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

Interpretive Report

to

Warren Netherton, Manager
Mystery Cave, DNR
Forrestville State Park
Rt. 2, Box 128
Preston, Mn. 55965

By

Richard Lively
Minnesota Geological Survey
2642 University Ave.
St. Paul, Mn 55114

and

Brian Krafthefer
Honeywell Technology Center
3660 Technology Drive
Minneapolis, Mn 55418

Consultant's Report

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INTRODUCTION

The radon project at Mystery Cave began as an attempt to understand more about the nature of the radon environment in the cave. Knowing the potential health risks posed by exposure to radon gas, the Park Service was concerned about the guides and park rangers working in the cave and their level of exposure to the gas. Although samples had been taken in several cave locations since 1981 to measure radon concentrations, the information from them did not include, for example, the day-to-day stability of the radon or what happened to radon concentrations from season to season and year to year. In addition to wanting to know this information, there was also interest in understanding the factors that affected those concentrations, such as ventilation and barometric pressure, and in linking meteorological conditions outside the cave to those inside. So the current study evolved from gathering information solely on radon concentrations in the cave to a broader, more comprehensive meteorological study of the cave environment and how that environment related to radon concentrations and surface meteorological conditions.

The objectives of the broader study were:

- Compile existing radon data,
- Gather baseline data on radon, radon decay products and meteorological conditions,
- Determine air flow produced by daily and seasonal surface weather events,
- Examine the relationship of radon to air flow and ventilation
- Correlate cave temperature and humidity levels with air movement,
- Determine effects of cave renovation.

This interpretative report is a summary of the detailed results and information concerning radon and Mystery Cave ventilation based on the accompanying technical report. This report is organized around questions that are intended to provide information that tour guides might want to know and visitors to the cave might ask about. There is more information provided in response to each question than most visitors would want at one time and it is suggested that only one or two points need to be brought up rather than risking confusion or information overload by going into too much detail.

WHAT DID THE RADON PROJECT INVOLVE?

Research in Mystery Cave, ongoing for over two decades, has resulted in detailed maps; ages of cave formations (speleothems); characterization of the sediments and, where possible, correlation with speleothem ages; and chemical/hydrologic analyses of ground water flowing through the cave. Over the past two years, new scientific studies were undertaken as the result of funding provided to the Department of Natural Resources by the Legislative Commission on Minnesota Resources (LCMR) for a project entitled Mystery Cave Resource Evaluation. As part of this project, Richard Lively from the Minnesota Geological Survey and Brian Krafthefer from Honeywell Inc. were responsible for studying radon its decay product concentrations over time, air flow inside and outside the cave, and for evaluating the relationship of radon variability to meteorological conditions.

WHAT ARE RADON AND RADON DECAY PRODUCTS?

Radon (Rn) is an inert, radioactive gas produced by the radioactive breakdown or decay of uranium and thorium in rocks, sediments and water. Radon exists naturally in three forms or isotopes: ^{219}Rn derived from ^{235}U decay, ^{220}Rn derived from ^{232}Th decay, and ^{222}Rn derived from ^{238}U decay. Radon-222, hereafter referred to as radon, was the only radon isotope measured in significant quantities in Mystery Cave. Both ^{219}Rn and ^{220}Rn have short half-lives and decay quickly enough so that little leaves the rock to accumulate in the cave air.

Radon does not form any chemical compounds. It decays (half-life of 3.8 days), into a series of short-lived, non gaseous elements (isotopes of lead (Pb), polonium (Po) and bismuth (Bi),see Figure 1) known as radon decay products or progeny (maximum half-life, 27 minutes). The decay products are solids, not gases and are classified into two groups (fractions): 1) those that attach to large particulates in the air and those that remain as unattached free ions or form molecular clusters. When the decay products, either attached or unattached, contact a surface, they stick, and as they decay they give up energy to that surface. The attached fraction tends to be less mobile and remains in air longer than the unattached fraction.

WHY WAS RADON BEING MONITORED?

Radon in Mystery Cave was being monitored because long-term (30 year) exposure to radioactivity associated with inhaled radon decay products is believed to increase the life-time risk of lung cancer. The level of increased risk is based on studies of lung cancer in uranium mine workers. The radon gas itself is not considered a large respiratory hazard because most is expelled from the lungs. Radon decay products, however, quickly attach to throat and lung tissue when inhaled and are considered the primary source of exposure. Of the decay products, the unattached fraction will be the most likely to remain in the body and therefore cause the most harm.

Radon concentrations are often measured because they are the source of the decay products and are easy to measure, particularly if a continuous record is desired. The radioactivity associated with radon decay products will always be less than or equal to the activity associated with radon. Therefore, radon measurements provide an estimate of the maximum exposure possible from the decay products. Radon decay products can also be measured directly using a filter system as is being done now in Mystery Cave. This method, however, does not provide continuous readings nor does it separate the attached and unattached fraction.

ARE THERE STANDARDS FOR RADON?

Federal agencies such as the Environmental Protection Agency (EPA), the National Institute of Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) have established exposure recommendations or limits for employees working in areas where significant radon, and therefore radon decay product, exposure may occur. Since caves are known to have radon concentrations well above outside air and also well above most indoor living spaces the Minnesota Department of Natural Resources (DNR) currently follows the EPA recommendation that full- and part-time employees working in caves not be exposed to more than two working level months (WLM, see definition) in a year. Visitors to the cave are not included in these recommendations because the length of exposure is short or visits are infrequent enough over a lifetime so there is no cumulative effect. If visitors ask if they risk getting lung cancer by visiting a cave, the simple answer is no. Most of the increased risk results from continual, lifetime exposure to a high radioactive environment. If they ask whether tour guides are increasing their risk, the simple answer is yes, but only by a very small amount because again, time spent as a tour guide is a very small part of the lifetime exposure, and guides' time in the cave is monitored to keep them below recommended exposure levels.

WHERE DO RADON AND RADON DECAY PRODUCTS IN THE CAVE COME FROM ?

The element radon is created naturally by radioactive decay of uranium in the matrix of the limestone, shale and sediment that make up the walls and floors of the cave. Measured levels of uranium in the limestone and sediment range 1 to 4 parts per million (ppm). Radioactive decay of uranium proceeds through the chain of isotopes shown in Figure 1. Radon is the only element of the series that is a gas. Because radon gas is very non reactive chemically, it is able to migrate (diffuse) away from the area where it formed until it decays to a non gaseous element. In rock, this diffusion length may be as much as one meter. Some of the radon in the air is the result of atoms diffusing out of the rock. Other radon atoms that don't reach the cave directly, may be drawn into the cave by air movement through small cracks and crevices. The amount of radon that enters the cave air relative to the total amount produced in the rock is called the emanation fraction. The fraction that escapes from rock is usually between 5% and 30%. Measurements in Mystery Cave indicate that about 5% of the radon escapes from the limestone and about 10% may escape from the sediment.

The other possible source of radon is the water entering the cave. Drip water passing through the soil zone will pick up radon and may release it into the cave atmosphere when the drop impacts a surface. The river water flowing through the lower levels of the cave may also discharge some radon into the cave. Drip and pool waters contain between 100 to 1000 pCi/L, the Root River near the entrance sink between 5 and 20 pCi/L in the summer and 100 pCi/L in the winter when ice covers the surface.

It is unlikely that water is a major source of radon in the cave. Drip waters are small in total volume and transient in many areas of the cave and unless a pool is disturbed, much of the radon will remain in the water, although some transfer will be occur at the air-water interface. The river has a large volume and radon, but measurements at springs where the water resurges, show that the concentration has increased along the flow path. An additional factor is that upon transfer from water to air, radon is diluted by a factor of about 10,000. The conclusion is that water in this cave is not a significant radon source. However, without further information this conclusion cannot be extended to other caves.

Outside air is not a possible source of high radon in the cave because it has an average content of under 0.2 pCi/L, several hundred times less than the cave air.

Once in an atmosphere, radon will 1) decay into the radon decay products (Figure 1); 2) be removed or brought in from another area by ventilation, 3) be diluted by air with lower radon concentrations or 4) attach to surfaces and then decay. Any combination of these methods of reducing radon may apply at any given time. If the system is closed, radon emanating into air will reach a state of equilibrium where it is removed from the air at the same rate is being produced from the rock. Most of Mystery is not a closed system and radon is seldom in equilibrium with its source.

Radon decay products occur in the cave air primarily as a result of radon decay in the air. Once formed, some of the decay products will combine with aerosols and some will remain free ions. A fraction of the decay products will quickly deposit (plate-out) on cave surfaces and not be a factor in determining exposure: the other fraction will remain in the air. Unless removed from the cave by ventilation, all of the radon decay products will eventually reach the cave walls, but will continually be replenished by radon. This has been demonstrated by measurements of ^{210}Pb (another isotope in the ^{238}U decay series, see Figure 1). Surface concentrations of ^{210}Pb on rock and sediment throughout the cave are as much as 500 times greater than within the interior and can only have been produced by continuous deposition of the radon decay products from a relatively high radon atmosphere.

HOW WAS THE MONITORING PROGRAM SET UP?

Measurements of radon in Mystery Cave began in 1981 and continued intermittently through 1988. Grab samples (collected in 0.1 liter Lucas Cells) from Mystery I and II between 1981 and 1983 ranged from 80 to 350 picoCuries per liter (pCi/L), with no obvious seasonal pattern. In 1988, the DNR placed three alpha track detectors in Mystery I and obtained an average radon concentration between 204 to 216 pCi/L for an exposure interval of 108 days between June and September. DNR personnel have also measured working levels along the tour routes in Mystery I and II. Working levels ranged from approximately 0.2 to 2.6 over the period of October 1991 to April 1993.

None of the above measurements could provide information on variations of radon over time or between different areas within the cave system. They did provide some average results that were used to set exposure limits for employees working in the cave.

Locations of equipment and collection devices are shown in Figure 2. Continuous radon monitors were installed in Mystery I at Bomb Shelter for all of the study and near the Entrance, in Formation Room, and about 300 ft. beyond the Bomb Shelter for short intervals during the study. In Mystery II a monitor was always at Angel Loop and for much of the time at 17-Layer Rock, both along the commercial tour routes. Temperature, barometric pressure and radon decay product monitors were placed at Angel Loop for a short period, then relocated to Bomb Shelter for the remainder of the study. Because the cave environment is cool and extremely damp, it is very harsh on metals and electrical equipment. The equipment was contained in sealed boxes with desiccant (a drying agent) to prevent damage from condensing moisture. A weather station was installed across the Root River from the entrance to Mystery I to record temperature, barometric pressure, rainfall, relative humidity, wind speed, and direction and river level.

Most of the data was collected with electronic data loggers. Data collection intervals were set at or averaged to four hours, which was the same period as the radon monitors. In addition to continuous monitoring, seasonal measurements were made of air flow direction within and around the Mystery I and II tour routes. Particle concentrations and size distributions were measured at Turquoise Lake and Bomb Shelter in Mystery I, and carbon dioxide levels were measured along the tour route in Mystery II.

Monitoring was conducted at the listed locations because 1) they were part of or near to the tour area and the results would apply to the areas where the majority of employees would spend the greatest amount of time; 2) some of the locations (such as Bomb Shelter) showed interesting results from earlier studies and; 3) the sites were fairly easy to get to for battery replacement, data collection, and eventually for obtaining electrical power.

WHAT WERE THE FINDINGS REGARDING THE CAVE ENVIRONMENT AND RADON?

Findings regarding various factors are described below.

TEMPERATURE

Cave temperature at Bomb Shelter, Mystery I in 1992 averaged just under 9.6°C during the summer and decreased to around 9.4°C in the winter. A three-day running average of temperatures at Bomb Shelter and from the weather station on the surface (Figure 3) show a good correlation with each other, particularly going from summer to winter. The cave temperature fluctuates by 0.2°C while the outside temperature spans about a 40°C range. This indicates a damped, thermal connection between the cave and outside that extends into the cave well beyond the entrance areas. The mechanism for temperature transfer may be related to simple air flow, movement of heated or cooled water vapor in the cave air, or heat transfer induced by water flowing at lower levels. It is likely that all three mechanisms play a role in influencing cave temperature.

The temperature difference between the cave and surface does contribute to air exchange in the cave. From the data collected, it appears that air flow into, out of and through the cave is mostly caused by temperature variations and the degree to which the cave is connected with the surface.

BAROMETRIC PRESSURE

Barometric pressure values were originally obtained from the Weather Service at the Rochester Airport. Later, monitors were installed at Bomb Shelter and the surface weather station outside Mystery I. The monitor inside the cave showed the same pattern and magnitude of pressure changes as the one outside the cave. Thus, if the barometric pressure outside the cave goes up or down when a weather front passes, the cave pressure also goes up or down an equal amount in phase with the surface pressure. This was true within the resolution of the monitors used. Additional monitors or more frequent measurements might detect some pressure differential between the surface and cave, or between other parts of the cave not as well connected to the surface, or between the cave atmosphere and the surrounding rock.

Based on interpretation of the data collected in this study, air exchange between the cave and surface does not appear to be caused by changes in barometric pressure, therefore Mystery Cave has no barometric winds.

PARTICLE CONCENTRATION AND SIZE DISTRIBUTION

Particle concentrations measured at Bomb Shelter and Turquoise Lake in Mystery I, ranged from 1 to 10 particles/cm^3 just after the researchers left the cave. The high initial levels due to particles generated by people gradually decreased over 1 to 2 hours to an equilibrium concentration of about 0.01 to 0.1 particles/cm^3. The low levels remained relatively constant during the remainder of the test interval. The range of concentrations was because different sizes of particles were measured, ranging from 0.3 microns to greater than 10 microns (1 micron = 0.000001 meters). The smaller particles were more abundant in the air than were the larger particles.

For comparison purposes, homes and commercial buildings have around 10,000 particles/cm^3. Class 100 clean rooms are built to have concentrations less than 0.0035 particles/cm^3 at 0.3 microns. Thus Mystery Cave has many fewer particles than typical buildings. As with other intermittent measurements, long-term variations may be different than those measured, or other parts of the cave may have different size distributions.

The particle measurements indicate that significant concentrations of particles can be generated by occupants of the cave system, either singly or in groups, but they also indicate that the particles are removed from the area within which they were generated within about three hours after the source has been removed. They either settle out on surfaces in the area or are carried by air currents to different locations before settling out. Particles that remain in the cave air under undisturbed equilibrium conditions are very small, less than 1.0 microns and usually less than 0.5 microns. When no one is in the cave, the atmosphere in terms of aerosols is considered very clean.

AIR EXCHANGE RATES

Air exchange rates were calculated from the decrease in particles over time. Rates of one to three air exchanges per hour are in relatively good agreement with estimates of air velocities through the constricted tunnel connecting Bomb Shelter with Door to Door route. These ranged from 2 to 80 ft/min. through an opening roughly 9 ft^2, giving volume flows of 18 to 720 ft^3/min. Estimating the volume of the Bomb Shelter to be approximately 4,500 ft^2 the turnover rate of air could range from once every 4 hours to 10 times per hour. A flow rate of about 20 ft/min. would be consistent with two to three air exchanges per hour for that room.

CARBON DIOXIDE

Carbon dioxide (CO_2) concentrations were measured in May 1991 with a Riken portable CO_2 monitor. The monitor was used to sample the air at various locations along the commercial tour in Mystery

II. This instrument can measure CO_2 concentrations between 0 and 10,000 ppm. Within the cave, levels were between 1700 to 1850 ppm. On the surface outside of the Mystery II entrance, CO_2 was 1200 ppm. For comparison, CO_2 levels in Carlsbad Caverns, New Mexico varied between 345 to 490 ppm; Lehman Caves, Nevada, 1,040 ppm; Black Chasm Cave, California, 3,000 ppm, and as high as 4700 ppm in Altamira Cave, Santillana Del Mar, Spain.

The CO_2 levels in buildings normally range between 600 to 1,200 ppm and the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE, 1989) currently recommends levels of 1,000 ppm in commercial buildings. Because the cave results were one-time measurements in late spring, we cannot say what variations could occur during other times of the year. The measured levels were within what could be considered a normal range for a limestone cave.

DIRECTIONS OF AIR MOVEMENT IN THE CAVE

Where does air go when it moves around in Mystery Cave? To answer that question we used a five tracer gases (called per fluorocarbon tracers (PFT), each with a unique signature) that were located at different sites in the cave (Figure 2). Air samples containing the PFTs were collected at 12 to 15 locations. Measured concentrations and the direction of the collector relative to the source provided an indication of how much and where air had moved during the collection period. The process is similar to tracing ground water flow in the subsurface using dyes or other materials.

The air tracer tests were done during June and November of 1992 and January and May of 1993.

The picture obtained from the PFT results is of a dominant movement of air toward the north and west in Mystery II and north-northeast between Mystery I and Mystery II during the winter. In the summer the air flow was less dominant in any one direction. A major result of the air tracing was the determination of an air connection between the Bomb Shelter and Garden of the Gods areas that appears to bypass currently mapped passages. The direction of air movement between these two locations was seasonally dependent. In summer, air moved from Bomb Shelter towards Garden of the Gods, in winter from Garden of the Gods towards Bomb Shelter. The wintertime pattern of air flow was mostly clockwise within the cave, the summertime pattern appeared to be more counterclockwise.

Wintertime air patterns also included a periodic influx of outside air that diluted the levels of PFT. Much of this air appears to have entered in Mystery I and then flowed east and northeast toward Mystery II. The level of dilution during the summer was much less, indicating that less surface air entered the cave.

RADON AND RADON DECAY PRODUCTS

One of the most significant findings from the study was an understanding of how variable radon concentrations in the cave were. There were significant seasonal changes (Figure 4), with the highest average radon concentrations occurring during the summer (Table 1). Large variations (about 50 times) occurred during the winter. Some of these correlated to changes in surface barometric pressure. Summer radon showed no correlation to barometric pressure but did occasionally respond to temperature changes. We also observed that during the winter when radon reached a maximum, it did so first and was highest at Bomb Shelter in Mystery I. Peaks at Angel Loop and 17-Layer Rock lagged by several hours and were lower in concentration. Radon concentrations during the winter also showed rapid fluctuations that are thought to be associated with ventilation with outside air. These were not observed during the summer when ventilation with surface air was reduced.

When radon changed, the decay products would also change either up or down in phase with the radon. In some instances, unattached activity would increase while total activity would decrease. In most environments, this is usually associated with changes in aerosol particle concentrations. Particle measurements indicate that aerosols in the cave were very low in concentration and the majority were less than 0.5 microns in size. When particulates were generated by persons near the detectors, there was no visible change in the ratio between total and unattached activity. This implies that aerosols that affect the decay products are different (possibly in size or concentration) from those generated by people.

Radon levels in Mystery Cave are higher than some. Maximum radon levels in Carlsbad Caverns, New Mexico were measured at 47 pCi/L, more than 100 times lower than the maximum measured in Mystery, 650 pCi/L. Mystery Cave radon levels may be comparable with some measurements from Mammoth Cave, Kentucky; however all of their measurements are given in working levels. Some of the Mystery Cave working levels exceed the maximum working levels listed for Mammoth. Grab sample measurements from other upper midwest caves give radon values that are comparable to those in Mystery.

Radon concentrations in the cave were compared with the working level measurements obtained by Park employees. Working levels showed a seasonal change similar to radon, and on the average, were about 50% lower than the radon activity. If only radon was measured, calculated working levels would need to be reduced by about a factor of two. This would account for the decay products that have settled onto surfaces and are no longer in the air. Although the data were limited, this relationship appeared to be similar in both Mystery I and Mystery II.

WHAT WERE THE CONCLUSIONS REACHED BY THE STUDY?

Conclusions reached by this study are summarized below:

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 three 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 four hours and over a change of seasons.

6. A model was developed suggesting 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 its decay products, 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 three hours.

This study 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.

DEFINITIONS

Element – a substance that cannot be reduced to a simpler material by ordinary types of physical and chemical changes or unions.

Nuclide – a species of atom characterized by the number of protons (atomic number), and neutrons in the nucleus which together constitute the atomic mass.

Isotope – nuclides that have the same atomic number and therefore are the same element, but with different numbers of neutrons giving them a different atomic mass. Isotopes of a particular element have the same number of protons but different numbers of neutrons.

Half-life – a measure of the rate of radioactive decay, i.e., the time it takes for a radioactive source to lose one half of its radioactivity. Radon-222 has a half-life of 3.82 days.

Radioactive decay mode – the process by which a radioactive substance gives up energy and is transformed into a different element. Emission is by alpha particles, beta particles or gamma rays (electromagnetic radiation).

Working level – any combination of radon decay products in air that results in the ultimate emission of 1.3×10^5 MeV (million electron volts) of potential alpha energy. This is derived from the energy released by the decay of the radon progeny in equilibrium with 100 pCi/L of ^{222}Rn in air. Progeny are not usually in equilibrium with radon because they are removed from the air at a faster rate. Working levels based solely on radon concentrations with the assumption of equilibrium will be maximum values.

Working level month (WLM) - a working level month is equivalent to 100 pCi/L x 170 hr/month or 17,000 pCi hr/L. This assumes that all of the radon decay products are in equilibrium with ^{222}Rn.

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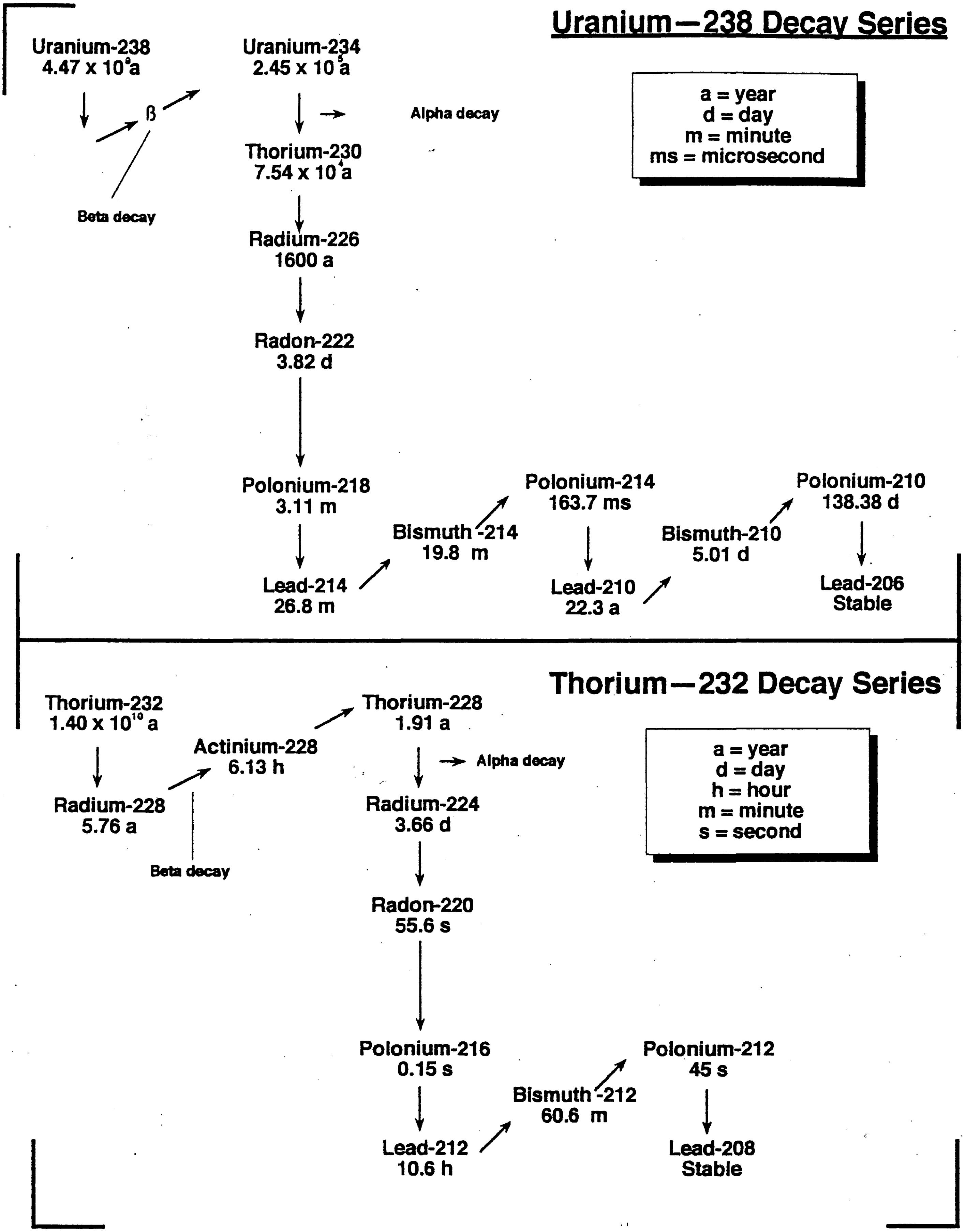

Chart of the Nuclides, Thirteenth Edition, 1983.

Figure 1. Uranium-238 and Thorium-232 decay series.

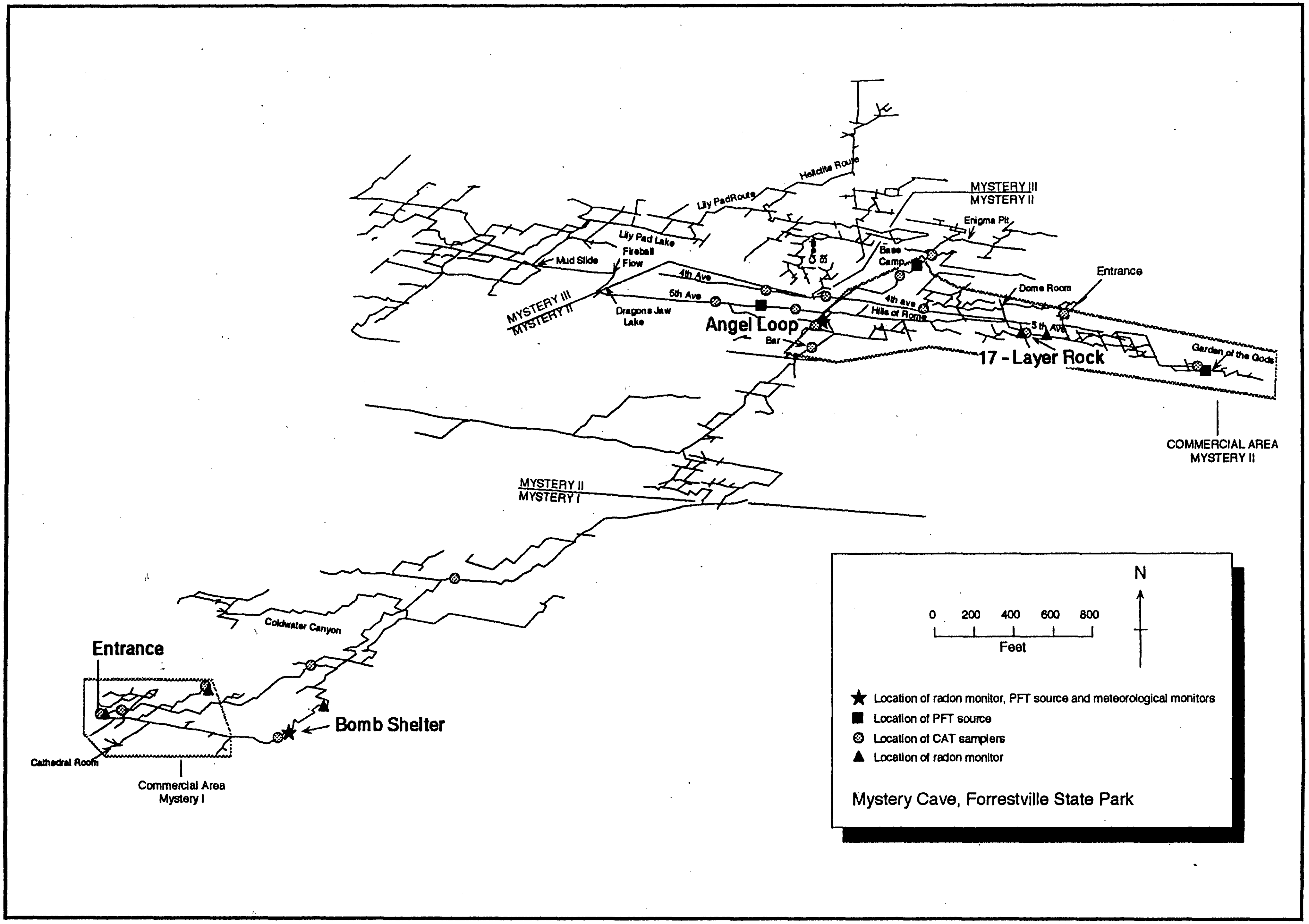

Figure 2. Plan view of Mystery Cave showing locations of radon monitors, PFT source locations and CATS sampling locations.

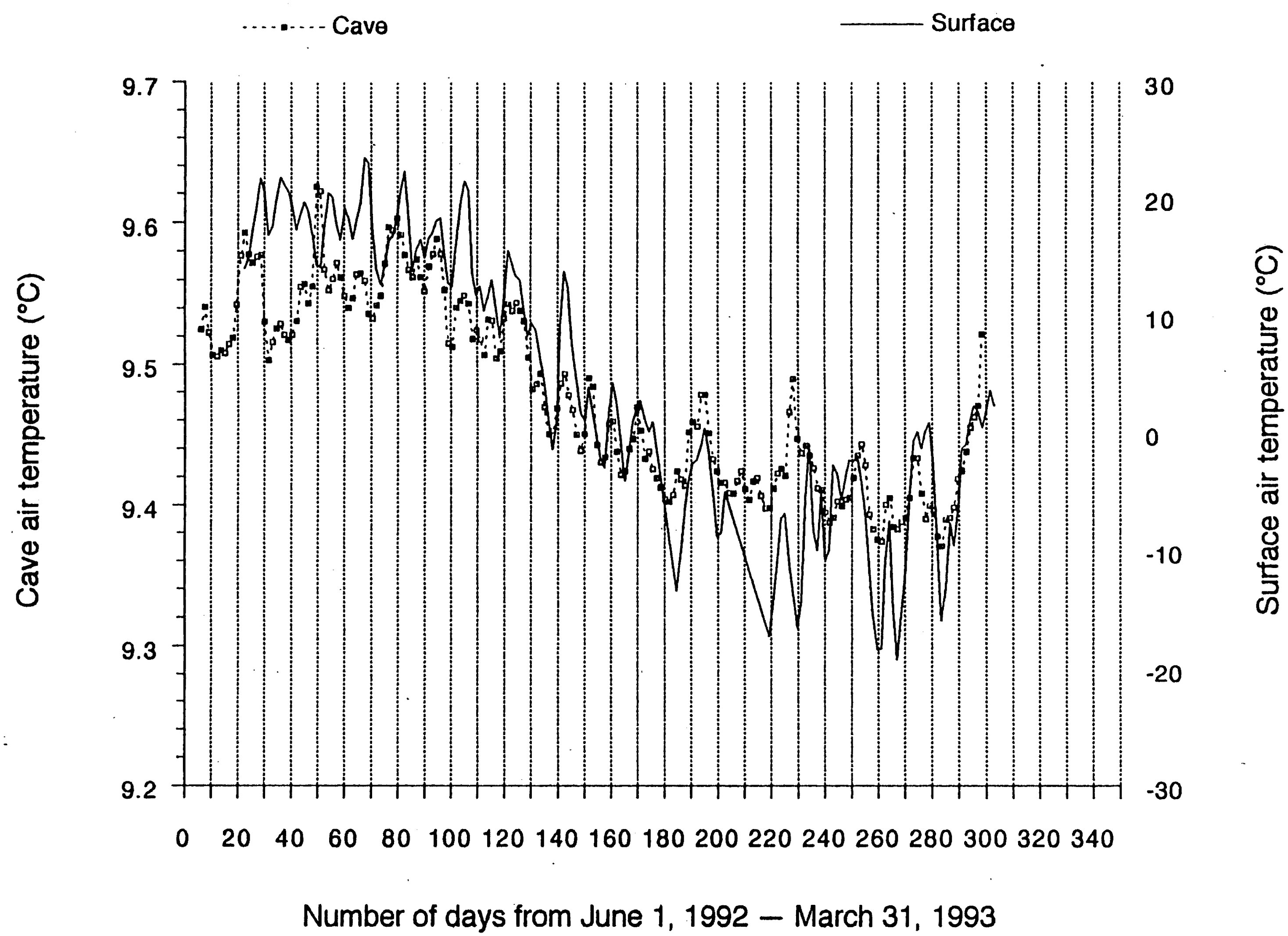

Figure 3. The 3-day average cave air temperature at Bomb Shelter and the 3-day average surface air temperature, June 1992 - March 1993.

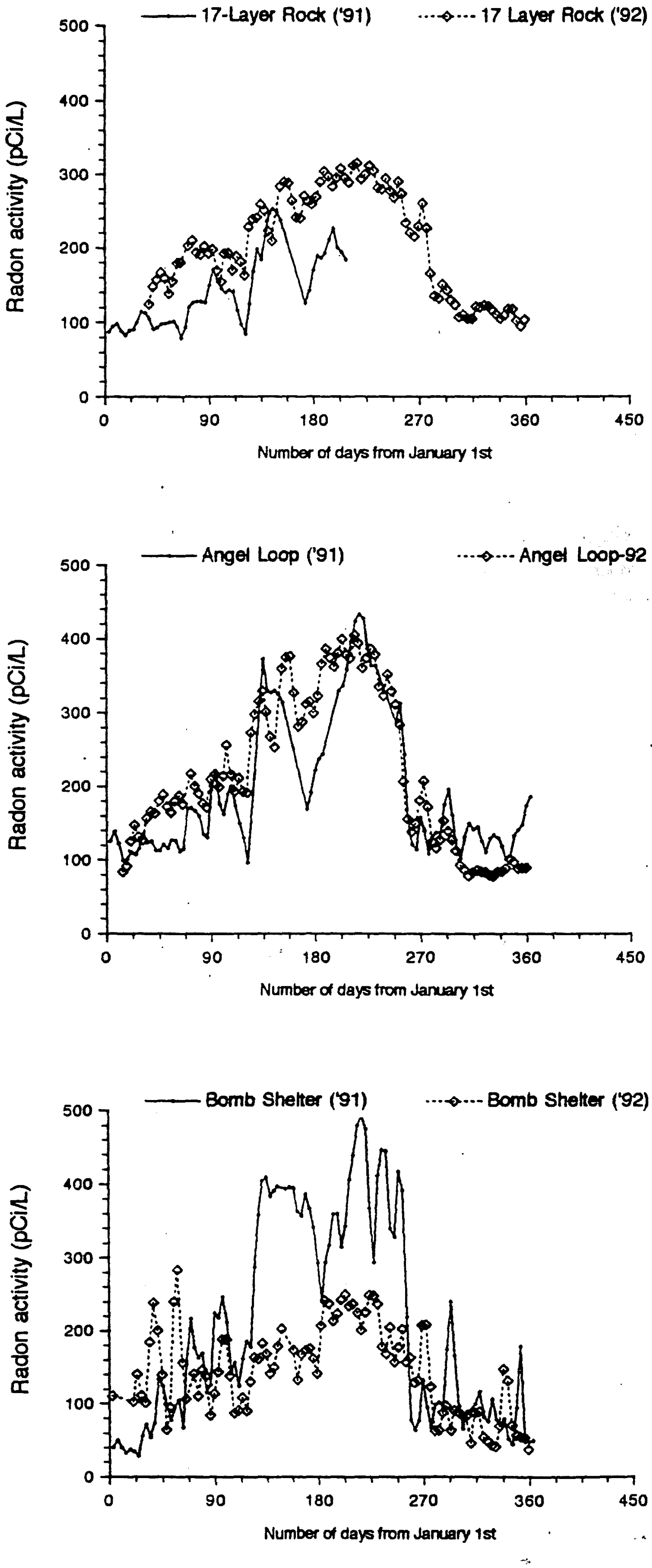

Figure 4. The 7-day running average radon concentrations at 17-Layer Rock, Angel Loop and Bomb Shelter for 1991 and 1992

Table 1. Seasonal and annual averages and summary statistics

Seasonal

		17-Layer Rock	Angel Loop	Bomb Shelter	House	Entrance
1991						
Winter 13:00 21 Dec. 91 - 12:00 21 Mar. 92	avg.	94	121	76	no data	42.7
	Stdev.	19	37	85	no data	56.6
Spring 13:00 21 Mar. - 12:00 21 June 92	avg.	165	207	264	no data	178.6
	Stdev.	54	83	134	no data	112.0
Summer 13:00 21 June - 12:00 21 Sept. 92	avg.	180	317	360	3.1	218.4
	Stdev.	30	98	118	2.2	59.2
Fall 13:00 21 Sept. - 12:00 21 Dec. 92	avg.	no data	133	99	3.6	no data
	Stdev.	no data	41	93	1.4	no data
1992						
Winter 13:00 21 Dec. 91 - 12:00 21 Mar. 92	avg.	161	161	153	4.2	
	Stdev.	24	45	138	1.4	
Spring 13:00 21 Mar. - 12:00 21 June 92	avg.	213	248	140	3.4	
	Stdev.	48	75	70	1.4	
Summer 13:00 21 June - 12:00 21 Sept. 92	avg.	288	345	207	2.9	
	Stdev.	29	54	63	1.1	
Fall 13:00 21 Sept. - 12:00 21 Dec. 92	avg.	148	115	96	5.7	
	Stdev.	55	41	70	1.9	
1993						
Winter 13:00 21 Dec. 92 - 12:00 21 Mar. 93	avg.	109	106	56	8.4	
	Stdev.	17	24	40	17.0	
Spring 13:00 21 Mar. - 12:00 21 June 93	avg.	146	143	no data	5.4	
	Stdev.	32	39	no data	1.8	
Summer 13:00 21 June - 12:00 21 Sept. 93	avg.	no data	no data	no data	no data	
	Stdev.	no data	no data	no data	no data	
Fall 13:00 21 Sept. - 12:00 21 Dec. 93	avg.	no data	no data	no data	no data	
	Stdev.	no data	no data	no data	no data	

Annual

		17-Layer Rock	Angel Loop	Bomb Shelter	House	Entrance
1991	avg.	137	179	197	3.6	119
	Stdev.	53	96	159	1.5	109
	Max.	274	463	665	8.8	372
	Min.	59	43	14	0.3	2
	Skewness	1	1	0	0.6	1
	Median	121	148	154	3.5	61
	Count	987	1679	1942	630	900
1992	avg.	206	219	148	4.2	
	Stdev.	74	109	94	2.0	
	Max.	356	486	566	11.9	
	Min.	69	46	25	0.5	
	Skewness	0	0	1	0.8	
	Median	208	193	131	3.8	
	Count	1705	1891	1879	1898	