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Radon Concentrations, Radon Decay Product Activity, Meteorological Conditions and Ventilation in Mystery Cave

Management Report

to

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Consultant's Report

INTRODUCTION

This project began as an attempt to understand more about the nature of the radon environment in Mystery Cave. The reasons for the study were the need by the Park Service to possibly limit exposure of the guides and park rangers, depending upon measured radon concentrations and that radon concentrations had been measured only by grab samples at several locations since 1981. However these measurements did not indicate how stable radon was from day to day, or what happened to radon concentrations from season to season or between consecutive years. There was also interest in understanding the factors that controlled radon concentrations, such as ventilation and barometric pressure changes and in linking meteorological conditions outside the cave to those within. The current study evolved from gathering information solely on radon concentrations into a broader meteorological study of the cave environment and how that environment was related to radon concentrations and surface meteorological conditions.

Objectives of the proposed study:

1. Gather baseline data on radon, radon progeny and meteorological conditions in selected areas of the cave system.
2. Determine air flow produced by daily and seasonal surface weather events.
3. Compile existing radon data
4. Examine relationship of radon to air flow and ventilation.
5. Determine effects of cave renovation.
6. Correlate cave temperature and humidity levels with air movement.

CONCLUSIONS

1. Radon levels in the cave were highly variable. In the winter, daily radon levels changed by factors of 50, usually correlated to changes in barometric pressure, in the summer, daily radon changes were much smaller and showed no apparent correlation to barometric pressure. On a longer time scale, average summer radon concentrations were as much as a factor of 3 higher than average winter levels. However, maximum winter values could be as high as or higher than summer values. Seasonal changes in radon have been observed in other caves, but not the extreme, rapid winter variations observed in Mystery.

2. The variation in radon concentrations observed in one part of the cave were also observed at other monitoring locations. The variations in Mystery II consistently lagged behind those observed in Mystery I.

3. A strong seasonal effect on air flow patterns was observed throughout the cave. Air flow in winter appeared to have a stronger pattern than in summer, and showed more exchange with surface air. Tracing also indicated internal circulation and mixed internal and surface circulation.

4. Air flow was observed between Bomb Shelter and Garden of the Gods that appeared to bypass the Door to Door route and 5th avenue. The connection is postulated to be a source for the winter radon peaks at Bomb Shelter. The connection could be through the lower levels, however the lack of tracer in the Drop Down and an apparent wintertime flow along Door to Door route from Bomb Shelter implies that there may be other connections.

5. Average temperature changes between 9.4 to 9.6 °C at Bomb Shelter correlated very well with average surface temperature changes between 20°C and -20°C. Correlations were observed on time scales as short as 4 hours and over a change of seasons.

6. A model was developed that suggests cave ventilation is controlled in winter by a thermal, density gradient between the cave and surface. Wintertime radon variations resulted from entry or blockage of surface air and were correlated with but not caused by barometric pressure changes. Low pressure systems in winter sometimes bring warmer surface air over the cave. It is thought that the warmer surface air prevents outside air from entering the cave and the result is a radon maximum. This could explain why not all barometric pressure events correlated with radon and why the magnitude of radon change did not correlate with the magnitude of the pressure change. Further investigation may explain how warmer air, even if still below the cave temperature can prevent surface air from entering the cave.

7. Activities of radon decay products fluctuated in phase with radon, but also at times acted independently of the radon. Given limited data, working level measurements in the cave roughly followed the radon concentrations. The equilibrium ratio between radon and progeny, estimated from the working levels, was about 50%, but could be higher or lower at any given time.

8. Particle concentrations in the cave air were very low and sizes were mostly less than 1 micron. Particulates produced by people were removed from the air of the area where they were generated, within about 3 hours.

The study just concluded has demonstrated that the cave atmospheric environment is complex but understandable. The existing data provide a good base for designing and establishing future research needs and projects. Because of the new data base, future studies do not need to take a shotgun approach, but can study certain areas of the system or a particular phenomenon with targeted data collection arrays.

RECOMMENDATIONS FOR THE DNR

1. For Mystery Cave, natural ventilation with outside air during the winter helps keep yearly average radon around 200 pCi/L. It does not seem likely that artificially ventilating the cave during the summer would be possible or desirable as it might have unexpected consequences on the stability of the existing cave environment. Cave air should never be used for ventilating buildings where people will spend significant time.

2. Further measurements should be made of thoron concentrations in the cave air (^{220}Rn derived from the ^{232}Th decay series). Although a previous measurement indicated levels 400 times lower than radon, this should not be the sole basis for establishing thoron concentrations. Thoron decay products can contribute to exposure at much lower concentrations than radon decay products.

3. Ventilation and air circulation appear to be independent of the artificial entrances. It is possible that excavations in Mystery I have increased the amount of surface air that could enter the cave during the winter and caused lower 1992 radon levels, but there may also be climatic reasons for the shift. Present data is not adequate to provide an answer.

4. Radon levels are highly variable in the winter and between winter and summer. Working level measurements could either overestimate or under estimate exposure depending upon when the measurements were made relative to the high radon events. Time that employees spend in the cave during high or low radon events may not be accurately reflected by exposure calculations based on annual averages.

SUGGESTIONS FOR FUTURE RESEARCH

1. Test the model that air flow into Mystery Cave is controlled by temperature gradients not barometric pressure. Does (as it appears), surface air enter mostly in the Mystery I region and move toward Mystery II? Additional tracer studies and use of gases such as SF_6 may be of use to study long and short-term air movement. As part of this research, measurements should also be made of wind speed and direction relative to topographic features on the surface. This would require sensors outside of the valley and electrical power in areas not readily available.

2. Determine if, or to what extent, barometric pressure changes contribute to the emanation of radon from the rock into the cave air or to air exchange within the cave. The present data imply very little barometric effect.

3. Identify the connecting route for air flow between Bomb Shelter and Garden of the Gods. This could involve further

experiments with PFT tracer gases and radon as well as physical inspection of possible routes.

4. Test the model that radon at Bomb Shelter is being drawn from passage(s) connecting to Garden of the Gods.

5. Measure the volume, flow velocity and short-term directional changes in flow of air entering the cave during winter. Compare with summer measurements. This might be most effective in Mystery I, if Mystery I is the main source of surface air to the rest of the cave in winter.

6. Along with more complete air flow data into and within the cave, other aspects of the cave atmosphere such as humidity, evaporation and CO2 concentrations should be studied in relationship to the cave's static and dynamic atmosphere.

7. Resume continuous radon monitoring to determine if the low 1992 levels are related to construction changes at entrance and therefore may be permanent, or are related to long-cycle climatic factors.

8. With the variations in radon in the Mystery Cave system, ranging from 25 pCi/L to above 600 pCi/L, dependent upon meteorological factors (e.g., temperature and possibly pressure differences between the outside air and the interior of the cave) the exposure of DNR personnel also depends on these factors. Exposures on certain days could be a factor of 2 - 4 greater or lower than the average or spot working level values would indicate.

In addition to working level measurements, the weather and seasonal factors could be used to predict what the radon levels would be in the cave system. This could be done by logging the weather data and using predictive equations to determine the radon. These predictions could then be used to estimate relative exposure of someone entering the cave at that time.

The development of such a system would occur in 2 phases. The first phase would be to develop the predictive algorithm from the existing weather and radon data. This algorithm would consist of a set of equations which would use the data from the existing surface weather station outside of Mystery I.

The second phase would involve development of an indicator display for the headquarters at Mystery Cave. The indicator would provide a pCi/L readout based on the input from the weather station. The advantage of such a system is that no interactions or data analysis is needed by cave personnel. It is likely that over time, the indicator would give a better estimate of exposure than the random walk through measurements that are currently being conducted. Additional analysis of the radon to radon progeny ratio would be needed as an addition to the predictive radon algorithm.

8a. Another way that radon could be monitored and exposures estimated would be to have continuous radon monitor(s) in the caves with a telemetering readout capability back at headquarters. This system would be more expensive from the standpoint of hardware costs but would give actual readings of radon in the cave system before the tour guides or other employees enter the cave and would be active at all times.

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