STRATEGY FOR MANAGING ALPHA RADIATION IN SHOW CAVES TO PROTECT CAVES, CAVE EMPLOYEES, AND CAVE BUSINESSES

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Abstract

Alpha radiation due to radon and thoron daughters is routinely encountered in show caves and has been the subject of several papers at previous cave management symposiums. Alpha radiation has been correlated with an increased risk of lung cancer. This correlation is largely based upon studies of lung cancer in career miners exposed to alpha radiation and other carcinogens and lung irritants. However, the general regulatory model is the "linear, no threshold" model, which means that any radiation increases the risk of subsequent lung cancer and that it is the lifetime dose, rather than the rate, that correlates with the risk. This approach was affirmed in June 2005 by a National Academy of Sciences panel.

The authors of this paper and their respective organizations recognized that a management strategy was needed to provide reasonable protection for show-cave employees, show caves, and show-cave businesses. To address the issue an Alliance Agreement was developed between the Occupational Safety and Health Administration (OSHA) and the Ozark Underground Laboratory. The National Caves Association funded the Ozark Underground Laboratory's participation. This paper summarizes results to date from the project, discusses the emerging cave radiation management strategy that we anticipate will be largely or completely implemented by the National Caves Association, and demonstrates the benefits of Alliance Agreements.

Introduction

One of the first times the cave radiation issue came to the attention of American cave managers was at the first Cave Management Symposium, which was held in Albuquerque, New Mexico (Van Cleave, 1976). The second Cave Management Symposium produced three papers on the issue; these were by Yarborough (1977); Ahlstrand (1977) and Aley (1977). Yarborough (1977) pro-

vided some basic information about alpha radiation in caves and then summarized radon daughter concentrations in National Park Service (National Park Service) caves. He also outlined a regulatory strategy for National Park Service show caves that was patterned after mining standards administered by the Mining Enforcement and Safety Administration (MSHA). Ahlstrand (1977) reported upon rather detailed and wide-ranging research investigations in Carlsbad Cavers. Aley (1977) was concerned that poorly conceived management efforts could damage cave resources and that regulatory strategies appropriate for mines were not well suited to show caves. Since the time of the Second Cave Management Symposium, little has changed relative to the management of the issue. The National Park Service has followed the approach outlined by Yarborough (1977) and this has resulted in about 30 years of alpha radiation monitoring at the larger National Park Service show caves and record keeping to ensure that no employee exceeds the annual alpha radiation dose permissible in the mining industry. Some state-operated show caves have adopted some similar strategies. In 1978 the National Caves Association adopted standards which, among other things, specified that cave employees working at National Caves Association-member show caves were not to exceed 700 hours of work underground per year unless the cave was monitored for alpha radiation and that monitoring demonstrated that they would not exceed the annual alpha radiation dose permissible in the mining industry.

What is alpha radiation and why is it of concern?

Uranium and thorium are radioactive elements that are widely, but unevenly, distributed in bedrock and soils. Elevated concentrations are sometimes (but not routinely) encountered in limestones, dolomites, and shales. No geologic setting can be assumed to be free of these elements.

One of the radioactive decay products of Uranium-238 is radium, which in turn decays to radon-222 (which we will simply call radon in this paper). Radon is a colorless and odorless gas with a half-life of 3.8 days. It has four radioactive decay products (called daughters) with half-lives ranging from 22 years to a fraction of a second.

The atomic decay of thorium similarly produces thoron gas, and the decay of that gas produces two radioactive decay products (again, called daughters). Thoron daughter concentrations in cave air are routinely much lower than are the concentrations of radon daughters. Total alpha radiation in a cave is the sum of radon daughter concentrations and thoron daughter concentrations. Based upon monitoring results from 71 show caves in the United States radon daughter concentrations average about 95% of total alpha radiation. In a few caves radon daughter concentrations can be as low as 63% of total alpha radiation, but in these cases total alpha radiation is typically relatively low.

During the radioactive decay of radon and thoron daughters they emit alpha particles. The particles are large and, as a result have little or no ability to penetrate most materials (including human skin). However, if alpha particles are inhaled they may reach cells in the lungs that are sensitive to damage from the ionizing charge of the particles. This damage may increase the risk of developing lung cancer at some time in the future.

Smoking is the leading cause of lung cancer in the United States. The lung cancer risk for smokers is about ten times greater than the risk for non-smokers (Cohen, 2000). Radon combined with cigarette smoking appears to act synergistically. The risk of both factors in combination is greater than the risk associated with the sum of the factors. The extent of the synergistic effect is unclear since the basic studies used data from underground miners in poorly ventilated, high-alpha-radiation environments where non-smokers were under-represented and where non-smokers were exposed to appreciable second-hand cigarette smoke and to industrial smoke (diesel fumes and fumes from explosives).

Cole (1993) provides an excellent summary of the alpha radiation issue and its associated politics. Papers by Yarborough (1977) and Aley (2000) provide readable summaries of alpha radiation conditions in caves. It is beyond the scope of this paper to consider the validity of the correlation between exposures to alpha radiation and an increased risk of ultimately developing lung cancer.

Alpha radiation is regulated in the mining industry and maintaining or creating low radon concentrations in homes is strongly recommended by various agencies including the U.S. Environmental Protection Agency. Aley (2002) suggested that

arguing that a causative link between alpha radiation as encountered in caves where cigarette smoke is absent and an increased risk of subsequent lung cancers is not going to be politically successful. In fact, he compared the likely success of such an argument to the likely success of arguing that you cannot hijack an airplane with a pair of nail clippers and thus you should be allowed to take them on through the airport security check point at which you have been detained. The political reality, and presumably also the technical reality, is that alpha radiation as encountered by employees in show caves must be approached as a valid employee health issue and addressed in a credible manner by management strategies.

There are several basic regulatory presumptions about alpha radiation. The first is that the risk is dependent upon the total amount of alpha radiation one receives (the dose) rather than the rate at which it is received. The second is that there is no safe threshold value below which there is no risk. The third is that the relationship between the total alpha radiation exposure and the risk is linear. The second and third presumptions were affirmed in June 2005 by a National Academy of Sciences panel.

Monitoring Radon and Alpha Radiation

Radon is a gas and is commonly the parameter measured in the basements of homes in units of picoCuries per Liter of air. In contrast, alpha radiation derived from radon and thoron daughters is measured in Working Levels (WL). One WL is defined as any combination of radon and/or thoron daughters in one liter of air that will result in the ultimate emission of 1.3 x 105 MeV of potential alpha energy. Cumulative exposure is measured in working level months (WLM). This is the exposure accumulated from breathing air at one WL concentration for 173 hours or other combination of time and radiation concentration.

There is no constant coefficient ratio for converting picoCuries per Liter to Working Levels since the ratio of the two is a function of the extent to which the radon daughter products are in equilibrium with the radon gas. In "real-world" conditions the equilibrium constant varies from about 0.1 to 1.0.

- The equilibrium constant in houses is typically about 0.5; this means that 200 picoCuries per Liter of radon equals 1 WL of alpha radiation.
- In well-ventilated mines it is typically about 0.3; this means that 300 pico Curies per Liter of radon equals 1 WL of alpha radiation.
- In unventilated mines it is about 1.0 since the gas and its decay products are at or near equilibrium (Aley, 2000); this means that 100 picoCuries per Liter of radon equals 1 WL of alpha radiation. The time required for radon and alpha radiation to reach equilibrium is about 3 hours (Aley, 2000).
- Except for some notable exceptions, in most show caves the equilibrium constant probably ranges from 0.5 to 1.0 and is commonly near the upper limit of this range, particularly in caves with higher alpha radiation concentrations. If the constant is near the upper limit of the range it is similar to that characterizing unventilated mines.

The standard method for monitoring caves (or for that matter, mines) for alpha radiation is by using a calibrated air sampling pump and pulling a known volume of air over a five-minute period through a filter that will trap the alpha particles. The filter is subsequently placed in equipment that will count the alpha emissions over a standard counting period. Equations are then used to calculate the alpha radiation in WL; the equations include time corrections to adjust for half-life decays. The filter is first counted for radon daughters 40 to 90 minutes after the air sample is collected, and then counted for thoron daughters 5 to 17 hours after sampling.

Alliance Agreement

In 2002 the National Caves Association contracted with the Ozark Underground Laboratory for a three year project (now expanded to four years) on alpha radiation in National Caves Association-member caves. The number of National Caves Association-member caves varies slightly from year to year; in 2005 National Caves Association had 92 members including ten caves owned by state or county governments; five federally owned and operated caves, and one cave in Bermuda. In a few cases there are two or more caves at a particular member site. We estimate that 85 to 90% of all show-cave visits in the United States are to National Caves Association-member caves. The National Caves Association is the logical representative of

the show-cave industry in the United States.

The Ozark Underground Laboratory established an Alliance Agreement with OSHA. While the agreement is between Ozark Underground Laboratory and OSHA, it is for the benefit of the National Caves Association. Alliance Agreements are formal agreements between OSHA and another entity (such as Ozark Underground Laboratory or National Caves Association) to work cooperatively on a particular issue that has safety or health implications for employees. The authors of this paper, who individually represent the Ozark Underground Laboratory, OSHA, and National Caves Association, have found the Alliance Agreement strategy to be an excellent vehicle for assessing the issues and developing a management strategy that will simultaneously protect show-cave employees, show caves, and show-cave businesses.

Early in the Alliance Agreement OSHA personnel noted that most of their work was associated with man-made environments rather than natural environments such as caves. They further noted that, unlike buildings, modifying caves in an effort to protect workers was unlikely to be an appropriate strategy. Throughout the Alliance Agreement OSHA has recognized the need to maintain the natural conditions found in caves. The natural significance of the National Caves Association-member caves is illustrated by the fact that a number of them are primary features in state and federal parks. Of the 71 private and state show caves monitored to date:

- Ten are designated National Natural Landmarks and five more have been proposed, evaluated, and recommended for National Natural Landmark designation. Natural features in these caves have federal legal protection.
- Twelve of the caves have state significance designations such as state natural area or state landmarks.
- Four of the caves provide habitat for federally listed threatened or endangered species and three provide habitat for state listed species. Changes in the cave environment that degraded the suitability of the habitat for federally listed species would violate the Endangered Species Act.

In recognition of the significant natural features that caves are (and that they contain) the parties to the Alliance Agreement agreed early in the process that management strategies for alpha radiation should not include artificially ventilating caves except, perhaps, in a localized and unique circumstance. Caves are best protected if their natural microclimates are preserved or, if they have been altered by past actions, returned to conditions as near-natural as possible. The importance of not artificially ventilating a cave to lower alpha radiation concentrations is demonstrated by a very unfortunate example. A number of years ago the National Park Service Superintendent at Oregon Caves National Monument ordered that the three entrances to the cave not be covered with canvas or lumber during the winter so as to maximize convective airflow through the cave and thus keep alpha radiation concentrations very low. Such strong convective airflows through the cave were not natural, and the highest elevation entrance is a man-made tunnel. The elevational difference between the top and bottom entrances is over 300 feet, and the result of the National Park Service action was that cold winter air at temperatures less than freezing was rapidly drawn into the lower entrance where it froze and shattered hundreds of soda straw stalactites along the first few hundred feet of the lower passage.

The Americans with Disabilities Act (ADA) provides a good precedent for not degrading historical or natural features in order to comply with fundamental ADA requirements for equal access. Exceptions to ADA requirements have been made, and supported by the courts, if compliance with the standards would alter the quality of the building or feature to the point that it no longer maintains its significance. As a case in point, if upgrading the public restrooms in an historic building degrades the significance of the historic architecture, then it is not reasonable to damage the feature to meet ADA standards. The same holds true with caves and is the reason that most caves are not handicapped accessible. Extending this to the cave radiation issue, ventilating a cave to reduce alpha radiation concentrations is not reasonable if it would damage or degrade the cave or the experience of the cave tour. In most cases ventilating a cave would cause significant damage.

Alpha Radiation Monitoring

A crucial part of the Alliance Agreement program was to develop a general understanding of

alpha radiation concentrations at National Caves Association-member show caves. The federally-operated show caves and three of the state-operated show caves did not contribute to funding the study and were not included in the study. Some of these government caves already have conducted alpha radiation monitoring. In addition, several of the state-operated caves that contributed to the study, plus some private caves, also had previous alpha radiation monitoring. As of September 1, 2005, a total of 71 caves in 19 states have been monitored for alpha radiation by the Ozark Underground Laboratory.

Papers by Yarborough (1977 and 1978) and Ahlstrand and Fry (1978) demonstrate that alpha radiation concentrations in caves vary diurnally as well as seasonally. To the scientist this suggests the necessity of collecting large amounts of data to characterize the variability and accurately estimate concentrations at particular points in the cave and at particular times. To the manager this variability suggests the risk of appreciable costs and open-ended studies. The common result of these conditions is that studies focus on collecting large amounts of data without reaching clear management conclusions, and that managers defer decisions until studies are completed. To avoid this "minimal-progress scenario" our program was designed to collect limited alpha radiation data from National Caves Association-member show caves and then to extrapolate the collected data to provide cave managers and the Alliance Agreement participants with a general understanding of the alpha radiation concentrations present in their show caves. To accomplish this we monitored all 71 caves studied to date at least once, and a few caves two or more times. During this monitoring we typically collected five to eight alpha radiation samples from the cave, and additional values from any attached building where employees spent any appreciable amounts of time. In one complex cave we collected 19 samples. We also conducted monthly monitoring of Tumbling Creek Cave at the Ozark Underground Laboratory. This is a large cave system with three sections that have dissimilar airflow patterns and alpha radiation conditions. At each of the show caves we determine which of the three cave segments in Tumbling Creek Cave (or all of them combined) was most similar to the microclimate conditions and airflow patterns encountered along the show-cave tour. We then indexed the measured mean tour route value from the show-cave against the same month value from Tumbling Creek Cave and then estimated the mean annual and mean monthly alpha radiation concentrations for the show-cave.

To date we have monitored 71 show caves in 19 states. There are six other states and Bermuda that have show caves. Table 1 summarizes estimated mean annual alpha radiation concentrations at the 71 caves.

Table 1. Estimated mean annual alpha radiation concentrations at 71 American show caves.

Estimated Mean Annual Alpha Radiation Concentrations (WL)	Number of Caves
0.00 to 0.10	18
0.11 to 0.20	14
0.21 to 0.40	12
0.41 to 0.60	9
0.61 to 0.80	7
0.81 to 1.00	4
1.01 to 1.50	3
1.51 to 2.00	2
3.51 to 4.00	1
6.01 to 6.50	1

The estimated mean annual alpha radiation in the 71 monitored caves is 0.53 WL. The distribution is skewed with 65% of the caves having estimated mean annual total alpha radiation of 0.40 WL or less; the median estimated mean annual alpha radiation is 0.22 WL.

In most cases employees spend more time working in caves during the summer travel season than during the rest of the year. Total alpha radiation concentrations in about 80% of the caves average 16 to 27% higher during the months of June, July, and August than the mean annual value. At the other 20% of the caves the values for June, July, and August average about half of the mean annual values for those caves. Each of the monitored show caves was provided with a report on the concentrations measured in their cave and with estimated mean concentrations for each month of the year.

At one show cave a small girl asked a cave guide whether all gift shops had caves under them. The

answer is clearly no, but 23 of the 71 caves (32%) monitored to date do have gift shops or other buildings in which employees routinely work which are directly attached to the cave. This percent does not include buildings that simply provide security for the cave and are used only to enter or exit the cave (or in one case to view the natural vertical entrance into the cave). Mean annual alpha radiation in the caves directly connected to buildings averaged 0.90 WL; the median value for the 23 caves was 0.29 WL. Of the seven show caves with estimated mean annual total alpha radiation in excess of 1.00 WL five of these (71%) have buildings connected to them.

In many cases having a building connected to the cave decreases natural air exchange between the cave and outside air. In most cases the air in the buildings is warmer than the cave air and the warm building air reduces the rate at which cave air can exchange with surface air. This is especially true when exterior doors to the surface building are closed due to heating or air conditioning of the building.

Occupied buildings connected to cave air often have elevated alpha radiation. At caves with connected buildings we monitored the buildings as well as the cave air. Monitoring points were typically at locations where employees spent appreciable amounts of time, such as at cash registers and ticket sales counters. Thirteen of the 23 buildings directly connected to caves had locations routinely used by employees where total alpha radiation concentrations were 0.04 WL or more. Five of these buildings had alpha radiation concentrations greater than 0.53 WL; this value is the estimated mean annual alpha radiation concentration in the show caves that we have monitored to date. The highest alpha radiation concentration measured in any of the buildings was 5.94 WL. This was at a ticket counter located perhaps 15 feet from a door open to the outside and pleasant fall weather. Elevated alpha radiation in buildings was found even when the building temperatures were much warmer than cave temperatures.

To demonstrate that low concentrations of alpha radiation are present essentially everywhere we measured the concentrations at outside locations away from buildings near show caves at 14 locations in 11 states. Values ranged from <0.001 at three sites to 0.010 WL; the mean was 0.004 WL. At the mean concentration for a week a person receives an alpha radiation dose equivalent to a one hour long dose at 0.67 WL. The typical cave tour at National Caves Association member caves spends about 45 minutes underground at a median concentration of 0.22 WL. This is equivalent to a one-hour alpha radiation dose at 0.165 WL, which in turn is equivalent to spending 41 hours in outside air at a mean alpha radiation concentration of 0.004 WL. Given these values it is obvious that cave tours do not produce an appreciable health risk to individual cave visitors.

Owners or managers were interviewed at each cave during the monitoring work. The following summarizes findings from these interviews:

- The average number of hours worked underground per calendar year by those employees who do cave work for private and state-operated show caves is 270 hours. The range is from 5 to 1,200 hours.
- The average maximum number of hours that any employee at a private or state-operated show-cave works underground per calendar year is 456 hours. The range is from 10 to 2,000 hours.
- An average of 44% of show-cave employees who work underground are employed for a total lifetime career of less than four months. 27% are employed for a total lifetime underground career of four to eight months, and 29% have underground careers lasting over eight months. Most of those with careers lasting over eight months are promoted to supervisory positions and spend less time in the caves.
- Smoking is not permitted at any National Caves Association-member cave and that prohibition is enforced on employees, contractors, and visitors.

Management Strategies

ALARA is an acronym brought to the attention of the parties in the Alliance Agreement by OSHA. It stands for As Low As Reasonably Achievable. As related to the alpha radiation issue, it is the objective of the Alliance Agreement participants to ensure that show-cave employees are exposed to total lifetime doses of alpha radiation which are as low as reasonably achievable.

ALARA is a philosophy used by the Nuclear Regulatory Commission. The following reference

to the ALARA philosophy is from Nuclear Regulatory Commission Regulatory Guide 10.8–Guide for the Preparation of Applications for Medical Use Programs; Section 1.3 As Low As Reasonably Achievable (ALARA) Philosophy: Paragraph 20.1 {c} of 10 CFR Part 20 states:

"... persons engaged in activities under licenses issued by the Nuclear Regulatory Commission pursuant to the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974 should, in addition to complying with the requirements set forth in this part, make every reasonable effort to maintain radiation exposures, and releases of radioactive materials in effluents to unrestricted areas, as low as is reasonably achievable."

In addition, Nuclear Regulatory Commission Regulatory Guide 8.10 (Operating Philosophy for Maintaining Occupational Radiation Exposures As Low As Is Reasonably Achievable) and Nuclear Regulatory Commission Regulatory Guide 8.18 (Information Relevant to Ensuring That Occupational Radiation Exposures at Medical Institutions Will Be As Low As Reasonably Achievable) provide the Nuclear Regulatory Commission staff position on this important subject. We believe that application of the ALARA philosophy to the issue of alpha radiation in show caves is consistent with the approach taken by the Nuclear Regulatory Commission.

Earlier we mentioned alpha radiation standards in force in the mining industry. The mining standards basically specify that alpha radiation in working sections of mines should not routinely exceed 0.3 WL, and that employees working in mines must not receive in excess of 4 WLM of alpha radiation per year (which would equal 120 WLM of alpha radiation in a 30-year career). For the mining industry this is basically an ALARA standard. Planned ventilation is a critical part of the design of a mine, and a properly designed mine should be able to routinely maintain alpha radiation concentrations at 0.3 WL or below. At this concentration people can work full time and not exceed the 4 WLM annual total dose.

Remember that the relationship of lifetime dose to increased lung cancer risk is linear and that there is no safe threshold. There is nothing particularly safe or unsafe about the 4 WLM annual dose value; it is simply a reasonably achievable standard for the mining industry. Just because it is a reasonable standard for the mining industry does not mean or suggest that it is a reasonable standard for the show-cave industry. In reality, applying the 4 WLM annual dose maximum used in the mining industry to the show-cave industry does not decrease the total cave employee risk. Exposing twice as many people to half as much risk still equals the same amount of total risk. The objective in sound employee health and safety protection is to reduce the total risk rather than to spread the risk around. The suggestion that setting an upper limit of 4 WLM per employee per year in show caves is a health standard that protects employees is specious. If managers wish to spread cave time around among a larger group of employees to minimize guide "burnout" or for some other reason that is within their purview, but they cannot credibly view such actions as protecting employee health from the potential risk of alpha radiation or as a component of a cave radiation management plan.

As demonstrated by the Ozark Underground Laboratory monitoring, the estimated mean annual alpha radiation concentrations at show caves in the United States vary by a factor of over 500. Work patterns and other conditions at show caves also vary tremendously. As a result, it is our conclusion that the best approach for ensuring that total employee exposure to alpha radiation in the show-cave industry is as low as reasonably achievable is for each cave to develop and implement a cave-specific cave radiation management plan.

The Ozark Underground Laboratory and National Caves Association are developing a set of Best Management Practices (BMPs) for the show-cave industry. Application of these BMPs will result in decreased employee exposure to alpha radiation. Each cave will review the BMPs and determine which of them (or alternate BMPs) can be reasonably applied at their cave and will commit to following the relevant BMPs at their show-cave operation. A partial list of the draft BMPs follows to give the reader an idea of practices that can be used. Not all of these will be possible at all caves, and some may already be in place and simply need to be documented and continued.

1. Give visitors "cave rules" and other introductory information outside the cave except during bad weather. This reduces total underground time.

One cave gives an impressive steam engine demonstration outside the cave that reduces the amount of time spent in the cave during the tour. As an alternate, give introductory information in a cave area with low alpha radiation concentrations.

2. Reduce or eliminate underground activities that do not require the use of a cave. The snack bar in the Big Room of Carlsbad Caverns is an example of such an activity, but other tangential activities may exist at other caves. We do not recommend elimination of special events in caves such as Boy Scout camping, science schools, or other special events. However, to the extent reasonable the location and timing of these events should give due consideration to alpha radiation concentrations.

3. Conduct major construction or maintenance work during periods of the year when alpha radiation concentrations are relatively low. This applies both to show cave employees and to contractors. It is the responsibility of the cave owners to provide contractors with information regarding the alpha radiation in the cave. Employee manuals can be amended fairly easily to read "Contractors Safety Information." Our monitoring program provides estimated mean monthly alpha radiation values for each cave so that member caves can use the data in scheduling work.

4. Adjust cave tours to spend as little time as possible in higher alpha radiation areas, and as much time as possible in lower alpha radiation areas. This is facilitated by the alpha radiation monitoring that we have been conducting.

5. Prevent cave employees from sitting in cave air during rest periods between tours.

6. Minimize the duration of underground tours while still providing an adequate visitor experience. In some cases this may require removing tour "bottlenecks." Large tour groups move more slowly than smaller groups and much time can be spent waiting for the last people in a group to reach an interpretive stop. While smaller tour groups may require more guides and thus more underground work time by employees this is offset by less alpha radiation exposure for visitors. Show caves should minimize unnecessary exposures to visitors as well as to employees.

7. Ensure that occupied buildings are separated from cave air. In many cases this can be done fairly simply. At two of the monitored caves small vent fans were in use in locations where they prevented almost all cave air from entering the connected building.

8. To the greatest extent reasonable place only non-smokers in cave work jobs. The lung damage resulting from smoking may increase smokers' risks of lung cancer from alpha radiation to levels several times greater than those for non-smokers at identical alpha radiation levels. Research work with which we are familiar has not assessed the issue of whether it is necessary for smokers to actually smoke in elevated alpha radiation environments to increase their lung cancer rates relative to non-smokers.

Cave Radiation Management Plans

As discussed earlier, it is the objective of the parties involved in the Alliance Agreement to reduce total alpha radiation exposures of show-cave employees to ALARA levels. Because alpha radiation concentrations and other conditions vary widely among caves each show-cave will develop its own cave-specific alpha radiation management plan. The following summarizes the proposed requirements for such plans. The strategy and an associated guidance document were approved in principal by the National Caves Association in October 2005 with the intent to ratify them in 2006. There may be some changes in the proposed requirements prior to their ratification by the National Caves Association, but the following list summarizes the strategy that is being implemented:

- National Caves Association will establish a policy that, as a requirement for new or continued membership in National Caves Association, each member cave will develop a Cave Radiation Management Plan ("Plan") for their particular cave. The plan will follow a general outline developed by the Ozark Underground Laboratory working under an Alliance Agreement with OSHA.
- Each National Caves Association-member show cave is to prepare a Cave Radiation Management Plan. The National Caves Association will certify that final plans comply with the National Caves Association requirements for a cave-specific Cave Radiation Management Plan.
- The Title Page will include the following information: Name of the cave, author and job title, date of preparation, dates of any updates or revisions, and date of National Caves Association certification that the plan complies with National Caves Association requirements.

• Part 1 of the Plan will include results from the Ozark Underground Laboratory/OSHA study and Alliance Agreement. This will be provided by National Caves Association/Ozark Underground Laboratory.

• Part 2 will include copies of all alpha radiation monitoring results from the cave. This will be provided by Ozark Underground Laboratory

• Part 3 will require a summary of typical monthly underground work time and total employee exposure by month. Estimated mean monthly total alpha radiation values for the cave will be provided by Ozark Underground Laboratory.

• Part 4 will identify cave features of special significance to ensure that they are not adversely impacted by the Plan and to help readers of the Plan more fully appreciate the features.

• Part 5 will deal with employee training; there are several requirements: (A) Employees must be trained about the cave radiation issue. Basic information on cave radiation shall be included in employee handbooks where such handbooks exist; employee handbooks are strongly recommended. Periodic re-training is mandatory.

(B) A member of management at each show-cave must receive specific training in the cave radiation issue so that he can answer employee questions.

(C) Records must be maintained and included in the Plan indicating training on the issue.

• Smoking by employees, contractors, or visitors must be prohibited in show caves, and this must be enforced.

• Management actions to reduce alpha radiation concentrations in caves to ALARA levels must be identified and implemented. Actions currently taken which help achieve this objective should also be identified.

• Management actions to reduce alpha radiation concentrations in occupied buildings connected to caves or cave air to ALARA levels must be identified and implemented. Actions currently taken which help achieve this objective should be also being identified. In most cases elevated alpha radiation levels in occupied buildings due to cave air are unacceptable.

Summary

Alpha radiation is naturally encountered in cave air, but the concentrations vary dramatically among caves, and vary substantially in individual caves seasonally. Alpha radiation has been correlated with an increased risk of lung cancer, yet the credibility of the correlation relative to air encountered by employees in show caves is at least somewhat questionable. However, the approach we are taking is to presume that alpha radiation as encountered by employees in show caves is a valid employee health issue and should be addressed in a credible manner by management strategies.

The alpha radiation issue has been of concern to show-cave managers and cave conservationists for 30 years. During this time a substantial amount of money has been spent by the National Park Service in alpha radiation monitoring in caves and in record keeping of time spent by employees working underground. One positive result of the National Park Service monitoring program was that cave air from Mammoth Cave, which formerly was used to cool National Park Service administrative offices, is no longer used for this purpose. Aside from this, the National Park Service monitoring and record keeping has resulted in little or no reduction of total employee exposure to alpha radiation. During the same 30-year period private National Caves Association-member caves kept employees from working more than 700 hours per year in caves. This also resulted in little or no reduction of total employee exposure to alpha radiation.

We have outlined a strategy by which the National Caves Association and its show-cave members will concurrently protect show-cave employees, show caves, and show-cave businesses. Based upon some "back-of-the-envelope" calculations we believe that the total alpha radiation exposure of show-cave employees to alpha radiation can be reduced on a nation-wide basis by 20 to 30%, and at some individual operations by up to 70%.

The development of the strategy outlined in this paper has been a cooperative effort of the National Caves Association, Ozark Underground Laboratory, and OSHA and has been conducted under an Alliance Agreement. All parties have had valuable and cooperative input into the development of the strategy. Alliance Agreements provide for a cooperative (rather than adversarial) approaches toward understanding, assessing, and solving industry-specific problems that relate to employee health and safety. The resulting National Caves Association standards and the cave-specific cave radiation management plans represent industry standards and are enforceable by OSHA.

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