine over a year. The output of this work is a Trip Plan which provides a detailed statement of the progress time between features, the intent of each pause in progress plus the dose estimate for the trip.

The simplistic approach detailed in Annex E ignores the potential for the person at work taking trips into other caves or mines, or indeed different trips within just one cave or mine. The Caver Annual Exposure Table E.2 can be modified to take account of such other trips. It also assumes that the person at work will not have separate work activities with other employers which involve exposure to radiation. If this is the case, then the individual must consult with the other employer so that an assessment can be made of all of the exposures. (The IRRs are written so that it is illegal for a person to exceed the dose limit even if the dose has been incurred by working for several different employers. Moreover, paragraph 286 of the ACoP (3) makes it clear that it is the employer who is responsible for exposing the employee to a dose of radiation which finally takes them over the limit who is responsible in law for the breach.)

If the predicted exposure based on the Caver Annual Exposure (Table E.2) is above 6 mSv per year, then either the proposed trips should be reconsidered to see if the exposure can be brought down to well below 6 mSv or else the employer or self-employed person MUST consult with an RPA. This publication does not deal with the situation where a person has the potential to receive doses of radiation above 6 mSv in the course of their work duties.

Having made an estimate of the potential exposure, then the employer or self-employed persons should create a record of actual hours exposed in each cave and mine and keep an up to date record so as to ensure that the exposure is monitored. The requirements of IRR17 in this respect are covered in the following subsections.

There is a moderate number of BCA training instructors who will use the same cave. So the BCA QMC has undertaken a major monitoring campaign across a range of caves to reduce costs on their behalf. From this work, the QMC has produced a Detailed Exposure Scheme spread sheet for each region which will be made available on request to appropriate persons. The Detailed Exposure Scheme will bring together the monitoring data and provide a dose estimate for a specified trip within a named cave. The Detailed Exposure Scheme is described in more detail in section 5.18.

5.7 IRR17 Regulation 20 – Continued Monitoring

Hyland (7), amongst many others, has noted that the level of radon in a cave or mine can change quite markedly from summer to winter. Thus a single area monitoring exercise conducted in the summer is likely to give a worse case value. If the first sampling programme was carried out in the months of June, July or August, and all the results were below 300 Bqm^{-3}, then it is considered unnecessary to conduct further sampling.

But if some of the results were above 300 Bqm^{-3}, then it is considered necessary to conduct further sampling. The sampling programme should be repeated at 3 month intervals to obtain 4 sets of results covering a whole year. As each set of data is acquired, it should be taken into account by averaging the results for each location, see Annex E. It is not considered necessary to conduct sampling over more than 4 separate months in one year, see Annex E.

After the first year's programme, there remains an ongoing need under Regulation 20 of IRR17 (3) to confirm that the measurements are a reasonable estimate of radon levels. In addition, there are foreseeable changes such as flooding changing sand or mud deposits or new entrances changing air flows which could occur and have an impact on radon levels. A judgement on the frequency of such a repeat programme is difficult and will depend upon many factors, including the significance of the contribution of a particular cave or mine to the overall exposure of the employees. But it seems unlikely that a frequency of less than once every few years would be justifiable though a frequency of more than once every five years would have to be justified by scientific evidence which as yet has not been acquired.

5.8 Use of Personal Dosimeter versus Area Monitoring

Any measurement is subject to errors and that is certainly true for measuring exposure to radon. Langridge et al. (12) undertook both personal dosimetry and environmental sampling (area monitoring). The paper notes that "*In the present study, the personal dosimetry results tend to be higher than doses derived from environmental monitoring implying that the personal dosimetry is giving a more conservative estimate of dose*". However, the paper goes onto state that poor agreement was found in a comparison of the personal and environmental monitoring techniques of three years' worth of personal dosimetry data for a single caving instructor. They comment that "*it takes approximately 25 min for the* [personal] *dosimeter to equilibrate with the radon in the surrounding atmosphere*".

In an unpublished report for the Peak Instructed Caving Affiliation, Gunn (30) stated that "*There are broadly two ways in which an individual's radiation dose may be assessed, personal dosimetry and area monitoring. In personal dosimetry the individual must wear a dosimeter at all times when at work underground. When outside the cave the dosimeter must be stored where it accrues minimal background radiation, ideally next to another dosimeter that is never taken underground so that the background dose can be subtracted. Although this should, in theory, be the most accurate method for assessing dose problems have arisen where it has been tried in Show Caves. These are thought to relate to variations in the equilibrium factor within caves/mines and to the fact that visits tend to be less than 90 minutes duration which may provide insufficient time for the dosimeter to reach equilibrium with the radon in the atmosphere. An alternative, used in most Show Caves, is to record the amount of time that an employee spends in the cave/mine and to multiply this by the average radon daughter concentration. The average is based on regular sampling*."

It is therefore considered more appropriate to use area monitoring radon detector results as a basis for estimating exposure and hence dose uptake than using personal dosimeters.

There will be cases were employers and self-employed persons will wish to use caves and mines for which there is no data on radon concentrations. Given the considered position that personal dosimeters are less accurate than area monitoring, it is recommended that personal dosimeters are not used. Instead, a programme of monitoring must be started using Annex E. Whilst the first results are awaited, a surrogate measure of peak radon concentration and hence estimated exposure may be used based upon the maximum value for the region cited in Table 1.1. It is considered that this is likely to give a highly conservative result, given the differences between maximum and mean values in Table 1.1 The alternative is that use of the cave or mine be suspended until the results have been received and assessed. The assumed value based on the peak regional must be replaced by the value estimated from the first set of results and further monitoring assessed on the basis of section 5.7 above.

5.9 IRR17 Regulation 21 – The 6 mSv Threshold

In addition to the uncertainties noted in section 5.8 above, there is also uncertainties in measurement of the equilibrium factor and the unattached fraction. ICRP 137 (31) notes variation in the equilibrium factor of between 0.2 and 0.5. Hyland (7) reported values between 0.05 and 0.98 and Cigna (32) reported similar values but with one outlier at 1.94. Whilst ICRP 65 (13) and ICRP 137 (31) use 0.4, NRPB (14) had suggested using 0.5 for caves, a value which had been adopted by Hyland (7) and which probably influenced NRPB.

ICRP 137 (31) provides a review of the unattached fraction in caves suggesting values between 0.1 and 0.6. (It appears as if there is little or no work done on unattached fraction in the UK.) It goes on to suggest a value of 0.15 compared to a value of 0.01 in mines and 0.08 in offices. Using the relationship given by ICRP 137 for the relationship between dose and unattached fraction, the increase in dose due to a switch in unattached fraction from 0.15 to 0.6 would be by a factor of 2.4.

Gunn (30) states "*For those caves / mines where a full years measurements have been obtained, and where there is relatively little variation from period to period through the year, the data may be used with confidence to estimate annual radiation dose from a particular pattern of activity. Even here it is strongly recommended that estimated dose be kept below 4.5 mSv to provide a margin of error. Where measurements are lacking, or where there is wide variation from measurement period to measurement period, the reliability of the estimates is reduced and it is recommended that estimated dose be kept below 3 mSv, providing a wider margin of error.*"

Because of the potential measurement errors and the smoothing associated with a 28 day measurement, see paragraph 8 in Annex B, it is considered that it is more appropriate to use the 4.5 mSv value as the Investigation Level in place of 6 mSv.

In addition, it is considered appropriate to operate a 3 mSv Action Level, where persons who exceed this level as estimated by the Radon Exposure Estimator are shifted to alternative lower radon level caves for the remaining part of the year.

5.10 IRR17 Regulation 8 – Risk Assessment

Regulation 8(1) states *"An employer, before commencing a new activity involving work with ionising radiation in respect of which no risk assessment has been made by that employer, must make a suitable and sufficient assessment of the risk to any employee and other person for the purpose of identifying the measures the employer needs to take to restrict the exposure of that employee or other person to ionising radiation*".

The hazard of radon gives rise to the potential consequence of lung cancer, the risk of which is proportional to the extent of exposure. Thus minimising the risk from radon links directly to minimising exposure. Minimising exposure can be achieved by selecting a cave or mine which has low radon levels and or carrying out the trip in the winter rather than the summer or minimising time underground. But they may well be incompatible with the need to select a cave or mine which has the features required to fulfil the objectives of the trip.

As mentioned in section 5.3, an alternative strategy of applying forced ventilation to the cave or mine will not be reasonably practicable given the sums involved, see Annex B. In rare circumstances it may be possible to undertake a trip in part of a show cave or show mine which has forced ventilation. In such cases, the trip should be conducted with the ventilation in operation. The wet and/or muddy nature of most caves and mines is such that respiratory protection using 'dust masks' is not considered practicable.

The BCA recognises that caving and mine exploration are activities with a danger of personal injury or death, even when lead by BCA instructors. A number of those risks are time variable. Thus any risk assessment should have a dynamic element to take account of variables such as the weather on the specific risk of rain causing flooding. There may well also be a need to offset one risk against another, such as in choosing a dry cave with high radon levels instead of a 'wet' cave with low radon levels and forecast rain.

It is noted that Regulation 3 of the Management of Health and Safety at Work Regulations (33) provides an exemption for employers with less than five employees from recording the risk assessment in writing. However, it is recommended that the risk assessment should be written down since it will provide a firm basis for Local Rules, and demonstrates that the risk of radon exposure has been considered and the appropriate justification and controls have been assessed. Annex F provides a generic overview of the hazards, scenarios and mitigation measures which might arise with regards the activity as well as a separate risk assessment with regard radon to comply with Regulation 8.

5.11 IRR17 Regulation 17 – Designated Areas

Regulation 17(1) of IRR17 (3) prescribes the designation of a controlled area as being where a person is likely to receive a dose of greater than 6 mSv. As this publication does not deal with such exposures, this aspect will not be further considered. However, Regulation 17(3) of IRR17 states that "An employer must designate as a supervised area any area under its control, not being an area designated as a controlled area … in which any person is likely to receive an effective dose greater than 1 mSv a year". This requirement triggers further requirements under the IRRs.

5.12 IRR17 Regulation 18 – Local Rules

Regulation 18(1) of IRR17 (3) requires that a set of Local Rules must be written and must be complied with by all employees when working within a Supervised Area. (This also covers self-employed persons who are required by Regulation 2(2) to treat themselves as both an employer and as an employee.) In addition, Regulation 18(5) requires that the employer must appoint a Radiation Protection Supervisor (RPS) who is named in the Local Rules. (This means that a self-employed person without other employees is their own RPS.) The requirement for the content of Local Rules is different for controlled areas; this publication only applies to supervised areas. The

material which follows is written on the premise of the caves or mines only being supervised areas.

The Local Rules must contain the following material and instructions:

A) The Trip Plan(s) including the name of the cave(s) or mine(s) plus a reference to where they may be studied;
B) The name of the Radiation Protection Supervisor (and if need be, details of how to contact that person);
C) The employee or self-employed person must keep an up to date log of their cave and mine trips, together with a record of the time spent underground and estimated dose in mSv from that exposure;
D) If the total estimated exposure exceeds 3 mSv Action Level, then the employer must direct the employee (or self-employed person take upon them self) to undertake trips in caves and mines of much lower potential exposure levels;
E) If the total estimated exposure exceeds 4.5 mSv Investigation Level, then the employee (or self-employed person take upon them self) must either be suspended from leading trips or shall be party to the employer's consultation with a Radiological Protection Advisor on further exposure to radon.

The above material should be either adopted as written with suitable inclusions as specified by the employer or may be used as a basis to write a set of Local Rules.

Although not a suggested Local Rule, it is recommended that employers should take a record of the log book of any person they employ who may have been exposed to radon in other work, having ensured that the log book is up to date.

As previously indicated it is recommended that the radiation risk assessments which have been customised to cover each specific cave or mine trip should also be provided alongside the Local Rules.

5.13 IRR17 Regulation 18 – Radiation Protection Supervisors

The role of a Radiation Protection Supervisor (RPS) is detailed by paragraph 346 of the ACoP as (3):

An employee who is appointed as an RPS should:
(a) know and understand the requirements of the Regulations and local rules relevant to the work with ionising radiation;
(b) command sufficient authority from the people doing the work to allow them to supervise the radiation protection aspects of that work;
(c) understand the necessary precautions to be taken and the extent to which they will restrict exposures;
(d) be given sufficient time and resources

It is therefore clear that an RPS must have the authority to carry out supervisory duties on behalf of the employer. It is considered that an RPS will be sufficiently trained if they read and understand this publication and the Local Rules. The duty of an RPS is to supervise employees so as to ensure that they are complying with the Local Rules. Due

to the nature of radon, there are no duties relating to monitoring radiation. The primary duties relate to ensuring that an estimate of exposure is recorded for each and every trip undertaken by an employee and that the employer is made aware if an employee approaches the Action or Investigation Level mentioned in section 5.12.

5.14 IRR17 Regulation 12 – Dose Limitation

Regulation 12 imposes a duty on all employers to not expose both their employees and also any other persons above certain limits. For employees and trainees over the age of 18, this limit is 20 mSv per year, with a lower threshold of 6 mSv for trainees under 18 years of age. This whole section has been written on the assumption that employee's doses are below the lower threshold of 6 mSv with an allowance for errors. The dose limit for any other person is 1 mSv.

But paragraph 155 of the ACoP (3) states that "Where employers anticipate that any work activity … is likely to expose members of the public to direct radiation … they should apply a dose constraint [which] should not exceed 0.3 mSv a year". So members of a party being instructed or led are bound by this 0.3 mSv value. Thus any proposed individual trip should not exceed 0.3 mSv or 75,000 $hBqm^{-3}$. As can be seen from the data listed in Table 5.2, the likelihood of this occurring is remote given the implications for the exposure of the employee. Because of the nature of radon, the Local Rules do not specify any detail relating to controlling exposure. So there is no requirement on the professional user to brief these other persons on such matters. But it is considered prudent to provide a brief statement on the risk associated with exposure to radon within the cave. Such a statement is set out in Annex G.

However, there may be instances where a person such as a teacher participating with their pupils in the activities of an outdoor activity centre may elect to undertake several cave or mine trips. In such cases, it is recommended that the employer of the employee(s) taking that person underground should make a record of the exposure using the Detailed Exposure Scheme so as to demonstrate that the person is not exposed to radon which would take them over their 1 mSv dose limit.

5.15 IRR17 Regulation 16 – Cooperation between Employers

Regulation 16 of IRR17 (3) requires that one employer, or self-employed person must share information to another employer where the work of one employer might impact on another employer. The aim of co-operation is to co-ordinate the measures taken to comply with statutory duties. The most significant requirement is to ensure that where an employee has several employers, those employers (or employer and self-employed person) must co-operate to make sure dose limits are applied to the total dose received by the employee. It is noted that paragraph 286 in the guidance in the ACoP (3) makes clear that if an employee does exceed the dose limit, then the employer at the particular point when the dose limit is exceeded is deemed to be responsible.

Thus it is important for employers to share information on the total dose received otherwise they will have difficulties in making the correct decisions on the need for

classification and ensuring compliance with relevant dose limits. This requirement places significant obligations on self-employed persons who may be employed by several employers as well as undertaking business on their own behalf. It points to a need for self-employed persons to maintain a fully up to date log book such as the Radon Exposure Estimator and share it with each employer before every trip. The employer should record the current total estimated dose received by the self-employed person as a means of demonstrating their compliance with the this regulation and as a defence if the 6 mSv threshold is breached.

Regulation 16 of IRR17 also applies when the trip under the control of one employer is taking place in a ventilated show cave under the control of a different employer. The act of shutting down the ventilation will obviously have an impact on exposure and should thus be coordinated.

5.16 IRR17 – Other Requirements

Given due to the unique nature of caving and radon exposures a pragmatic approach is to be adopted to ensure compliance with the ionising ration regulations. Based on discussions with the HSE's Radiation Specialist Inspectors, it is considered that employers of employees or self-employed persons whose exposure is clearly below 6 mSv using either the Simple Exposure or Detailed Exposure Schemes or the above set of Local Rules will meet both the specific requirement of Regulation 14 to consult with an RPA as well as the requirements of Regulation 18.

It is considered that professional employers of employees or self-employed under IRR17 will be able to demonstrate compliance with the regulations through the implementation of the actions discussed within this document/guidance.

An employer must provide training on the radon hazard under Regulation 15 to the employees. An outline of a training programme is offered in Annex H.

Regulation 19 of IRR17 (3) states that any designated supervised area requires that where an employer has control of an area such as a cave or mine, then they should place warning signs marking that area. In most circumstances, the employer will not have control of the cave or mine specified in part A of the Local Rules since they do not own, lease or have such a right of control over the cave or mine. However, the employer should make it clear during the training given in compliance with Regulation 15, that the areas identified in part A of the Local Rules would, were it not for the absence of control, be supervised areas.

5.17 Record Keeping

The mandatory requirement for keeping records of an employee's exposure to radiation only applies to classified persons and is thus not considered further. Other regulations refer to the keeping of records but are not directly relevant. However, as good practice, it is recommended that employers and self-employed persons should keep the risk assessment, local rules and related documentation along with training and refresher

training records of employees undertaking duties laid out in those documents. Although there is no legal basis, a period of two years is considered to be sufficient to enable an employer to demonstrate compliance with IRR17 in line with paragraph 203 of IRR17 (3). Area monitoring records form the basis of estimating exposure and making estimates of doses received by employees as well as by other persons such as clients. Again a period of two years is considered to be sufficient to enable an employer to demonstrate compliance with IRR17, if the data has not been published elsewhere.

IRR17 does not require the keeping of exposure estimates for persons who do not exceed the 6 mSv threshold. However, again there is value in in keeping such records for a period of time to enable an employer or self-employed person to demonstrate compliance with IRR17. Also, there is potential value from a civil liability aspect. Darby (4) notes that the impact of radon to cause lung cancer might only arise between 5 and 35 years after exposure. Thus a liability could remain for over 30 years. Although there is a limit of 6 complete years under the 1980 Limitations Act (34), Section 11 states that the period is 3 years from the date of knowledge of the injury for personal injuries. Thus the period of limitation only starts when the person becomes aware that they have lung cancer. It is suggested that records made under Local Rules C, D and E are kept for at least 30 years from the date of entry.

5.18 Detailed Exposure Scheme

QMC on behalf of BCA has carried out a series of measurements across a number of caves and mines which can be incorporated into a spreadsheet called the Detailed Exposure Scheme. This spread sheet also incorporates automatic summing capability so provided the sheets are filled in, then an up to date total estimated exposure can be read off. Self-employed professional cavers may need to use more than one calculator. There is space for these cumulative estimates to be included on one primary Detailed Exposure Scheme so that an overall total may be calculated.

The calculator should include a description and survey covering each trip together with the details of the calculations on an individual sheet. It should also include a Risk/Benefit justification as to why that venue may be used given the levels of radon measured within it. This Risk–Benefit justification should also include any considerations to further reduce exposure to radon. If need be, a new sheet should be created to reflect a variation of the provided trips. The front sheet provides for a linking page into which one enters the trip undertaken and the sheet automatically calculates exposure and estimated dose in mSv and computes a total exposure, with the second sheet providing a summary of the Risk/Benefit justification. The Detailed Exposure Scheme must only be used for one calendar year in order to match with the IRRs definition of annual exposure.

Further details on the Detailed Exposure Scheme will be provided by QMC as part of the LCMLA and CIC award schemes.

Employers and self-employed persons may choose to design their own Detailed Exposure Scheme tool, an outline of the requirements for this are outlined in Annex E, Table E.1.

6 Guidance for Recreational Persons and Owners on Minimising Exposure to Radon

These Guidelines are designed to assist organisations and individuals concerned with or engaged in underground activities to adopt practices that will enhance awareness of the problems of controlling exposure to radon and its daughter products.

These Guidelines do not apply to underground voids where radon concentrations are abnormally high, such as certain metalliferous mines. In such places where only breathing apparatus might provide adequate protection from radon, specific advice must be sought from a competent person before entering them.

These Guidelines also take account of the fact that any health risks arising from exposure to radon are cumulative and so any unnecessary exposure should be avoided. Readers are reminded that Kendal & Dixon (14) of PHE / NRPB have proposed for recreational caving a time-integrated dose limit of 1,000,000 $hBqm^{-3}$ per year.

6.1 Recreational Persons

6.1.1 Cavers and Mine Explorers

Cavers and Mine Explorers should use the information available to plan trips that will minimise their exposure to radon and avoid, wherever possible, taking others into underground voids with high concentrations. Individuals who spend hundreds of hours per year underground, should seriously consider keeping a log of exposure. As has been argued in section 5.7, the use of personal dosimeters is not considered to be an effective way of monitoring exposure. An alternative, but less effective way of estimating exposure is to use available data on radon concentrations in the voids visited to obtain an approximate cumulative figure. They should comply with any rules that a land or void owner imposes as a condition of entry to an underground void. Such rules could be needed by the owner to protect his/her legal interests which may or may not contain references to radon.

6.1.2 Voluntary Group Leaders

Voluntary Group Leaders are not covered by the HSW Act but have a common-law duty to members of their party. As part of their leadership function, they should advise members of their party about the hazard of radon and give them the best available information about the levels of risk associated with the proposed trip, see Annex G. If underground voids known or suspected to have high concentrations of radon are avoided, it should be sufficient to advise the party that radon is present, but the anticipated levels are such that the estimated risk is not out of proportion to other risks. The party should also be made aware of the cumulative risk. The Leader should ensure that the party complies with any rules made by the Land or Void Owner (see below).

6.1.3 Members of Instructed or Led Parties

Professional instructors or leaders have duties under the HSW Act to ensure that members of their parties are provided with adequate information, instruction and supervision, see section 5. The principal measure to minimise exposure will often be the choice of suitable underground voids or parts of an underground void. Any member of such a party should follow the instructor or leader's instructions relating to the parts of the void to be visited. Although voluntary group leaders are not covered by the HSW Act they have a common-law duty to members of their party.

6.2 Owners

6.2.1 Private Void Owners

Private void owners have no duties under either the HSW Act or the IRRs because they are not engaged in a business. Providing an adequate sign may discharge any duties under the Occupiers' Liability Acts. However, if they "own" a mine, or the entrance(s) to one, they have a duty under the Mines and Quarries Act to maintain the entrance(s) secure so as to prevent a person from accidentally entering.

6.2.2 Private Land Owners

Private land owners have no duties under either the HSW Act or the IRRs because they are not engaged in a business. If they have a mine entrance on their land, they may have a duty under the Mines and Quarries Act to maintain the entrance(s) secure so as to prevent a person from accidentally entering.

6.2.3 Business Void Owners

Most business void owners are Show Cave or Mine owners. They have duties under both the HSW Act and the IRRs because of the foreseeable presence of radon, at least insofar as access to that part of the underground void which is defined as the Show Cave or Mine is concerned. It is likely that they have already appointed an RPA (see section 4.3 above). Other business void owners should determine the extent to which the IRRs apply and hence whether they need an RPA. The RPA should provide advice covering all types of persons who may enter the void. Providing an adequate sign may discharge any duties under the Occupiers' Liability Acts. However, if they "own" a mine, they have a duty under the Mines and Quarries Act to maintain the entrance(s) secure so as to prevent a person from accidentally entering.

6.2.4 Business Land Owners

Although they have duties under Section 4 of the HSW Act to persons at work entering an underground void through an entrance on their land, these duties are limited to taking such measures as are reasonable. The principal duty to comply with the IRRs lies with the employer of those persons (or self-employed person) who are entering the void and who should have taken advice from their RPA.

Duties in respect of the radon hazard are unlikely to extend beyond providing any relevant information to the employer. This duty is one of providing such information that they hold on the hazard from radon to the person who seeks that information.

7 References

1 Public Health England, The risks to your health from radon, https://www.ukradon.org/information/risks as at 27/1/2024

2 World Health Organisation, Radon and health, https://www.who.int/news-room/fact-sheets/detail/radon-and-health as at 27/1/2024

3 Ionising Radiations Regulations: see Working with ionising radiation. Ionising Radiations Regulations 2017. Approved Code of Practice and guidance. https://www.hse.gov.uk/pubns/books/l121.htm as at 27/1/2024

4 Darby, S. et al., 'Residential radon and lung cancer – detailed results of a collaborative analysis of individual data on 7148 persons with lung cancer and 14208 persons without lung cancer from 13 epidemiologic studies in Europe', *Scandinavian Journal of Work, Environment and Health* 32, Supplement 1 (2006)

5 Field, M.S., 'Risks to cavers and cave workers from exposures to low-level ionizing α radiation from ^{222}Rn decay in caves', *Journal of Cave and Karst Studies* 69, No. 1 (2007), 207–228 (http://www.caves.org/pub/journal/PDF/v69/cave-69-01-207.pdf as at 27/1/2024)

6 World Health Organisation, *WHO Handbook on Indoor Radon: A Public Health Perspective* (2009) (https://iris.who.int/bitstream/handle/10665/44149/9789241547673_eng.pdf?sequence=1&isAllowed=y) as at 27/1/2024)

7 Hyland, R.Q.T., 'Spatial and temporal variations of radon and radon daughter concentrations within limestone caves', unpublished PhD thesis, University of Huddersfield 1995 (http://eprints.hud.ac.uk/id/eprint/4839/1/DX193594.pdf as at 27/1/2024)

8 Friend, C.R.L. & Gooding, T., 'Variations in the concentration of radon in parts of the Ogof Ffynnon Ddu system, Penwyllt, South Wales and estimates of doses to recreational cavers', *Journal of Environmental Radioactivity* 58 (2001), 45–57

9 Taylor, P., Personal communication 2011

10 Friend, C.R.L., 'Researching cave radon', *Descent* 203 (2008), 30–31

11 Friend, C.R.L., 'Radon in South Wales', *Descent* 214 (2010), 19

12 Langridge, D. et al., 'Monitoring of radon gas in caves of the Yorkshire Dales, United Kingdom', *Journal of Radiological Protection* 30 (2010), 545–556

13 International Commission on Radiological Protection, *Protection against Radon-222 at Home and at Work*, ICRP Publication 65, *Annals of the ICRP* 23, No. 2 (1993) (https://www.icrp.org/publication.asp?id=ICRP Publication 65 as at 27/1/2024)

14 Kendall, G.M. & Dixon, D.W., 'Controlling radon exposures during recreational caving and similar activities', NRPB-M814 (1997), 8pp

15 Health Protection Agency, *Limitation of Human Exposure to Radon: Advice from the Health Protection Agency*, Documents of the Health Protection Agency: Radiation, Chemical and Environmental Hazard*s*, RCE-15 (July 2010) (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/335000/RCE-15_for_website.pdf as at 27/1/2024)

16 International Commission on Radiological Protection, *Lung Cancer Risk from Radon and Progeny and Statement on Radon*, ICRP Publication 115, *Annals of the ICRP* 40, No. 1 (2010) (https://www.icrp.org/publication.asp?id=ICRP Publication 115 as at 27/1/2024)

17 British Caving Association, BCA 2019 AGM Reports, Item 13, 'Membership Administrator's Report' (https://british-caving.org.uk/about-bca/bca-council/official-documents/) as at 27/1/2024
)

18 British Cave Rescue Council, British Cave Rescue Council Incident Reports, https://www.caverescue.org.uk/wp-content/uploads/2019/03/2009_Report.pdf as at 27/1/2024

19 British Cave Rescue Council, British Cave Rescue Council Incident Reports, https://www.caverescue.org.uk/about-cave-rescue/incident-reports/ as at 27/1/2024

20 Advisory Group on Ionising Radiation, *Radon and Public Health: Report of the independent Advisory Group on Ionising Radiation*, Documents of the Health Protection Agency: Radiation, Chemical and Environmental Hazards, RCE-11 (June 2009) (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/335102/RCE-11_for_website.pdf as at 27/6/2020)

21 Health and Safety Executive, Amateur sports clubs: Guidance on running a safe sports club: The HSW Act and safety during the field of play, https://www.hse.gov.uk/entertainment/leisure/amateur-sports-club.htm as at 27/1/2024

22 Occupiers' Liability Act (1957), Chapter 31, http://www.legislation.gov.uk/ukpga/Eliz2/5-6/31/contents as at 27/1/2024

23 Occupiers' Liability Act (1984), Chapter 3, http://www.legislation.gov.uk/ukpga/1984/3/introduction as at 27/1/2024

24 Occupiers' Liability (Scotland) Act (1960), Chapter 30, http://www.legislation.gov.uk/ukpga/Eliz2/8-9/30/introduction as at 27/1/2024

25 Occupiers' Liability Act (Northern Ireland) (1957), Chapter 25, http://www.legislation.gov.uk/apni/1957/25/contents as at 27/1/2024

26 The Occupiers' Liability (Northern Ireland) Order (1987), Statutory Instrument No. 1280 (NI. 15), http://www.legislation.gov.uk/nisi/1987/1280/contents as at 27/1/2024

27 Health and Safety at Work etc. Act (1974), Chapter 37, http://www.legislation.gov.uk/ukpga/1974/37/contents as at 27/1/2024

28 Mines Regulations (2014), Statutory Instrument No. 3248, https://www.hse.gov.uk/pubns/priced/l149.pdf as at 27/1/2024

29 Mines and Quarries Act (1954), Chapter 70, http://www.legislation.gov.uk/ukpga/Eliz2/2-3/70/contents as at 27/1/2024

30 Gunn, J., 'Radon Concentrations in Selected Peak District Caves and Implications for Instructed Caving', unpublished draft report of the Limestone Research Group, University of Huddersfield, LRG 03/2003 (2003)

31 International Commission on Radiological Protection, *Occupational Intakes of Radionuclides: Part 3*, ICRP Publication 137, *Annals of the ICRP* 46, No. 3/4 (2017)

32 Cigna, A.A., 'Radon in Caves', *International Journal of Speleology* 34 (1–2), 1–18 (https://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1203&context=ijs as at 27/1/2024)

33 The Management of Health and Safety at Work Regulations (1999), Statutory Instrument No. 3242, http://www.legislation.gov.uk/uksi/1999/3242/made as at 27/1/2020

34 Limitation Act (1980), Chapter 58, http://www.legislation.gov.uk/ukpga/1980/58 as at 27/6/2024

35 Hyland, R. & Gunn, J., 'International comparison of cave radon concentrations identifying the potential alpha radiation risks to British cave users', *Health Physics* 67, No. 2 (1994), 176–179

36 Badino, G., 'The legend of carbon dioxide heaviness', *Journal of Cave and Karst Studies* 71(1) (2009), 100–107 (https://caves.org/pub/journal/PDF/v71/cave–71-01-100.pdf as at 27/1/2024)

37 British Cave Research Association, BCRA Survey Grades, http://bcra.org.uk/surveying/index.html as at 27/1/2024

38 Office for National Statistics, Homicide in England and Wales: year ending March 2019, https://www.ons.gov.uk/peoplepopulationandcommunity/crimeandjustice/articles/homicideinenglandandwales/yearendingmarch2019 as at 27/1/2024

39 Malhotra, A. et al., 'Outcomes of cardiac screening in adolescent soccer players', *New England Journal of Medicine* 379 (2018), 524–534 (https://www.nejm.org/doi/full/10.1056/NEJMoa1714719 as at 27/1/2024)

Annex A: Dose Conversion

1. The conversion of $hBqm^{-3}$ to mSv is based on some exceedingly complex arguments formulated in ICRP 65 (13). A major complication is that in 2017, ICRP issued a new recommendation in ICRP 137 (31), which awaits adoption by the authorities. If and when adopted, it will have a significant impact on the conversion factor increasing dose per unit exposure.

2. The current value comes from Table 3 and Section 2.2.5 of ICRP 65. Section 2.2.5 states that the conversion factor is 5.06 mSv / WLM. Table 3 states that when radon is at equilibrium with its daughter products, then there are:

$$1.57 \times 10^{-6} \text{ WLM / hBqm}^{-3}$$

If radon is not at equilibrium with its daughter products, as is usually the case, then the relationship is:

$$F \times 1.57 \times 10^{-6} \text{ WLM / hBqm}^{-3}$$

where F is the Equilibrium factor and normally has a value between zero and one.

Although ICRP 65 suggests a value for F of 0.4 (13), work by Hyland and Gunn in limestone caves in the UK (35) suggests a more accurate value is 0.5. Thus the conversion factor using ICRP 65 is:

$$[5.06 \text{ mSv / WLM}] \times [0.5 \text{ x } 1.57 \times 10^{-6} \text{ WLM / hBqm}^{-3}]$$
$$=$$
$$3.97 \times 10^{-6} \text{ mSv / hBqm}^{-3}$$

3. ICRP 65 decided to not take into account variations in unattached fraction.

4. Table A1 gives the $hBqm^{-3}$ values for the various levels of dose mentioned in the text.

Table A.1 List of thresholds and limits mentioned in this advice

Dose mSv	$hBqm^{-3}$	Comment
0.3	76,000	Sec 5.13 individual trip limit
1.0	250,000	Sec 5.13 IRR17 dose limit for any other person
2.4	610,000	Annex B Cost–Benefit threshold
3.0	760,000	Sec 5.18 suggested threshold for modifying duties
4.5	1,100,000	Sec 5.8 proposed limit for application of this advice
6.0	1,500,000	Sec 5.1 absolute limit of this advice / IRR17 limit for non-classified person

5. ICRP 137 (31) adopted a different approach and, for the first time, specifically covers exposures to radon in tourist caves. Table 12.7 cites a value for the conversion factor of 1.50 x 10^{-5} mSv / hBqm^{-3} with a value for the Equilibrium Factor of 0.4. For an Equilibrium Factor of 0.5 as recommended for UK caves, the conversion factor becomes 1.88 x 10^{-5} mSv / hBqm^{-3}. This change means that for an exposure to the same amount of radon the mSv dose has increased by a factor of 4.7!

6. ICRP 137 also adopted a value of 0.15 for the unattached fraction in tourist caves based on an assumption of no additional ventilation (such as by fans) but notes measured values vary between 0.1 and 0.6. No reference has so far been found for measurement of the unattached fraction within caves in the United Kingdom. It is therefore considered there is no justification for adopting an alternative value from that which ICRP 137 has adopted in respect of unventilated caves. However, it is noted that some tourist caves and mines do have forced ventilation. It is suggested that consideration should be given to adopting the ICRP conversion factor for mines which would reflect the similarities in ventilation practices. The adoption of a different conversion factor to that recommended by ICRP will require not only consultation with an RPA but also the Approved Dosimetry Service and the Health and Safety Executive.

Annex B: Cost–Benefit Analysis

1. As noted in section 2.1, ICRP 115 (16) recommended a relationship between detriment (being both death and hereditary effects) and dose as an estimated risk of death of 5 x 10^{-4} per WLM. It also notes that the relationship between WLM and mSv varies between 10 and 20 mSv per WLM depending upon the exposure scenario. For cavers, it is prudent to assume a value of 20 mSv per WLM giving a value for risk of death of 2.5 x 10^{-5} per mSv.

2. As of 5/3/2020 the cost of a fatality is estimated by HSE to be £1,6000,000[1] but notes cancers should be costed at twice the value[2], i.e. £3,200,000. So the cost risk is £3,200,000 * 2.5 * 10^{-5} = £80 per mSv.

3. At the heart of the Health and Safety at Work Act is to take reasonably practicable steps to avoid a harm. This is means there may be a gross disproportion between cost of avoidance and the cost risk of occurrence. This is known as a disproportion factor. The HSE suggests[3] the disproportion factor will not exceed 10. Consequently, the spend does not need to exceed £800 per year for a 1 mSv per year exposure.

4. ICRP 137 (31) uses the same probability of death of 5 x 10^{-4} per WLM as ICRP 115. But it cites a higher mSv per WLM relationship for exposure in a tourist cave of 24 mSv per WLM. So the risk of death from 1 mSv each year is 5 x 10^{-4} / 24 = 2.1 x 10^{-5} per year. So the cost risk is £3,200,000 x 2.1 x 10^{-5} = £67 and hence the spend does not need to exceed £670 per year for a 1 mSv per year exposure.

5. However, given a normal occupancy time for a worker of approximately 40 hours in 50 weeks, then the threshold for the IRRs to apply of 300 Bqm^{-3} is equivalent to an annual exposure of around 600,000 $hBqm^{-3}$. Noting the conversion factor of 3.97 x 10^{-6} mSv / $hBqm^{-3}$, see paragraph 2 of Annex A, that is equivalent to 2.4 mSv. Thus there is an argument for not needing to take precautionary measures for exposures below 2.4 mSv.

6. PHE offer personal dosimeters at £50 for a 3 month period of usage. Assuming PHE can turn around a personal dosimeter within the 30 day period used for monitoring, then it might seem a reasonable practicable spend to deploy a single personal dosimeter on the placement trip to provide an estimate of exposure for the two monitoring trips as well as an early warning indicator of whether the proposed trip is likely to be acceptable in terms of radon exposure. But, as noted in section 5.7, there is concern over their reliability in measuring exposures in atmospheres which have quickly varying radon concentrations as found in caves and mines.

7. Hyland (7) reports a world record radon concentration of 155,000 Bqm^{-3} which was found in a cave in the United Kingdom (Giants Hole). This was measured using a spot Working Level meter. He contrasts it to his measurement of 46,080 Bqm^{-3}

[1] http://www.hse.gov.uk/economics/eauappraisal.htm as at 27/1/2024.
[2] http://www.hse.gov.uk/risk/theory/alarpcheck.htm as at 27/1/2024.
[3] http://www.hse.gov.uk/risk/theory/alarpcheck.htm as at 27/1/2024.

taken using a time integrated concentration over a one week period. This suggests variations in spot to time integrated concentrations could differ by as much as a factor of three.

8. Obviously high concentrations of radon will be recorded by the area monitoring radon detectors so an estimate of the exposure incurred in obtaining the result can be made. The world record equates to an exposure rate of 0.6 mSv per hour. The two trips to deploy and retrieve the area monitoring radon detectors are extremely unlikely to take more than 10 hours in total (estimates range between 1 and 5 hours). So in the worst case, the dose received might reach around 6 mSv. Wearing a personal dosimeter in such a situation would provide the benefit of stopping the second exposure, assuming the personal dosimeter managed to record the exposure. But as presented in section 5.8, personal dosimeters are not considered sensitive enough to pick up varying radon concentrations as would be seen in a typical caving trip. So in the extreme case, that might save 3 mSv exposure. It is therefore considered that on balance it is not worth the effort of using a personal dosimeter when making deploying area monitoring radon detectors.

9. The cost of an instrument with sufficient response sensitivity (i.e. minutes) so as to react to radon concentrations on a timeframe consistent with the passage of a caver through the cave or mine is understood to be similar to £800 and hence not reasonably practicable. There is also a serious question as to their usability in caves and mines without significantly adding to the trip time.

10. Installing fans to provide for forced ventilation is a substantial project and cost way beyond the £800 per mSv threshold.

11. Many forms of radioactive material require care to avoid inhaling or ingesting or getting the material on one's skin. The use of 'dust masks' as respiratory protection will not filter radon gas and have limited impact on filtering the daughter products. Their use is likely to be compromised by the wet and / or muddy conditions within most caves or mines. They are thus not considered a practicable means of reducing exposure. The other potential routes for exposure by ingestion or skin contamination could be safeguarded against. But there is no need to take any safety measures because the dose received by those routes is trivial compared to the dose by inhalation.

Annex C: Derivation of Values contained in Table 5.2

1. In the first instance, a programme of work should be carried out in each cave or mine following that laid down in Annex E parts 1, 2 and 3. This will result in a single set of data of the radon concentration for a number of locations at a given point of the year, normally summer. As further sampling is done, then averaging as outlined in Annex E may be incorporated.

2. The radon concentration used in Table 5.2 is the highest annual averaged value found in the given cave or mine. The 'maximum hours per year at this site to reach 6 mSv' value is computed by simply dividing the radon concentration into 1,500,000 $hBqm^{-3}$. The use of 6 mSv is justified on the grounds that by using the peak value for the highest cave, the estimate for exposure across all caves will be grossly pessimistic.

3. As subsequent monitoring is undertaken in other seasons, the data for each location gathered over those seasons should be taken into account by averaging the data obtained at each location as indicated by Annex G.

Annex D: Worked Example of the Simple Exposure Scheme

1. A self-employed cave instructor based in South Wales working in an Outdoor Education Centre plans to lead one group each week in either Porth yr Ogof, Eglwys Faen, Ogof y Ci, Bridge Cave or Ogof Clogwyn. They should be listed in a table, see Table C.1 for example, together with the maximum number of hours value taken from Table 5.2.

Table C.1 Selected caves and mines within Simple Exposure Scheme

Cave/Mine	Highest average Radon Measurement Bqm^{-3}	Max hours	Hours to Investigation Level	Hours to Action Level	Justification for use and considerations (Risk/Benefit)
Ogof Clogwyn	8,180	183	134	92	Active stream but no flood risk. Useful wet weather option.
Eglwys Faen Cave	3,517	426	320	213	Dry cave, no flooding issues but limited challenges. Useful alternative venue during wet days.
Ogof y Ci	3461	433	325	217	Active stream which only floods in very high-water conditions. Useful when water levels at other venues a concern. Challenging trip
Bridge Cave	1217	1233	925	617	Active river cave which only floods if water levels very high. Useful alternative to PyO (if busy) or as a mixed trip given other caves in close proximity
Porth yr Ogof excluding Howells Grotto	327	4587	3440	2294	Excellent, varied cave with a range of caving challenges, water levels need consideration. Can be very busy.

2. From Table 5.2, Ogof Clogwyn has a value of 8180 Bqm^{-3} Which gives a potential of 183 hours underground per year. As the instructor plans to work for 43 weeks in the year, that gives a little over 4 hour each week which the instructor decides is too small a margin.

3. The next significant measurement of all the caves the instructor proposes to work in is Eglwys Faen with 3,517 Bqm^{-3} which gives a potential of 426 hours. Based on one trip per week over 43 weeks, that allows 10 hours per trip. Not only does that give the Instructor a wide margin for the time for each trip but also scope to undertake other work which might be offered during the year.

4. Based on subsection 5.9, the Instructor then calculates the Investigation Level at which consultation with an RPA must take place based on a value of 1,100,000 hBqm-3 (i.e. 4.5 mSv), or 75% of maximum number of hours. The Instructor also calculates the Action Level at which a review of the use of caves and mines is conducted at 760,000 hBqm-3 (i.e. 3 mSv), or 50% of maximum number of hours.

5. The Instructor then lists the justification for using the various caves. Depending upon the intent of the trip, the Instructor uses the location with least radon concentration.

6. Hence for this example, the Instructor would normally use Porth yr Ogof for a trip for its variety and challenges. But in wet conditions, Bridge Cave might be used or, if very wet, Eglwys Faen would be chosen. (It can thus be seen that by the simple of use of hours underground and comparing the total to the Action Level based on the highest radon concentration, the scheme is overly conservative in controlling exposure.)

Annex E: Radiological Assessment of a Cave or Mine

1. A list of objectives of the trip should be drawn up and from that, a list of features required in the cave or mine to meet those objectives should be extracted. The range of caves or mines available should be reviewed and the chosen cave(s) or mine(s) justified against that list of features. (It may well be that only one location satisfies that list.)

E.1 Initial Considerations

2. A survey of the cave or mine is a prerequisite for being able to demonstrate a systematic assessment for radon. The survey can be a BCRA Grade 1 sketch (37) and must cover all parts of the cave or mine which are proposed to be included in the trip

3. The survey should be annotated with locations where the trip is either likely to pause for any time to discuss a feature, rest, or prepare for a challenge such as a squeeze or pitch. The survey should be annotated with estimated times for such pauses as well as travel times between locations. The nature of the trip and the route needs to be recorded in moderate detail so that other persons understand the route. The record of the trip should note both passage into and back out of the cave or mine for a 'there and back again' trip via one entrance. A 'round' trip or a trip between an entrance and a separate exit should detail all passages traversed including any passage traversed more than once. If need be, different trips should be recorded on separate surveys to minimise confusion. This annotated survey forms the Trip Plan and is the basis for ensuring that the exposure to radon is minimised.

4. A review of literature published on the cave or mine should be undertaken to note of the location of potential radon producing sources, including:

   - Possible higher uranium concentration strata,
   - Sediment banks,
   - Inflowing underground water sources, and
   - Mineral veins.

The survey should be annotated with such information.

5. Hyland (7) provides some useful information covering the United Kingdom. The British Cave Research Association[1] has substantial resources covering mostly caves. The bibliography produced under the auspices of the International Union of Speleology[2] can also be searched for useful material relating mainly to caves. It is anticipated that many of references found in the bibliography will be available from the British Caving Library[3]. The National Association of Mining History Organisations[4] has resources covering mines.

[1] http://bcra.org.uk/ as at 27/1/2024
[2] https://www.ssslib.ch/bbs/ as at 27/1/2024
[3] http://caving-library.org.uk/ as at 27/1/2024
[4] https://www.namho.org/ as at 27/1/2024

6. Air movements are key to dispersing radon and the survey should be annotated to indicate areas where there are:

- Entrances,
- Known reliable drafts,
- Drafts which vary with the seasons,
- Waterfalls,
- Streams, and
- Blind end passages.

It is emphasised that radon diffuses in air and Badino (36) demonstrates that it will not 'collect' in pits. (Though it will be present at higher concentrations nearer the source which could be mistaken for 'collecting'.) Hence away from localised sources, the radon levels should not change with height above ground level.

7. Potential sampling locations for area monitoring radon detectors should be chosen to reflect the groups of factors mentioned in paragraphs D3 D4 and D6, decreasing (for sources or longer passage lengths) or increasing (for dispersion or shorter passage lengths) the distance between locations as appropriate. Thought should also be given to the detailed positioning of sampling locations so as to minimise problems from floods, inquisitive persons etc. Hyland's work (7) indicates moderate sized (thousands of ppm) changes in radon concentration may occur within a hundred metres (though this is obviously dependent upon many factors). There is also obviously no need to sample for radon by the entrance since this will be close to the fairly low out of door's level. Experience has shown there is value in over sampling during the summer sampling campaign since this can provide reassurance that the results are comprehensive.

8. A review of the potential sampling locations should then be conducted to assess the cost of making measurements. Other factors which may be taken into account include measurements made in nearby caves or mines, any previous collected data of uncertain provenance and the frequency of repeated trips. It is likely that the outcome is the selection of a handful of sites for a trip covering many hundreds of meters.

E.2 Initial Measurements

9. Radon levels in caves are known to vary between highs in the summer and lows in the winter. Thus the initial set of measurements are best conducted in the summer months of either June, July or August so as to obtain a 'worse case' set of data. The simplest manner of measuring radon levels is to deploy radon detectors supplied by Public Health England (PHE) as area monitoring radon detectors. (PHE can be contacted at the Centre for Radiation, Chemical and Environmental Hazards, Chilton, Didcot, Oxon, OX11 0RQ. It is recommended that PHE are contacted well in advance to discuss practical measures before placing any order.) Alternative methods can be used including measuring radon or its daughter products in real time using instruments. However, the instruments need to be formally calibrated so as to provide confidence in the results and need to be operated over reasonable periods of time to give a representative result. Such alternative methods will not be further considered.

10. A potential major problem with any radon monitors is storage in unsuitable conditions when not in use. (There have been a number of cases where the storage location had higher radon levels than the exposure location, thus invalidating the result.) Care must be taken with radon monitors to store them when not in use above ground level, preferably on the first floor in a building and in a secure dry and well ventilated location such as the boot of a car. Alternatively, reassurance that the chosen storage location is acceptable can be obtained by getting a supplementary monitor and leaving it in the storage location whilst the other monitors are deployed. Radon monitor should be promptly returned to PHE at the end of the exposure period in the supplied packaging.

11. Area monitoring radon detectors should be deployed for the period of time specified by PHE, usually 28 days. Deployed radon detectors must not be placed in or under protective containers; it is important that there is a free exchange of air around the monitor. However, detectors may be laid on a 'plate' so as to protect them from a muddy or wet floor or have a roof to keep drips off the monitor. (It is essential that there are no 'walls' else the detectors could see a reduced level of radon, thus potentially biasing the measurements.)

12. The work of Hyland (7) suggests that it is unlikely that the persons will receive a significant dose in deploying and retrieving the area monitoring radon detectors. The peak concentration cited in Table 1.1 is 49,000 Bqm^{-3}. Estimating a trip to deploy or retrieve detectors will take 5 hours indicates an overall exposure of some 490,000 $hBqm^{-3}$. Using the dose conversion factor of 3.97×10^{-6} mSv / $hBqm^{-3}$ cited in Annex A, the extreme exposure would be under 2 mSv. But this assumes the concentration of radon is constant throughout the cave or mine, contrary to all experience. Based upon mean data in Table 1.1, the possible exposure is likely to be well under 1 mSv. It also argued that personal dosimeters are not effective in recording exposure in fluctuating radon levels as is seen in caves and mines, see paragraph B9 in Annex B.

E.3 Processing Results

13. On receipt of the results from the area monitoring radon detectors, a table should be drawn up with columns of location, time, details of the detector and concentration value in Bqm-3 for each radon monitors, see Table E.1 for an example. (It is emphasised that all data must be input into the table, even if some locations had results of less than 300 Bqm-3.)

Table E.1 Cave/mine exposure table

Cave/Mine 'xyz' Trip 'pqr'					
Date placed			Date Removed		
Location	Time minutes	Radon Detector's Unique Ref. No.	Measured Radon Concentration Bqm^{-3}	Average Concentration Bqm^{-3}	Exposure minute * Bqm^{-3}
Entrance					
moving	a			(0 + x)/2	(0 + x)/2 * a
site of 1st monitor	b		x		x * b
moving	c			(x + y)/2	(x + y)/2 * c
'stop point'	d			(x + y)/2	(x + y)/2 * d
moving	e			(x + y)/2	(x + y)/2 * e
site of 2nd monitor	f		y	y	y * f
moving	g			(y + z)/2	(y + z)/2 * g
site of 3rd monitor	h		z		z * h
moving	j		z		z * j
site of 3rd monitor	k		z		z * k
moving	g			(y + z)/2	(y + z)/2 * g
site of 2nd monitor	l		y		y * l
moving	m			(x + y)/2	(x + y)/2 * m
site of 1st monitor	n		x		x * n
moving	a			(0 + x)/2	(0 + x)/2 * a
Entrance					
Sum		–	–	–	
Sum of Exposure ($hBqm^{-3}$)					

14. Table E.1 reflects a hypothetical 'there and back again' trip. Moving normally includes all the time taken in transit between the two locations (or location and location) including pauses due to overcoming obstacles and such like. In this example however, a pause at a stop point is built in to cover a discrete stop made for a reason specified in the record of the trip described in paragraph E3 above. But on the way out, no such pause is made so the movement between locations is reflected as a single row in the table. The table also assumes there is some passage beyond location 3 which is traversed.

15. In completing the Cave/Mine Exposure Table, the name of the cave plus the date when the detectors were placed and the date when they were removed should be

included in the table so as to ensure the data is complete. (It would be of value to also include the date and reference details of the letter providing results so as to facilitate detailed follow up enquiries if they should be needed.) The column of locations should mimic the route for the trip as detailed in paragraph 3 above in the Trip Plan. If several routes within the cave or mine are available, then the table should be repeated to reflect each possible trip for each different Trip Plan. The fifth column should then contain the average of the two monitoring results. A final column should then be completed with the product of concentration and time, having units of minuteBqm-3. This column should then be added up to produce the total exposure in units of minuteBqm-3 for the trip. Then in the bottom row the exposure should be presented in units of hBqm-3 by dividing the minuteBqm-3 value by 60.

16. Table E.1 must repeated to cover each additional data set obtained during the subsequent quarterly periods.

E.4 Assessment of Exposure

17. The resultant value of exposure per trip should then be entered into a suggested Table E.2 under the appropriate month. Where sampling covered two months, then the data should be assigned to the month which had the most days of exposure.

Table E.2 Caver annual exposure

Cave 'xyz' Trip 'pqr'												
	Summer			Autumn			Winter			Spring		
Month	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May
$hBqm^{-3}$ / trip												
mSv / trip												
No. trips												
Total dose mSv / month												

The transformation of the $hBqm^{-3}$ exposure into units of mSv has a complex background which is covered in Annex A. In simple terms one just multiplies the $hBqm^{-3}$ value by the relevant parameter of 3.97×10^{-6} mSv / $hBqm^{-3}$ from Annex A to produce an estimated dose in mSv for a single trip over a specified period of time using the Table E.2 to provide an estimate of the exposure from carrying out one trip according the Trip Plan.

18. With only one month's data, the approach is to use that value as an estimate for all the other months. Normally the first batch of data will be collected in the Summer quarter, then followed by a batch in Autumn, Winter and Spring. When a second and subsequent batches of data has been collected, then the underlying principles for completing Table E.2 are as follows:

    - If Summer, Autumn (or Spring) and Winter quarter data are available, then allocate Summer data to the 3 months of the Summer quarter, allocate the

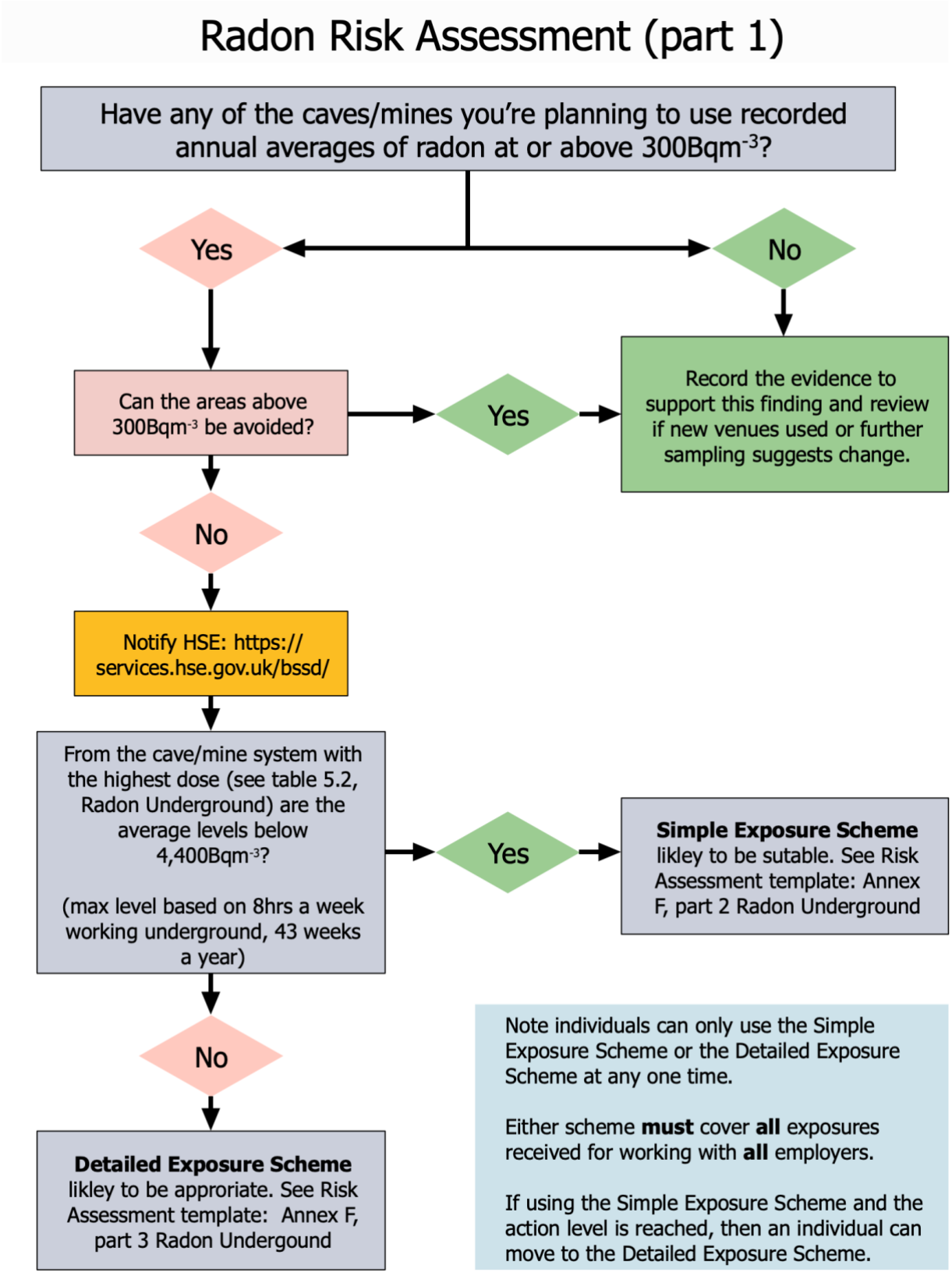
Winter data to the 3 months of the Winter quarter and the Autumn (or Spring) data to the other quarters.

- If only Summer and Winter quarter data is available, then allocate Summer data to the 3 months of the Summer quarter, allocate Winter data to the 3 months of the Winter quarter and the average of the Summer and Winter data to the Autumn and Spring Quarters.
- If data is collected in a different sequence, then Table E2 should be completed using the underlying principles of spreading autumn or spring data into summer or winter as needed.

19. The number of trips in each month over a one year period that any one person at work might take should be estimated and recorded in a Table E2. Using the estimated number of trips per year, one can then estimate the annual dose from using the specific cave or mine by multiplying the estimated dose per trip by the estimated number of trips. Table E2 may be expanded to include further sets of rows to reflect the different trips being undertaken by a person.

Annex F: Risk Assessment and Guidance Notes

Part 1 Radon Risk Assessment



Part 2 Risk Assessment Consideration with regard to HSE's ACoP for the Simple Exposure Scheme

The following Risk Assessment template is based on the applicable guidelines outlined in HSE's Work with ionising radiation Approved Code of Practice (3) paragraphs 70 and 71. The following notes should provide a firm basis to an employer or self-employed person in drawing up their own Radon Risk Assessment. Note, a number of items have been omitted from the list below on the grounds that they are not relevant to the radon radiation hazard. These considerations are drawn up on the basis that the Simple Exposure Scheme (and not the Detailed Exposure Scheme) is being employed.

Table F.2 Risk Assessment for Simple Exposure Scheme

Paragraph 70 ACoP: *"Where an employer is required to carry out a radiation risk assessment, the following matters need to be considered, where they are relevant"*	
ACoP Guideline	**Comment**
(a) the nature of the sources of ionising radiation to be used, or likely to be present, including accumulation of radon in the working environment;	The only source of radiation present is naturally occurring radon.
(b) estimated radiation dose rates to which anyone can be exposed;	The estimate is based on the calculations performed in subsection 5.5 of this document and should be presented as part of the risk assessment, see Table F.3 below. Through following the Simple Exposure Scheme dose will not exceed 6 mSv.
(d) the results of any previous personal dosimetry or area monitoring relevant to the proposed work;	Monitoring results are listed in Table 5.2 of this document.
(g) any planned systems of work;	Control on exposure is achieved by controlling time exposed.
(k) possible accident situations, their likelihood and potential severity;	Accidents or incidents underground may result in longer than anticipated time spent exposed to radon on one trip. Exposure over a single trip is small.

Table F.3 Measures adopted by Employer / Self Employed person to minimise risk from radon

Paragraph 71 ACoP: *"This radon risk assessment will help the employer decide:"*	
ACoP Guideline	**Actions by the employer, self-employed person, Radiological Protection Supervisor and employee(s)**
(a) the action needed to make sure the radiation exposure of all people is kept as low as reasonably practicable (regulation 9(1));	Through considering radon levels and potential exposure to radon in the process of selecting an appropriate venue for the activity, and where possible selecting venues with low levels of radon in accord with those listed under the Simple Exposure Scheme by the employer or self-employed person. In addition, the employee(s) maintain a log record of hours spent underground.
(b) the steps necessary to achieve this control of exposure … develop systems of work (regulation 9(2)(b));	The log record is the basis of the system of work supervised by the Radiation Protection Supervisor (RPS) and monitored by the employer or self-employed person.
(d) whether it is appropriate to establish any dose constraints for planning or design purposes and if so, what values will be used (regulation 9(4));	An Action Level of 760,000 $hBqm^{-3}$ (3 mSv) where the choice of caves and mines must be reviewed or deciding to change to the Detailed Exposure Scheme and an Investigation Level of 1,100,000 $hBqm^{-3}$ (4.5 mSv) when the employer or self-employed person should consult with a Radiological Protection Advisor (RPA).
(e) the need to alter the working conditions of any employee who declares they are pregnant or breastfeeding (regulation 9(6));	Guidance by the HSE[1] notes that because radon is a gas "the exposure to a baby in the womb is very small"
(f) an appropriate Investigation Level to check that exposures are being restricted as far as reasonably practicable (regulation 9(8));	The RPS will conduct a review of the caves and mines used if an employee exceeds the Action Level noted in the Form F.4 beneath with the view to amending the choice of caves and mines to lower exposure or adopt the Detailed Exposure Scheme. The employer or self-employed person will conduct an investigation if the Investigation Level is reached and cease the employee's further exposure until a consultation with an RPA has taken place.

[1] https://www.hse.gov.uk/pubns/indg334.pdf as at 27/1/2024

(i) the training needs of … non-classified employees (regulation 15);	See Annex H.
(o) the responsibilities of managers and workers (including outside workers) for ensuring compliance with these regulations;	The RPS should regularly supervise the employee's log record of exposure times including checking for accuracy and, if needed, implement a review at the Action Level. Records evidencing these checks should be kept. The employer must cease exposing the employee to radon if the Investigation Level is reached until a consultation with an RPA has taken place to decide on other options.
(p) an appropriate programme of monitoring or auditing of arrangements to check the requirements of these regulations are being met.	The employer or self-employed person should undertake monitoring of employee's logs and venue choices as outlined in the notes below.

F.4 Form for the Simple Exposure Scheme site list

Employer's Name		Date produced	
Radon Protection Supervisor (RPS) Name		RPS Contact details	

Cave/Mine	**Highest average Radon Measurement Bqm^{-3}**	**Hours to Action Level (3mSv)**	**Hours to Investigation Level (4.5mSv)**	**Justification for use & considerations (Risk/Benefit)**

See Annex C for method of filling in. If need be add more rows to cover all locations intended to be used by employees.

Employee's Duties

The employee shall keep the log record up to date.

F.5 Form for the Simple Exposure Scheme Employee Log Record

Employee Name:		Calendar Year:	
Action Level Hours (hours to 3mSv)		Investigation Level Hours (hours to 4.5mSv)	

This record is for the employee to complete after each trip and ensure is kept up to date

Date	Venue	Hours Underground	Hours left to Investigation Level		Date	Venue	Hours Underground	Hours left to Investigation Level

Extend as needed.

Radiation Protection Supervisor Duties

1. The Radiation Protection Supervisor (RPS) shall check Maximum Hours per Year is correct and that the list is amended if needed to include possible other locations where the employee might be exposed to Radon when working for other employers.
2. The RPS shall check that locations logged are all on the Site List.
3. The RPS shall check from time to time that the hours logged for a given trip are a true record.
4. The RPS shall confirm from time to time that employee's exposure for other employers are also included in the log.
5. If the Action Level is reached, the RPS shall review with the employee as to which locations with lower radon levels can be used with modified objectives or whether the employee shall adopt the Detailed Exposure Scheme and incorporate existing exposures into it. Record result of the review and nature of outcome and inform the employer or self-employed person.
6. If the Investigation Level is reached, the RPS shall notify the employer of the need to either suspend the employee from exposure to radon or to consult with an RPA.

Employer's or Self Employed Person's Duties

1. The employer or self-employed person should satisfy themselves that the environmental sampling conducted to compile the calculations in table F.4 are reflective of the planned trips.
2. The employer or self-employed person shall ensure that employees are trained in the hazard of radon and are competent in respect of the radon hazard to lead parties underground.
3. The employer or self-employed person shall supervise the RPS in undertaking their duties.
4. The employer or self-employed person shall check the adequacy of the review if an employee has reached the Action Level.
5. If an employee reaches the Investigation Level, then the employer or self-employed person must either suspend the employee from leading trips for the rest of the year or along with the employee, consult with a Radiological Protection Advisor on the employee's further exposure to radon.
6. The employer or self-employed person shall monitor the implementation of the procedures adopted to provide for compliance with the IRRs and the employee's logs and venue choices.

Part 3 Risk Assessment Consideration with regard to HSE's ACoP for the Detailed Exposure Scheme

The following Risk Assessment template is based on the applicable guidelines outlined in HSE's Working with ionising radiation Approved Code of Practice (3) paragraphs 70 and 71. The following notes should provide a firm basis to an employer or self-employed person in drawing up their own Radon Risk Assessment. Note, a number of items have been omitted from the list below on the grounds that they are not relevant to the radon radiation hazard. These considerations are drawn up on the basis that the Detailed Exposure Scheme is being employed.

Table F.6 Risk Assessment for Detailed Exposure Scheme

Paragraph 70 ACoP: *"Where an employer is required to carry out a radiation risk assessment, the following matters need to be considered, where they are relevant"*	
ACoP Guideline	**Comment**
(a) the nature of the sources of ionising radiation to be used, or likely to be present, including accumulation of radon in the working environment;	The only source of radiation present is radon.
(b) estimated radiation dose rates to which anyone can be exposed;	The estimate is based on the Detailed Exposure Scheme spreadsheet or equivalent document.
(d) the results of any previous personal dosimetry or area monitoring relevant to the proposed work;	Results are provided in the Detailed Exposure Scheme spreadsheet or equivalent document.
(g) any planned systems of work;	Control on exposure is achieved by closely controlling time exposed on each trip as per the Trip Plan.
(k) possible accident situations, their likelihood and potential severity;	Accidents or incidents underground may result in longer than anticipated time spent exposed to radon on one trip. Exposure over a single trip is small.

Table F.7 Measures adopted by Employer / Self Employed person to minimise risk from radon

Paragraph 71 ACoP: *"This radon risk assessment will help the employer decide:"*	
ACoP Guideline	**Actions by the employer, self-employed person, Radiological Protection Supervisor and employee(s)**
(a) the action needed to make sure the radiation exposure of all people is kept as low as reasonably practicable (regulation 9(1));	The Trip Plan provides a justification of the trip and the incurred exposure.
(b) the steps necessary to achieve this control of exposure by systems of work (regulation 9(2)(b));	The main control is adherence to the Trip Plan through the application of the Detailed Exposure Scheme spread sheet document via the implementation of the Local Rules. Deviations of more than 30 minutes from planned times should be recorded by the employee. These controls are supervised by the Radiation Protection Supervisor (RPS) and monitored by the employer or self-employed person.
(d) whether it is appropriate to establish any dose constraints for planning or design purposes and if so, what values will be used (regulation 9(4));	An Action Level of 3 mSv where the choice of caves and mines must be reviewed and an Investigation Level of 4.5 mSv when the employer or self-employed person should consult with a Radiological Protection Advisor (RPA).
(e) the need to alter the working conditions of any employee who declares they are pregnant or breastfeeding (regulation 9(6));	Guidance by the HSE[1] notes that because radon is a gas "the exposure to a baby in the womb is very small"
(f) an appropriate Investigation Level to check that exposures are being restricted as far as reasonably practicable (regulation 9(8));	The RPS will conduct a review of the caves and mines used if an employee exceeds the Action Level noted in the Form F.4 beneath with the view to amending the choice of caves and mines to lower exposure or adopt the Detailed Exposure Scheme. The employer or self-employed person will conduct an investigation if the Investigation Level is reached and cease the employee's further exposure until a consultation with an RPA has taken place.

[1] https://www.hse.gov.uk/pubns/indg334.pdf as at 27/1/2024

(i) the training needs of classified and non-classified employees (regulation 15);	See Annex H.
(j) the need to designate specific areas as controlled or supervised areas and to specify local rules (regulations 17 and 18);	See below.
(k) the actions needed to make sure access is restricted and other specific measures are put in place in controlled or supervised areas (regulation 19);	The employer or self-employed person does not have control over access since they will almost certainly not own the cave(s) or mine(s).
(o) the responsibilities of managers and workers (including outside workers) for ensuring compliance with these regulations;	The RPS should regularly supervise the employee's Detailed Exposure Scheme spread sheet including checking for accuracy. If there is a significant deviation (more than 30 minutes) from the estimated trip time, then the estimated exposure for the trip should be adjusted. The RPS must implement a review at the Action Level. Records evidencing these checks and review should be kept. The employer must cease exposing the employee to radon if the Investigation Level is reached until a consultation with an RPA has taken place to decide on other options.
(p) an appropriate programme of monitoring or auditing of arrangements to check the requirements of these regulations are being met.	The employer or self-employed person should undertake monitoring of employee's logs and venue choices as outlined in the notes below.

Note: references in the tables above and to the Detailed Exposure Scheme spread sheet below include not only the QMC version but also those produced by employers or self-employed persons.

Local Rules

The Local Rules are:

A) The Trip Plan(s) including the name of the cave(s) or mine(s) plus a reference to where they may be studied;
B) The name of the Radiation Protection Supervisor (and if need be, details of how to contact that person);
C) The employee or self-employed person must keep an up to date log of their cave and mine trips, together with a record of the time spent underground and estimated dose in mSv from that exposure;

D) If the total estimated exposure exceeds 3mSv Action Level, then the employer must direct the employee (or self-employed person take upon themself) to undertake trips in caves and mines of much lower potential exposure levels;
E) If the total estimated exposure exceeds the 4.5 mSv Investigation Level, then the employee (or self-employed person) must either be suspended (or suspend themself) from leading trips or shall be party to the employer's consultation with a Radiological Protection Advisor on further exposure to radon.

Employee's Duties

1. The employee shall demonstrate their understanding of every Trip Plan they are required to carry out. That includes demonstrating that they know their way around the caves and mines.
2. The employee must provide their employer with a complete list of all other caves and mines that they may descend whilst in the employment of other persons and the exposure thereby incurred.
3. The employee must keep an up to date log of their cave and mine trips, together with a record of the time spent underground. They shall also keep an estimated dose in mSv from their exposure using the Detailed Exposure Scheme spread sheet. (Local Rule C)

Radiation Protection Supervisor Duties

1. The Radiation Protection Supervisor (RPS) shall check that the Detailed Exposure Scheme spread sheet covers all other caves/mines in which compliance with IRR17 are necessary including sited which may be working for other employers.
2. The RPS shall observe all hours logged by the employee and adjust the exposure estimate if there is a significant deviation (more than 30 minutes) from the estimated trip time. The RPS shall check from time to time that the hours logged for a given trip are a true record.
3. The RPS shall confirm from time to time that employee's exposure for other employers are also included in the Detailed Exposure Scheme spread sheet.
4. If the Action Level is reached, the RPS shall review with the employee as to which locations with lower radon levels within the Detailed Exposure Scheme spread sheet can be used with modified objectives. Record result of the review and nature of outcome and inform the employer or self-employed person. (Local Rule D)
5. If the Investigation Level is reached, the RPS shall notify the employer of the need to either suspend the employee from exposure to radon or to consult with an RPA. (Local Rule E)

Employer's or Self Employed Person's Duties

1. The employer or self-employed person shall make available the Trip Plan(s) including the name of the cave(s) or mine(s) to all employees and manage the process by which every employee demonstrates their competence in implementing every Trip Plan they are instructed to carry out. (Local Rule A)
2. The employer or self-employed person shall provide the name of the Radiation Protection Supervisor and if need be, a means to enable an employee to contact that person. (Local Rule B)
3. The employer or self-employed person shall provide a Detailed Exposure Scheme spread sheet for each and every employee. That document must include every cave or mine the employee intends to descend whilst in the employment of other persons.
4. The employer or self-employed person shall ensure that employees are trained in the hazard of radon and are competent in respect of the radon hazard to lead parties underground.
5. The employer or self-employed person shall check the adequacy of the review if an employee has reached the Action Level.
6. If an employee reaches the Investigation Level, then the employer or self-employed person must either suspend the employee from leading trips for the rest of the year or along with the employee, consult with a Radiological Protection Advisor on the employee's further exposure to radon. (Local Rule E)
7. The employer or self-employed person shall supervise the RPS in undertaking their duties.
8. The employer or self-employed person shall monitor the implementation of the procedures adopted to provide for compliance with the IRRs and the employee's logs and venue choices.

Annex G Statement on Risks from Radon

1. The following is offered as a basis for informing persons of the risk from radon they are about to be exposed to in undertaking the trip into the cave or mine.

   Radon is a radioactive gas, you can't see, smell or taste it: you need special equipment to detect it. It comes from the rocks and soil found everywhere in the UK. The radon level in the air you breathe outside is very low but can be higher inside buildings[1] and also caves / mines.

   Radon increases your risk of lung cancer.[2]

   Generally, there is unlikely to be a health risk to members of the public who make brief visits underground.[3]

2. If it considered appropriate, then a comparison could be made of the estimated exposure from the trip. Given the estimated value of hBqm^{-3} for the trip, then a comparison with exposure within a home could be made on the basis that HPA (15) state that the typical house contains around 20 Bqm^{-3}. Dividing the trip value by 20 would give the number of hours one would have to sit in one's house in order to get the same exposure. So for a typical trip into a radon concentration of 3000 Bqm^{-3} lasting 4 hours giving an exposure of 12,000 hBqm^{-3}, that would be equivalent to being exposed in a typical house for

   12,000 / 20 = 600 hours = 25 days.

Or to put it another way, the 4 hour trip underground will give someone a dose of radiation similar to that received by stopping in one's house for 25 days. The comparison should be modified to reflect the estimated exposure for the specific trip.

3. An alternative comparison is based on risk of death. Section 2.2 noted that the risk of death from a typical trip into a radon concentration of 3000 Bqm-3 lasting 4 hours was 1 in 200,000. The Office for National Statistics (38) cites the risk of being murdered as approximately 1 in 100,000. A study of youths participating in soccer by Malhotra et al. (39) found that the incidence of sudden cardiac death was 1 per 15,000 athletes.

4. More detailed comparisons are provided in section 2.2.

[1] Text taken from https://www.ukradon.org/information/whatisradon as at 27/1/2024.
[2] Text taken from https://www.ukradon.org/information/risks as at 27/1/2024.
[3] Text taken from AGIR Section 2.5 page 18, reference 20.

Annex H: Training Programme on Radon for Employees

Both employees and Radiation Protection Supervisors are required by IRR17 to be trained before starting work. The following offers a comprehensive list of topics and links to supporting detail which is considered to meet that requirements.

The types of radiation – see Public Health England's "Basic Concepts of Radiation"[1].

The impact of radiation – see Public Health England's "Ionising Radiation and you"[2]

The risks from radiation – see section 2.

Protection from radon – see paragraph 9 in Annex B.

Supervised Areas – see discussion on Regulation 17 in section 5.11

Compliance with Local Rules – see the Employer's Local Rules, as well as section 5.12 and referenced surveys and other papers. The employee should demonstrate that they know each trip route that they are required to led parties on.

Pregnant Women – see HSE's "Guidelines for expectant or breastfeeding mothers"[3] and in particular page 2.

Briefing parties you lead underground – see Annex G.

Additional material for a Radiation Protection Supervisor – see section 5.13.

Employees may wish to consider obtaining more information on the exposure to radon in their own home by consulting UK Radon's guide to radon[4].

[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/467205/Basic_concepts_of_radiation_October_2015.pdf as at 27/1/2024
[2] https://www.phe-protectionservices.org.uk/radiationandyou/ as at 27/1/2024
[3] https://www.hse.gov.uk/pubns/indg334.pdf as at 27/1/2024
[4] https://www.ukradon.org/ as at 27/1/2024

Abbreviations

ACoP	Approved Code of Practice
AGIR	Advisory Group on Ionising Radiation
BCA	British Caving Association
BCRA	British Cave Research Association
BCRC	British Cave Rescue Council
$hBqm^{-3}$	hour becquerel per cubic metre
HPA	Health Protection Agency
HSE	Health and Safety Executive
HSW Act	Health and Safety at Work Act etc 1974
ICRP	International Commission on Radiological Protection
IRR	Ionising Radiations Regulation
LCMLA	Local Cave and Mine Leader Assessment Scheme
mSv	millisievert
NRPB	National Radiological Protection Board
PHE	Public Health England
QMC	BCA Qualifications Management Committee
RCE	Radiation, Chemical and Environmental Hazards
RPA	Radiological Protection Advisor
RPS	Radiological Protection Supervisor
SSSI	Site of Special Scientific Interest
Sv	sievert
WHO	World Health Organisation
WL	Working Level
WLM	Working Level Month