

UNITED STATES DEPARTMENT OF THE INTERIOR
MINING ENFORCEMENT AND SAFETY ADMINISTRATION

TECHNICAL SUPPORT

RADIATION SURVEY
OF
MAMMOTH CAVES
NATIONAL PARK

National Park Service
Department of the Interior
Mammoth Cave, Kentucky

April 20-22, 1976

By

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INTRODUCTION

This survey was made at the request of National Park Service (NPS) officials, J. Bainbridge, Southeastern Regional Manager, and J. Kulesza, Superintendent, Mammoth Cave, Kentucky. The survey was made to confirm results obtained by Dr. Keith Yarborough, NPS, Santa Fe, New Mexico, to determine the severity of the hazard, and to conduct informational seminars for management and employees at Mammoth Caves National Park.

GENERAL INFORMATION

Mammoth Cave National Park is located near Cave City, Kentucky, in south-central Kentucky. The mailing address for the park headquarters is Mammoth Cave, Kentucky 42259.

Present NPS employment is 100 persons; 64 persons spend a portion of their time underground and 36 persons work in the Visitor Center or Administration Building. During the summer, NPS employment is 165; with 123 underground a portion of the time and 42 in the two surface buildings. The Park concessionaire presently employs about 5 persons in the Snowball Lunchroom; these employees number about 10 persons during the summer season. Hours of operation are 8:00 a.m.-5:30 p.m. now and will be 7:30 a.m.-7:00 p.m. during the summer.

The Mammoth Cave is a series of solution cavities formed in the limestone beds which were deposited during the Mississippian Period of the Paleozoic Era. The solution cavities formed in the limestone led to the formation of sinks on the surface which permitted surface run off and streams to enter the cave system; the underground openings were further enlarged by the eroding action of this water. The underground openings at Mammoth Cave are quite large, but not extensively decorated with stalagmites and stalagmites except in a few areas. Mammoth Cave is interconnected with the Flint Ridge Cave System, which includes the Great Onyx and Crystal Caves, and the entire Flint Mammoth Cave System has been mapped for 175-185 miles. Figure 1 is a map developed by the Cave Research Foundation (CRF) with the assistance of The National Park Service. Figure 2 is an NPS map of the toured portions of Mammoth Cave, and figure 3 is a map of Great Onyx Cave adapted from a CRF map.

Relatively high radon-daughter concentrations were first detected March 26-30, 1976, by Dr. Keith Yarborough, Physical Scientist, SWRO, NPS, and reported in his memo of April 7, 1976 ⁽⁵⁾1. Dr. Yarborough measured radon-daughter levels of 0.22 to 1.24 working levels (WL) in Mammoth Cave, 0.83 to 1.49 WL in Crystal Cave, 0.68 to 1.22 WL in Great Onyx Cave, and 0.01 to 0.61 WL in the Visitor's Center and Administration Building.

1/ Underlined numbers in parentheses refer to references listed at the end of this report.

RADIATION SAMPLING

Radon-daughter samples taken during the survey are shown in table 1; also shown in this table are thoron-daughter levels extracted from the same aerosol samples from which radon-daughter concentrations were determined. The radon-daughter measurements were made by the standard Kusnetz method described by the American National Standards Institute (1); the thoron-daughter concentrations were measured by a method developed by the U.S. Public Health Service later modified and described by Rock (4).

Table 2 lists the radon gas concentrations measured during the survey and the equilibrium ratios indicated by the concurrent radon-daughter sample. The gas measurements were made with Lucas cells (2) and a special photomultiplier-digital counter instrument.

A number of water and solid samples were taken by Dr. Yarborough during his survey to see if any of these might indicate the presence of primary contributors of radon gas to the cave air. The results from the solid samples, analyzed by gamma ray spectroscopy by personnel of the Denver Mining Research Center, USBM, are given in table 3. The results are given in equivalent thorium, uranium, and potassium---this is based on the assumption that these elements are in equilibrium with their respective daughter products. Potassium-40 is not, of course, a member of a decay series. The water samples were analyzed by methods described by Misaqi (3), the results are given in table 4.

Several cave air samples taken by Dr. Yarborough during his initial survey are given in table 5. These samples were analyzed by gas chromatography by personnel at DTSC.

DISCUSSION

The radon-daughter samples taken (table 1) were reasonably uniform in the various sections of Mammoth Cave. The average values for the various tour routes are Historic Tour, 0.72 WL; Scenic Tour, 0.52WL; Lantern Tour, 0.64 WL; and Bicentennial Tour, 0.80 WL. The average values for the other three caves sampled are White Cave, 0.64 WL; Crystal Cave, 0.95 WL; and Great Onyx Cave, 0.72 WL. Radon-daughter concentrations of 0.21 to 0.51 WL were measured in the Administration Building and Visitor's Center while cave air was being used to cool the buildings; concentrations of 0.01 WL were measured after the use of cave air had been eliminated and the building atmospheres had been flushed. Hopefully this radiation concentration will continue to diminish within a short time.

The thoron-daughter levels (table 1) were fairly low, ranging from 0.01 to 0.08 WL for all samples taken April 20 and 21. Time limitations on April 22 precluded thoron-daughter sampling. Even though the thoron-daughter concentrations were low, radon- and thoron-daughter concentrations are additive, e.g., 0.65 WL radon daughters and 0.05 WL thoron

daughters is equivalent to 0.70 WL; thus the thoron daughters cannot be discounted even though by themselves they should not pose much of a health threat.

Present MESA standards allow only 4 WLM radon (and thoron) daughter exposure per year for any mining employee; this is an average exposure of 0.3 WL (8 hours per day, 5 days per week). The MESA standards apply only to the mining industry; however, OSHA and EPA have adopted the same 4 WLM per year standard for persons whose occupations expose them to respirable alpha-emitting particulates.

The natural ventilation throughout the cave system was very torpid and erratic. Airflow reversals were noted within the short time of a 5-minute sample; however, the general flow tended to be toward the Historic Entrance. The extremely high equilibrium ratio measured at the Historic Entrance (table 2) indicates that the radon daughters are very near equilibrium with the radon gas. This equilibrium, in turn, indicates that the radon gas has on the average spent a long time in the cave (over 3 hours) and that the radon-daughter concentrations cannot increase without an increase in the radon gas concentration. The equilibrium results (table 2) obtained at Crystal and Great Onyx Caves are somewhat less definitive without further study and additional measurements---the 50 percent equilibrium may be caused by short radon residence times (40 to 45 minutes), even though significant airflows could not be discerned, or, by attachment of a significant portion of the radon daughters to solid surfaces within the cave because of a paucity of condensation nuclei. If the low equilibrium ratio is occurring as a result of daughter "plateout", then the radon-daughter concentrations will increase as condensation nuclei are added by visitor activity or lantern smoke.

Gamma-ray spectroscopy analyses of the solid samples taken by Dr. Yarborough (table 3) indicate that none of the solid samples collected were highly anomalous in radioactivity. Studies done by Lawrence Radiation Laboratory indicated that carbonate rock samples taken in California range from 0.3 to 4.9 ppm eU with an average of 1.25 ppm eU. The Clarke (average terrestrial) values are 3-4 ppm uranium and 11-12 ppm thorium.

The water analyses in table 4 show the radium-226 content of the waters sampled by Dr. Yarborough during his survey; the radon-222 content could not be determined because of the sampling method. These samples were taken from standing pools and running streams, which can be assumed to have lost a major portion of the radon originally present through aeration and radioactive decay occurring while the water migrated and collected in these areas. Federal Radiation Council guidelines for drinking water (1962) recommend less than 3 pCi/l soluble Ra-226.

In addition to the survey, the author spent some time on April 20, 1976, describing the hazard and its control to Park management officials and, during another meeting, to the union representatives (Local 557, Service Employees International Union, AFL-CIO). To better acquaint Park employees

with the hazard and control measures being undertaken, Supt. Kulesza arranged two one-hour meetings on April 21 so that the author could discuss the hazard and answer any questions that the employees might have. All meetings were well attended and many pertinent questions were answered.

CONCLUSIONS

The radon- and thoron-daughter levels measured during the survey were quite high; the values are sufficiently high to limit the amount of time spent underground by NPS personnel to ensure that the personnel are not exposed to more than 4 WLM per year. Regular radon-daughter sampling should be initiated as soon as possible in the occupied portions of the cave and exposure records should be maintained for all employees who spend any time underground. The exposures in the Administration Building and Visitor's Center were also quite severe when cave air was used to cool the buildings; this practice was suspended on April 21, 1976, and should not be resumed. The thoron-daughter levels are fairly low, but samples should be taken periodically to determine an average value which can be added to the measured radon-daughter concentrations for exposure-record values. The tourist exposures, assuming the present radon-daughter concentrations, are: Historic (2 hrs., 0.72 WL) 1.44 WLH, Scenic (4 hrs., 0.52 WL) 2.08 WLH, Lantern (3 hrs., 0.64 WL) 1.92 WLH, and Bicentennial (time unknown, 0.80 WL) 0.80 WLH per hour of tour. Tours through the other caves sampled (not presently being toured) would give the following exposures: White Cave, 0.64 WLH per hour of tour; Great Onyx Cave, 0.72 WLH per hour; and Crystal Cave, 0.95 WLH per hour. The tourist exposures for the tours of known duration are 1.5 to 2.0 WLH, which should be acceptable, but the exposures for some of the other tours could be as high as 4 or 5 WLH, depending on duration. OSHA, EPA, or NIOSH should be contacted regarding permissible tourist exposures.

The major reason for the magnitude of the radiation problem is the absence of mechanical ventilation. More beneficial natural ventilation may occur during the winter months, but the extent of improvement could and probably will be quite variable. The radon daughters in Mammoth Cave seem to be near equilibrium with the parent radon gas (on the basis of one observation) and will not increase unless the radon gas concentration is increased for some reason. The equilibrium in Great Onyx and Crystal Caves is only about 50 percent---the radon-daughter concentrations could increase if additional condensation nuclei are introduced into the cave air. Additional data regarding condensation nuclei, unattached ions, and radon-gas concentrations would be extremely helpful in an analysis of the situation, but sufficient time was not available to make these measurements.

Some of the water and solid samples did show above-background radiation levels, but no single source seems to contribute a major amount of radon gas. The radon-daughter, water, and solid sample results indicate that

the radon and thoron are probably emanating throughout the caves from the low levels of radioactivity in the large masses of limestone and other sediments present throughout the caves. The search for primary localized radon sources is probably entirely academic; even if the source could be found, it could not be isolated by any method compatible with the cave esthetics.

RECOMMENDATIONS

1. NPS should begin weekly radon-daughter sampling in all toured portions of the caves and should initiate a record-keeping system to determine cumulative employee exposures (for both NPS and concessionaire personnel) to ensure that no person receives more than 4 WLM of radon- and thoron-daughter exposure per year. The exposures of personnel who perform volunteer services for Cave Research Foundation during their non-duty hours should also be recorded. These exposures could be even more significant than the exposures during duty hours because of the long exposure times and should be recorded for the employee's protection. The initiation of a sampling program will require that someone be trained in radiation monitoring. This can probably be best accomplished by having someone attend our course, "Radiation Monitoring and Control", which will be presented in Denver, May 18-20, 1976.

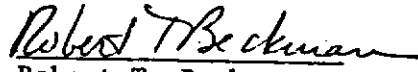
Mechanical ventilation for radon-daughter control does not appear to be either esthetically or practically feasible; exposures of underground personnel can be controlled best by limiting exposure times.

2. OSHA, EPA, or NIOSH should be contacted to determine acceptable tourist exposures. Tourist exposures could be as high as 4 or 5 WLH, depending on tour durations. After the acceptable tourist exposures have been determined, some adjustment of tour routes and times may be necessary to limit their exposures, however, it would be the author's opinion that tourists' short-term cumulative exposures would ordinarily not be large enough to be of concern.
3. Smoking should be banned anywhere in the cave. Employees should be encouraged to stop smoking entirely because of the synergistic or promotional effect smoking has been shown to have on the radiation hazard.
4. The use of cave air for cooling of surface buildings was discontinued on April 21, 1976, but measures must be taken to eliminate the possibility of again using cave air for ventilation, either by mistake or on purpose. This will probably require the installation of a permanent stopping in the airway from the cave to the Visitor's Center. The portion of the airway between the stopping and the Visitor's Center should be sampled periodically to be sure that radon is not leaking through the stopping.

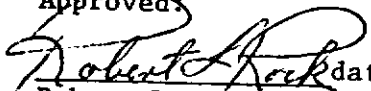
5. NPS should continue educating underground personnel regarding the radiation hazard so that these personnel are more familiar with the hazard, its effects and control.
6. Sputum cytology studies of some of the long-term employees should be initiated to attempt to determine if any cell changes can be detected in their bronchial systems.

ACKNOWLEDGMENTS

I thank all of the personnel of Mammoth Caves National Park for their enthusiastic cooperation and assistance during this survey. Special thanks to Mr. Joe Kulesza, Superintendent; Mr. Doyle Kline, Assistant Superintendent; Mr. Jack Chadwell, Chief of Maintenance; Mr. Steven Smith Chief Interpreter; and Mr. Ray Sellers, Southeast Regional Safety Manager, all of whom expressed great interest and concern regarding the problem. Special thanks are also given to Dr. Keith Yarborough, Physical Scientist, Southwest Regional Office; and Mr. Joe McGown, Park Technician, Mammoth; who performed the original survey and who accompanied the author throughout the labyrinthine passages of the caves during this survey.


Robert T. Beckman

Approved:

 date: 4-29-76
Robert L. Rock, Chief
Radiation Group

REFERENCES

1. American National Standards Institute, Inc. Supplement to Radiation Protection in Uranium Mines and Mills (Concentrators). ANSI N 7. 1a-1969, 16 pp.
2. Lucas, H. F. Improved Low-Level Alpha-Scintillation Counter for Radon. Rev. Sci. Instru., v. 28, 1957, pp. 680-683.
3. Misaqi, F. L. Monitoring Radon 222 Content of Mine Waters. MESA IR 1026, 1975.
4. Rock, R. L. Sampling Mine Atmospheres for Potential Alpha Energy Due to the Presence of Radon-220 (Thoron) Daughters, MESA IR 1015, 1975, 15 pp.
5. Yarborough, Keith A. Radon and Thoron Daughter Radiation Concentrations at Mammoth Cave National Park, Memorandum Report to Superintendent, Mammoth Cave. April 7, 1976, 11 pp.

Table 1. - Radiation Sample Data

Sample number and location	Town	Date- Time	Comments	Radon-daughter concentration, WL		Thoron-daughter concentration, WL	
				MESA	NPS	MESA	MESA
1. Historic Entrance to Rotunda	Historic	4-20-76 10:58	Walking sample	0.85	0.86		0.05
2. Intake to Visitor Center	"	11:05	Stationary sample	0.86	0.82		0.07
3. Rotunda Entrance to Gothic and Broadway	"	11:13	Walking sample	0.77	0.75		0.04
4. Gothic and Broadway to Mummy	"	11:22	Walking sample	0.85	0.88		0.08
5. Mummy to Bottomless Pit	"	11:29	Walking sample	0.61	0.60		0.04
6. Bottomless Pit to River Hall	"	11:36	Walking sample	0.56	0.53		0.04
7. River Hall to base of Mammoth Dome	"	11:45	Walking sample	0.53	0.51		0.03
8. Base of Mammoth Dome to Audibon Ave and Little Bat	"	11:52	Walking sample	0.58	0.56		0.01
9. Audibon Ave and Little Bat to Historic Entrance	"	11:59	Walking sample	0.87	0.85		0.05
Average (9 readings) Historic				0.72 ($S_x = 0.15$)			

Table 1. - Radiation Sample Data

Sample number and location	Town	Date- Time	Comments	Radon-daughter concentration, WL		Thoron-daughter concentration, WL	
				MESA	NPS	MESA	MESA
10. Path to Historic Entrance (outside)	None	12:07	Wind blowing from Historic Entrance along path	0.09	0.04		not meas.
11. Auditorium in Visitor's Center	All	14:37	Stationary sample	0.51	not meas.		not meas.
11a. Administration Bldg.	Admin.	14:06	Walking sample	not meas.	0.38		not meas.
11b. Visitor's Center	All	14:13	Walking sample	not meas.	0.21		not meas.
11c. Air duct in Visitor's Center basement	All	14:43	Air from cave for air conditioning	not meas.	0.58		not meas.
12. Carmichael Entrance to Cleveland Ave	Scenic	16:04	Walking sample, air outcast	0.74	0.59		0.05
13. Cleveland Ave to Specimen Ave (Four Roses)	"	16:12	Walking sample	0.79	0.63		0.07
14. Specimen Ave to Orphan's Garden	"	16:19	Walking sample	0.66	0.54		0.08
15. Orphan's Garden to Cleveland's Cabinet	"	16:25	Walking sample	0.58	0.52		0.05
16. Cleveland's Cabinet to Snowball Lunchroom	"	16:32	Walking sample	0.50	0.41		0.06
17. Elevator shaft at Snowball Lunchroom	"	16:44	Sample in shaft	0.34	0.29		0.04

Table 1. - Radiation Sample Data

Sample number and location	Town	Date- Time	Comments	Radon-daughter concentration, WL		Thoron-daughter concentration, WL	
				MESA	NPS	MESA	MESA
18. Historic Entrance	Historic	18:14	Air outcast	0.78	not meas.	not meas.	not meas.
19. Old ticket office near Historic Entrance	None	18:21	Wind blowing toward Historic Entrance	0.00	0.01	not meas.	not meas.
20. Administration Building	Admin.	19:27	Cave air off, some windows open	0.26	not meas.	not meas.	not meas.
21. Snowball Lunchroom to Florence Williams Dome	Scenic	4-21-76 9:24	Walking sample	0.50	0.43	0.06	0.06
22. Florence Williams Dome to Martell and Boone's Aves.	"	9:31	Walking sample	0.42	0.38	0.04	0.04
23. Martell and Boone's Aves. to Island Rock	"	9:38	Walking sample	0.44	0.44	0.05	0.05
24. Island Rock to Alice's Grotto	"	9:45	Walking sample	0.60	0.53	0.08	0.08
25. Alice's Grotto to Harding's Dome	"	9:52	Walking sample	0.55	0.47	0.05	0.05
26. Harding's Dome to Grand Canyon	"	9:59	Walking sample	0.42	0.35	0.04	0.04
27. Grand Canyon to Arrow Bridge Canyon	"	10:06	Walking sample	0.47	0.35	0.04	0.04

Table 1. - Radiation Sample Data

Sample number and location	Town	Date- Time	Comments	Radon-daughter concentration, WL		Thoron-daughter concentration, WL	
				MESA	NPS	MESA	MESA
28. Arrow Bridge Canyon to Big Break	Scenic	10:13	Walking sample	0.30	0.28		0.07
29. Big Break to Flat Ceiling	"	10:20	Walking sample	0.46	0.36		0.06
30. Flat Ceiling to Frozen Niagara	"	10:27	Walking sample	0.32	0.24		0.04
Average (15 readings) Scenic				0.52 ($S_x = 0.14$)			
31. Administration Building	Admin.	11:07	Cave air off at 10:30	0.27	not meas.		0.01
32. Visitor's Center	All	11:17	Cave air off at 10:30	0.03	not meas.		0.01
33. Historic Entrance	Historic	13:28	Airflow reversing	0.82	0.80		0.01
34. Mummy to past Star Chamber	Lantern	13:46	Walking sample	0.87	0.84		0.07
35. Past Star Chamber to Wright's Rotunda	"	13:53	Walking sample	0.72	0.62		0.02
36. Wright's Rotunda to Cataracts Waterfall	"	14:00	Walking sample	0.62	0.48		0.07
37. Cataracts Waterfall to Chief City	"	14:07	Walking sample	0.64	0.55		0.02

Table 1. - Radiation Sample Data

Sample number and location	Town	Date- Time	Comments	Radon-daughter concentration, WL		Thoron-daughter concentration, WL	
				MESA	NPS	MESA	MESA
38. Chief City to Mummy Ledge	Lantern	14:14	Walking sample	0.71	0.68		0.04
39. Mummy Ledge to Kemper Hall	"	14:22	Walking sample	0.42	0.42		0.02
40. Kemper Hall to Violet City Entrance	"	14:29	Walking sample	0.50	0.38		0.01
Average (7 readings) Lantern				0.64 ($S_x = 0.15$)			
41. Historic Entrance	Historic	20:50	Stationary sample, 1.00 air outcast		not meas.		not meas.
42. Administration Building	Admin.	21:11	Outside temps. 550 FW, 60°F, 73 pct RH	0.04	not meas.		not meas.
43. Hotel Room	None	4-22-76 6:48		0.01	not meas.		not meas.
44. Gift Shop	None	7:40		0.01	not meas.		not meas.
45. Historic Entrance	Historic	8:03	Outside temps 560 FW, 61°F, 74 pct RH	lost	0.68		not meas.
46. Entrance White Cave	White	8:58		lost	0.45		not meas.
47. White Cave	White	9:05	Stationary sample	0.64	not recorded		not meas.
Average (1 reading) White				0.64			

Table 1. - Radiation Sample Data

Sample number and location	Town	Date- Time	Comments	Radon-daughter concentration, WL		Thoron-daughter concentration, WL	
				MESA	NPS	MESA	MESA
48. Pit at end of Dyer Ave	Crystal	11:21	Stationary sample Temps. 56°F, 58°F, 88 pct RH	0.84	not recorded	not recorded	not meas.
49. Pit to D48	"	11:27	Walking sample	0.79	"	"	"
50. D44 to Red Lipstick Rock	"	11:35	Walking sample	0.87	"	"	"
51. Red Lipstick Rock to Collins Ave	"	11:41	Walking sample	0.89	"	"	"
52. End of Collins Ave	"	11:55	Stationary sample	1.45	"	"	"
53. End of Collins Ave to C1	"	12:00	Walking sample	1.02	"	"	"
54. C1 to cave entrance	"	12:08	Walking sample	0.81	"	"	"
Average (7 readings) Crystal				0.95 ($S_x = 0.23$)			
55. River Descent	Great Onyx	14:48	Stationary sample	0.62	not recorded	not recorded	not meas.
56. River Descent to Bench in Main Passage	"	14:55	Walking sample	0.57	"	"	"
57. Bench in Main Passage	"	15:03	Stationary sample temps. 57°F, 58°F, 95 pct RH	0.78	"	"	"
58. Bench to loop at thermometer	"	15:10	Walking sample	0.80	"	"	"

Table 1. - Radiation Sample Data

Sample number and location	Town	Date- Time	Comments	Radon-daughter concentration, WL		Thoron-daughter concentration, WL	
				MESA	NPS	MESA	NPS
59. Thermometer to mouth of cave	Great Onyx	15:17	Walking sample	0.80	not recorded	not recorded	not meas.
60 Mouth of cave	"	15:24	Stationary sample	0.74			
Average (6 readings) Great Onyx				0.72 ($S_x = 0.10$)			
61. Administration Building	Admin	15:52	Walking sample	0.01	not recorded	not recorded	not meas.
62. Visitor's Center		16:00	Walking sample	0.004	"	"	"
63. Lee's Cistern	Bicenten- nial	17:18	Stationary sample	0.52	"	"	"
64. Lee's Cistern to before Joe's Pit	"	17:30	Walking sample	0.74	"	"	"
65. Before Joe's Pit to Dressed Turkey	"	17:36	Walking sample	0.94	"	"	"
66 Dressed Turkey to Gothic Ave	"	17:44	Walking sample	0.99	"	"	"
67. Gothic Ave to Rotunda	"	17:53	Walking sample	0.80	"	"	"
68. Rotunda to Historic Entrance	"	18:00	Walking sample	0.80	"	"	"
Average (6 readings) Bicentennial				0.80 ($S_x = 0.17$)			

Table 2. - Radon-gas Concentrations and Equilibrium Ratios

Sample number and location	Date	Time	Radon gas concentration, pCi/l	Radon daughter concentration, WL	Equilibrium ratio
33 Historic Entrance (Mammoth Cave)	4-21-76	13:28	80.4	0.82	1.02*
52 End of Collins Ave (Crystal Cave)	4-22-76	11:55	276.6	1.45	0.52
55 River Descent (Great Onyx Cave)	4-22-76	14:48	117.1	0.62	0.53

* The maximum equilibrium ratio theoretically possible is 1.00, but this is within experimental error.

Table 3. - Radiometric Analyses of Solid Samples

<u>Sample Number</u>	<u>Location</u>	<u>eTh, ppm</u>	<u>eU, ppm</u>	<u>eK, pct.</u>
1.	*	8.9	7.3	1.67
2.	Mammoth Cave, Lake Purity	1.4	5.2	0.19
3.**	Mammoth Cave, Lake Purity	0	18.8	0.08
4.	Mammoth Cave, Floating Cloud Chamber	1.1	4.4	0.13
5.	Mammoth Cave, Mammoth Dome	5.2	4.6	0.61
6.	Mammoth Cave, Little Bat and Big Bat Avenues	1.6	3.9	0
7.	Mammoth Cave, Wild Cave Tour Route	0.5	10.2	0.32
1.	Great Onyx Cave, Sediment on Tour Route	14.0	9.9	2.18
2.	Great Onyx Cave, Kty	0.5	2.0	0.09
3.	Crystal Cave, Kty, Cave walls and ceiling	1.5	4.0	0
4.	Crystal Cave, Kty, Grant Ave passage	12.5	4.6	1.13
5.	Crystal Cave, Kty, Gypsum	0.7	5.6	0.43
1.***	Crystal Cave, End of Collins Ave	13.1	3.7	1.58

* Sample 1, from Mammoth Cave, had an illegible ticket.

** Sample 3, from Mammoth Cave, lacks sufficient material for a reliable measurement.

*** Clay sample collected by the author 4-22-76.

Table 4. - Water Analyses

<u>Sample</u>	<u>Ra-226,</u> <u>pCi/l</u>
Mammoth Cave, Wandering Willie Spring	22
Mammoth Cave, Cataract Falls	31
Mammoth Cave, Richardson Spring	Nil
Mammoth Cave, Lee's Cistern	13
Mammoth Cave, Joseph's Pit and Waterfall	Nil

TABLE 5 - ANALYSES OF AIR SAMPLES COLLECTED 3/28-30/76

MINE/MILL Mammoth Cave
 COLLECTED BY R. Rock, K. Yarbrough
 COMPANY NPS
 STATE Kentucky
 SUBDISTRICT OFFICE DTSC, NPS
 DATE REC'D 4-15-76

BOTTLE NUMBER	LAB NUMBER	LOCATION IN MINE	DATE AND TIME	CARBON DIOXIDE	OXYGEN	METHANE	CARBON MONOXIDE
5347	G6-1398	Led Cistern on Bicentennial Tour	3-28-76 8:20pm	.07	20.87	.00	.0000
5329	G6-1399	Gothic Ave & Main Cave	3-29-76 10:20am	.07	20.87	.00	.0000
5333	G6-1400	Floating Cloud Chamber	3-29-76 11:10am	.08	20.88	.00	.0000
5335	G6-1401	River Hall	3-29-76 11:30am	.08	20.87	.00	.0000
5338	G6-1402	Bleeding Hart Springs near Echo River	3-30-76 4:40pm	.07	20.90	TRACE LESS THAN .01	.0000

DATE 4-16-76
 SIGNATURE Fred C. R...



Figure 1. - THE FLINT MAMMOTH CAVE SYSTEM

Mammoth Cave National Park, Kentucky, U.S.A.