RADON UNDERGROUND

RADON EXPOSURE DURING UNDERGROUND TRIPS:
A SET OF GUIDELINES FOR CAVING AND MINE EXPLORATION

prepared by

the British Caving Association Radon Working Party

in consultation with

the Health Protection Agency

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THE BRITISH CAVING ASSOCIATION is the national body representing the interests of caving 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.

The National Radiological Protection Board was incorporated in the Health Protection Agency in 2005.

1. INTRODUCTION

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

Presently there is no indisputable proof that cavers' health has been adversely affected by exposure to radon and its daughters during caving activities. However, research in uranium mines and homes worldwide, together with numerous animal studies have shown that a risk clearly exists and that smoking significantly increases this risk.

It was in response to this that the then National Caving Association commissioned the preparation of the first edition of this booklet. This second edition, commissioned by the British Caving Association (BCA), is an update of the text in light of the revised IRRs (1999), changes to legislation and relevant case law, as well as subsequently published work on the impact of radon.

This booklet 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 together with guidance on meeting legal requirements.

For professionals and those in positions of responsibility, the information in these Guidelines is to be considered in conjunction with:

- the requirements of the current health and safety laws;
- the Ionising Radiations Regulations 1999: and
- the requirements of the Cave Instructor Certificate (CIC) and the Local Cave and Mine Leader Assessment (LCMLA) Schemes, both administered by the BCA.

1.1 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), is of predominant concern, and decays to isotopes of the metals lead, polonium and bismuth. These radon daughters have very 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 very 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. It is the organic matter that 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), could also be uraniferous. As this uranium naturally decays the radon gas produced can seep out through fissures, either up or down, and may collect in voids. Similarly, in mines the source of radon remains the same - any 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 efficient mixing 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 high concentrations of radon to build up in the trapped air. In active mines this problem is circumvented by forced ventilation that keeps the concentrations down below specified legal limits. This concept has been adopted successfully in many 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.

The amount of ionising radiation emitted also depends upon the extent to which radon is in equilibrium with the decay of its daughters, described by a parameter known as the equilibrium factor. 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, described by a parameter known as the unattached fraction. 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 equilibrium factor and the unattached fraction 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 the 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.

Field (2007) 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.

1.2 MEASUREMENT OF RADIOLOGICAL IMPACT

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. A useful review of methods to measure radon in air has been compiled by the World Health Organisation (2009).

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 (Bq), a Becquerel being the disintegration of one atom in one second. More conveniently, activity concentrations per cubic metre (Bq m^{-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 below.

Table 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 (1995), b) Friend & Gooding (2001), c) Taylor (pers. Comm. 2011), d) Friend (2008), e) Friend (2010) and f) Langridge et al. (2011).

Radon Concentration Bq m^{-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, for which measuring instruments have been developed. However, because of the complexity of the behaviour of radon and its daughter products, there is no simple relationship between Bq m^{-3} and Working Level. The Working Level is not further considered in this booklet.

The potential impact of exposure to radiation is measured in terms of time-integrated exposures or "dose". The dose of radiation received by a person is thus related to the concentration of radon and daughters and the length of time the air is breathed, i.e. Bq m^{-3}h.

Dose is measured in Sieverts (Sv), but because this is large, the unit more normally used is the milli-Sievert (mSv). The IRRs (1999) revised downwards the dose limits beyond which it is illegal to expose a person in a working situation. These values are 20 mSv for an employee and 1 mSv for any other person. It is emphasised that because of the nature of radon, the IRRs (1999) specifically stated that the regulations apply to “any work [...] carried out in an atmosphere containing radon” so as to ensure that exposure to radon is covered by the regulations (Regulation 3.1.b).

Because of the ubiquitous nature of radon, Kendall and Dixon (1997) of the Health Protection Agency (HPA) have issued advice on limits for exposure in non-work situations. This includes the advice that recreational cavers should limit their annual exposure to below 1,000,000 Bq m^{-3} h. 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.

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 HPA (2010) have promulgated advice that a new "Target Level" be introduced and set at a factor of two beneath the retained Action Level.

The problem of calculating dose from radon concentrations is exacerbated as equilibrium factor and unattached fractions need to be considered. Kendal & Dixon (1997) of the HPA have advised BCA to calculate dose from concentration using the formula:

$$\text{Dose (mSv)} = \frac{(\text{Concentration Bq m}^{-3}) \text{ x duration in hours}}{254000}$$

which includes an allowance for the equilibrium constant. This relationship means that existing HPA advice is equivalent to limiting annual exposure to under 4 mSv.

1.3 HEALTH RISKS ASSOCIATED WITH RADON EXPOSURE

Vanmarcke (2008) has reviewed the health risks from radon as derived from a range of sources. He notes there is a range of values relating exposure in terms of Bq m^{-3} to risk of death arising from different origins, mostly from uranium miners. He cites a range of dose conversion factors of between 6 and 11 (nSv h^{-1}) / (Bq m^{-3}). These are based on radon in equilibrium with its daughter products and hence an equilibrium factor of 1.0. In addition, he cites a computer-based model calculation which resulted in a dose conversion factor of 23 (nSv h^{-1}) / (Bq m^{-3}) for radon at equilibrium with its daughter products. Field (2007) reports a similar value using another computer-based model.

It is worth recalling that the impact of the equilibrium factor is to pro-rata reduce the dose for a given concentration of radon. Thus the HPA advisory limit for cavers is based on an equilibrium factor of 0.5, as is the dose conversion factor. Hence the equivalent HPA-advised dose conversion factor for an equilibrium factor of 1 is 8 (nSv h^{-1}) / (Bq m^{-3}), a value which fits within the range reported by Vanmarcke (2008).

The International Commission on Radiological Protection (ICRP) (1993) recommended a value of 0.4 for the equilibrium factor in the absence of direct measurements. Hyland & Gunn (1994) have suggested using a value of 0.5 for radon in caves, although Field (2007) comments that "a strong basis for this contention has not been reported". Cigna (2005) reports some 1,000 equilibrium factors measured in caves across the world ranging between 0.2 and 1.9 with an average value of 0.6. Kendall & Dixon (1997) recommend using a value of 0.5 in the absence of direct measurements.

ICRP (1993) note that dosimetric models lead to the conclusion that the bronchial dose per unit of exposure increases as the fraction of the radon progeny attached to condensation nuclei decreases. This is due to several factors, one of which is that unattached radon-daughter products affect different parts of the lung compared to attached radon-daughter products. Until the past few years, the impact of the unattached fraction has largely been ignored, mainly due to the fact that the dose conversion factor in use is founded principally on observations of the actual exposure of miners, dosimetric models being used as reassurance. But at least one recent paper, Vaupotic & Kobal (2004), suggests that this assumption may be inappropriate within a cave, having identified potential enhancements of the dose due to an increased unattached fraction by a factor of three. But given the variation in dose conversion factor already described, the impact of the variation of the unattached fraction is usually ignored.

There is some evidence to suggest that exposure to higher levels of radon, as found in mines, gives rise to different risk levels. Darby et al. (2005) published an analysis of a number of studies into the relationship between radon in homes and the incidence of lung cancer. They compared their estimate with a number of estimates arising from more detailed analysis of the miners' data, including work focusing on data involving lower exposure levels by miners. They report that the miners' estimates "are higher than, but compatible with, the present estimate" derived from their work. This provides an indication of the continued range of uncertainty in the health impact of radon.

The most recent ICRP (2007) recommended relationship between detriment (being both death and hereditary effects) and dose gives an estimated risk of death of 5.7 % per Sv. This represents a small reduction on the previous ICRP (1991) figure of 7.3 % per Sv. Using the dose conversion factor recommended by the HPA and a detriment dose relation factor of 5.7 % per Sv, gives a detriment value of about 2×10^{-10} per Bq h m^{-3}. Given the range of dose conversion factors, roughly a factor of two, it is not felt appropriate to cite the detriment value with any greater precision.

Darby et al. (2006) also published an analysis of the impact of smoking on the relationship between radon in homes and incidence of lung cancer. 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 beneath:

Table 2: Absolute Risk of Lung Cancer with increasing Radon in home level and Smoking status

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

There are two 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.

1.4 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. Some of these 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.

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. However, at present, BCA is not aware of any information to suggest that there is a high death rate from lung cancer among elderly or retired cavers.

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 Bq m^{-3} (see Table 1) and using the risk relationship computed above of 2 x 10^{-10} per Bq h m^{-3}, gives an increased risk of lung cancer from one trip of about 1 in 370,000.

In comparison, it is possible to make an order-of-magnitude estimate of the actual risk from caving. BCA (2009) reported to the AGM state that its active caving membership for 2008 was 4,423. 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 annual report of the British Cave Rescue Council (2009), states that between 1983 and 2007 the total number of underground incidents was 992, including 50 fatalities, 7 of whom 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 1.6 deaths per year over the last 25 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 30,000.

To place these figures in a broader context, the HPA (2010) cite the average concentration of radon in the air in UK homes at about 20 Bq m^{-3}, with a range of 5 to 10,000 Bq m^{-3} and higher. The Advisory Group on Ionising Radiation (AGIR) (2009) states that at the average national long-term residential radon concentration of 21 Bq m^{-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 as limited as possible but, as with anything, there is a risk. BCA recommend that, wherever possible, individuals should:

- attempt to find out as much as possible regarding likely exposure to radiation from radon on each trip undertaken;
- use known values to make rough calculations of the potential cumulative dose during a year;
- attempt to keep exposure within HPA-recommended values.

2. 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.

2.1 BRITISH CAVING ASSOCIATION

The 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. 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.

2.2 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 document 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.

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

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

3. Show Cave and Show Mine - that part of a cave or mine which is maintained as a business to high safety standards 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.

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

2.3 USERS ENGAGED IN UNDERGROUND ACTIVITIES

Three broad groups of people may be engaged in underground activities. It should be noted that an individual 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.

1. Recreational Users

i) Cavers and Mine Explorers - persons who explore underground voids as a pastime, usually 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.

2. Professional Persons

i) Professional Instructors or Leaders - persons such as holders of the BCA Cave Instructor Certificate or Local Cave and Mine Leader Award 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 document.

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 appointed by their employer, they are excluded from this document.

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 document as they have well-understood legal obligations.

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 document.

2.4 Owners of Underground Voids and Land

Owners may be individuals, incorporated and unincorporated bodies, lessees, licensees or other associations within this definition. There are two distinct types of owners. 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:

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).

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. 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).

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).

5. Mine Managers – these are appointed under The Management and Administration of Safety and Health at Mines Regulations (1993). Mine Managers are specifically excluded from this document as they have well-understood legal obligations.

3. 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. BCA understands that Health and Safety Executive policy is that health and safety legislation should not be used to cut across the freedom of individuals who voluntarily take risks outside their working environment. 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.

3.1 DUTY OF CARE

In England and Wales the Occupiers' Liability Acts (1957) and (1984) 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 (1960) - and in Northern Ireland - the Occupiers' Liability Act (Northern Ireland) (1957) and the Occupiers' Liability (Northern Ireland) Order (1987). 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 visitor, might not reasonably be expected to foresee.

Over recent years case law that has been pursued as far as the Law Lords (now known 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 not likely 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."* But today these are largely irrelevant and carry little or no legal effect.

3.2 THE WORK SITUATION

The Health & Safety at Work etc. (HSW) Act (1974) 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). The HSW Act applies in any place made available or used as a place of work and hence can include underground voids. The IRRs (1999) were created under the HSW Act and lay down criteria for protecting employees and other persons against ionising radiation arising from or affecting any work activity (see Annex A). A key feature of the IRRs is that they apply to any work activity undertaken in an atmosphere containing radon above a threshold value of 400 Bq m^{-3}. As underground voids have been shown to contain radon above this threshold (Table 1), the IRRs apply to the activities of professional cavers, their employers, members of parties they instruct or lead underground, and any other persons who may be affected by these activities.

Any person controlling access to an underground void in connection with a trade, business or other work undertaking there has a duty (Section 4) 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.

Persons employing professional instructors or leaders and/or in charge of activity centres etc. have a duty to take account of such risks to health and safety from exposure to radon. Consequently, they may also be deemed to control access to a void because they have the authority to regulate, restrict or deny entry to underground voids for their employees and their instructed parties and because they are more likely to have relevant information with which to make a decision as to whether a void will be entered. Such persons will therefore also be required to comply with the requirements of the HSW Act and thus the IRRs.

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 the IRRs in reducing risks, especially exposure to radon, 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, neither the HSW Act nor the IRRs will apply. However, this does not remove the usual duty of care regarding foreseeable injury to an unsuspecting party.

3.3 ABANDONED MINES

The Mines and Quarries Act (1954) 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. 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.

4. GUIDELINES FOR 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.

They are in addition to the normal codes of practice for conducting parties underground prepared by BCA through its various Standing Committees and also provide a framework to which the Cave Instructor Certificate and Local Cave and Mine Leadership Assessment Scheme can refer.

These Guidelines do not apply to underground voids where radon concentrations are abnormally high, such as certain metalliferous mines. In such places where only respiratory protection 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. Kendal & Dixon (1997) of the HPA have proposed for recreational caving a time-integrated dose limit of 10^6 Bq m^{-3} h per year.

4.1 RECREATIONAL USERS

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 carrying a dosemeter. 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.

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. 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 above).

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. 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.

4.2 PROFESSIONAL USERS

1. Employers
Employers are required to comply with the HSW Act and the IRRs (see Annex A). Annex B outlines a monitoring scheme based on one developed by an Education Authority in responding to the duties laid upon it.

2. Professional Instructors or Leaders
Professional instructors or leaders have legal duties under the IRRs. In the first instance they should either, if self-employed, consult a suitable Radiation Protection Advisor (RPA), or if employed, be briefed by the RPA or Radiological Protection Supervisor appointed by their employer. Annex B outlines a monitoring scheme based on one developed by one Education Authority in responding to the duties laid upon it. In addition, professional instructors or leaders should comply with any conditions for entry to the underground void that the Land or Void Owner consider necessary to protect his/her legal interest, including any duties under Section 4 of the HSW Act.

3. Research Scientists
The work of research scientists is potentially so variable that it is not practical to give specific guidance, other than that the advice of an RPA will be needed. Comments on the HSW Act will apply according to whether you are an employee or self-employed.
In addition, research scientists should also comply with any conditions for entry to the underground void that the Land or Void Owner considers necessary to protect his/her legal interest, including any duties under Section 4 of the HSW Act.

4.3 OWNERS

1. Private Void Owners
Private void owners have no duties under either the HaSW 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.

2. Private Land Owners
Private land owners have no duties under either the HaSW 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.

3. Business Void Owners
Most business void owners are Show Cave or Mine owners. They have duties under both the HaSW 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. They should have already appointed an RPA (see Annex A). 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.

4. Business Land Owners

Although they have duties under Section 4 of the HaSW 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.

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ANNEX A - SUMMARY OF DUTIES UNDER THE IONISING RADIATIONS REGULATIONS

The IRRs (1999) place a number of duties upon employers and the self-employed in respect of ionising radiation. As underground voids have been shown to contain radon, the regulations will almost certainly apply to the activities of professional cavers and their employers. Employers must be familiar with their duties under the IRRs. In particular they should:

- 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;
- 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 to ensure that Local Rules are followed;
- consider whether voids under their control should be designated as Controlled Areas;
- assess whether any staff should be Classified Workers and make suitable arrangements for any who are (e.g. personal dosemeters from an approved dosimetry service);
- keep records of staff exposures required by the IRRs (Annex B gives an example of a monitoring scheme devised by an Education Authority);
- 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. 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.

The identification of a suitable RPA would best be achieved by identifying those who have already been consulted within the region. The RPA will be able to advise on an approved dosimetry service. The foremost body for such matters is the Health Protection Agency.

Choosing suitable voids for led parties involves a number of considerations, such as matching the degree of difficulty to the experience of the party. Knowledge of radon concentrations is one such consideration. However, there may be occasions when a void with higher than average radon concentrations has particular features that would otherwise make it the best option for a particular party or activity. In this case the estimated risk from radon exposure should be taken into account in the overall risk assessment for the activity. In all instances of rationalisation of the number of sites used, the suitability and availability of the site must be given due consideration. This will include conservation and access matters because more often low-radon sites are used, the greater the environmental impact on that site. Increased use of particular sites could also lead to problems with landowners over access.

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.

Employers, activity centre heads etc. should consider the overall package of measures they may need to reduce individual exposures. This might include using primarily "low-radon" caves and rotating professional instructors' or leaders' duties if high-radon caves are to be visited.

ANNEX B - MONITORING RADON EXPOSURE: GUIDANCE TO EMPLOYERS AND SELF-EMPLOYED INSTRUCTORS OR LEADERS

Employers and self-employed instructors or leaders are reminded that they have specific legal duties and these must be followed. A description of the work undertaken for one such scheme has been published by Langridge et al (2010). The following steps are suggested in establishing a history of radiation-dose monitoring such that a person/centre has knowledge of the radon exposure in any of the underground voids that are used. The precise monitoring regime will be dependent upon activities and will be established in consultation with a Radiological Protection Adviser - see 2 below. Because of the variability of radon concentrations it is recommended that the monitoring of an underground void should take place for as long a time as possible.

1. All underground voids that have been previously used should be assessed regarding what they each have to offer. Additionally, each underground void should be assessed in terms of how the total number of voids can, at least initially, be rationalised. Those voids that have good natural ventilation should figure at this stage as they are likely to have the lowest radon concentrations. This will limit the overall costs of the monitoring procedures. At this assessment stage it is most important that very careful consideration of the conservation aspects and access problems be undertaken.

2. A monitoring scheme should be set up in consultation with a Radiological Protection Adviser competent in these matters. It may be that some County Councils have such a designated officer. Otherwise it may mean going to other bodies, for example the Health Protection Agency.

3. As long a period of monitoring as is possible of each of the proposed underground voids should be initiated. In any one underground void, monitors should be placed in several locations along projected trip routes and replaced every three months for at least a year and ideally as long a period as possible. This would enable a meaningful body of data to be gathered for each underground void used that potentially represents the changes through different seasons and in different atmospheric conditions.

4. Underground, void-specific monitors might be allocated to be taken down on each trip, thus giving a relative reading for the total number of trips when compared with those left permanently underground.

5. Personal dosemeters should be carried by the staff involved in underground duties during this initial monitoring period. This allows a body of data to be accumulated for the habits of individuals. This may allow the identification of trips with lower radon exposure, for example.

6. When not in use all monitors should be kept in a suitable (low-radon) store with its own monitor, which thus gives the background radiation level.

7. All underground trips to each void must be logged for personnel, duration and the passages visited. A record of all this information should be maintained allowing the calculation of individual doses per year and providing an accumulating database of the changes that might be expected within the various underground voids.

There may be many different outcomes from such a monitoring scheme. It will hopefully identify suitable underground voids, or possibly parts of voids, that should not be visited at particular times of the year. This means that there will need to be a detailed record of suitable underground voids, along with when they can be used.

This type of information will at least demonstrate that exposure to radon is being limited as much as possible. It will also mean that staff will have to be familiar with this extra detail i.e. some form of leadership scheme will be required.