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Evaluation of Radon Sources and Phosphate Slag in Butte, Montana

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Larry L. Lloyd
Occupational Health Bureau
Montana Department of Health
and Environmental Sciences

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Project Officer
Michael F. O'Connell

Office of Radiation Programs
U.S. Environmental Protection Agency
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DISCLAIMER

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FOREWORD

In 1977, The Montana Department of Health and Environmental Sciences (DHES) initiated an investigation of the use of phosphate slag in Butte and Anaconda, Montana. Phosphate slag, a waste product from a nearby elemental phosphorus smelter, was of concern because of its elevated content of natural radioactivity, particularly radium-226.

During the investigation of phosphate slag, DHES discovered elevated radon and radon progeny concentrations in many structures in Butte. The cause of these elevated concentrations was unknown.

DHES requested assistance from the U.S. Environmental Protection Agency (EPA). The EPA's Office of Radiation Programs subsequently entered into a contract with DHES to identify the sources of radon and radon progeny in structures and in the ambient air in the Butte area. The scope of the contract was expanded in 1981 to include an intensive sampling program designed to evaluate the state-of-the-art in indoor radon measurement equipment and methods.

This report is the first of a series summarizing the EPA sponsored work conducted in Butte. The DHES investigation into the contribution of phosphate slag and the mineralized geology as sources of elevated radon and radon progeny levels in Butte structures are described in this report.

Future reports will summarize the extensive indoor air measurement data, describe the statistical relationships between the various sampling methodologies, and discuss sampling and data management.

ACKNOWLEDGEMENTS

This project was made possible by the U. S. Environmental Protection Agency's (EPA) Office of Radiation Programs through a contract (EPA Contract No. 68-01-6100) with the Montana Department of Health and Environmental Sciences (DHES).

It could not have been completed without the cooperation and assistance of numerous federal, state, and local governmental agencies, private individuals, and particularly the homeowners in Butte, Montana, and the surrounding areas.

The EPA's Las Vegas Facility and the Eastern Environmental Radiation Facility (Montgomery) provided both technical and laboratory support as needed throughout the duration of the study.

The U. S. Bureau of Mines provided radon and radon progeny calibration facilities and technical consultation at its Denver Research Center. The Bureau of Mines' Spokane Research Center computerized the bulk of the data acquired by DHES in addition to available geological information pertaining to the Butte area. The Bureau of Mines computer was used for data comparison and evaluation and for the graphic production of numerous figures in Section 5 of this report.

The U. S. Department of Energy's Environmental Measurement Laboratories (EML) provided DHES with semi-annual radon measurement intercomparison exchanges to assure the accuracy of radon measurement calibrations.

The Montana Bureau of Mines assisted in the evaluation and understanding of the Butte geology and with the description of the Butte geology.

The Anaconda Company provided DHES with a detailed geological map of the Butte area which was used extensively to locate veins, fractures, and surface geological formations.

The cooperation and assistance provided by the Butte/Silver Bow Government's Chief Executive's Office and Health Department helped to maintain good public relations throughout the study.

The friendly cooperation of Butte homeowners in allowing DHES to perform measurements in their homes was essential to the completion of the project.

A special appreciation is expressed to the DHES staff members who conducted the field operations of the study. Their continued commitment to detail, quality assurance, and accurate data collection was paramount to the successful conclusion of this project.

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ABSTRACT

In 1978, DHES began investigating the potential sources of radon (radon-222) which contribute to the elevated ambient and indoor concentrations of radon and its decay products in Butte, Montana. During the early stages of the investigation, efforts were directed toward the evaluation of phosphate slag which has been used extensively for paving and graveling and building materials in the Butte area. The phosphate slag proved not to be a significant source of radon.

In July, 1980, DHES contracted with the EPA to further investigate the potential sources of radon in Butte. Under the agreement with EPA, surface geological constituents, air, water and natural gas supplies, and building materials were investigated as potential radon sources.

Butte Geology

The northern part of Butte is located on a hill interlaced with geological fractures and richly mineralized veins. Extensive mining of gold, silver, copper, manganese and other metals has been conducted on the Butte hill during the past hundred years. The most prevalent rock type in the area, commonly known as "Butte granite", is technically quartz monzonite. Aplite and alaskite dikes are prevalent in the quartz monzonite. Rhyolite, which is of volcanic origin, is found in the most northwestern part of the city. Alluvium is the prevalent geology in the southern portions of the city. The alluvium is predominantly sand and gravel that resulted from the erosion of the surrounding hills so that in gross composition it is nearly the same as the quartz monzonite, rhyolite, and aplite.

Geological Constituents

Soil samples were collected throughout the Butte area and analyzed for radium (radium-226) content. The radium content of the samples ranged from 0.7 to 3.2 picocuries per gram (pCi/gm) with a mean of 1.84 pCi/gm.

Alpha track detectors were used to measure radon soil gas concentrations during both summer and winter months. The average radon soil gas concentration measured during summer months was 1082 picocuries per liter (pCi/l), whereas the average winter concentration was 1407 pCi/l. While radon soil gas concentrations of less than 100 pCi/l were measured, concentrations in excess of 5000 pCi/l were not uncommon. The highest radon soil gas concentrations were associated with measurement sites located over major fractures and mineralized veins. The lowest concentrations were measured in rhyolite. At many measurement sites it was impossible to determine if the underlying rock was quartz monzonite or aplite or if the alluvial cover was of sufficient depth to prevent the upward migration of radon to the detector location. Consequently, it was impossible to determine radon soil gas concentration differences resulting from these different formations.

Radon exhalation tests were performed on 25 cm depths of quartz monzonite, aplite, alluvium, and mineralized vein samples. The highest

radon exhalation rates were from mineralized vein material which averaged 2139 picocuries per square meter per minute ($pCi/m^2/min$). Aplite samples showed exhalation rates (713 $pCi/m^2/min$. average) that are about three times the exhalation rates from quartz monzonite (237 $pCi/m^2/min$. average) and alluvium (226 $pCi/m^2/min$. average).

Air

Radon concentrations in ambient air were monitored at the Hebgen Park station, using radon gas monitors that provided hourly data printouts, from August 1980 through August 1981. Monthly average ambient radon concentrations ranged from a high of about 3 pCi/l to a low of less than 0.25 pCi/l. The highest concentrations were observed between August and November. Concentrations diminished through the winter months and reached a low in May and June.

Outdoor air (not considered ambient because of the location of the intake) was monitored at the Hornet Street station from February 1982 through January 1983. Outdoor radon concentrations at this location averaged 3.25 pCi/l for the entire monitoring period.

Water Supplies

The Butte municipal water supply system is fed by surface water sources. Of these sources, the highest dissolved radon content measured was 69 pCi/l, thus eliminating water supplies as a suspect radon source.

Natural Gas

The radon content of natural gas in Butte averaged 14 pCi/l. This low concentration eliminated natural gas as a suspect source.

Building Materials

Radon exhalation tests were performed on numerous building materials. Building materials proved not to be a significant radon source in Butte.

Following the investigation of potential radon sources in Butte, it was concluded that ambient air, soils and surface geology all contribute to Butte's radon problem.

It is believed that homes constructed over major factures or mineralized veins are the most severely impacted. Aplite and quartz monzonite also contribute to the problem, but to a lesser extent. Ambient air is probably a major source of indoor radon in structures having low concentrations.

1. INTRODUCTION

Many mineral deposits contain uranium and thorium as natural constituents. When these naturally-occurring radionuclides and their radioactive decay products (see Figure 1-1) are underground, they normally present no significant impact to man except for the possibility of leaching into groundwaters. These naturally-occurring radionuclides become a concern when there is an insufficient layer of overburden to provide adequate gamma radiation shielding or to prevent the occurrence of abnormal radon entry into structures built on these locations. In some instances, the occurrence of insufficient layers of protective overburden is a natural phenomenon. In other instances, the mining and processing of mineral deposits removes the protective overburden and redistributes the radioactivity. Distribution of these naturally-occurring radioactive materials can increase the public exposure to ionizing radiation.

Studies performed by DHES have confirmed that the Butte, Montana vicinity has high levels of gamma radiation resulting from both natural phenomena and the redistribution of natural radioactivity from mining and smelting operations. Also, a large number of structures in the Butte vicinity have exhibited significantly elevated concentrations of the radioactive gas radon-222 (radon) and its particulate decay products (radon progeny).

An elemental phosphorus smelter is located approximately seven miles west of Butte. In early 1977, DHES suspected that slag, which is produced as a byproduct at this smelter, was elevated in content of natural radioactivity. Slag samples were sent to the EPA Las Vegas Facility for analysis. As suspected, the EPA Laboratory reports revealed the slag to be elevated in uranium and radium-226 content.

During the period between the fall of 1977 and the spring of 1978, DHES learned that phosphate slag had been used extensively throughout the Butte area for construction purposes. Since the 1950's, slag had been used for ballast in railroad beds, for road and highway construction, for graveling roads, for building construction and for aggregate in asphalt surfacing materials.

EPA sent a van equipped with a large collimated gamma scintillation detector and a pressurized ion chamber to Butte in April, 1978. This van was used to identify locations in Butte having elevated gamma radiation levels. Data accumulated through the use of this van assisted DHES in locating numerous homes constructed with building materials containing phosphate slag.

It was suspected that the decaying radium present in concrete blocks containing phosphate slag could cause elevated radon and radon progeny concentrations in structures constructed of these materials. In April, 1978, DHES obtained from the EPA's Las Vegas Facility several Radon Progeny Integrating Sampling Unit (RPISU) instruments to measure radon progeny concentrations, and soon after began monitoring homes containing phosphate slag building materials. Numerous Butte homes were

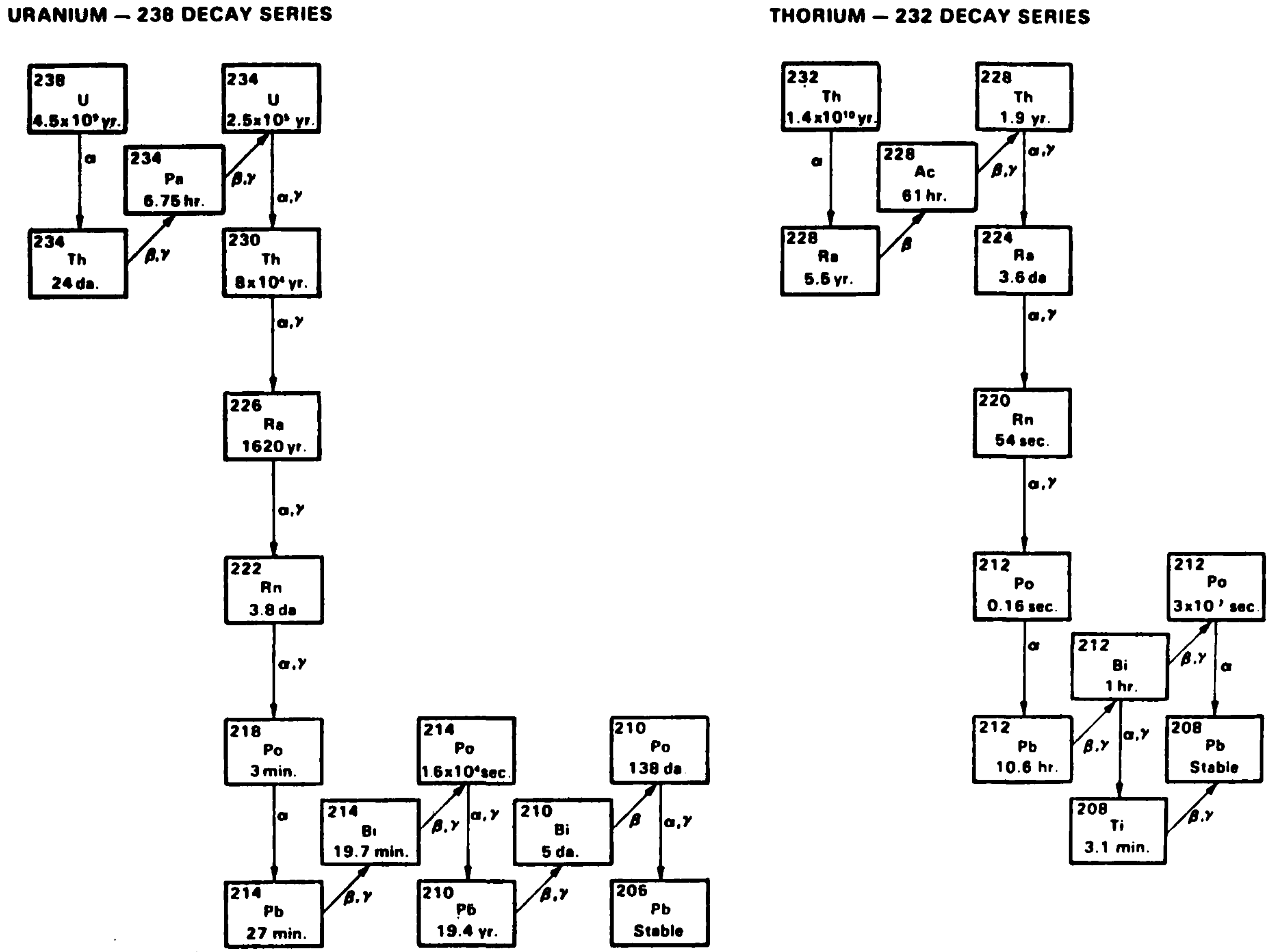


FIGURE 1-1

NATURALLY OCCURRING RADIONUCLIDES

found to have radon progeny concentrations sufficiently elevated to constitute a potential health risk.

Following this discovery, then Governor Thomas Judge was advised of the Butte area radiation problems and associated health risks. The Governor responded by supporting a program to determine the magnitude of the radiation problem, assess health risks and initiate necessary measures to protect the health and safety of the exposed people . Through the Governor's efforts, funds to initiate this program were made available July 1, 1978.

Many Butte homes having elevated radon progeny concentrations were identified by the fall of 1978, and it was determined that phosphate slag had been used extensively in the Butte and Anaconda areas for the paving and graveling of streets, parking lots, and playgrounds. Copper and manganese slags in the Butte and Anaconda areas were also found to be elevated in radioactivity, although to a lesser extent than the phosphate slag. For these reasons, DHES requested that the 1979 State Legislature fund a study to determine the extent of these radiation sources and, if necessary, initiate controls concerning the use of these materials. The legislature provided DHES with $100,000 to conduct this study during the 1980-1981 biennium.

By early 1979, it was apparent that the source of indoor radon was not clear-cut. Some Butte structures did not contain phosphate slag, but were sampled to determine background levels. Of these structures, a number were found to have higher radon progeny concentrations than structures containing phosphate slag. It was determined that construction-related use of phosphate slag was not a principal radon source and that other sources would require investigation. It was determined that the radiation hazard associated with phosphate slag was primarily gamma radiation, and that the slag was not responsible for the elevated radon levels in Butte. Therefore, it was necessary to alter the direction of the study.

Numerous potential sources became suspect. There have been extensive disturbances to the surface and subsurface geology in the Butte area due to underground and surface mining. It was suspected that this mining activity in conjunction with the subsidence it creates and the presence of natural geologic fault zones could be causing a higher radon flux than would occur in an undisturbed location.

A study that originally appeared to be straightforward became more complex. During the original study it was envisioned that approximately 150 homes constructed with phosphate slag building materials would have to be investigated. The re-directed study required the investigation of several thousand homes.

Additional staff were needed to expand the scope of the Butte Radiation Study. In July, 1979, DHES made application to the EPA Office of Radiation Programs for a grant to enable DHES to expand the scope of the study during fiscal years 1980 and 1981. EPA awarded DHES a contract for $81,804 to acquire data and information concerning the radon and radon progeny levels in Butte. The scope of the work specified in the EPA/DHES contract consisted of two main tasks. The principal task was to perform measurements of radon and radon progeny inside and outside structures. The measurements were to be directed toward identifying, to the extent possible, the source of elevated radon concentrations inside structures and in the community. A second task was to emplace approximately 200 alpha-track detectors in the soil on a grid basis in the Butte area to determine radon soil-gas concentrations. The EPA and DHES agreed to keep the plan flexible in order to provide for additional work and re-direction as data was acquired.

2. BUTTE DESCRIPTION

History

Butte originated in 1864 as a gold mining camp following a placer strike. Later, underground silver mining led to the discovery of large deposits of copper and other metals, giving it the title of "the richest hill on earth." More than two hundred mines have operated in the Butte area during the past hundred years. These mines have honeycombed the Butte hill with shafts and tunnels and have littered the surface with mine wastes. During Butte's early years, nine smelters and numerous stamp mills were in operation. Subsidence resulting from underground mining is an ongoing phenomenon as the hill area continues to settle and shift.

The emphasis of mining operations in Butte shifted from underground to open pit mining in 1955 when The Anaconda Company began stripping overburden from the Berkeley Pit. In 1975 underground mining in Butte was discontinued.

The Anaconda Company was acquired by the Atlantic Richfield Company in the late 1970's. The Atlantic Richfield Company continued the Berkeley Pit operations until July, 1982, when mining in the pit ended. In early 1983, the Atlantic Richfield Company announced that its Butte mining operations would terminate on July 1, 1983.

Geography

Butte is a city with a population of approximately 25,000 people, and is situated on the west side of the Continental Divide in southwestern Montana. The city is sited on the north end of a high mountain valley which is surrounded, except to the west, by mountains. Butte has been called the "Mile High City" because its entire area is at least one mile above sea level. The Butte Airport which is located in the valley to the south of Butte has an elevation of 5540 feet.[2]

Climate

Severe seasonal temperature extremes are encountered in the Butte area. The annual mean temperature is 38.8°F (3.8°C) with extremes ranging from near -40°F (-40°C) to over 90°F (32°C).[3] There are periods, especially during winter when the Butte area is subjected to severe atmospheric temperature inversions. During these times atmospheric pollutants are trapped in the valley bowl.

Geology

Butte lies within the Boulder Batholith, a mass of granitic rock that congealed from a molten liquid mass about 70 million years ago. The batholith is from 10-15 kilometers thick. As the liquid rock cooled, certain chemical elements became preferentially separated and as a result, different rock types were formed. The most prevalent type in the area, commonly termed the "Butte granite", is technically quartz monzonite. Within the quartz monzonite are further effects of segregation. When the quartz monzonite solidified, aplite and alaskite dikes were still liquid or semi-liquid and were injected into cracks and fissures. Depending on the rate at which the injections cooled, aplite or alaskite resulted. Both rock types have approximately the same chemical composition, but different textures--individual grains (minerals) comprising alaskite grew to a larger size than those in aplite bodies. Another rock type commonly found in the northwest part of Butte is rhyolite. This rock also was molten, but was formed in a volcanic environment, either on the surface of the earth or in the neck of a volcano.

During the time the Boulder Batholith was created and cooled, the earth's crust was subjected to stresses coming from outside the immediate area. In addition, stress fields were established within the body as a result of cooling and solidification processes. Effects of these stresses are seen as breaks in the rocks (faults and fissures). The faults vary in size from a fraction of an inch thick to tens of feet thick and from simple tensional openings to much more complex structures with hundreds of feet of both horizontal and vertical movement. Because of their open nature, some of the faults of the Butte area provided a plumbing system for hot fluids that gave rise to many mineral deposits. In this case, veins formed along the faults and fissures. The more prominent faults, veins and rock types of Butte are shown in Figure 2-1. Although a multitude of separate veins exist at Butte, collectively they are regarded as a single deposit. Chemical zoning along particular veins both horizontally and vertically is duplicated in all of the veins so that the district as a whole exhibits zoning from a copper-rich central core to a silver-rich peripheral band.

From an areal viewpoint the most prevalent geologic unit in Butte is the alluvium along the flood plain of Silver Bow Creek and in the basin. This material is predominantly sand and gravel and resulted from the erosion of the surrounding hills so that in gross composition it is nearly the same as the quartz monzonite, rhyolite and aplite.

The Butte mineral deposit is a world class deposit. According to Meyer[4] and others (1968) the Butte district produced 3.3 x 10^8 tons of ore from 1880 to 1964. From this ore more than 16 billion pounds of copper have been produced, greater than 4 billion pounds of zinc, 3 billion pounds of manganese, more than 600 million ounces of silver and in excess of two and a half million ounces of gold. Additionally, lead, cadmium, bismuth, arsenic, selenium and tellurium have been produced. In order to extract these metals, the area was opened by more than 40 miles of vertical shafts and literally thousands of miles of tunnels and other underground passageways. The latest mining resulted in the excavation of the Berkeley pit, an open pit mine within the town proper and two smaller pits on the eastern fringe of the residential area.

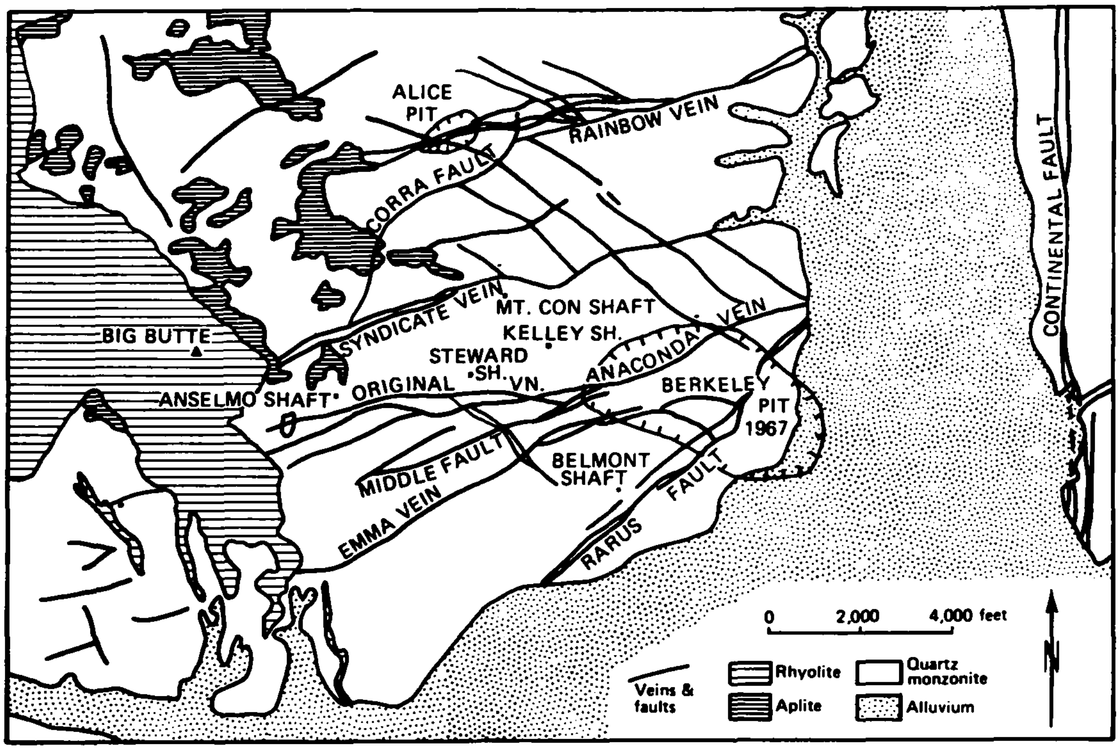


FIGURE 2-1

PROMINENT FAULTS, VEINS, AND ROCK TYPES OF BUTTE

3. EVALUATION OF PHOSPHATE SLAG USE

Elevated radioactivity in phosphate rock was noted as early as 1908.[5] According to Habashi[5] uranium normally occurs in phosphate rock in concentrations ranging between 100 and 200 parts per million (ppm). Andrews and Bibb[6] report that concentrations observed in the United States range from 8 to 399 ppm, with the highest concentrations being found in ore from South Carolina and the lowest in Tennessee ore. The radioactivity in phosphate rock is due almost exclusively to uranium and its decay products (see Figure 3-1).

An elemental phosphorus smelter operated by the Stauffer Chemical Company is sited approximately seven miles west of Butte. Phosphorus smelting at this plant began in the early 1950's. During its first decade of operation, the plant processed ore from an underground mine in the Maiden Rock area, which is about 25 miles south of the smelter. Mining at Maiden Rock was discontinued in the 1960's. The ore processed since that time has been shipped by rail from a mine-site located near Soda Springs, Idaho.

In early 1977, the DHES obtained samples of slag produced as a by-product from the smelting operation. The samples were sent to the EPA Las Vegas Facility for analyses. The results of the laboratory analyses for the slag from Montana mined ore and Idaho ore are in Table 3-1.

TABLE 3-1

RADIOACTIVITY IN PHOSPHATE SLAG PRODUCED
FROM ORE MINED IN MONTANA AND IN IDAHO

	Nuclide	pCi/gm 2 sigma
Montana Slag	^{226}Ra	28.0 ± 0.9
	^{238}U	21.0 ± 4.7
	^{235}U	1.3
	^{234}U	20.0 ± 4.6
	^{230}Th	20.0 ± 4.6
	^{232}Th	0.77± 0.19
Idaho Slag	^{226}Ra	48.0 ± 1.2
	^{238}U	41.0 ± 6.2
	^{235}U	2.4 ± 1.6
	^{234}U	40.0 ± 6.3
	^{230}Th	35.0 ± 7.4
	^{232}Th	0.5 ± 0.22

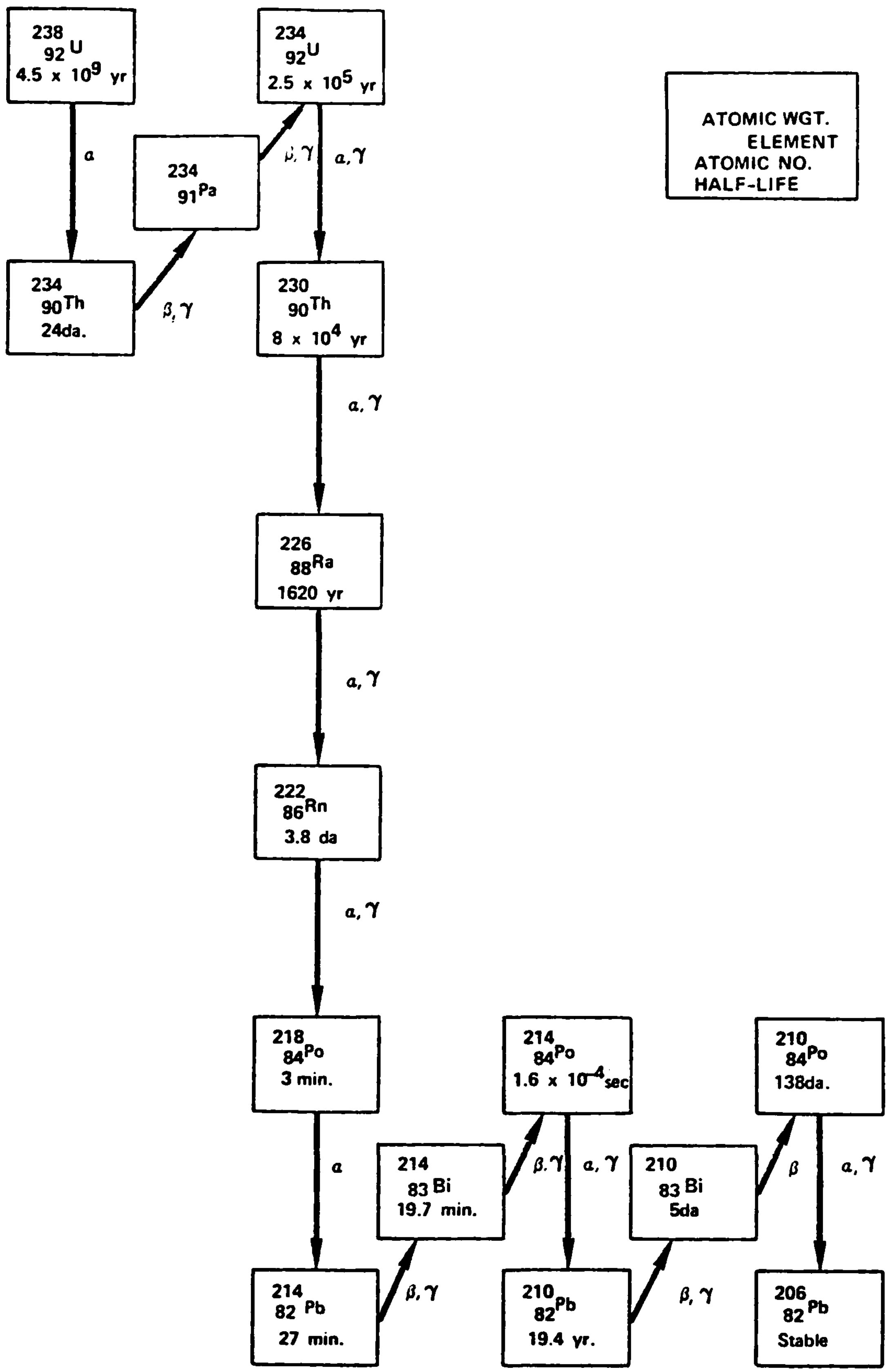


FIGURE 3-1

URANIUM-238 DECAY SERIES

As shown in Table 3-1, the radioactivity contained in the Idaho slag is nearly twice that of Montana slag.

Following the receipt of the EPA laboratory report, DHES initiated an investigation to determine the off-site uses of the phosphate slag. It was learned that slag had been used extensively throughout the Butte area for construction purposes.

Since the 1950's phosphate slag has been used for ballast on railroad beds, road and highway construction, graveling and for asphalt aggregates. Also, a company produced concrete blocks and pre-stressed concrete beams and slabs during the late 1950's, using phosphate slag for aggregate. These concrete products were used in the construction of homes, schools, hospitals and commercial buildings.

The EPA's Las Vegas Facility sent a van, fitted with a Pressurized Ion Chamber (PIC) and a collimated NaI (Tl) detector coupled to a multichannel analyzer, to Butte in April, 1978. Two EPA radiation specialists accompanied the van. Data accumulated through use of this van assisted in locating numerous homes containing phosphate slag building materials.

The occupants of each home containing slag were contacted and, with their permission, gamma radiation and radon progeny measurements were made. Similar measurements were also made in a number of homes that did not contain phosphate slag (non-slag homes).

Radon Progeny Integrating Sampling Units (RPISUs) loaned to DHES by the EPA Las Vegas Facility were used to measure indoor radon progeny concentrations. A RPISU was installed in a home for a period of one week and then the detector head was removed and sent to Las Vegas for analysis. The minimum time of data acquisition when using the RPISU approached one month because of the time requirements for sampling, transportation, readout and reporting.

After several months of sampling , it was apparent there was no difference in radon progeny concentrations between slag homes and non-slag homes.

Two Radon Gas Monitors (RGMs) were acquired in early 1979. These instruments enabled the direct measurement of radon. Using these RGMs, radon exhalation tests were performed on samples of phosphate ore, phosphate slag and decomposed granite soils from the Butte area.

Radon exhalation measurements were performed by placing a sample 25 cm deep in an air-tight cylindrical container having an inside diameter of 28 cm and a 35 cm depth. Air from the container was drawn into the RGM and recirculated back to the container in a closed-loop design. The rate of increase of the radon concentration in the air space above the sample and in the RGM scintillation cell was measured and the radon exhalation rate calculated. As the 25 cm sample depth does not constitute a diffusion path length for radon in the samples tested, the data derived are valid only for comparative purposes.

Data from the comparative radon exhalation measurements are shown in Table 3-2.

TABLE 3-2

COMPARATIVE RADON EXHALATION MEASUREMENTS PERFORMED ON 25 CM DEPTHS OF PHOSPHATE ORE, PHOSPHATE SLAG, AND DECOMPOSED GRANITE SOILS FROM BUTTE

Material	Radon Exhalation Rate ($pCi/m^2/min.$)
Stauffer Phosphate Ore (Idaho)	3822
Stauffer Crushed (3/4") Slag (Idaho)	18
Concrete Block (Phosphate Slag)	30
Butte Decomposed Granite Soils	100 - 1000
Monsanto Phosphate Ore (Idaho)*	3402
Monsanto Uncrushed Slag (Idaho)*	18
Monsanto Crushed (3/4") Slag (Idaho)*	30

*The Monsanto Corporation provided samples from their Pocatello, Idaho, phosphate smelting plant to enable DHES to conduct comparative measurements.

An evaluation of Table 3-2 shows that phosphate slag exhales less than 1 percent of the radon that is exhaled by the phosphate ore. The radium-226 content of the slag and the ore is essentially the same. The smelting of the ore apparently creates a matrix that inhibits the exhalation of radon. Table 3-2 also shows that phosphate slag exhales less radon than do native soils from the Butte area. In 1982, Andrews and Bibb[6] reported results of radon flux measurements performed on phosphate ore, slag and soil at the Stauffer plant site. Their data concur with the DHES findings.

Elevated gamma radiation was found in building materials containing phosphate slag. A Pressurized Ion Chamber (PIC) was used to measure gamma radiation levels in approximately 90 homes partially constructed with concrete blocks containing phosphate slag and 12 homes not containing phosphate slag. A comparison between gamma radiation levels in slag homes and non-slag homes proved difficult. Due to the variability of the mineralized soils in the Butte area, gamma radiation measurements made at one meter above the ground ranged from a low of 15 μR/hr to about 30 μR/hr. The number and the placement of the concrete blocks varied from structure to structure. Some homes had foundations totally constructed of slag blocks. Other homes had only a shower stall or one or two basement walls constructed of the blocks. No home was identified where slag blocks were used in construction above the basement level.

The average gamma radiation level was 19.6 μR/hr on the main floor of slag homes and 37.1 μR/hr in the basement. In non-slag homes gamma radiation levels averaged 15.5 μR/hr on the main floor and 20.7 μR/hr in the basement. All measurements were made at a distance of 1 meter above the floor.

The results indicate that use of the slag blocks for foundation construction elevates the gamma radiation level in basements by an average of 16 to 17 μR/hr and by about 4 to 5 μR/hr on the main floor.

Measurements made in three schools, where additions were constructed with phosphate slag beams in the ceilings, showed gamma radiation levels averaging 35.7 μR/hr in the slag additions and 15.9 μR/hr in the older parts of the buildings where slag building materials were not used . In these structures, the presence of phosphate slag appeared to increase the gamma radiation level by approximately 20 μR/hr. The presence of phosphate slag thus increases the gamma radiation dose to a school child exposed 6 hours per day, 180 days per year, by about 21 milliroentgens per year.

The determination of ambient gamma radiation attributable to use of phosphate slag for paving and other surfacing in Butte is difficult because of the many variables involved. Natural radiation levels vary by as much as 15 μR/hr. Most of the phosphate slag used for surfacing came from smelted Montana ore. Recently, slag produced by smelting Idaho ore has been used. Also, the depth of slag used in streets and for surfacing differs from project to project.

Street measurements of gamma radiation levels were made in Butte, Anaconda and Helena to determine background radiation levels. Measurements in Anaconda average 15 μR/hr; Helena, 13 μR/hr; and Butte, 19 μR/hr in areas where no phosphate slag was present.

Radiation levels at one meter above Butte streets paved with Montana slag average 28 μR/hr; whereas, the radiation levels above streets paved with Idaho slag averaged approximately 45 μR/hr. Some measurements as high as 50 μR/hr were recorded on streets paved with Idaho slag. Numerous streets which were originally paved using Montana slag have been repaved using Idaho slag. Radiation measurements on these streets generally range between 30 and 40 μR/hr.

Most streets, alleys, parking lots and some school grounds are paved or graveled with phosphate slag. It is estimated that approximately one-fourth to one-third of the populated area of Butte is covered with phosphate slag or phosphate slag bearing materials.

Because of the variability in natural background radiation levels, and in radiation levels measured in areas covered with phosphate slag, it was not possible to measure the overall radiation exposure attributable to the phosphate slag used in Butte. However, it has been estimated[7] that the use of phosphate slag in Butte may have elevated the average radiation exposure rate within the city by as much as 10 μR/hr.

The use of phosphate slag for graveling creates another potential health risk. Phosphate slag is rapidly pulverized by traffic. During dry periods, roads graveled with phosphate slag become extremely dusty. Individuals driving on, or living near, these roads are exposed to high concentrations of slag dust. Because of the elevated content of natural radioactivity contained in the phosphate slag (see Table 3-1), and particularly because of the radium-226 and thorium-230 content, phosphate slag should not be used for road gravel. When inhaled or ingested, if soluble, radium and thorium metabolize to the bone and increase the risk of bone tumors and leukemia.

The potential for contaminating ground and surface water by radioactivity leached from phosphate slag was investigated. Samples of phosphate slag were crushed into powder and placed in beakers containing water having pH values ranging between 5 and 9. Each sample was periodically agitated, then filtered after a period of 24 hours. One hundred ml of filtrate from each sample was dried in a planchette and counted for gross alpha and gross beta activity. Nothing above normal background levels was detected in any of the samples, indicating that phosphate slag was insoluble in water under most environmental conditions. As this was a short-term test, the potential for long-term chemical and solubility changes was not determined.

From the evaluation of data concerning use of phosphate slag for building and construction purposes, it is concluded that:

1. Phosphate slag should not be used as an ingredient when building structures for human occupancy. Such use elevates gamma radiation exposure rates and results in unnecessary radiation exposure to occupants.

2. Phosphate slag should not be used for road or area graveling. The slag is readily pulverized and produces dust elevated in radium-226, thorium-230 and other nuclides in the uranium-238 decay series. This potential hazard should be further studied.

3. Phosphate slag can be used for some purposes without significant risk to the public health. However, any use of phosphate slag should be strictly controlled. Some uses which may be acceptable on a case-by-case basis are construction of highways, airport runways, bridges, culverts and other underground pipe and for railroad ballast.

   The use of phosphate slag should be limited to projects where no significant human exposure to increased gamma radiation levels will occur. Control measures should be implemented to prevent the use of slag for unacceptable purposes.

4. Human exposure to radon and radon progeny is not a health risk that is associated with use of phosphate slag for building and construction purposes since radon exhalation from phosphate slag is relatively insignificant. Radon exhalation rates from the slag are lower than those normally expected from native soils in the Butte area.

4. RADON/RADON PROGENY MEASUREMENTS

Selection of Homes for Measurement

Initially, homes containing phosphate slag building materials were the subject of investigation. Radon progeny measurements were made in these homes and other, non-slag homes using RPISUs. Equipment for making short-term "grab" sample (less than 10 minute) measurements was also acquired. Soon after this equipment was obtained, it was learned that the most severely impacted area of Butte was the northwest section. The first indication of elevated radon concentrations in northwest Butte occurred when a home on Waukesha Street, which contained phosphate building blocks, was found to have radon progeny concentrations in excess of 0.25 Working Levels (WL). Comparing measurements from other homes containing phosphate slag building materials, it was apparent that the phosphate slag was not responsible for this high radon progeny concentration.

Following the discovery of the elevated levels of radon progeny in the Waukesha Street home, measurement activities were intensified to determine the boundaries of the impacted area. Occupants were contacted on a house-to-house basis and were asked for permission to measure radon progeny concentrations. The people were generally cooperative, with only about a ten percent rejection rate.

The radiation study received considerable publicity from the news media. Consequently, many local homeowners became aware of the potential health risks and requested that radon progeny concentrations be measured in their homes. DHES performed measurements in each home where the measurement was requested.

In 1979, the U. S. Department of Housing and Urban Development (HUD) initiated a requirement that all HUD-subsidized housing be measured to determine radon progeny concentrations. At the same time, HUD's Federal Housing Administration (FHA) instituted a requirement that radon progeny concentrations had to be determined for all FHA-insured home loans. Following the initiation of HUD's measurement requirements, DHES entered into a contract with HUD to perform these measurements in HUD-subsidized housing.

After DHES acquired grab sampling equipment, all homes studied were initially measured using the grab sample method. Radon and radon progeny concentrations in structures are subject to significant variability. Because of this, RPISUs were installed in homes measuring 0.03 WL or higher to obtain long-term integrated measurements. Long-term measurements were also performed in numerous homes where the measurement was requested by the occupants.

In summary, structures chosen for grab sample measurement of radon progeny were selected because:

1. The homes contained phosphate slag building materials.

2. The homes were located in areas known to be elevated in indoor radon concentrations.

3. Individuals requested sampling of their homes because of health concerns.

4. The sampling was required by HUD or FHA.

Structures selected for long-term integrated measurement were, for the most part, homes in which grab samples showed elevated radon progeny concentrations.

Because of the selection criteria, structures chosen for both short-term and long-term measurements constitute a biased sample. Data obtained from these measurements should not be extrapolated for a city-wide average.

Indoor Measurement of Radon and Radon Progeny

Radon and radon progeny concentrations were determined by using both short-term and long-term sampling techniques. There are inherent advantages and disadvantages to each technique. Because of this, the purpose of measurement and data needs were carefully evaluated prior to beginning each phase of the study and determining which measurement technique would be used.

Measurement of Indoor Radon Progeny

Short-term sampling

The grab sample method for measuring radon progeny concentrations was used to obtain rapid measurements in many homes. This technique enabled the screening of large numbers of homes and apartments to determine which areas of the city were most severely affected.

Most screening by grab sampling was done during cold weather when it could be assured that doors and windows were closed. When homes were measured during warm periods, occupants were contacted in advance and asked to close all doors and windows for a period of at least eight hours prior to sampling. For HUD and FHA sampling, the occupant was requested to sign a statement that the house had not been ventilated for a period of at least three hours prior to measurement. No actual ventilation rate measurements were made.

Grab sampling provides a reasonably accurate measurement of the radon progeny concentration present at the time of sampling; however, extrapolation of short-term data to estimate long-term averages is subject to considerable error because of the daily and seasonal fluctuations in radon and radon progeny concentrations.

Long-term sampling

Long-term measurement of indoor radon progeny was used to estimate average concentrations for a period of one year. Throughout the study

RPISUs, loaned by the EPA Las Vegas Facility, were used to obtain integrated measurements of radon progeny concentrations.

In most homes, the RPISUs were used for a period of one week every three-months for a year. This sampling schedule was established to enable the collection of one week's data during each season of the year. The four week's data were equally weighted and averaged to estimate the "Annual Average Concentration."

Measurement of Indoor Radon

Short-term sampling

Short-term measurements of indoor radon concentrations were made using Eberline 500-ml scintillation cells . This measurement device provides an accurate assessment of the indoor radon concentration at the specific time of sample collection. Most radon grab samples were collected simultaneously with radon progeny grab samples. This enabled the calculation of the percentage equilibrium of the radon progeny with the parent radon-222.

Long-term sampling

Few long-term measurements of indoor radon concentrations were done during the study. DHES acquired two Eberline Radon Gas Monitors (Model RGM-1) in early 1980. These were the only integrating radon monitors available during most of the study, and were mainly used for ambient monitoring, radon exhalation and radon flux measurements.

Factors Affecting Radon and Radon Progeny Concentrations in Structures

Concentrations of indoor radon and its progeny are subject to variation. Factors that affect structure ventilation rates and those that affect radon soil gas concentrations in soils adjacent to structures are probably responsible for most of the fluctuations.

It is believed that radon soil gas concentrations near a structure can be elevated by the installation of adjacent concrete or asphalt slabs, driveways or sidewalks. These appurtenances create a capping effect that inhibits the exhalation of radon from the soil. This capping increases radon soil gas concentrations and can elevate the radon concentration within the structure itself.

Naturally-occurring phenomena that affect radon exhalation from the soil adjacent to structures can also change concentrations of indoor radon. Some examples of these phenomena are changes in soil moisture and the ground frost during winter.

Factors affecting structure air change rates are open doors and windows, wind speed and traffic in and out of the building. In structures that have combustion-type heating systems, the combustion air demands of the heating system can significantly affect the air exchange rate.

Radon progeny concentrations are also affected by ventilation changes and by conditions that alter the plateout of the progeny. The plate-out of radon progeny is affected by airborne nuclei concentrations, humidity, air motion, home furnishing types, the number of occupants and even the living habits of the occupants themselves.

Use of Indoor Measurements to Identify Geographical Areas Impacted by Elevated Indoor Radon Concentrations

During the period between early 1979 and mid-1981, emphasis was placed on research to determine the geographical areas of Butte most severely affected by elevated indoor radon concentrations. Initial screening of neighborhoods was conducted by the grab sample method. Homes were sampled only when the occupants provided assurance that the house had not been ventilated for at least three hours. Through September, 1981, 2884 grab samples had been collected in homes to determine radon progeny concentrations. Through December, 1982, the total increased to 3099 grab samples. These measurements were distributed in housing units as shown in Table 4-1. Many homes showing elevated radon progeny concentrations were sampled more than once to substantiate the measurements.

TABLE 4-1

INDOOR RADON PROGENY GRAB SAMPLE MEASUREMENTS
IN BUTTE (1979 - 1982)

Working Level	Total Housing Units*
Less than 0.010	1102
0.010 - 0.019	426
0.020 - 0.049	187
0.050 - 0.100	43
Greater than 0.100	13
Total Samples	1771

*A single family house or living unit in a multifamily structure is defined as a "housing unit".

Integrated radon progeny measurements were completed in 254 housing units with the use of RPISUs. The average annual concentrations in homes measured with RPISUs are shown in Table 4-2.

TABLE 4-2

AVERAGE ANNUAL CONCENTRATIONS OR RADON PROGENY IN HOUSING UNITS MEASURED WITH RADON PROGENY INTEGRATING SAMPLING UNITS

Working Level	Main Floor Measurements	Basement Measurements
Less than 0.010	58	9
0.010 - 0.019	39	12
0.020 - 0.050	76	16
Greater than 0.050	37	7
Total Housing Units Measured	210	44

5. RADON SOURCE ASSESSMENT

Summary

The objective of this study was to identify, to the extent possible, the source or sources of the elevated radon in structures in Butte and the Butte vicinity.

Tasks performed in the radon source assessment were:

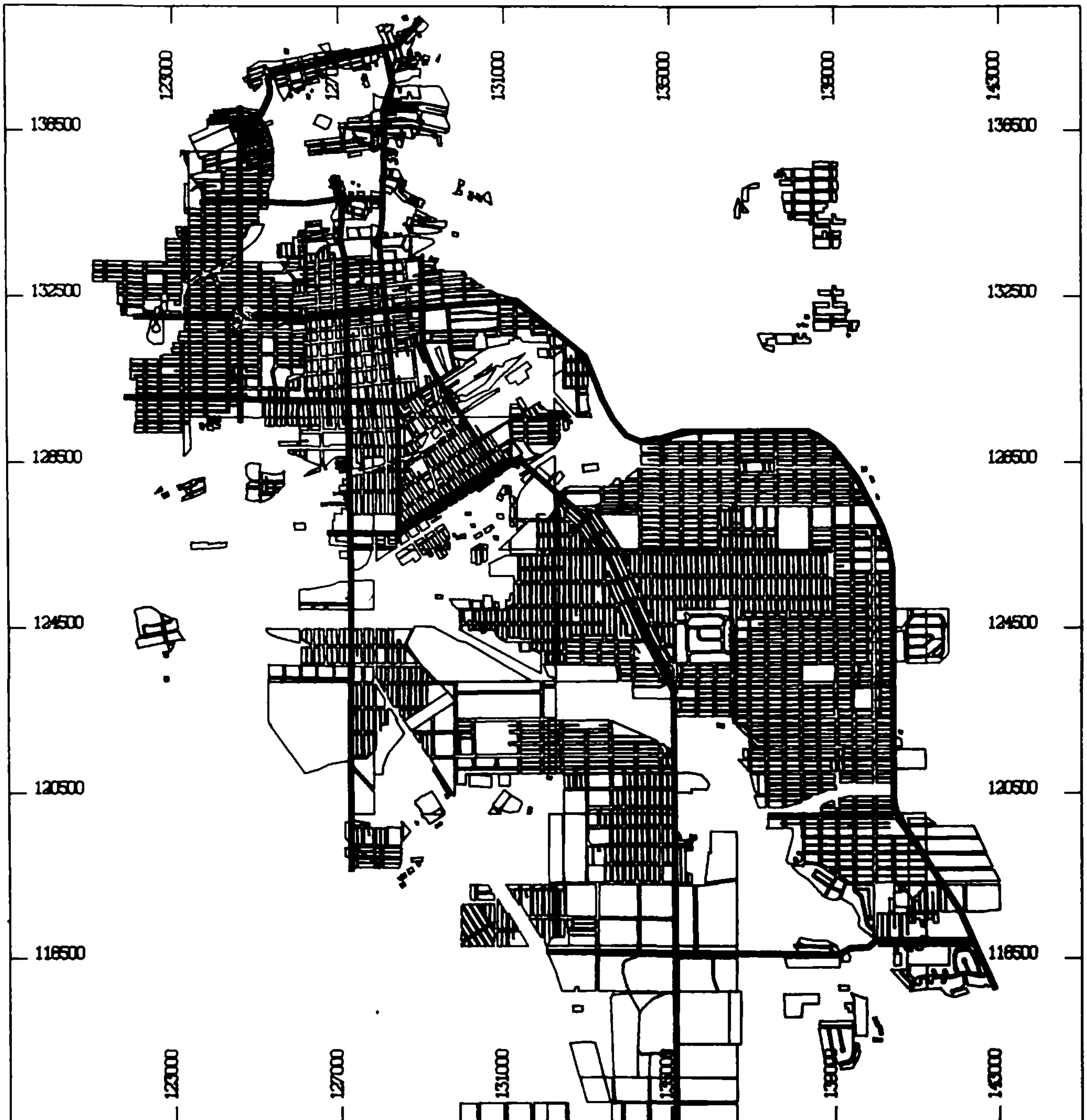
1. the measurement of radon and radon progeny in ambient air;
2. analysis of soil for radioactivity content;
3. measurement of radon/radon progeny concentrations in structures;
4. measurement of radon soil gas concentrations;
5. investigation of possible interrelationships between radon concentrations in structures, radon soil-gas concentrations and the surface geology;
6. measurement of dissolved radon concentrations in water supplies, and
7. evaluation of miscellaneous other potential sources of radon in structures.

Through an agreement with the U. S. Bureau of Mines (BOM), Spokane Research Center, acquired data were digitized and programmed into the BOM computer along with the coordinates of a Butte city map and available geological information. The BOM computer enabled the graphical display and evaluation of data. Numerous figures in this section were produced by the BOM computer system.

Figure 5-1 shows a city map of Butte with reference streets emphasized. The reference streets are identified by name in Figure 5-2. Reference streets shown in Figures 5-1 and 5-2 are used in most figures in this section to orient measurement sites. The grid markings shown in Figures 5-1 and 5-2 were established by the Anaconda Company for land survey purposes. The Anaconda grid was used by DHES and BOM to plot measurement sites and data points.

Ambient Measurements

In August, 1980, an ambient radon monitoring station was established at Hebgen Park (see Figure 5-2, location A). Hebgen Park is situated two blocks east of Arizona Street and one block north of Front Street. An Eberline Radon Gas Monitor, Model RGM-1, with an air intake located approximately 6 feet above ground level, was used to measure the ambient radon concentrations and was programmed to provide an hourly

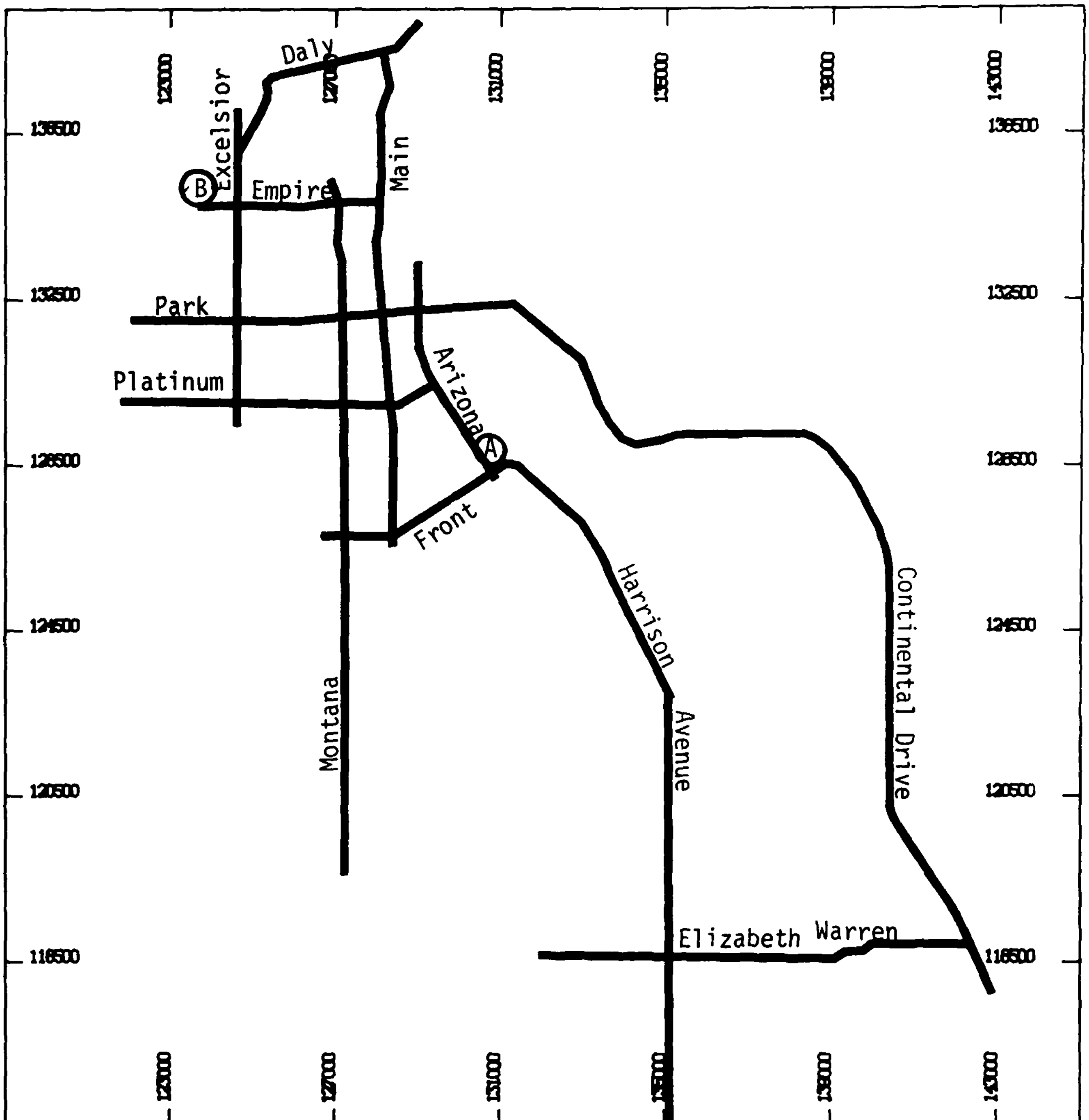


SCALE 1" = 4000. '

BOUNDARY				BOUNDARY		
EAST	=	145000.00	0 — 4000 FEET	NORTH	=	139500.00
WEST	=	119000.00		SOUTH	=	112500.00

FIGURE 5-1

CITY MAP OF BUTTE SHOWING
LOCATIONS OF REFERENCE STREETS



SCALE 1" = 4000. '

BOUNDARY

EAST - 145000.00

WEST - 119000.00

0 4000

FEET

BOUNDARY

NORTH - 139500.00

SOUTH - 112500.00

FIGURE 5-2

REFERENCE STREETS
AND OUTSIDE AIR MONITORING STATION LOCATIONS

printout of measurement data. Ambient radon measurements were collected almost continuously at the Hebgen Park Station between August, 1980, and August, 1981, with the exception of October, 1980. In October, the radon gas monitor was removed for maintenance and quality assurance tests.

The Butte area is subject to severe atmospheric thermal inversions that often trap atmospheric pollutants, including radon, in the Butte Basin during certain periods of the day. The inversion periods follow a diurnal pattern with the highest concentrations of radon occurring at approximately 6:00 a.m. and the lowest concentrations at about 6:00 p.m. The pattern of diurnal thermal inversions occurs throughout the year, but is frequently interrupted by winds and storms. The radon concentrations shown in Figures 5-3 through 5-6 are seasonally selected examples based on three-hour averages to show the effect of the diurnal thermal inversions on the ambient radon concentrations at the Hebgen Park monitoring station.

Figure 5-7 shows ambient radon concentrations averaged weekly and Figure 5-8 shows average monthly ambient radon concentrations at the Hebgen Park Monitoring Station for the period August, 1980 through August, 1981. It is interesting to note that average ambient radon concentrations ranged from a high of about 3 pCi/l to a low of less than 0.25 pCi/l. The highest concentrations were observed between August and November. Concentrations diminished through the winter months and reached a low in May and June.

Measurements of soil moisture were not made, but it is believed that the soil moisture content is probably responsible for the differing ambient radon concentations seen in Figures 5-7 and 5-8. In the winter months, the soil in the Butte area freezes to a depth of several feet. DHES believes that the frozen soil produces a capping effect that inhibits radon exhalation. Radon soil gas measurements made in the alluvium at a depth of 30 inches showed a radon soil gas concentration in winter months 69 percent higher than in summer months.

The spring of 1981 was unusually wet in western Montana. Precipitation in Butte during the months of April, May and June totaled 7.62 inches. The ambient radon concentrations for May and June, when the soil was heavy with water, were the lowest of the year. These measurements also indicate that an inverse relationship most likely exists between soil moisture content and the soil radon flux.

In February, 1982, an outside radon and radon progeny monitoring station was established at 933 Hornet Street (see Figure 5-2, location B). This station is situated in the first block west of Excelsior Street, one block north of Empire Street. The Hornet Street monitoring site is in the area of the city exhibiting the highest radon soil gas concentrations and the highest density of homes affected by elevated radon concentrations.

Unlike the Hebgen Park station, the air intake for the Radon Gas Monitor at the Hornet Street station was located about one foot above the ground and between two houses that are spaced by only six feet. The

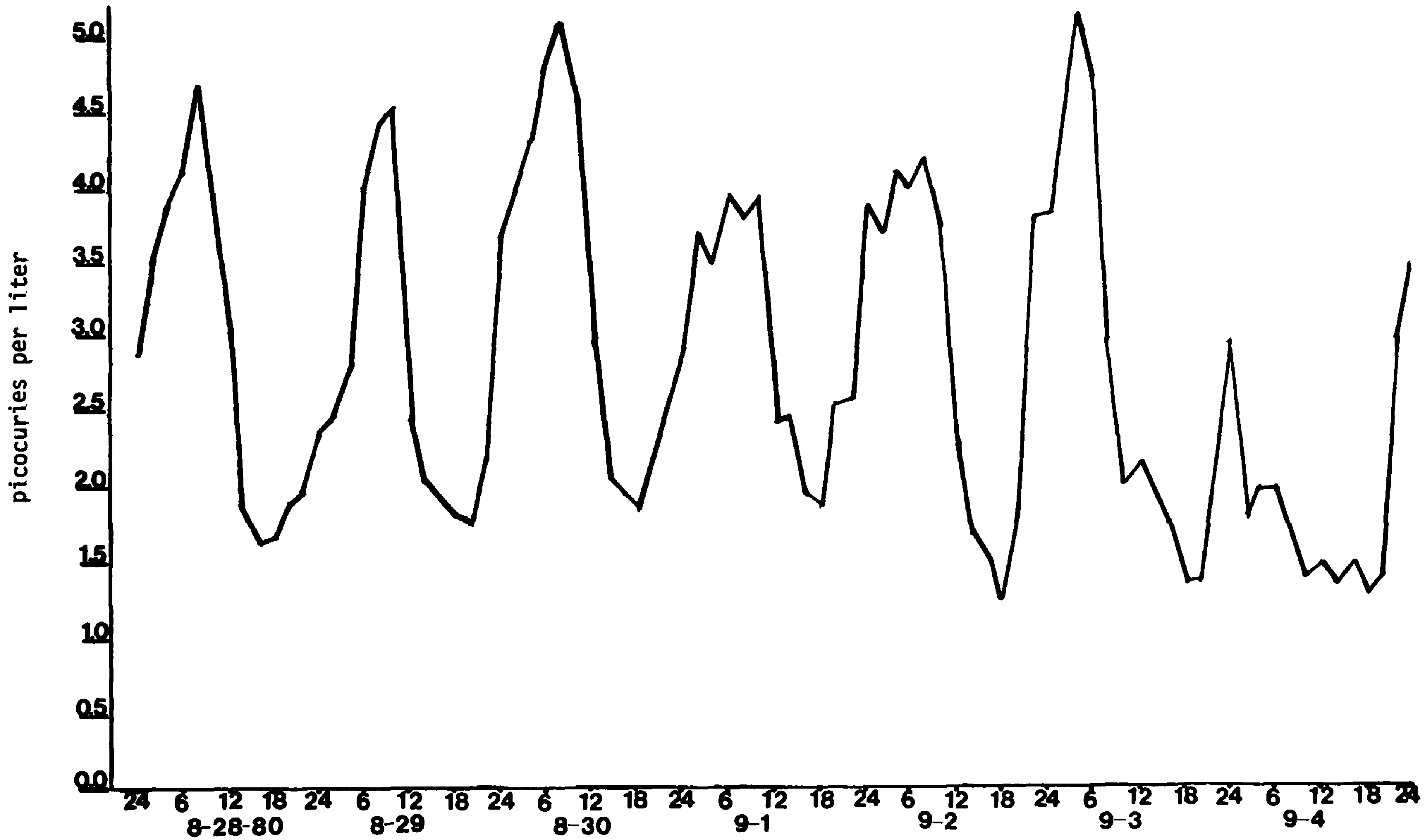


FIGURE 5-3

AMBIENT RADON CONCENTRATIONS
HEBGEN PARK MONITORING STATION, AUGUST 8 - SEPTEMBER 4, 1980

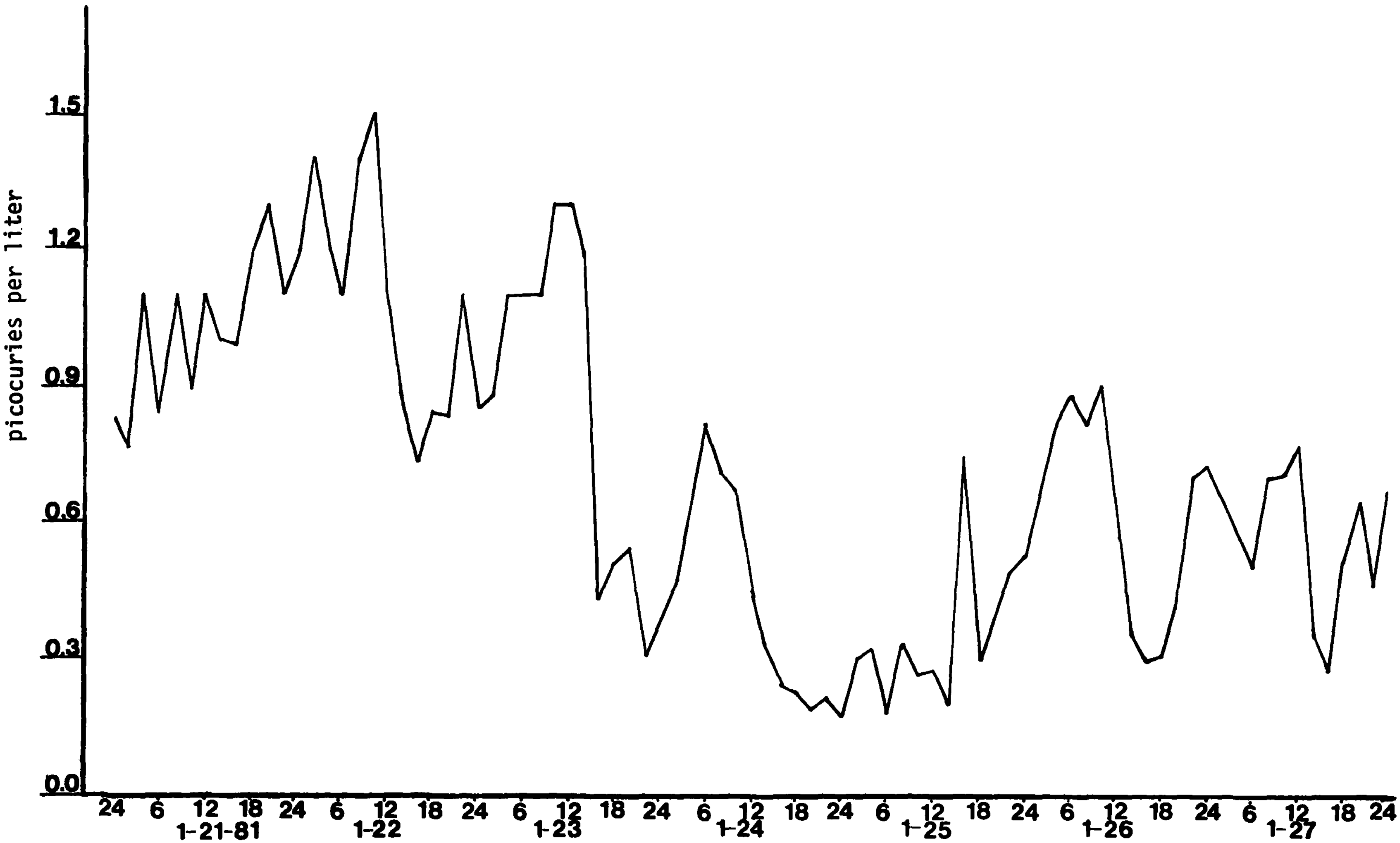


FIGURE 5-4

AMBIENT RADON CONCENTRATIONS
HEBGEN PARK MONITORING STATION, JANUARY 21 - JANUARY 27, 1981

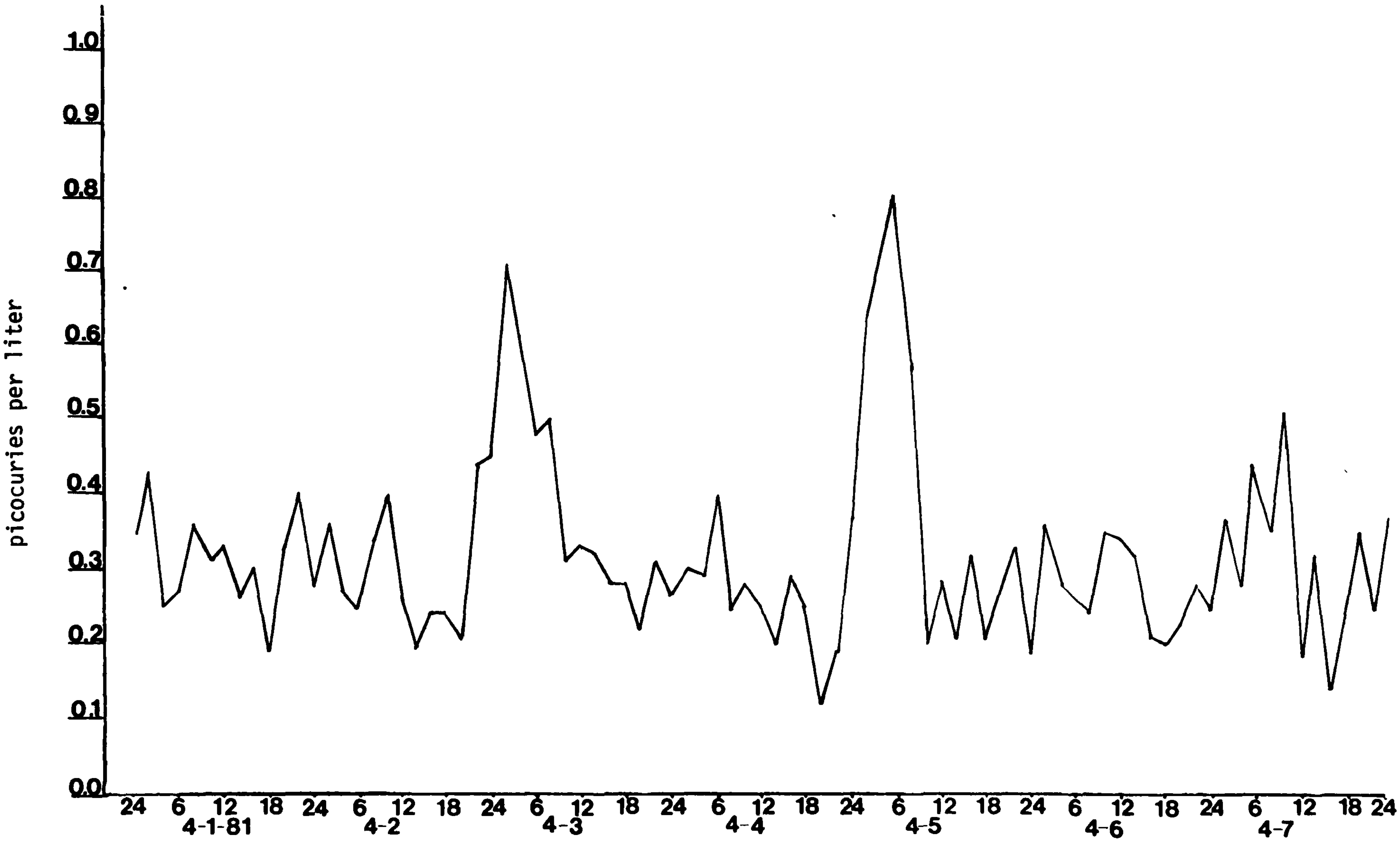


FIGURE 5-5

AMBIENT RADON CONCENTRATIONS
HEBGEN PARK MONITORING STATION, APRIL 1 - APRIL 7, 1981

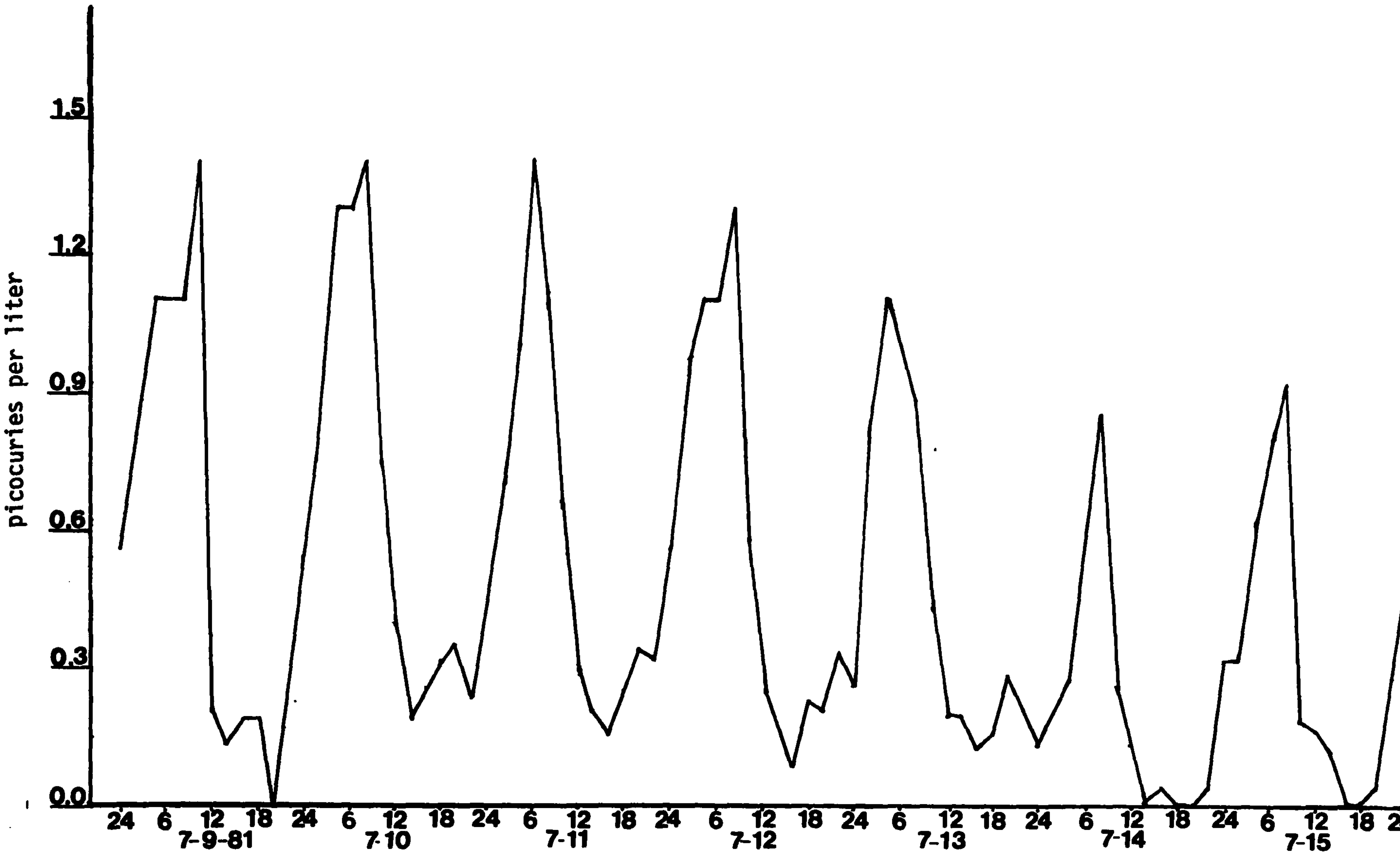


FIGURE 5-6

AMBIENT RADON CONCENTRATIONS
HEBGEN PARK MONITORING STATION, JULY 9 - JULY 15, 1981

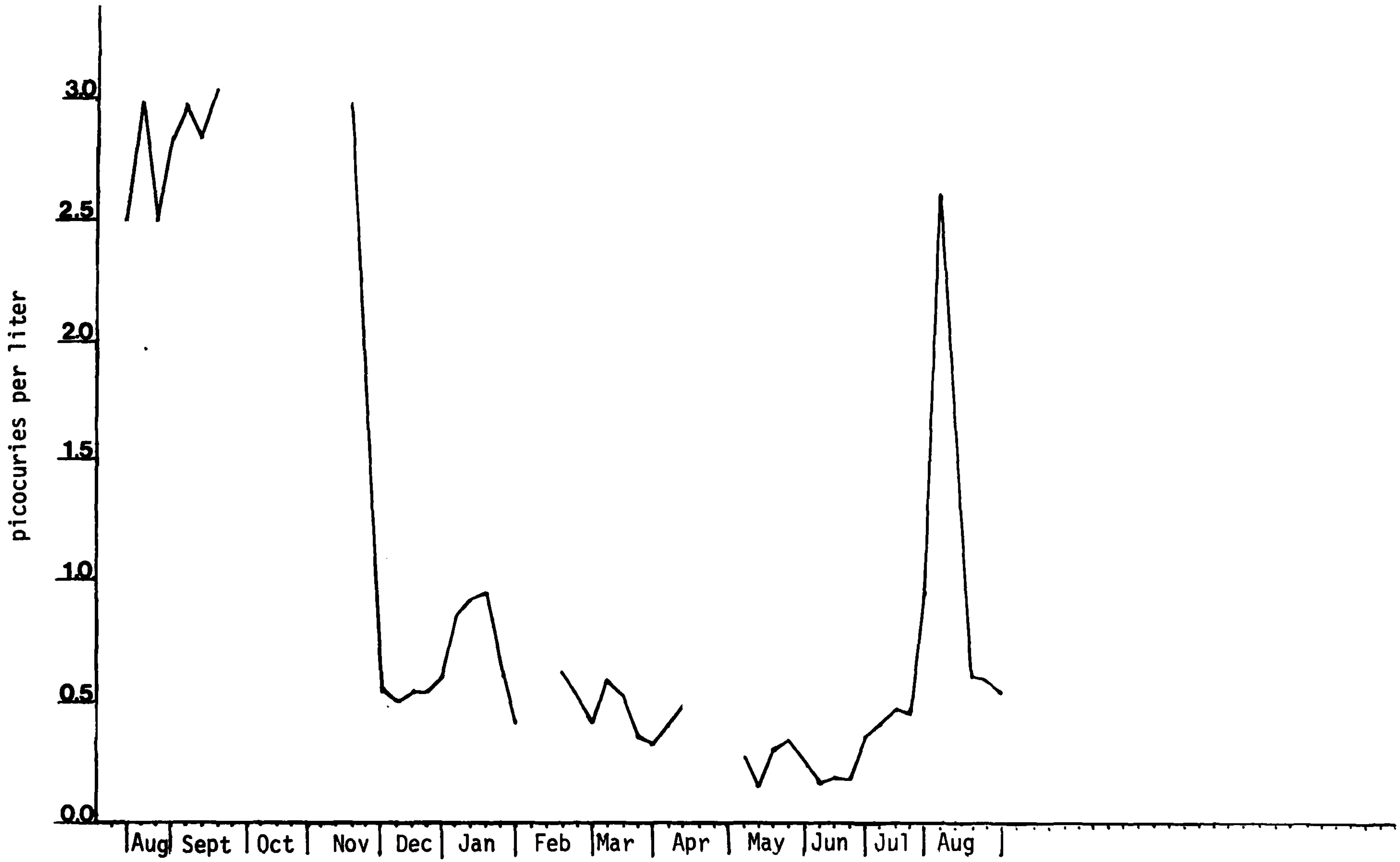


FIGURE 5-7

AVERAGE WEEKLY AMBIENT RADON CONCENTRATIONS
HEBGEN PARK MONITORING STATION, AUGUST, 1980 - AUGUST, 1981

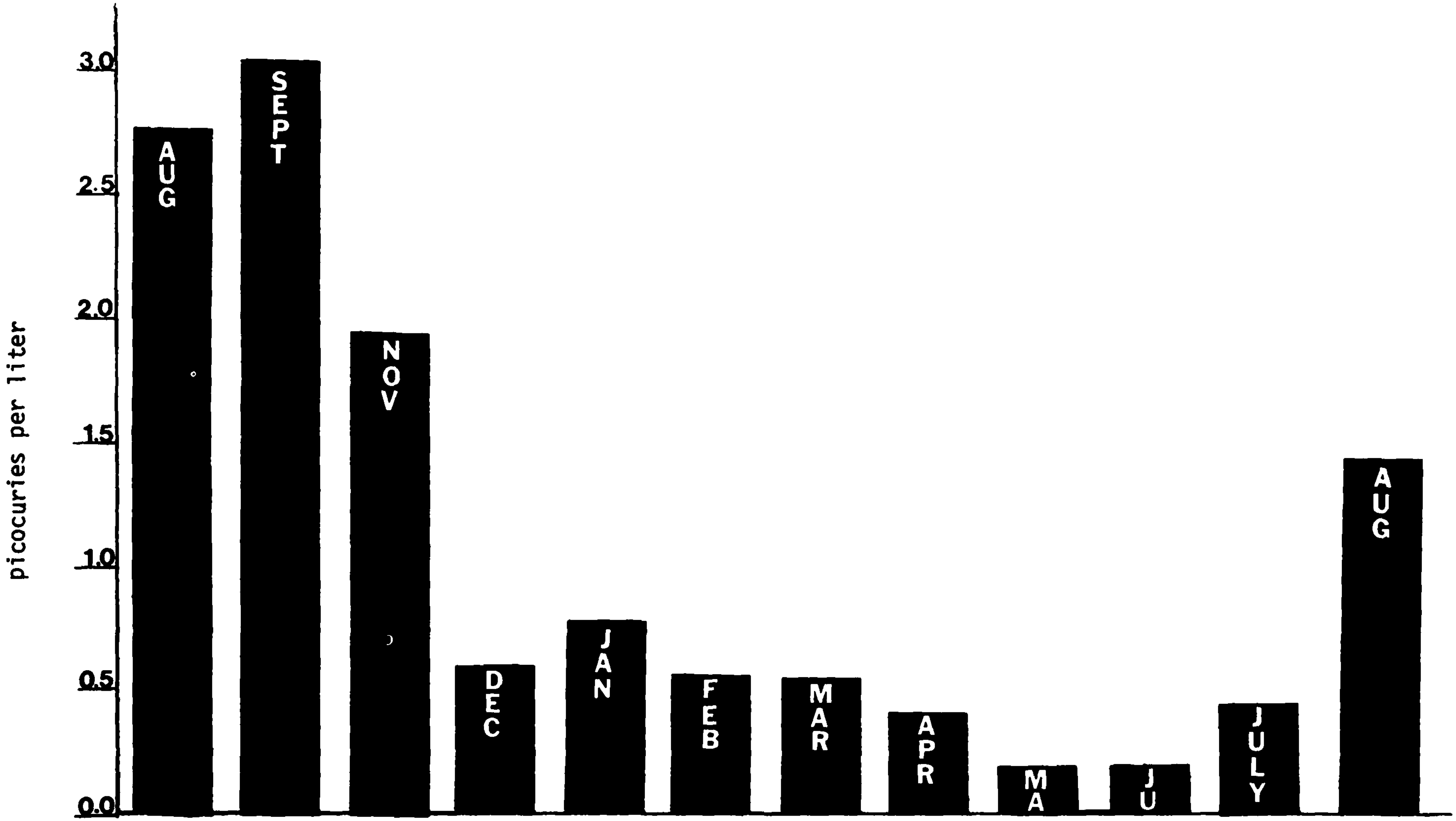


FIGURE 5-8

AVERAGE MONTHLY AMBIENT RADON CONCENTRATIONS
HEBGEN PARK MONITORING STATION, AUGUST, 1980 - AUGUST, 1981

location of the air intake probably accounts, at least partially, for the high outside radon measurements at the Hornet Street station.

Outside radon concentrations measured at the Hornet Street station averaged 3.25 pCi/l for the period February, 1982, through January, 1983. This average was substantially higher than the Hebgen Park station average of 0.98 pCi/l for the period August, 1980, through July, 1981.

The weekly average outside radon concentrations measured at the Hornet Street Station are shown in Figure 5-9. The average monthly measurements are presented in Figure 5-10. As seen in Figure 5-10, the monthly average outside radon concentrations at the Hornet Street Station ranged from a low of 1.47 pCi/l in February, 1982, to a high of 5.86 pCi/l in August, 1982.

The outside radon concentrations measured at the Hornet Street Station are higher than normally expected. Worldwide, ambient radon measurements normally vary from less than 0.1 pCi/l to about 1 pCi/l[8].

A RPISU was used at the Hornet Street station to monitor outside radon progeny concentrations. The average outside radon progeny concentration for the period February, 1982, through January, 1983, was 0.0031 WL. The outside radon progeny/radon equilibrium averaged about 10 percent for the period. The equilibrium from November through February averaged 17.5 percent. The equilibrium during the remaining months averaged 7 percent.

Soil Sampling and Analysis

Twenty-six soil samples were collected at selected sites ranging from Walkerville on the north to the airport on the south. These sampling site locations are shown in Figure 5-11. With the exception of Sample No. 7 which was collected at a soil depth of 10-15 cm, all soil samples were collected from the top 5 cm of soil. The soil samples were analyzed at the EPA's Las Vegas Facility for U-234, U-235, U-238, Th-230, Th-232, and Ra-226 content. The data for these 26 soil samples are shown in Table 5-1.

The normal Radium-226 content of soils ranges from about 0.4 to 1.3 picocuries per gram of soil[9]. The Ra-226 content in the samples shown in Table 5-1 averages 1.58 ± 0.59 picocuries per gram of soil with a range of 0.7 to 3.2 picocuries per gram. The Ra-226 content of soil in sections of the city experiencing elevated indoor radon concentrations does not differ substantially from concentrations in areas experiencing little or no problem.

Measurement of Radon Progeny Concentrations (WL) in Structures

Radon progeny concentrations measuring 0.02 WL or greater are found in structures scattered throughout the Butte area. The majority of the severely affected structures are in the northwest section of the city roughly bounded by Excelsior Street on the east and Park Street on the south.

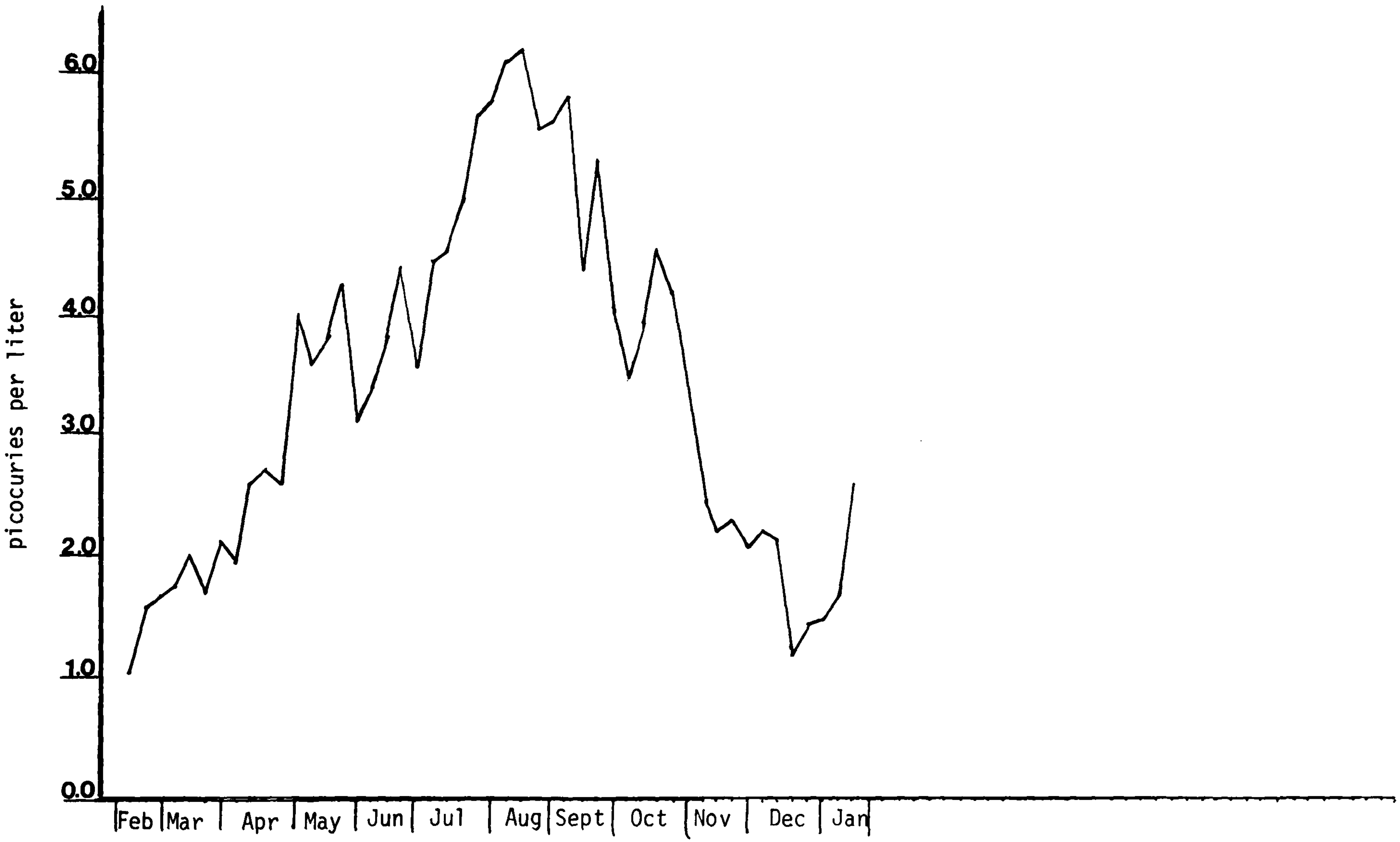


FIGURE 5-9

AVERAGE WEEKLY OUTSIDE RADON CONCENTRATIONS
HORNET STREET MONITORING STATION, FEBRUARY, 1982 - JANUARY, 1983

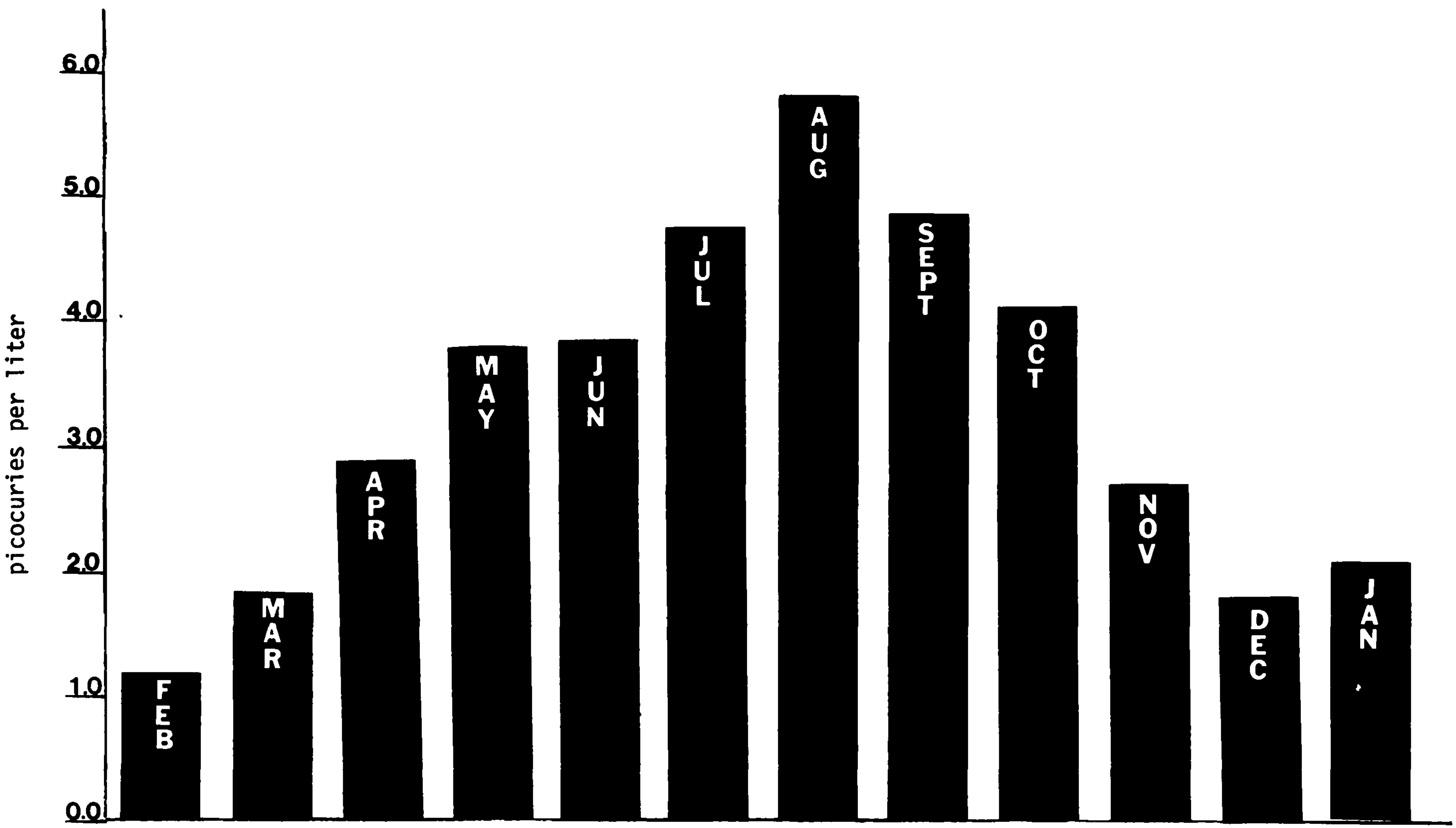


FIGURE 5-10

AVERAGE MONTHLY OUTSIDE RADON CONCENTRATIONS
HORNET STREET MONITORING STATION, FEBRUARY, 1982 - JANUARY, 1983

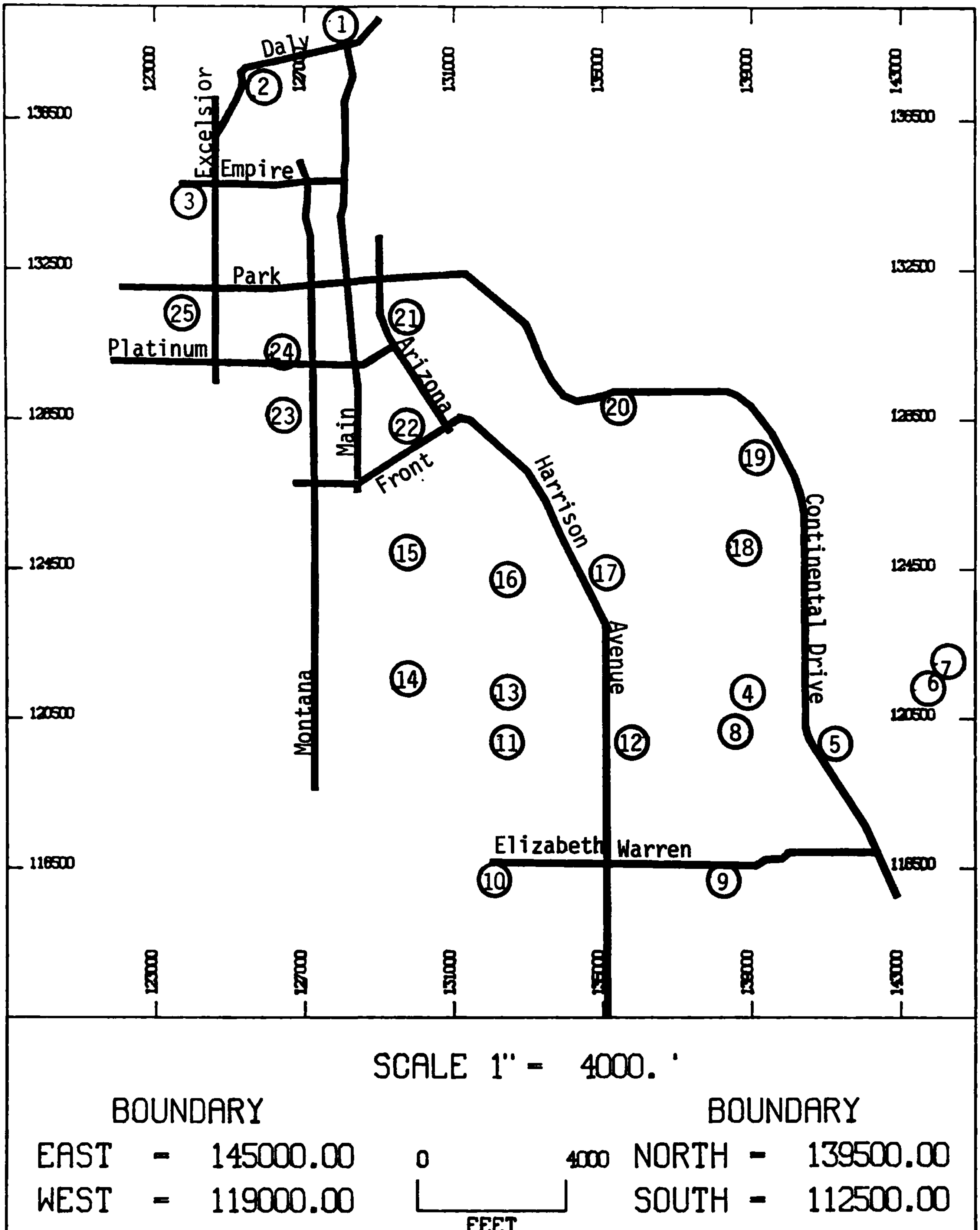


FIGURE 5-11

SOIL SAMPLING SITE LOCATIONS

TABLE 5-1

RADIOACTIVITY IN SOIL SAMPLES FROM BUTTE

Sample No.	Analysis	Result	2 Sigma*	Units
1 Walkerville-Sunview Terrace	234U	1.3E00	1.2E-01	PCI/GM
	235U	3.4E-02	1.9E-02	PCI/GM
	238U	1.4E00	1.3E-01	PCI/GM
	232TH	2.1E00	2.9E-01	PCI/GM
	230TH	1.3E00	2.0E-01	PCI/GM
	226RA	1.7E00	2.3E-01	PCI/GM
2 Walkerville-Missoula Gulch	234U	1.4E00	1.3E-01	PCI/GM
	238U	1.3E00	1.2E-01	PCI/GM
	235U	4.4E-02	2.1E-02	PCI/GM
	232TH	1.8E00	2.5E-01	PCI/GM
	230TH	1.5E00	2.1E-01	PCI/GM
	226RA	2.2E00	2.6E-01	PCI/GM
3 Western at Waukesha	235U	4.1E-02	2.1E-02	PCI/GM
	234U	7.5E-01	9.0E-02	PCI/GM
	238U	7.7E-01	9.2E-02	PCI/GM
	232TH	6.4E-01	2.3E-01	PCI/GM
	230TH	7.7E-01	2.7E-01	PCI/GM
	226RA	1.0E00	1.8E-01	PCI/GM
4 Amherst at Sheridan	238U	2.0E00	1.6E-01	PCI/GM
	234U	1.9E00	1.6E-01	PCI/GM
	235U	5.9E-02	2.4E-02	PCI/GM
	232TH	2.9E00	4.6E-01	PCI/GM
	230TH	1.8E00	3.0E-01	PCI/GM
	226RA	1.4E00	2.1E-01	PCI/GM
5 Keokuk at Continental	234U	2.5E00	1.9E-01	PCI/GM
	238U	2.6E00	1.9E-01	PCI/GM
	235U	1.0E-01	3.2E-02	PCI/GM
	232TH	8.2E00	1.2E00	PCI/GM
	230TH	3.2E00	5.1E-01	PCI/GM
	226RA	3.0E00	3.0E-01	PCI/GM
6 Foothills East Ridge	235U	<2.7E-02		PCI/GM
	234U	1.0E00	1.1E-01	PCI/GM
	238U	1.0E00	1.1E-01	PCI/GM
	232TH	1.9E00	2.7E-01	PCI/GM
	230TH	1.1E00	1.7E-01	PCI/GM
	226RA	1.3E00	2.0E-01	PCI/GM

Sample No.	Analysis	Result	2 Sigma*	Units
7 Foothills East Ridge	234U	1.2E00	1.1E-01	PCI/GM
	238U	1.3E00	1.2E-01	PCI/GM
	235U	4.9E-02	2.2E-02	PCI/GM
	232TH	2.4E00	3.8E-01	PCI/GM
	230TH	1.4E00	2.5E-01	PCI/GM
	226RA	1.4E00	2.1E-01	PCI/GM
8 Quincy at Banks	235U	< 3.6E-02		PCI/GM
	234U	1.6E00	1.6E-01	PCI/GM
	238U	1.4E00	1.5E-01	PCI/GM
	232TH	3.0E00	3.8E-01	PCI/GM
	230TH	1.6E00	2.2E-01	PCI/GM
	226RA	3.2E00	3.1E-01	PCI/GM
9 Greenlane	238U	7.0E-01	8.9E-02	PCI/GM
	234U	7.5E-01	9.2E-02	PCI/GM
	235U	< 2.9E-02		PCI/GM
	232TH	1.5E00	2.1E-01	PCI/GM
	230TH	7.0E-01	1.4E-01	PCI/GM
	226RA	9.6E-01	1.8E-01	PCI/GM
10 Lowell at Warren	235U	4.3E-02	2.1E-02	PCI/GM
	234U	1.4E00	1.3E-01	PCI/GM
	238U	1.3E00	1.3E-01	PCI/GM
	230TH	1.5E00	2.3E-01	PCI/GM
	232TH	2.3E00	3.3E-01	PCI/GM
	226RA	1.8E00	2.4E-01	PCI/GM
11 Wynne at Garfield	234U	1.0E00	1.1E-01	PCI/GM
	238U	1.0E00	1.1E-01	PCI/GM
	235U	3.5E-02	1.9E-02	PCI/GM
	230TH	1.1E00	1.9E-01	PCI/GM
	232TH	1.9E00	2.9E-01	PCI/GM
	226RA	1.3E00	2.1E-01	PCI/GM
12 Butte Ranger Station	235U	4.0E-02	2.2E-02	PCI/GM
	234U	1.1E00	1.2E-01	PCI/GM
	238U	1.1E00	1.2E-01	PCI/GM
	230TH	1.4E00	2.1E-01	PCI/GM
	232TH	2.1E00	3.1E-01	PCI/GM
	226RA	1.6E00	2.3E-01	PCI/GM
13 Shelly at Hill	238U	1.5E00	1.3E-01	PCI/GM
	234U	1.5E00	1.3E-01	PCI/GM
	235U	5.2E-02	2.2E-02	PCI/GM
	230TH	1.3E00	4.6E-01	PCI/GM
	232TH	1.7E00	4.7E-01	PCI/GM
	226RA	2.0E00	2.5E-01	PCI/GM

Sample No.	Analysis	Result	2 Sigma*	Units
14 Colusa at Hobson	235U	4.8E-02	2.3E-02	PCI/GM
	234U	1.3E00	1.3E-01	PCI/GM
	238U	1.4E00	1.3E-01	PCI/GM
	230TH	1.2E00	2.6E-01	PCI/GM
	232TH	2.7E00	4.0E-01	PCI/GM
	226RA	1.7E00	2.3E-01	PCI/GM
15 Cobban at Lexington	234U	1.7E00	1.5E-01	PCI/GM
	238U	1.7E00	1.5E-01	PCI/GM
	235U	6.2E-02	2.5E-02	PCI/GM
	230TH	1.5E00	1.9E-01	PCI/GM
	232TH	3.8E00	3.4E-01	PCI/GM
	226RA	1.4E00	2.1E-01	PCI/GM
16 Warren at A Street	235U	5.6E-02	2.4E-02	PCI/GM
	234U	1.3E00	1.3E-01	PCI/GM
	238U	1.3E00	1.2E-01	PCI/GM
	230TH	1.4E00	1.3E-01	PCI/GM
	232TH	1.9E00	1.5E-01	PCI/GM
	226RA	1.8E00	2.4E-01	PCI/GM
17 Mass at Majors	234U	1.4E00	1.3E-01	PCI/GM
	238U	1.3E00	1.2E-01	PCI/GM
	235U	5.1E-02	2.3E-02	PCI/GM
	230TH	1.5E00	1.7E-01	PCI/GM
	232TH	1.9E00	1.9E-01	PCI/GM
	226RA	2.0E00	2.5E-01	PCI/GM
18 Cobban at Porter	235U	5.5E-02	2.5E-02	PCI/GM
	234U	1.5E00	1.4E-01	PCI/GM
	238U	1.5E00	1.4E-01	PCI/GM
	230TH	1.6E00	2.1E-01	PCI/GM
	232TH	2.5E00	2.7E-01	PCI/GM
	226RA	2.2E00	2.6E-01	PCI/GM
19 Lafayette at Grand	234U	2.0E00	1.7E-01	PCI/GM
	238U	1.9E00	1.6E-01	PCI/GM
	235U	5.9E-02	2.5E-02	PCI/GM
	230TH	1.9E00	1.4E-01	PCI/GM
	232TH	2.0E00	1.4E-01	PCI/GM
	226RA	2.6E00	2.8E-01	PCI/GM
20 Silverbow at Carolina	235U	8.7E-02	2.9E-02	PCI/GM
	234U	2.4E00	1.8E-01	PCI/GM
	238U	2.3E00	1.7E-01	PCI/GM
	230TH	2.1E00	1.5E-01	PCI/GM
	232TH	2.3E00	1.6E-01	PCI/GM
	226RA	2.0E00	2.5E-01	PCI/GM

Sample No.	Analysis	Result	2 Sigma*	Units
21 Ohio at Davidson	238U	1.2E00	1.2E-01	PCI/GM
	234U	1.0E00	1.1E-01	PCI/GM
	235U	<3.1E-02		PCI/GM
	230TH	9.8E-01	2.9E-01	PCI/GM
	232TH	1.8E00	3.9E-01	PCI/GM
	226RA	1.8E00	2.4E-01	PCI/GM
22 1st at California	235U	7.7E-02	2.9E-02	PCI/GM
	234U	2.2E00	1.8E-01	PCI/GM
	238U	2.1E00	1.7E-01	PCI/GM
	230TH	1.9E00	4.6E-01	PCI/GM
	232TH	1.0E00	3.4E-01	PCI/GM
	226RA	2.2E00	2.6E-01	PCI/GM
23 Zinc Street	238U	1.0E00	1.1E-01	PCI/GM
	234U	1.0E00	1.1E-01	PCI/GM
	232TH	1.5E00	1.2E-01	PCI/GM
	235U	4.2E-02	2.1E-02	PCI/GM
	230TH	1.2E00	1.1E-01	PCI/GM
	226RA	7.0E-01	1.5E-01	PCI/GM
24 Jackson at Gold	232TH	3.1E00	3.6E-01	PCI/GM
	235U	5.5E-02	2.2E-02	PCI/GM
	230TH	2.0E00	2.8E-01	PCI/GM
	234U	1.6E00	1.3E-01	PCI/GM
	238U	1.6E00	1.3E-01	PCI/GM
	226RA	2.3E00	2.6E-01	PCI/GM
25 Diamond at Girard	232TH	3.5E00	2.3E-01	PCI/GM
	234U	1.2E00	1.2E-01	PCI/GM
	230TH	2.0E00	1.6E-01	PCI/GM
	238U	1.4E00	1.3E-01	PCI/GM
	235U	4.1E-02	2.2E-02	PCI/GM
	226RA	2.3E00	2.6E-01	PCI/GM
26 Sutter Street	232TH	2.5E00	1.8E-01	PCI/GM
	235U	4.4E-02	2.0E-02	PCI/GM
	230TH	2.1E00	1.6E-01	PCI/GM
	234U	1.6E00	1.3E-01	PCI/GM
	238U	1.5E00	1.3E-01	PCI/GM
	226RA	2.0E00	2.4E-01	PCI/GM

*The number following the "E" is the exponent of ten by which the preceding number should be multiplied. There is a 95 percent assurance that the true value lies between the reported value ± 2 sigma.

An intrusive rhyolite plug known as "Big Butte" adjoins the northwest side of this area. The remainder of the Butte surface geology consists primarily of quartz monzonite interspersed with aplite dikes and areas of alluvium. The Butte hill is interspersed with mineralized veins which have been actively mined for the last hundred years. The surface geology is highly fractured. The fracturing becomes extreme at the periphery of Big Butte, and underlies the area of the city most seriously affected by high indoor radon concentrations.

The surface geology of the Butte hill is shown in Figure 5-12. Veins and fractures are shown in Figure 5-13. Veins are shown as solid lines and fractures by dashed lines.

Efforts to correlate specific geologic types with indoor radon measurements and with radon soil gas concentrations were only partly successful. No home investigated that was built over rhyolite had indoor radon progeny concentrations exceeding 0.02 WL. Radon soil gas measurements in rhyolite were low. Six radon soil gas measurements (see Figure 5-21, sampling sites numbers 54, 55, 92, 108, 116 and 117) in rhyolite averaged 80 pCi/l during summer months as compared to an average of 1082 pCi/l for the Butte area as a whole.

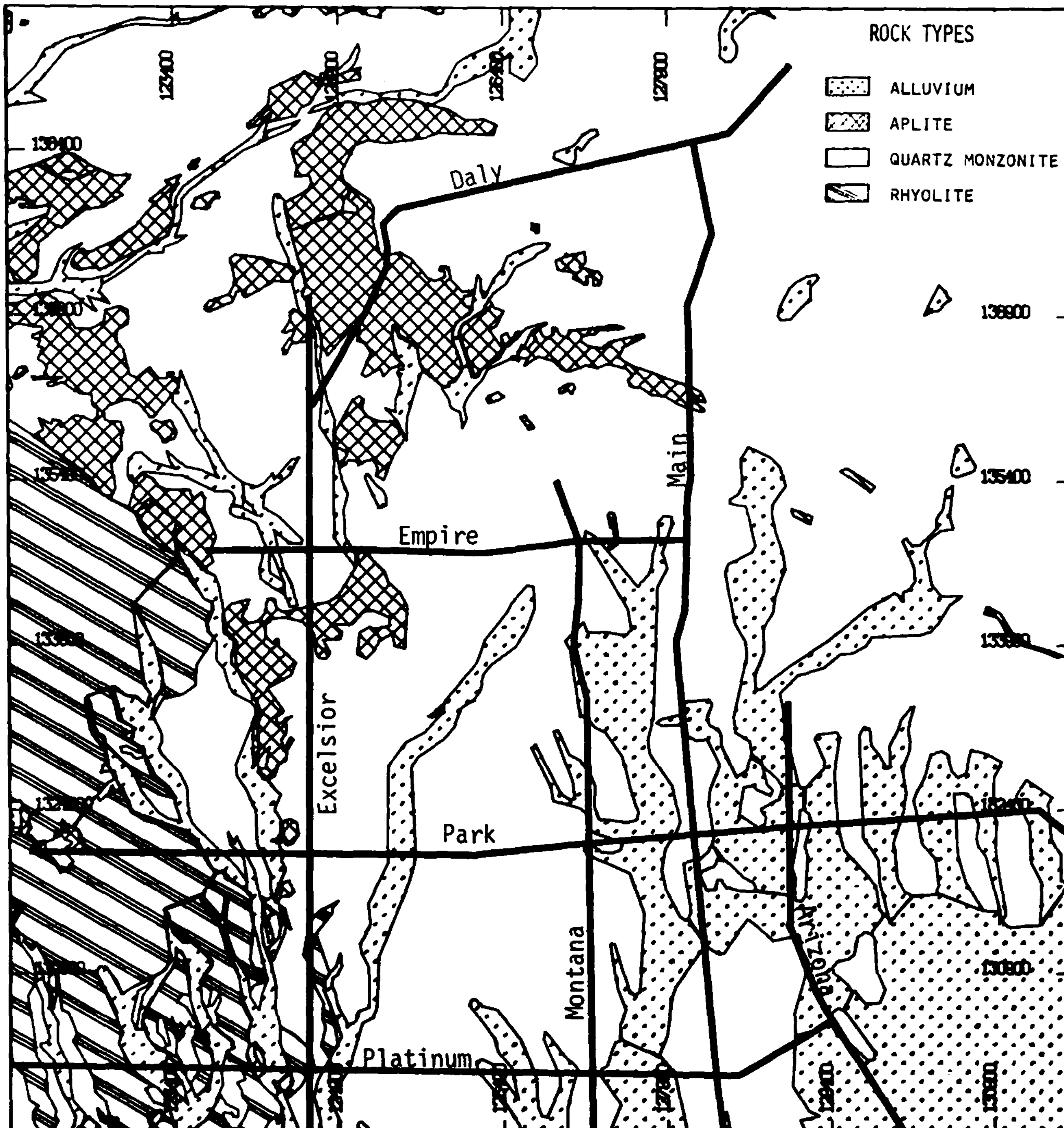
In an area west of Excelsior Street and particularly between Lewisohn Street on the south and Zarelda Street on the north, dramatic changes were noted in indoor radon progeny concentrations as measurements progressed from structures built over rhyolite to structures built over aplite and quartz monzonite. In some instances measurements changed from less than 0.02 WL to over 0.1 WL in less than one city block.

Most of the homes that measured in excess of 0.10 working levels were in the northern section of the city west of Excelsior Street (see Figure 5-14). The surface geology in this area is primarily quartz monzonite with some outcroppings of aplite, is severely fractured and interlaced with mineralized veins. McClernan[10] believes that the severe fracturing in this area resulted when the rhyolite plug forming Big Butte was thrust upward through the underlying quartz monzonite basement rock.

Radon soil gas measurements in this area are high and fluctuate erratically with location as do indoor measurements of radon and radon progeny. The rock type upon which structures are built is not totally responsible for the elevated indoor radon concentrations. Measurements of radon soil gas concentrations over mineralized veins and over major fractures show radon levels considerably higher than those measured in the surrounding rock.

The elevated radioactivity content of mineralized veins is easily demonstrated by a portable gamma scintillometer. The gamma radiation levels of some veins are an order of magnitude higher than the gamma measurements of surrounding rocks.

It is believed that many structures having high concentrations of indoor radon are built over mineralized veins or over fractures which

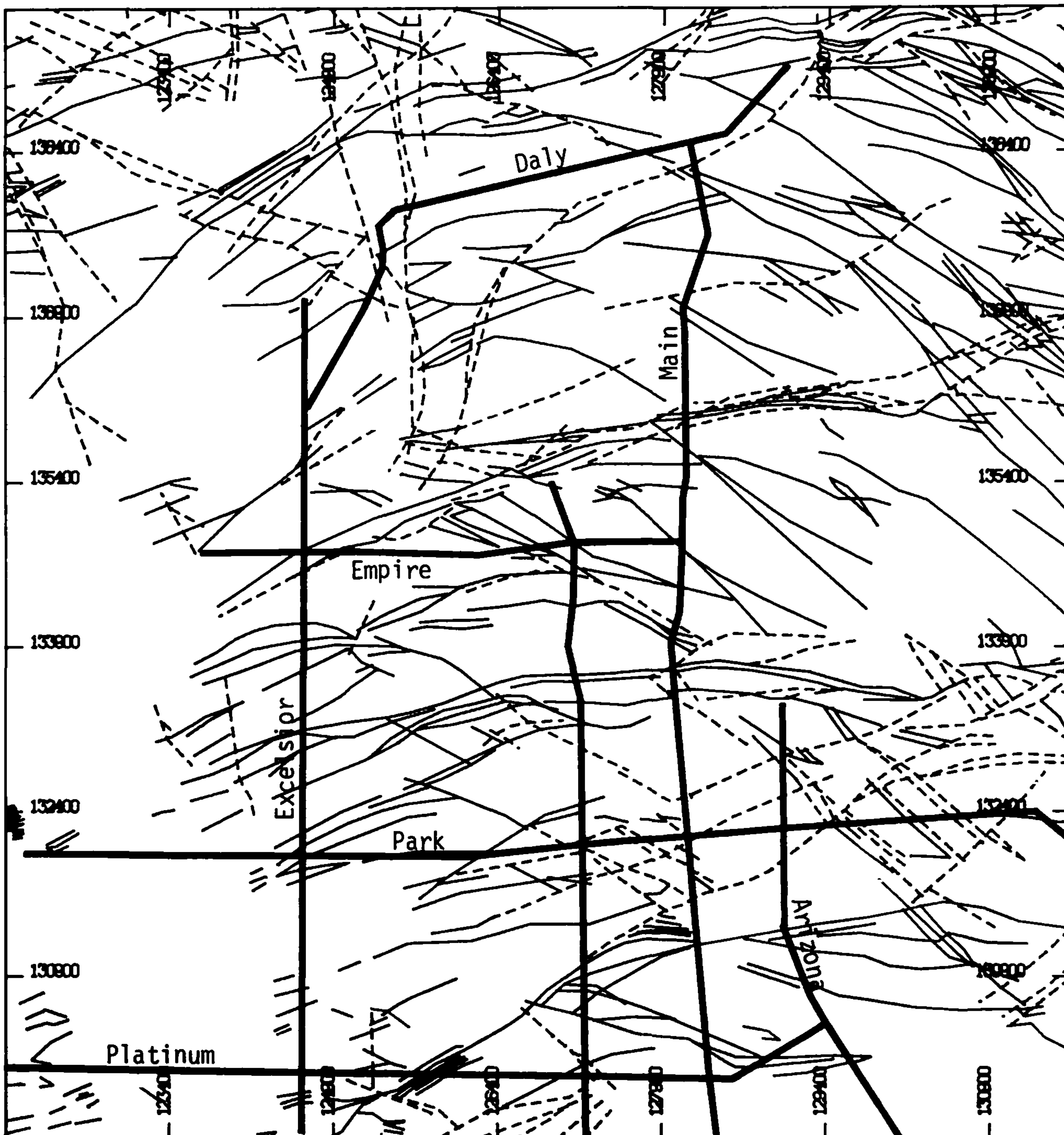


SCALE 1" = 1500.'

BOUNDARY			BOUNDARY	
EAST -	131625.00	0 — 1500 FEET	NORTH -	139700.00
WEST -	121900.00		SOUTH -	129400.00

FIGURE 5-12

NORTHWEST BUTTE SURFACE GEOLOGY



SCALE 1" = 1500.'

BOUNDARY

EAST = 131625.00

WEST = 121900.00

0 1500

FEET

BOUNDARY

NORTH = 139700.00

SOUTH = 129400.00

FIGURE 5-13

VEINS AND FRACTURES IN
NORTHWEST BUTTE GEOLOGY

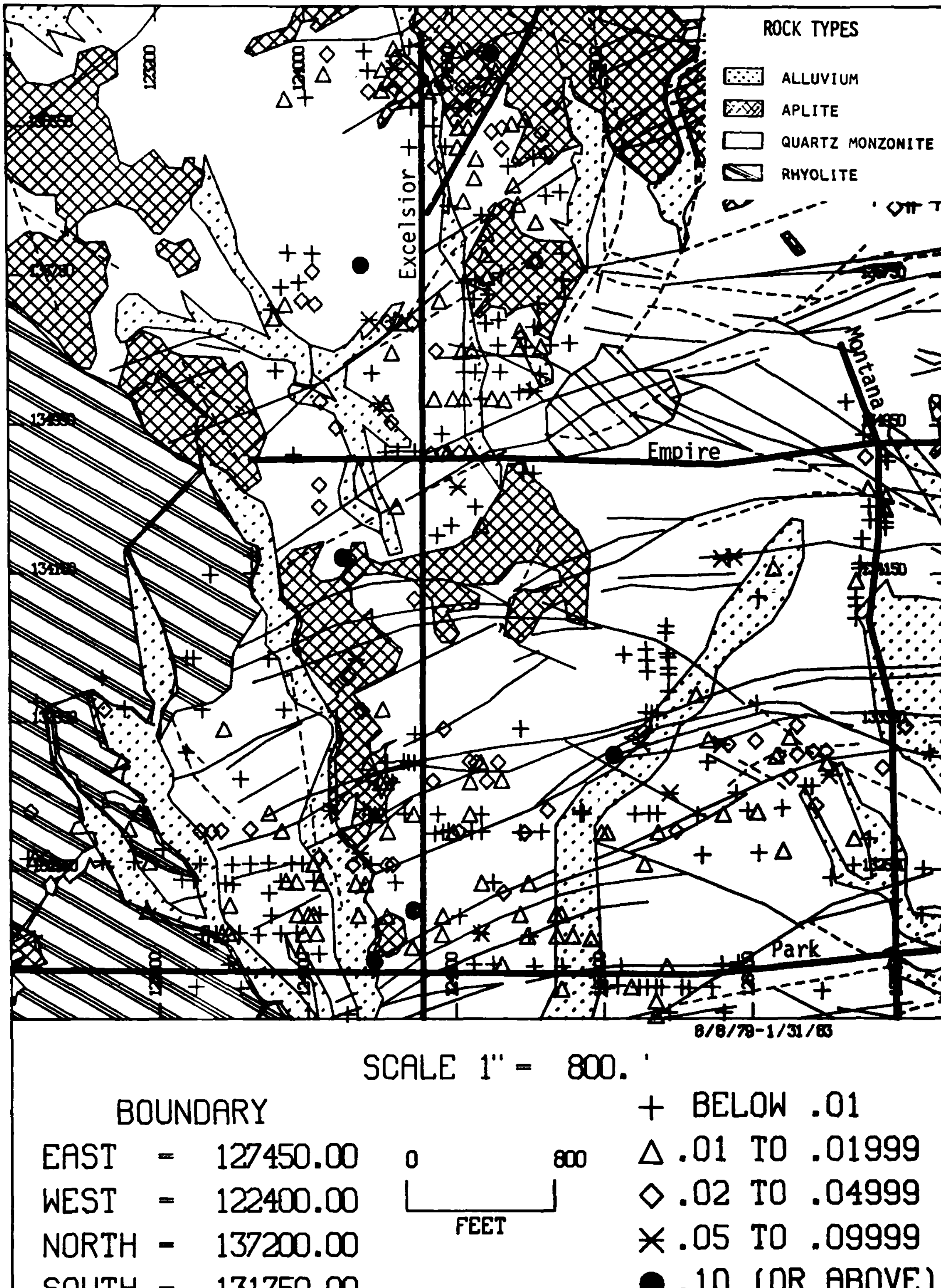


FIGURE 5-14

BUTTE GEOLOGY/INDOOR RADON PROGENY CONCENTRATIONS (WL) IN INDIVIDUAL STRUCTURES act as conduits for transporting radon to the structure. This theory would also account for the erratic soil gas measurements in fractured areas and areas interlaced by veins.

Structures having radon progeny concentrations exceeding 0.02 WL are distributed throughout the city. Figures 5-15 and 5-16 show the aggregate average of all indoor radon progeny measurements based upon a 300 foot grid.

Besides the northwest section of the city, two other areas have a relatively high density of structures with indoor radon progeny concentrations that exceed 0.02 WL. A community housing project known as Silver Bow Homes is in one of these areas. Silver Bow Homes consists of 19 two-story apartment buildings, and is on the east side of Arizona Street between Park and Front Streets. Skyway Park is in the second area. Skyway Park is located on the south side of the city just north of the airport, between Harrison Avenue and Continental Drive. Except for a multi-family housing project known as Town and Country Apartments, the Skyway Park addition consists primarily of single-family housing.

Silver Bow Homes

In September, 1979, HUD initiated a requirement that all subsidized housing units in Butte must have radon progeny concentrations of 0.02 WL or less. Under contract with HUD, DHES measured each apartment in the Silver Bow Homes complex, with results as shown in Figure 5-17. Fifty-seven of the 225 apartments in the Silver Bow Homes complex exceeded the 0.02 WL criteria established by HUD. In 1980, HUD provided funds to Silver Bow Homes to remediate the radon problem.

In 1982, the remediation of Silver Bow Homes was accomplished by sealing penetrations between the crawl spaces and the apartments. The undersides of the floors were sprayed with one and one-half inches of closed-cell polyurethane foam and passive ventilation stacks were installed from the crawl space through the roof of each structure.

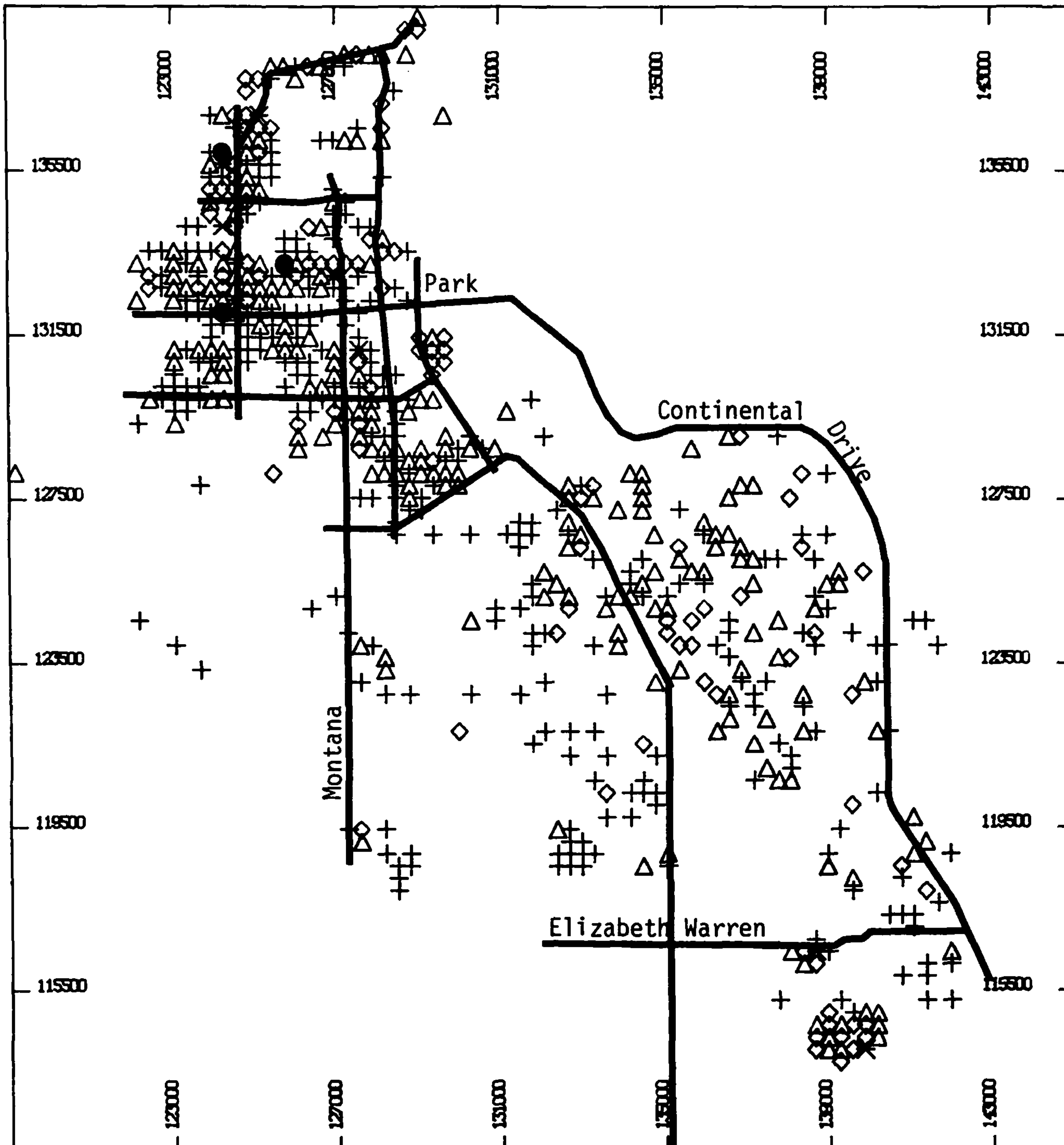
After remediation, each apartment which originally measured in excess of 0.02 WL was remeasured. All apartments were found to meet the HUD criterion.

Skyway Park

The surface geology in Skyway Park is alluvium estimated to be approximately one hundred feet deep. Because of the deep alluvium, it was not anticipated that structures in this area would be troubled by indoor radon; however, measurements of radon progeny concentrations in some Skyway Park structures were surprisingly high. These measurements are shown in Figure 5-18.

Radon Soil Gas Measurements

Soil gas measurement sites were located throughout the Butte area on a one-half mile grid. In northwest Butte additional sampling sites were established on a sub-grid of one city block.



8/8/79-1/1/83

SCALE 1" = 4000. '

BOUNDARY

EAST = 145000.00

WEST = 119000.00

NORTH = 139500.00

SOUTH = 111500.00

0 4000

FEET

+ BELOW .01

△ .01 TO .01999

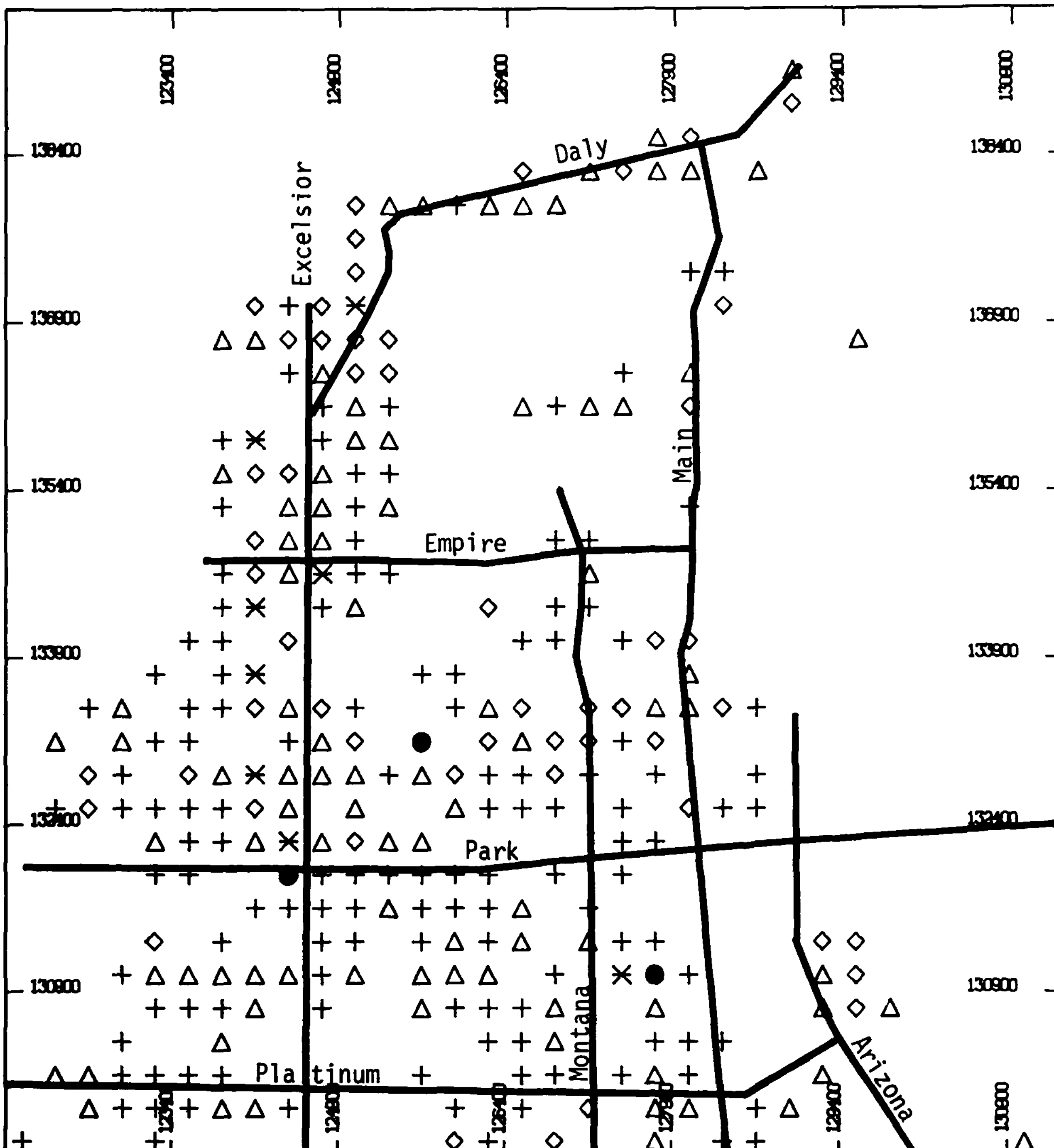
◇ .02 TO .04999

✕ .05 TO .09999

● .10 (OR ABOVE)

FIGURE 5-15

THREE HUNDRED FOOT AGGREGATE AVERAGE OF INDOOR RADON PROGENY CONCENTRATIONS (WL) IN BUTTE



8/8/79-1/1/83

SCALE 1" = 1500. '

BOUNDARY

EAST = 131390.00

WEST = 121900.00

NORTH = 139700.00

SOUTH = 129400.00

0 1500

FEET

+ BELOW .01

△ .01 TO .01999

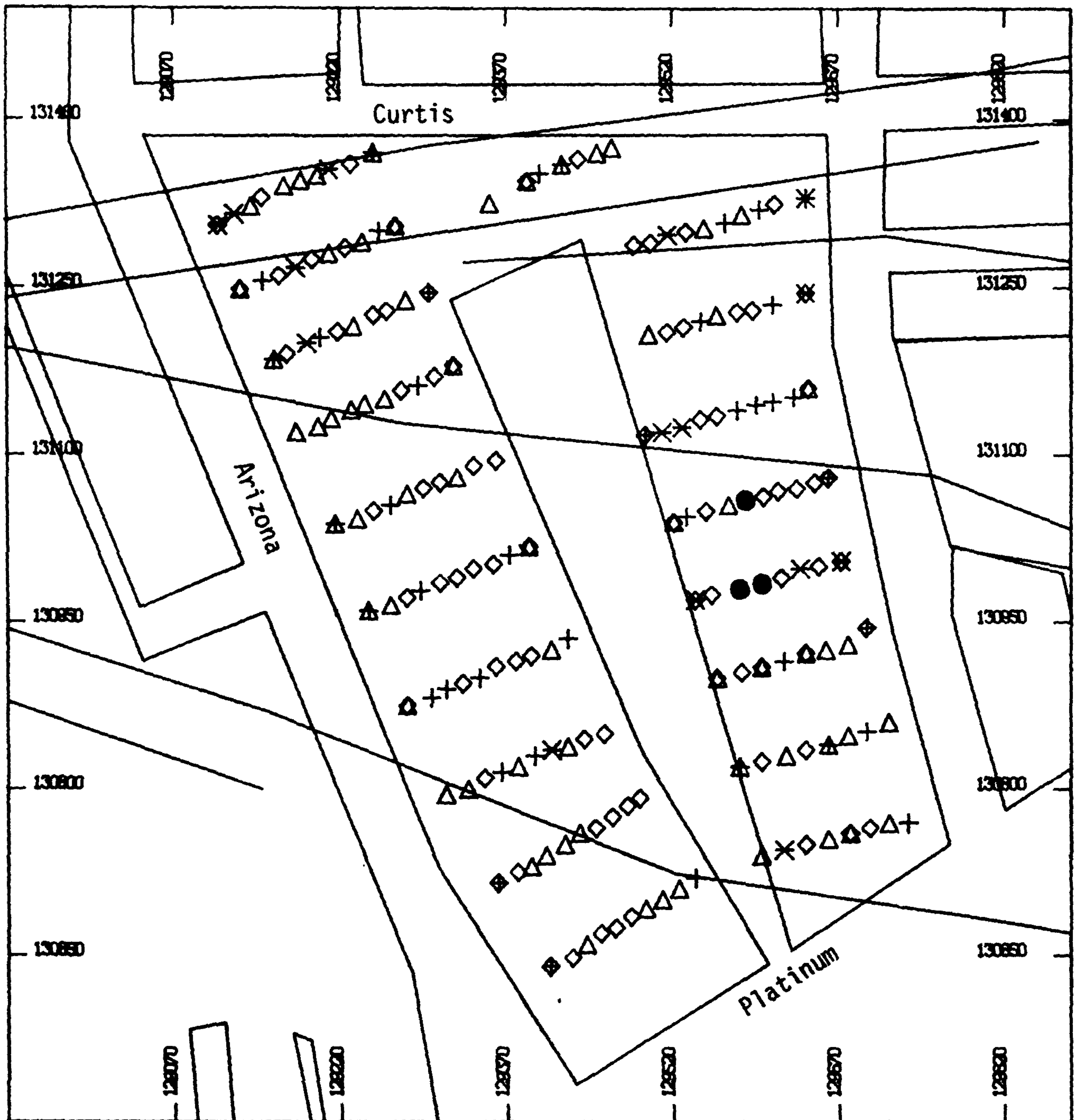
◇ .02 TO .04999

✕ .05 TO .09999

● .10 (OR ABOVE)

FIGURE 5-16

THREE HUNDRED FOOT AGGREGATE AVERAGE OF INDOOR RADON PROGENY CONCENTRATIONS (WL) IN N.W. BUTTE



8/8/79-1/31/83

SCALE 1" = 150.'

BOUNDARY

EAST - 129880.00
WEST - 128920.00
NORTH - 131500.00
SOUTH - 130500.00

0 150
FEET

+ BELOW .01
△ .01 TO .01999
◇ .02 TO .04999
✳ .05 TO .09999
● .10 (OR ABOVE)

FIGURE 5-17

INDOOR RADON PROGENY MEASUREMENTS (WL) - SILVER BOW HOMES

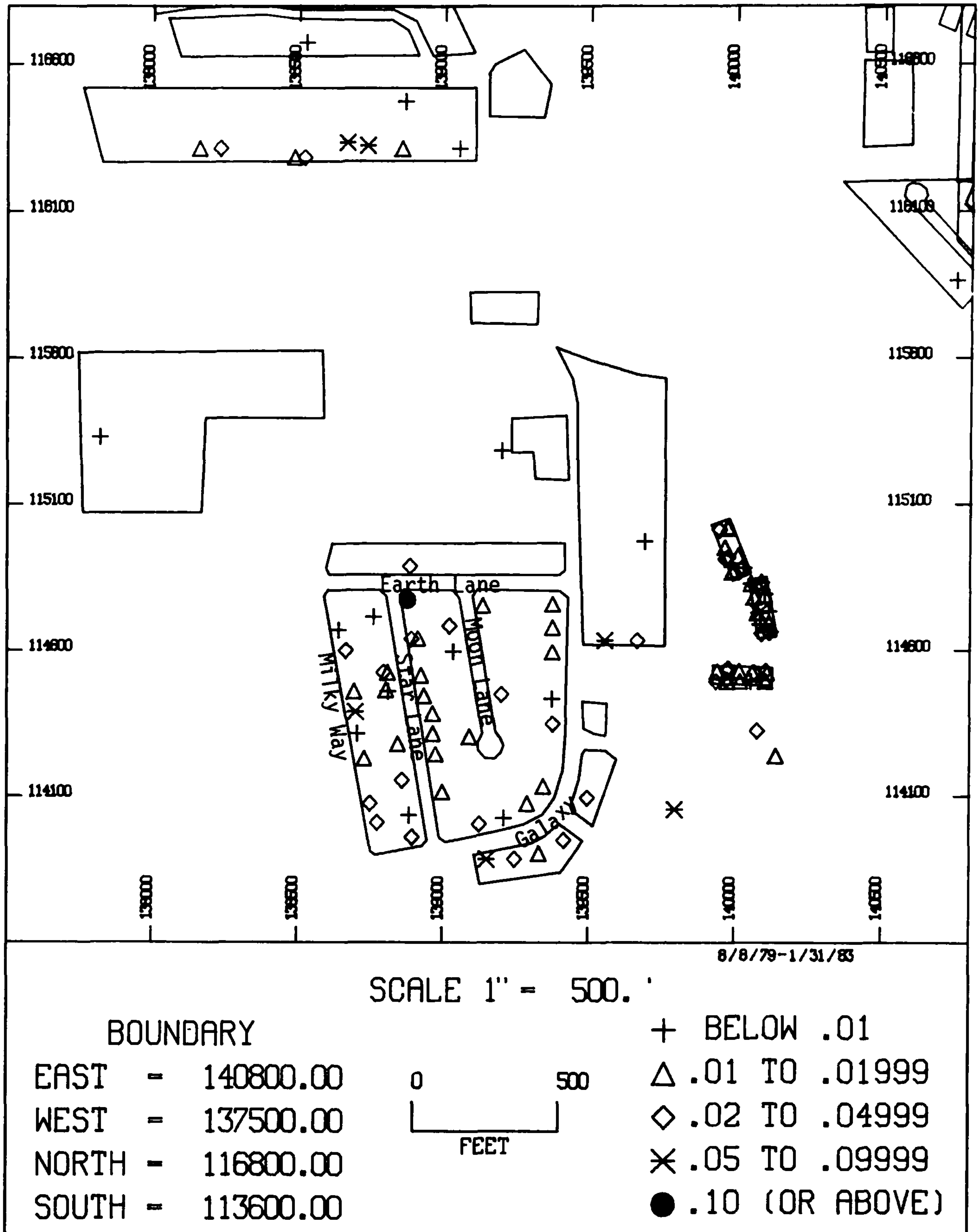


FIGURE 5-18

INDOOR RADON PROGENY MEASUREMENTS (WL) - SKYWAY PARK

Alpha track detectors were used for measurement of radon soil gas concentrations. The alpha-track detector is a plastic chip which, after processing, shows tracks (damaged areas) where the detector was struck by alpha particles. The tracks are counted under magnification. The number of tracks in a given area is proportional to the concentration of radon to which the detector was exposed and to the time of exposure.

The alpha-track detectors were placed in plastic cups, with the tops covered by a thin membrane (thoron filter) that prevents the penetration of thoron (radon-220) but allows the entry of radon (radon-222).

Precautions were taken during the placement of the alpha-track detectors. For the safety of personnel and to assure that underground utilities would not be damaged while digging holes, utility companies were given maps showing proposed measurement site locations. Utilities included were electric, natural gas, telephone and cable television. After a review by the companies, two sites had to be relocated a few feet to avoid lines.

When alpha-track detectors are used for uranium exploration, the location of the detector is generally marked with a flag. There was concern that the detectors would be removed by vandals or curiosity seekers if the locations of the detectors were visibly marked in a populated area. To simplify recovery and to prevent theft, the alpha-track detectors were placed at a soil depth of 30 inches in a 4-inch PVC sleeve. A string was attached to the detector cup to lower it into the sleeve. An ample length of string was attached to the detector cup to allow the string to extend through the top of the sleeve. A pipe cap was then placed on the sleeve. The sleeves were cut at a length of 26 inches to provide for a detector depth of 30 inches with a 4-inch soil cover over the pipe cap. An iron washer was placed on top of the pipe cap prior to covering the cap with soil.

The location of each detector was carefully logged with reference to readily identifiable landmarks. For recovery, a metal detector was used to locate each sleeve. Only 3 out of more than 400 detectors which were emplaced were lost. These detectors were lost because road grading excavations had removed the iron washer or possibly even the sleeve and detector.

Figure 5-19 shows the alpha-track detector placed in the PVC sleeve assembly. Figure 5-20 shows the locations where alpha-track detectors were placed throughout Butte on a one-half mile grid. Figure 5-21 shows the locations where alpha-track detectors were placed in northwest Butte on a grid of one city block.

Alpha-track detectors were emplaced from July through October, 1980, and again from October, 1980, through April, 1981, to obtain measurements in both the summer and winter seasons. The radon soil gas concentration measured at each site during each sampling period is shown in Table 5-2. In Table 5-2 there is an uncertainty of the stated concentrations in pCi/l. It is believed that the relative intercomparisons between values are more valid.

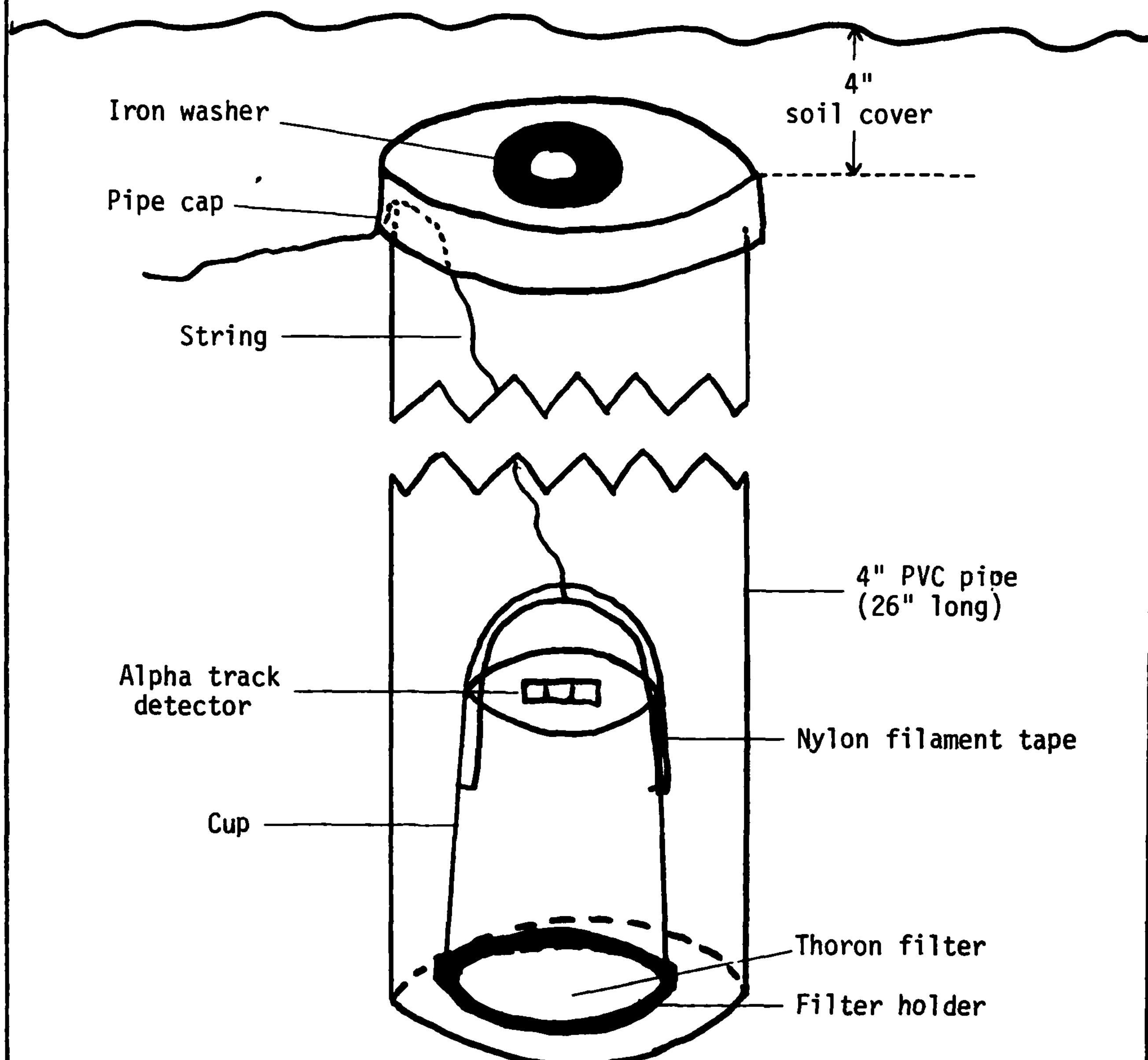
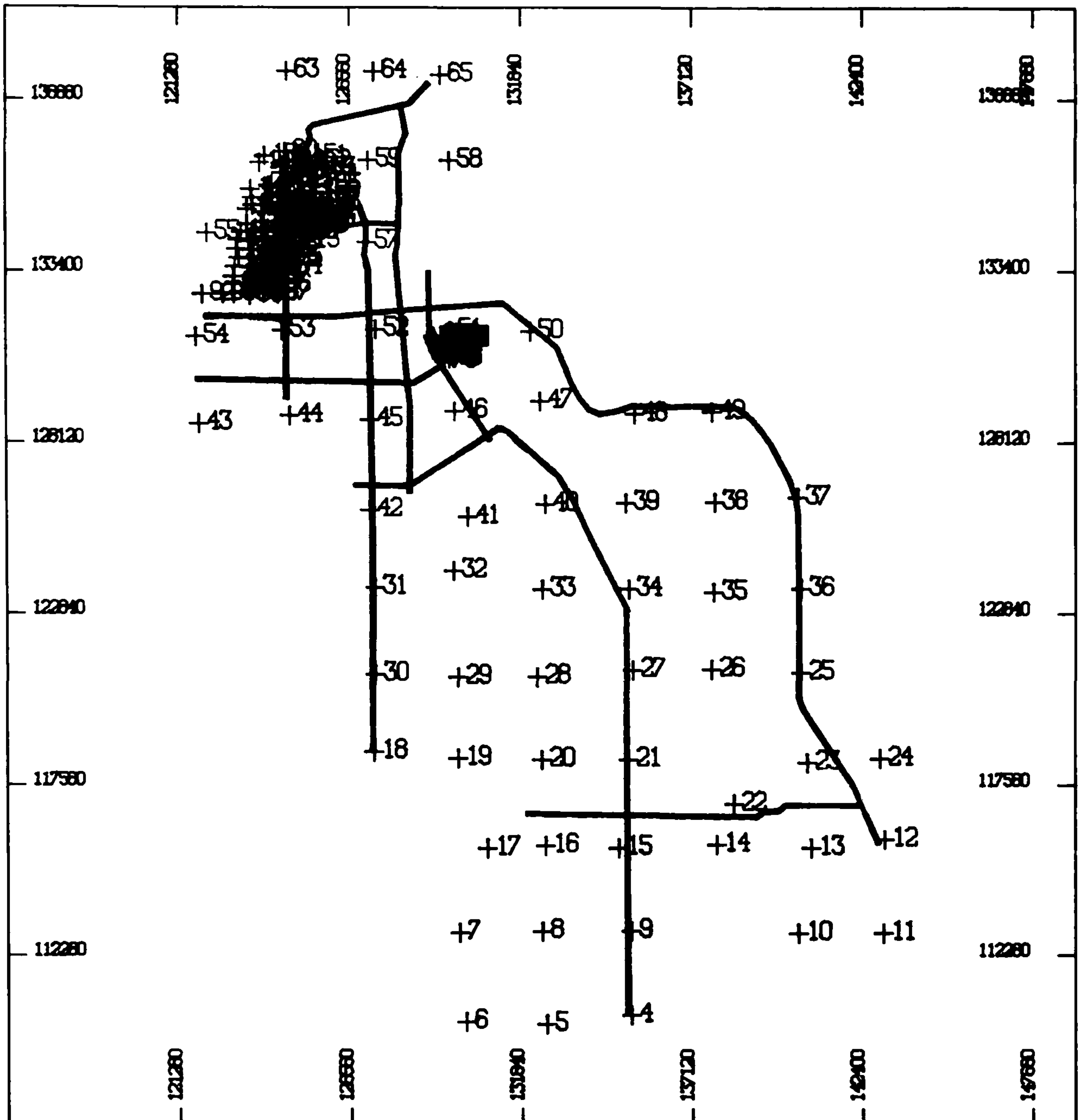


FIGURE 5-19

ALPHA TRACK DETECTOR IN PVC SLEEVE ASSEMBLY

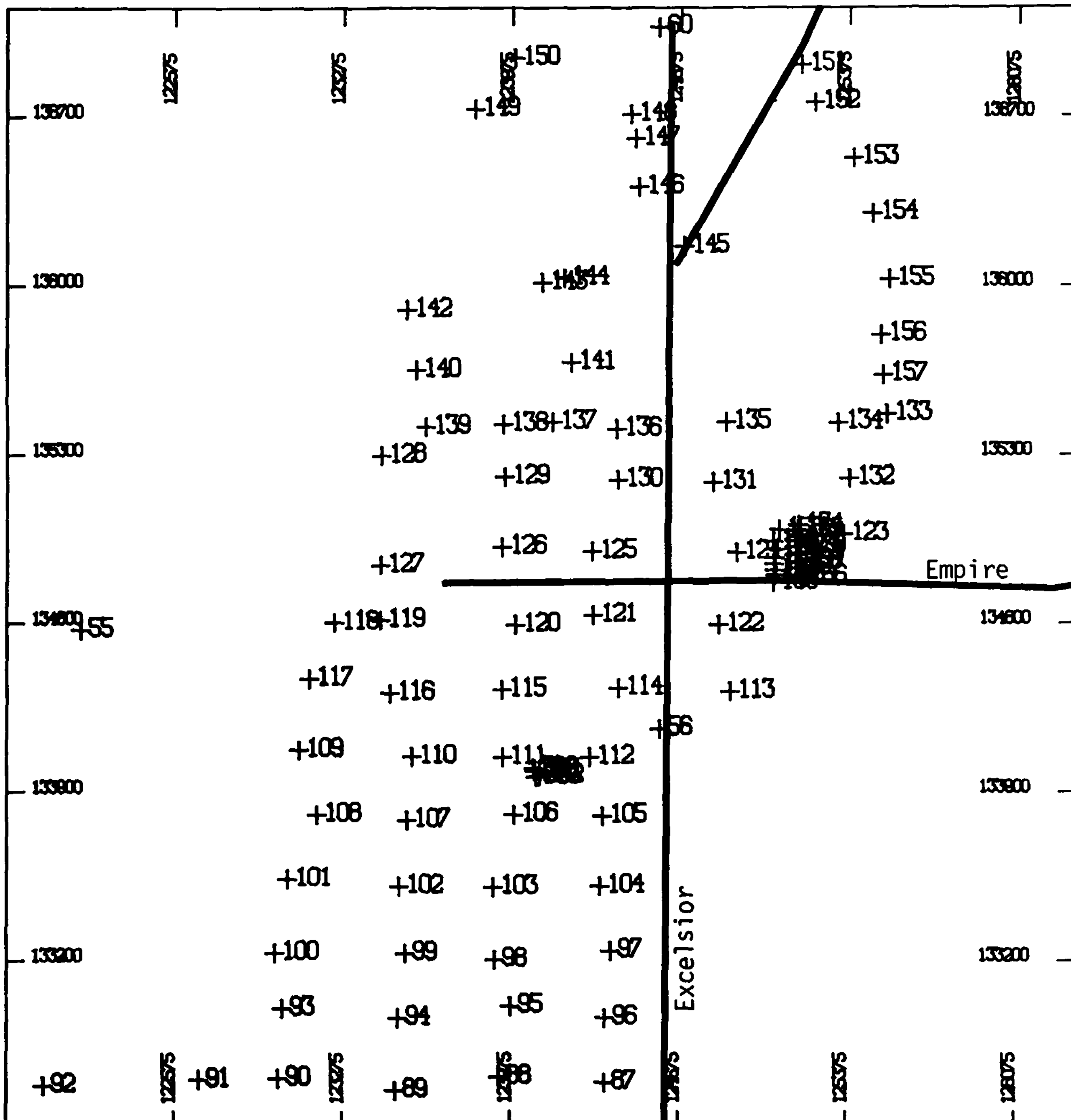


SCALE 1" = 5280. ' (TE 11/24/80-11/24/80)

BOUNDARY				BOUNDARY		
EAST	=	149000.00	0 — 5280 FEET	NORTH	=	141500.00
WEST	=	116000.00		SOUTH	=	107000.00

FIGURE 5-20

BUTTE RADON SOIL GAS MEASUREMENT SITES



(TE 11/24/80-7/15/82)

SCALE 1" = 700.'

BOUNDARY

EAST = 126325.00

WEST = 121875.00

0 700

FEET

BOUNDARY

NORTH = 137150.00

SOUTH = 132500.00

FIGURE 5-21

RADON SOIL GAS MEASUREMENT SITES IN N.W. BUTTE

TABLE 5-2

RADON SOIL GAS MEASUREMENTS
IN BUTTE, 1980-1981

	Measurement Site	July, 1980 - December, 1980 pCi/l	October, 1980 - April, 1981 pCi/l
001	Harrison-5 Mile	362.35	757.19
002	So. End Warren	277.67	261.34
003	500 Ft. West No. 2	131.15	596.42
004	Harrison-Legion Lane	246.95	709.11
005	Motor View-Warren	363.13	1337.19
006	West End Motor View	263.91	999.11
007	4 Mile View-Utah	462.35	423.62
008	4 Mile View-Warren	640.93	450.67
009	4 Mile View-Harrison	404.80	869.89
010	NW Norm Ch-4 Mile View	678.64	814.29
011	4 Mile View-McGuiness	696.50	1277.09
012	Continental Dr-Fleecer Dr	434.57	495.75
013	Blacktail-Rampart	533.98	1338.69
014	Highland-Meadow Lark	364.92	279.38
015	Harrison-Lowell	387.54	407.09
016	Lowell-Warren	698.48	1520.50
017	Lowell-Western	438.53	277.87
018	South Montana	825.48	470.20
019	Nansen Road-Holmes	316.70	670.05
020	Holmes-Warren	540.53	842.84
021	Harrison-Holmes	192.88	201.24
022	N End Burning Tree	462.35	548.34
023	Burlington-Augusta	1083.44	1628.69
024	Burlington-Interstate	519.89	1168.90
025	Continental-Edwards	213.24	1134.34
026	Porter-Edwards	999.17	1123.82
027	Harrison-I15	688.45	766.21
028	Hill-Sampson	523.95	665.54
029	Lexington-Sampson	385.86	1194.45
030	Montana-Hanson Rd	743.28	1106.54
031	Montana-Greenwood	372.79	974.69
032	Lexington-Greenwood	278.08	68.47
033	Warren-C Street	165.64	1412.22
034	Ottawa-Massachusetts	491.68	1718.26
035	Ottawa-Porter	584.88	460.09
036	Ottawa-Continental	381.80	259.84
037	Continental-Gagnon	345.24	574.19
038	Porter-George	980.89	924.82
039	George-Massachusetts	509.74	1332.87
040	George-Whitman	253.85	530.37

	Measurement Site	July, 1980 - December, 1980 pCi/l	October, 1980 - April, 1981 pCi/l
041	George-Lexington	120.63	241.71
042	Montana-Silverbow Cr	264.01	802.40
043	I15-South Big Butte	773.74	702.66
044	Excelsior-I15	400.07	1593.57
045	Montana-Iron	1751.59	1668.38
046	3rd-Utah	312.75	813.74
047	1st-Warren	237.61	602.91
048	Monroe-Pine	696.57	1706.92
049	Stuart-Pine	2290.77	1720.52
050	Continental-Warren	566.60	1462.09
051	Mercury-Ohio	38.07	73.95
052	Montana-Mercury	74.30	201.24
053	Galena-Excelsior	556.73	129.72
054	Oredigger Field	76.76	322.95
055	Big Butte M	176.68	112.34
056	Lewisohn-Excelsior	1209.36	1038.17
057	Montana-Boardman	2296.86	1137.91
058	Bennett	868.18	689.05
059	La Platta-Montana	566.60	963.36
060	17th-Excelsior	1620.60	1230.86
061	Brown's Gulch Road	960.98	1060.84
062	W of Ryan's Tower	464.63	1634.38
063	E of Ryan's Tower	798.26	2470.89
064	WM Street Walkerville	558.78	734.39
065	E of Walkerville	2014.07	*
066	Silver Bow Homes 107	361.49	371.91
067	Silver Bow Homes 106	276.19	1118.28
068	Silver Bow Homes 206	501.61	2346.41
069	Silver Bow Homes 306	521.92	476.20
070	Silver Bow Homes 406	132.82	469.20
071	Silver Bow Homes 506	259.95	1181.32
072	Silver Bow Homes 606	233.54	754.05
073	Silver Bow Homes 706	218.11	217.81
074	Silver Bow Homes 806	278.22	1106.61
075	Silver Bow Homes 906	371.64	1223.35
076	Silver Bow Homes 1006	542.23	334.55
077	Silver Bow Homes 1909	148.60	747.04
078	Silver Bow Homes 1902	605.86	1410.14
079	Silver Bow Homes 1107	378.66	655.98
080	Silver Bow Homes 1207	315.21	1029.56
081	Silver Bow Homes 1306	452.35	1487.19
082	Silver Bow Homes 1407	665.22	2311.39
083	Silver Bow Homes 1506	478.96	590.61
084	Silver Bow Homes 1607	245.62	653.65
085	Silver Bow Homes 1707	268.20	1428.82
086	Silver Bow Homes 1806	350.72	348.56
087	Granite-Excelsior	760.18	1774.37
088	Granite-Henry	727.41	1641.29
089	Granite-Emmett	1022.31	1420.49
090	Granite-Western	515.52	964.22

	Measurement Site	July, 1980 - December, 1980 pCi/l	October, 1980 - April, 1981 pCi/l
091	Granite-Prospect	178.25	308.32
092	Granite-Ophir	44.61	27.67
093	Quartz-Western	323.83	270.89
094	Quartz-Emmett	526.50	*
095	Quartz-Henry	2821.95	2673.46
096	Quartz-Excelsior 18"	315.02	923.22
097	Copper-Excelsior	697.23	2495.23
098	Copper-Henry	637.75	777.07
099	Copper-Emmett	249.81	459.82
100	Copper-Western	266.55	780.64
101	Caledonia-Western 18"	203.48	216.94
102	Caledonia-Emmett	210.03	294.04
103	Caledonia-Henry	253.94	227.70
104	Caledonia-Excelsior	1649.45	910.85
105	Woolman-Excelsior 14"	169.18	424.93
106	Woolman-Henry	1057.41	2338.13
107	Woolman-Emmett	106.40	69.91
108	Woolman-Western	66.09	252.80
109	Antimony-Western	414.15	190.04
110	Antimony-Emmett	54.85	40.86
111	Antimony-Henry 15"	592.22	367.56
112	Antimony-Excelsior	867.99	3837.12
113	Lewisohn-Alabama	727.85	437.49
114	Lewisohn-Excelsior	1586.80	3478.51
115	Lewisohn-Henry	2271.70	3944.71
116	Lewisohn-Emmett 13"	28.75	158.96
117	Lewisohn-Western	94.26	394.45
118	Waukesha-Western	211.57	292.25
119	Waukesha-Emmett	1528.89	5271.57
120	Waukesha-Henry	1953.01	5250.05
121	Waukesha-Excelsior	1624.66	3885.44
122	Waukesha-Alabama 11"	362.56	2010.44
123	Empire-Clark	933.75	1504.26
124	Empire-Alabama	920.07	463.38
125	Empire-Excelsior	1351.03	1432.97
126	Empire-Henry	4282.26	5706.97
127	Kennedy School	1073.99	4491.43
128	Brown's Gulch-Zarelda	679.51	723.60
129	Hornet-Henry	1857.24	1896.37
130	Hornet-Excelsior	2544.73	3814.15
131	Hornet-Alabama	1228.42	1076.50
132	Hornet-Pit	3554.12	4455.78
133	Zarelda-Clark East	1228.42	2495.23
134	Zarelda-Clark	186.33	484.77
135	Zarelda-Alabama	292.61	862.62
136	Zarelda-Excelsior 20"	1490.66	3457.68
137	Zarelda-Henry 21"	855.75	3029.93
138	Zarelda-Henry	434.78	2709.11
139	Zarelda-Hornet	10295.22	7172.21
140	End Prospect	5472.54	6454.99

	Measurement Site	July, 1980 - December, 1980 pCi/l	October, 1980 - April, 1981 pCi/l
141	616 Butte Fire St 20"	1371.56	7172.21
142	Missoula West End	244.30	54.80
143	Missoula Green Apt.	2870.91	3872.99
144	Missoula White Apt.	678.62	281.49
145	Excelsior-Walker 20"	630.31	1004.09
146	Excelsior-12th	2022.05	2402.68
147	Excelsior-14th	1269.82	1169.05
148	Excelsior-15th	775.24	720.79
149	Henry-15th	625.71	1384.22
150	Henry-17th 20"	156.66	92.32
151	Excelsior-17th	1469.96	3119.90
152	14th-Clark 20"	1863.33	989.75
153	11th-Clark 20"	1055.89	846.30
154	9th-Clark 20"	743.03	1047.12
155	Missoula-Clark	683.22	2689.57
156	Clark-6th	394.75	591.69
157	Kenwood-Clark	502.41	824.79
158	Alabama-Empire 20"	1059.78	2920.99
159	Alabama-Empire	1839.62	3401.67
160	Alabama-Empire	*	1663.85
161	Alabama-Empire	1066.44	451.07
162	Alabama-Empire 20"	290.61	1116.62
163	Alabama-Empire 20"	679.86	843.01
164	Alabama-Empire 30"	737.62	650.74
165	Alabama-Empire 15"	249.68	204.57
166	Alabama-Empire	1327.09	3327.72
167	Alabama-Empire	978.22	2699.14
168	Alabama-Empire	1347.61	3253.77
169	Alabama-Empire 20"	515.33	2292.42
170	Alabama-Empire	1005.58	3031.92
171	Alabama-Empire	1015.84	2551.24
172	Alabama-Empire	1224.48	4030.24
173	Alabama-Empire	2202.70	6285.71
174	Alabama-Empire	1522.05	3253.77
175	Silver Bow Homes 1904	140.92	232.92
176	Silver Bow Homes 1904	214.11	573.09
177	Silver Bow Homes 1904	239.47	467.71
178	Silver Bow Homes 1904	249.13	691.41
179	Silver Bow Homes 1112	400.27	769.06
180	Silver Bow Homes 1112	240.85	103.51
181	Silver Bow Homes 1112	185.64	84.28
182	Silver Bow Homes 1112	724.63	1072.25
Mean		1082.39	1407.2

*Alpha-track detector lost.

Gingrich[11] reports that worldwide radon soil gas concentrations average about 100 pCi/l. According to Gingrich, radon soil gas concentrations can be expected to vary by a factor of about 2 to 5 from the 100 pCi/l value. Gingrich's information is based on data acquired from more than 300 different surveys in which the alpha-track detectors were used. According to Gingrich, only 12 of the 300 areas measured had radon soil gas concentrations averaging above 1000 pCi/l. Butte was one of the 12 areas.

The average radon soil gas concentration measured during summer months was 1082 pCi/l. The average radon soil gas concentration measured in the winter was 1407 pCi/l. The higher winter concentration was attributed to the capping effect created by the freezing of the top layers of soil.

The depth to which soil freezes in Butte during the winter exceeds the depth at which the alpha-track detectors were placed. The difference between the winter and summer measurements would likely have been greater if the detectors had been placed below the frost line.

From Table 5-2, it can be seen that radon soil gas concentrations ranged from lows of less than 100 pCi/l to a high that exceeded 10,000 pCi/l.

Homes having indoor radon progeny concentrations of 0.02 WL or less were not considered to have a significant indoor radon problem based on the U. S. Surgeon General's guidelines for Grand Junction, Colorado, and the EPA standards for inactive uranium mill sites (10 CFR 192). Generally, radon progeny concentrations in homes did not exceed 0.02 WL where radon soil gas concentrations were less than 500 pCi/l. However, there were exceptions. These exceptions may be due to construction differences or variations in radon soil gas concentrations between structure locations and the sites where radon soil gas concentrations were measured.

As seen in Table 5-2, radon soil gas concentrations frequently exceed 1000 pCi/l in northwest Butte where high levels of indoor radon are found.

There appears to be a sufficient enough relationship between radon soil gas measurements and indoor radon concentrations to predict that elevated radon soil gas concentrations may be an indicator of potential indoor radon problems in Butte.

Localized Measurements of Radon Soil Gas Concentrations

In addition to the grid measurements of radon soil gas, alpha-track detectors were used to measure radon soil gas concentrations in straight lines traversing identifiable fractures, mineralized veins, and areas of specific geologic composition.

Silver Bow Homes

At Silver Bow Homes, alpha-track detectors were placed between apartment buildings at locations shown in Figure 5-22. The values to the left of the site location (+) are measurements made during the months of August, September and October, 1981. The values to the right of the site marker are measurements made between the months of November, 1981 and April, 1982.

At Silver Bow Homes the average radon soil gas concentration in the summer (362 pCi/l) and in the winter (964 pCi/l) was lower than the overall average soil gas concentration for the city during the summer and winter (1082 pCi/l and 1407 pCi/l, respectively).

Mineralized veins, shown as solid lines in Figure 5-22, traverse the Silver Bow complex in an east-west direction. The veins are covered with soil and are not visible.

Figure 5-23 shows radon soil gas measurement sites traversing two mineralized veins. Positioning the alpha-track detectors proved difficult due to the rock encountered while digging in the southernmost sites shown in Figure 5-23.

Skyway Park

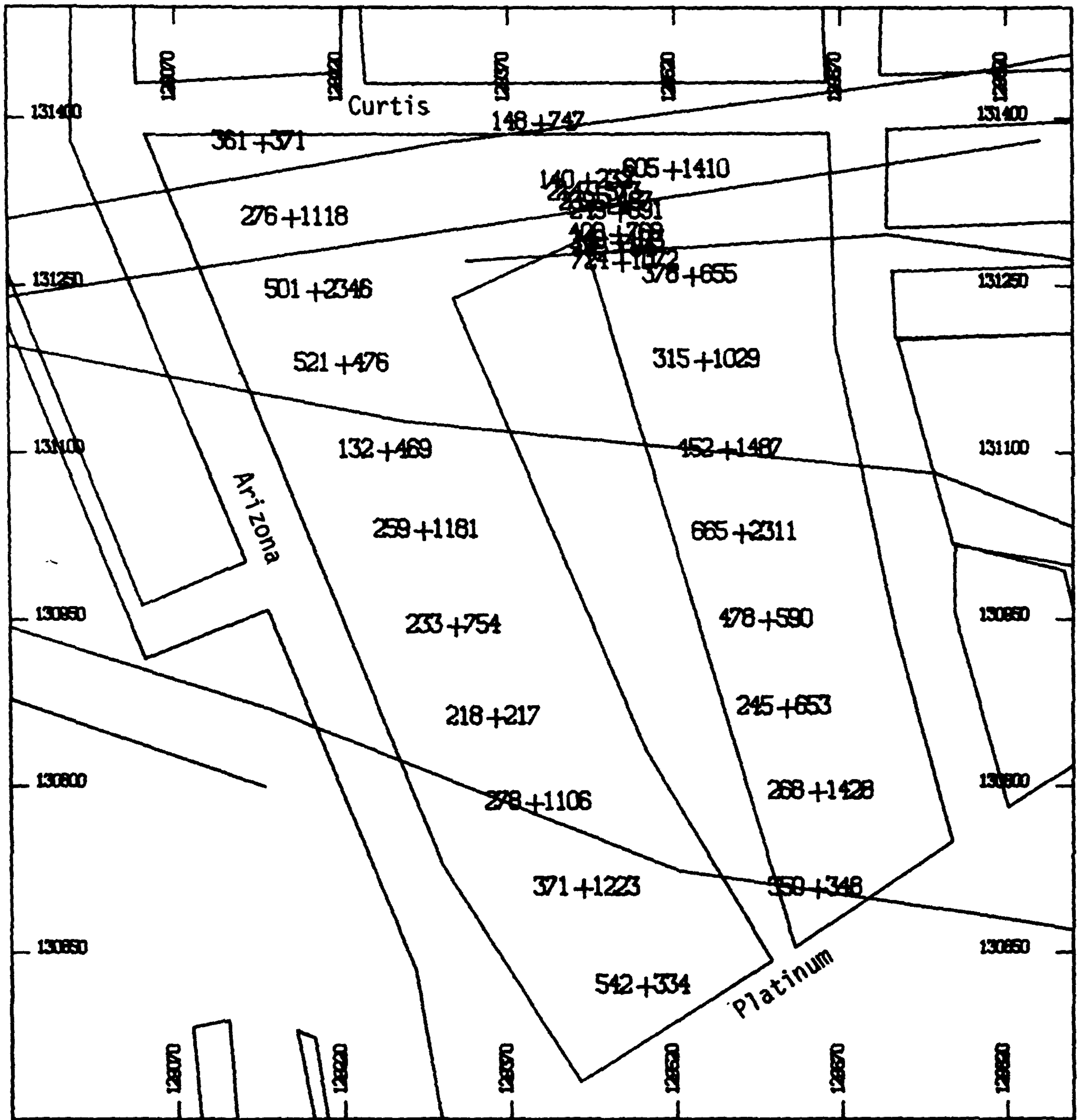
Skyway Park is in the Butte valley where the alluvium is estimated to range between 80 and 200 feet in depth.

Radon soil gas measurements were made in Skyway Park between November, 1981, and April, 1982. Difficulty was encountered in establishing locations where alpha-track detectors could be placed in this area. The streets in Skyway Park are paved and there are no alleys. Nearly all the residences have been landscaped. It would have been desirable to position some alpha-track detectors near homes having elevated indoor radon concentrations but this was generally not possible due to the landscaping. With few exceptions, the alpha-track detectors were placed on vacant lots.

The average radon soil gas measurement in Skyway Park was 666 pCi/l which is less than half the average radon soil gas concentration measured in Butte during the winter months, yet still significantly higher than what Gingrich considers normal. The Skyway Park radon soil gas measurement sites and data in pCi/l are shown in Figure 5-24.

Radon and radon progeny concentrations were measured in several Skyway Park homes by long-term integrating methods; however, most homes were measured by grab sampling. Of the 56 homes tested in the Skyway Park area, 22 measured in excess of 0.02 Working Levels.

No mineralized veins, fractures, or unusual geologic features are found in Skyway Park, and the radon soil gas concentrations are relatively constant. It is not known if the difference in radon progeny concentrations between homes in this area is due to structural



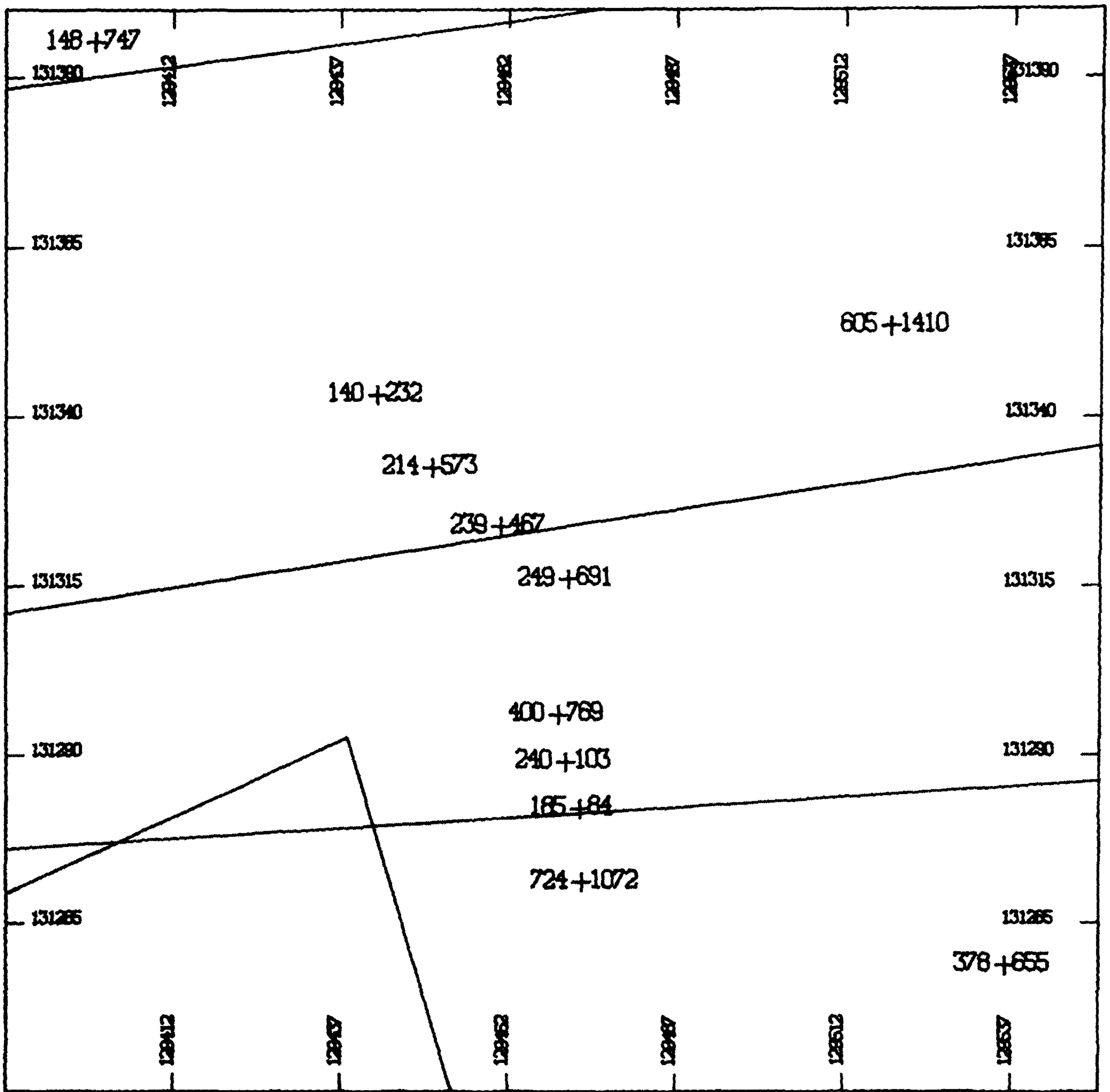
SCALE 1" = 150.'

(TE 11/24/80-7/15/82)

BOUNDARY			BOUNDARY	
EAST	= 129880.00	0 — 150 FEET	NORTH	= 131500.00
WEST	= 128920.00		SOUTH	= 130500.00

FIGURE 5-22

RADON SOIL GAS CONCENTRATIONS (pCi/l) - SILVER BOW HOMES



SCALE 1" = 25.'

(TE 11/24/80-7/15/82)

BOUNDARY

EAST = 129550.00
WEST = 129387.00

______ = Veins

0 25
FEET

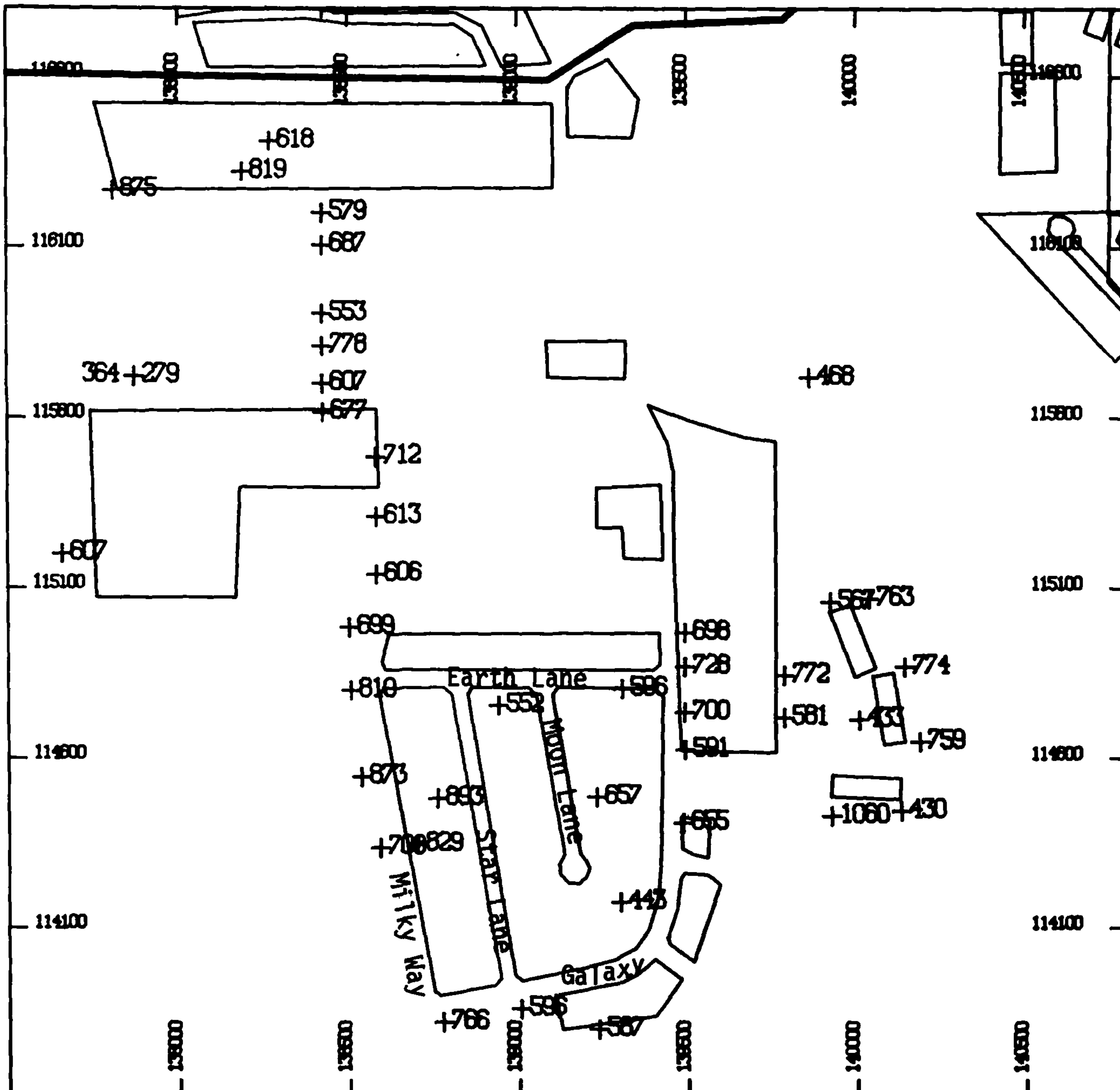
BOUNDARY

NORTH = 131400.00
SOUTH = 131240.00

\+ = Measurement Location
xxx+yyy = Summer & Winter Measurement

FIGURE 5-23

RADON SOIL GAS CONCENTRATIONS (pCi/l) AT MEASUREMENT SITES TRAVERSING MINERALIZED VEINS - SILVER BOW HOMES



(TE 11/24/80-7/15/82)

SCALE 1" = 500.'

BOUNDARY			BOUNDARY	
EAST	- 140800.00	0 — 500 FEET	NORTH	- 116800.00
WEST	- 137500.00		SOUTH	- 113600.00

\+ = Measurement Site

FIGURE 5-24

RADON SOIL GAS CONCENTRATIONS (pCi/l) - SKYWAY PARK differences, differing lifestyles or if there are localized areas having high soil radium-226 content that were not indicated by the radon soil gas measurements.

McClernan[10] believes that Skyway Park was marshy or underwater at one time and that there may be small localized areas having soils with elevated radium content that may have resulted from either the precipitation or organic concentration of radium.

Walkerville

Radon soil gas measurements were made in aplite in the Walkerville area which is located on the north side of Butte. The measurement site selected was from about 30 to 200 feet west of Walkerville Drive with the northernmost sampling point approximately 200 feet south of where Walkerville Drive curves into Daly Street. Eleven alpha-track detectors were emplaced in October, 1981, and recovered in April, 1982. The measurements and locations are shown in Figure 5-25.

The line of alpha-track detectors crossed a major fracture (shown as a dotted line in Figure 5-25). The radon soil gas measurements at the two measurement points near the fracture averaged 7171 pCi/l; whereas, the other nine measurement points averaged 1226 pCi/l. The average of the nine measurement points located away from the fracture compares closely with the overall average for the Butte area during winter months (1407 pCi/l).

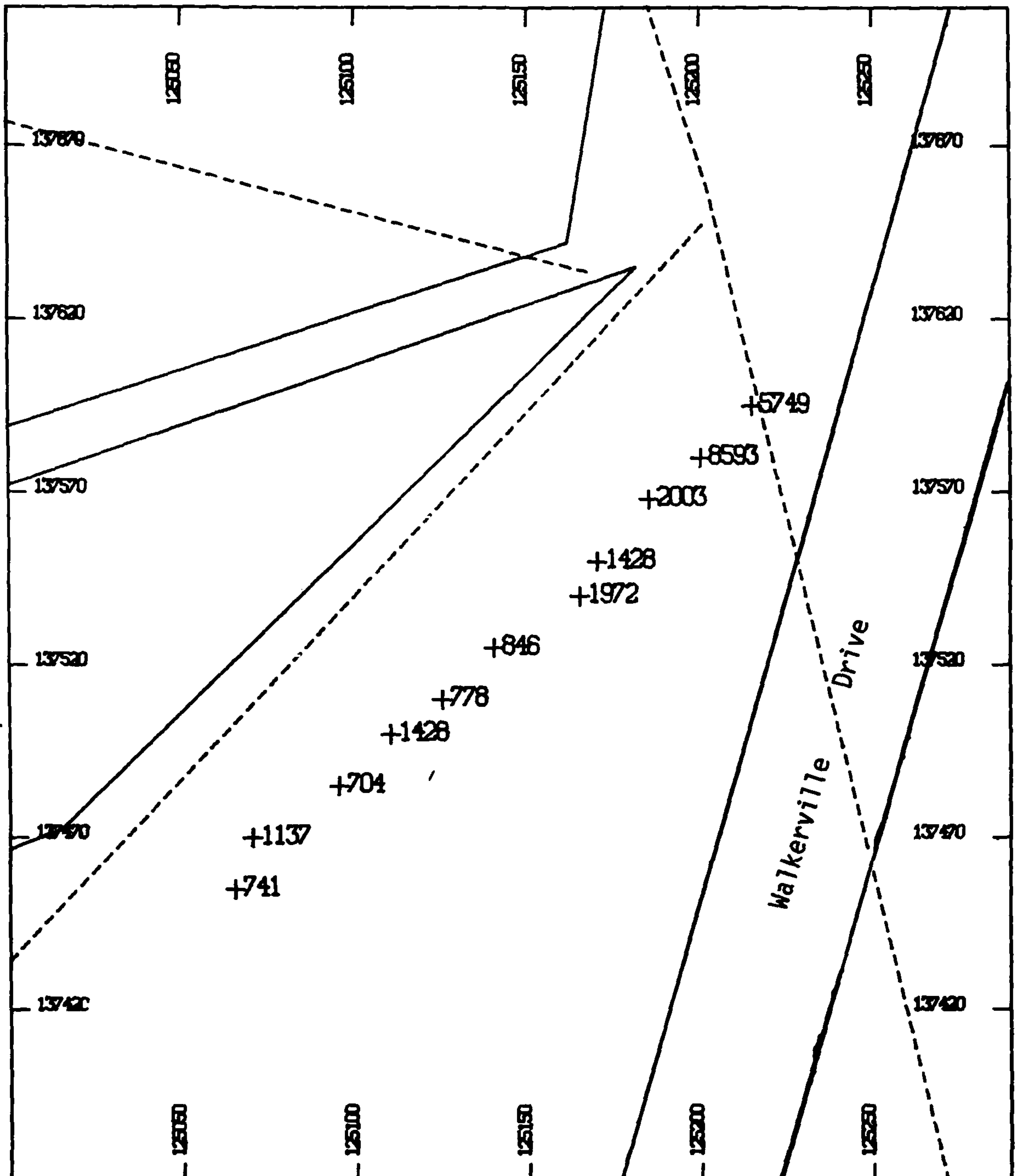
Fractures in underlying geology are believed to act as conduits for transporting radon to the surface. The measurements at the two sites near the fracture support this theory.

The purpose in placing the alpha-track detectors in the aplite was to determine if the radon soil gas concentrations in the aplite varied significantly from the concentrations measured in other surface rock and soil types. When the two measurement points near the fracture are excluded, the average (1226 pCi/l) compares closely with the overall radon soil gas concentration average for Butte, but is still nearly double the average measurement for the Skyway Park area and is about 25% higher than the average radon soil gas concentration during a comparable time period at Silver Bow Homes.

West Junior High School

Six measurement points in aplite were established at a site north of the Interstate 90 on-ramp at a distance of about 200 feet south of the West Junior High School. The locations of the measurement points and the radon soil gas measurement data in pCi/l are shown in Figure 5-26. Fairly consistent concentrations averaging 547 pCi/l were measured at five of the six sampling points. The sixth point measured 1766 pCi/l. The anomalous measurement was near a small mineralized vein.

If the anomalous measurement is discounted, the radon soil gas measurements at the West Junior High School average only about one-half



(TE 11/24/80-7/15/82)

SCALE 1" = 50.'

BOUNDARY

EAST = 125290.00

WEST = 125000.00

0 50

FEET

BOUNDARY

NORTH = 137710.00

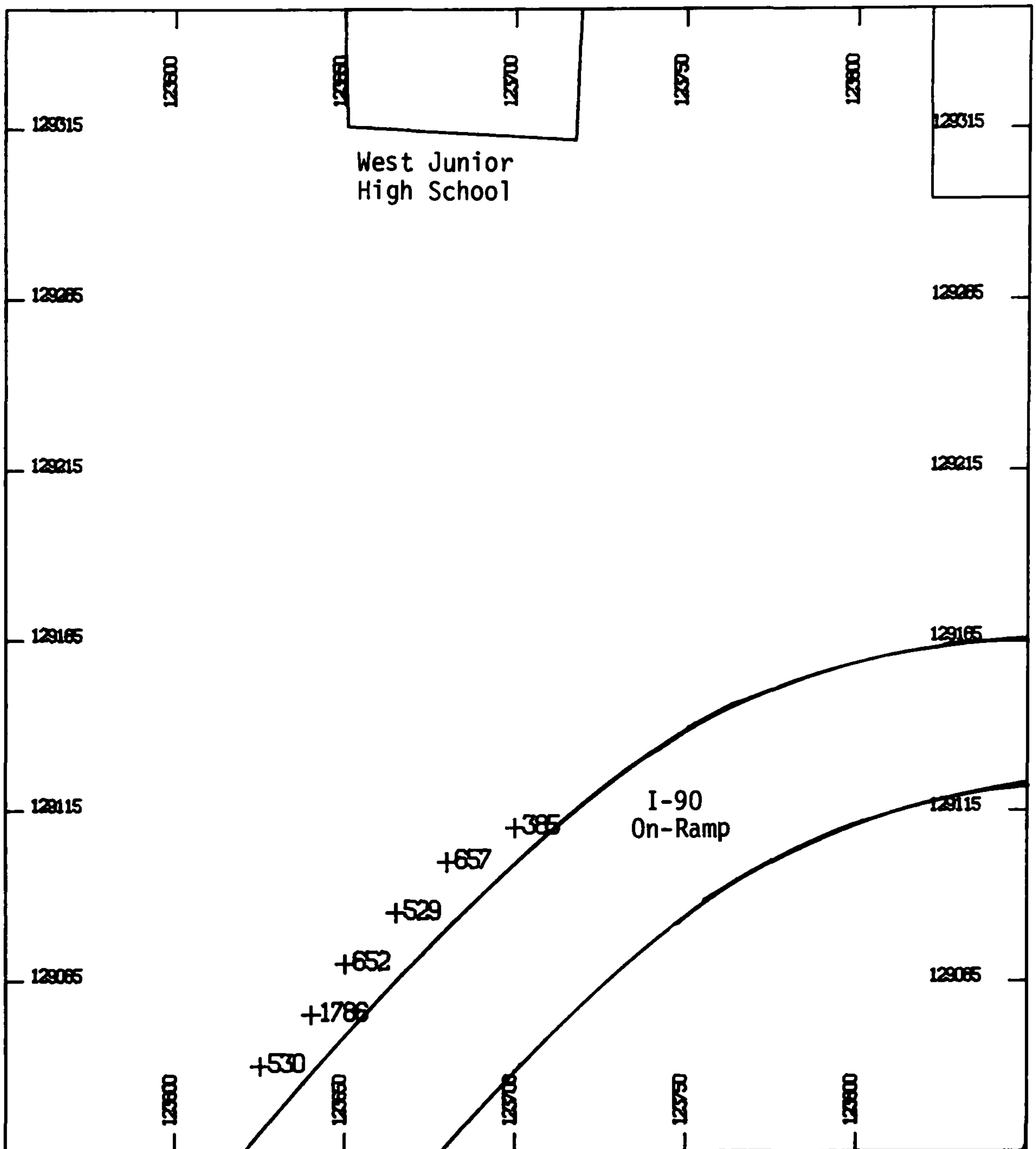
SOUTH = 137370.00

--- = Fractures

\+ = Measurement Site

FIGURE 5-25

RADON SOIL GAS CONCENTRATIONS (pCi/l)
IN APLITE - WALKERVILLE



(TE 11/24/80-7/15/82)

SCALE 1" = 50. '

BOUNDARY			BOUNDARY		
EAST	=	123850.00	NORTH	=	129350.00
WEST	=	123550.00	SOUTH	=	129015.00

0 50 FEET

\+ = Measurement Site

FIGURE 5-26

RADON SOIL GAS CONCENTRATIONS (pCi/l) IN APLITE -
WEST JUNIOR HIGH SCHOOL

the concentration measured at the Walkerville site. Although no laboratory analyses were made, it appears that either the radium content of the aplite varies or that the radon permeability of aplite varies between the two sites.

Yellow Jacket Vein

Radon soil gas measurements were made on both sides of Alabama Street between Hornet and Empire Streets, traversing two forks of the Yellow Jacket Vein. The sampling points and measurement data in pCi/l are displayed in Figure 5-27. The measurements recorded to the left of the sampling point (+) are summer measurements and the measurements on the right side are winter measurements. As seen in Figure 5-27, the radon soil gas concentrations measured over veins are higher than measurements which were not over veins.

Gold Street

Radon soil gas measurements were made at a site near Gold and Jackson Streets. At this site a number of exposed mineralized veins traverse Jackson Street in an east-northeast direction. Six alpha-track detectors were placed, traversing the exposed veins as shown in Figure 5-28. The average radon soil gas concentration at this site was 3396 pCi/l, approximately three times the average for the Butte area.

Henry Street

Another series of exposed mineralized veins traverses Henry Street at its intersection with Antimony Street. As at the Gold Street site, the veins traverse Henry Street in an east-northeast direction.

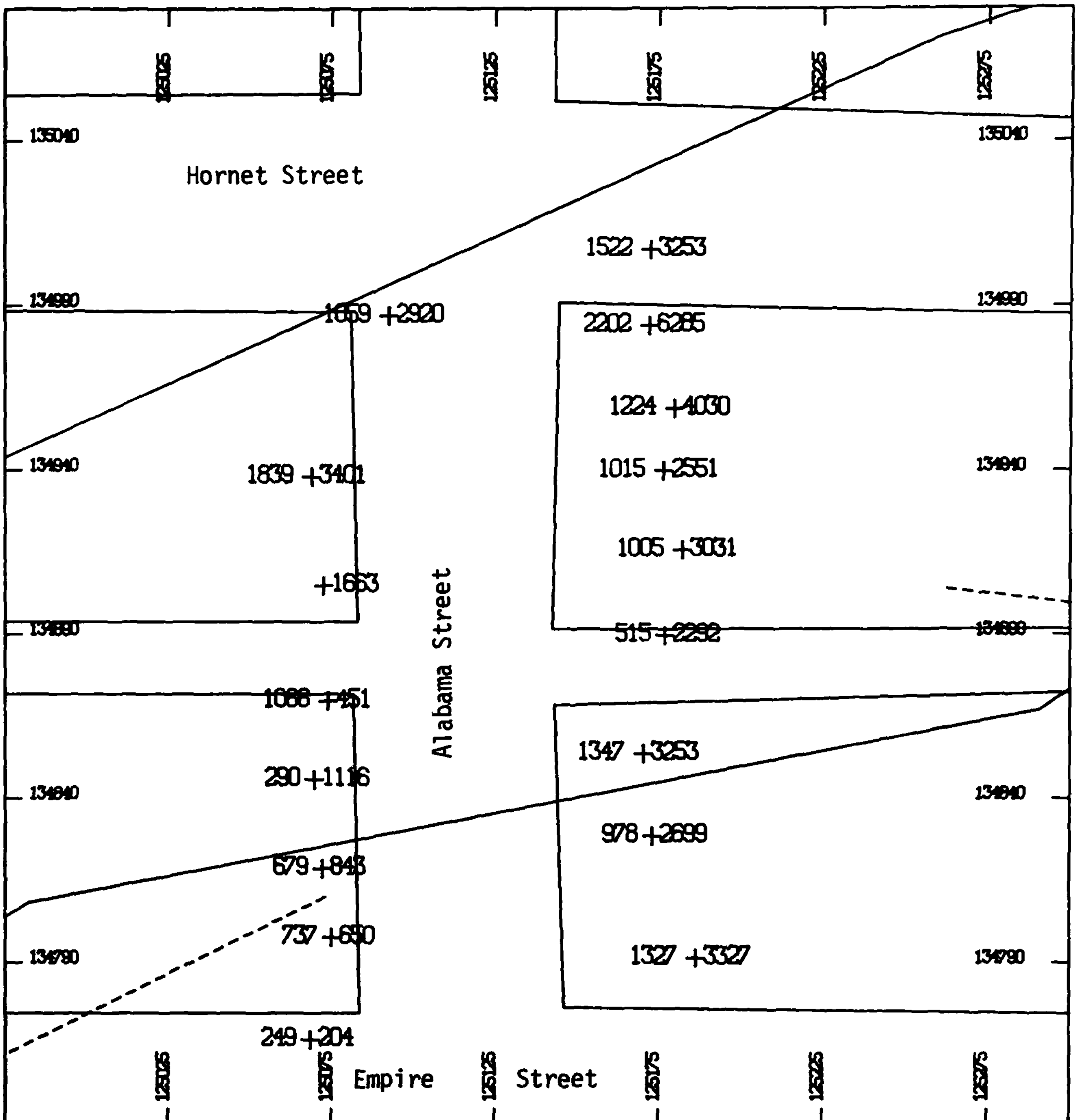
The average radon soil gas measurement at the Henry Street site was 4979 pCi/l, about four times the average for the Butte area, with a range from 1391 to 10591 pCi/l. The mineralized veins (solid lines) and radon soil gas measurement data for this site are displayed in Figure 5-29.

Radon Exhalation Measurements

Rock and Soil

Rock and soil samples were collected at ten sampling sites located in and near Butte. The locations of eight of these sampling sites are shown in Figure 5-30. Sites numbers 9 and 10 are located on Homestake Pass, eight miles east of Butte where Interstate 90 crosses the Continental Divide. Comparative radon exhalation measurements were made using 25 cm sample depths with results as shown in Table 5-3.

As seen in Table 5-3, the highest radon exhalation rates were from mineralized vein material. The aplite samples showed exhalation rates that are about three times the exhalation rates from quartz monzonite and alluvium. From these tests, mineralized vein material and aplite appear to be the most important sources of radon in the Butte area.



(TE 11/24/80-7/15/82)

SCALE 1" = 50.'

BOUNDARY			BOUNDARY	
EAST	= 125300.00	0 — 50 FEET	NORTH	= 135080.00
WEST	= 124975.00		SOUTH	= 134740.00

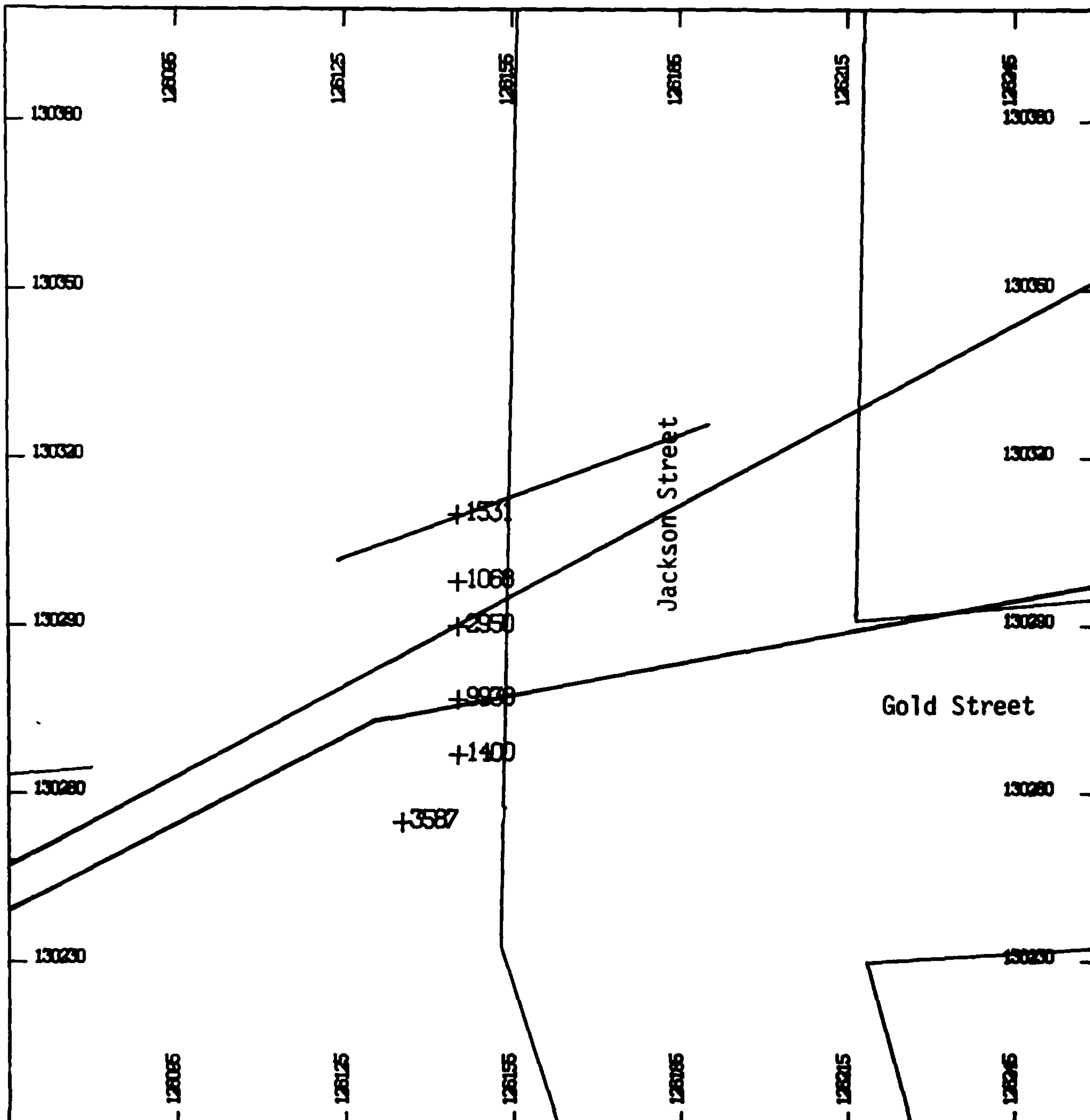
——— = Veins

\+ = Measurement Sites

xxx+yyy = Summer & Winter Measurements

FIGURE 5-27

RADON SOIL GAS CONCENTRATIONS (pCi/l) AT MEASUREMENT POINTS TRAVERSING THE YELLOW JACKET VEIN

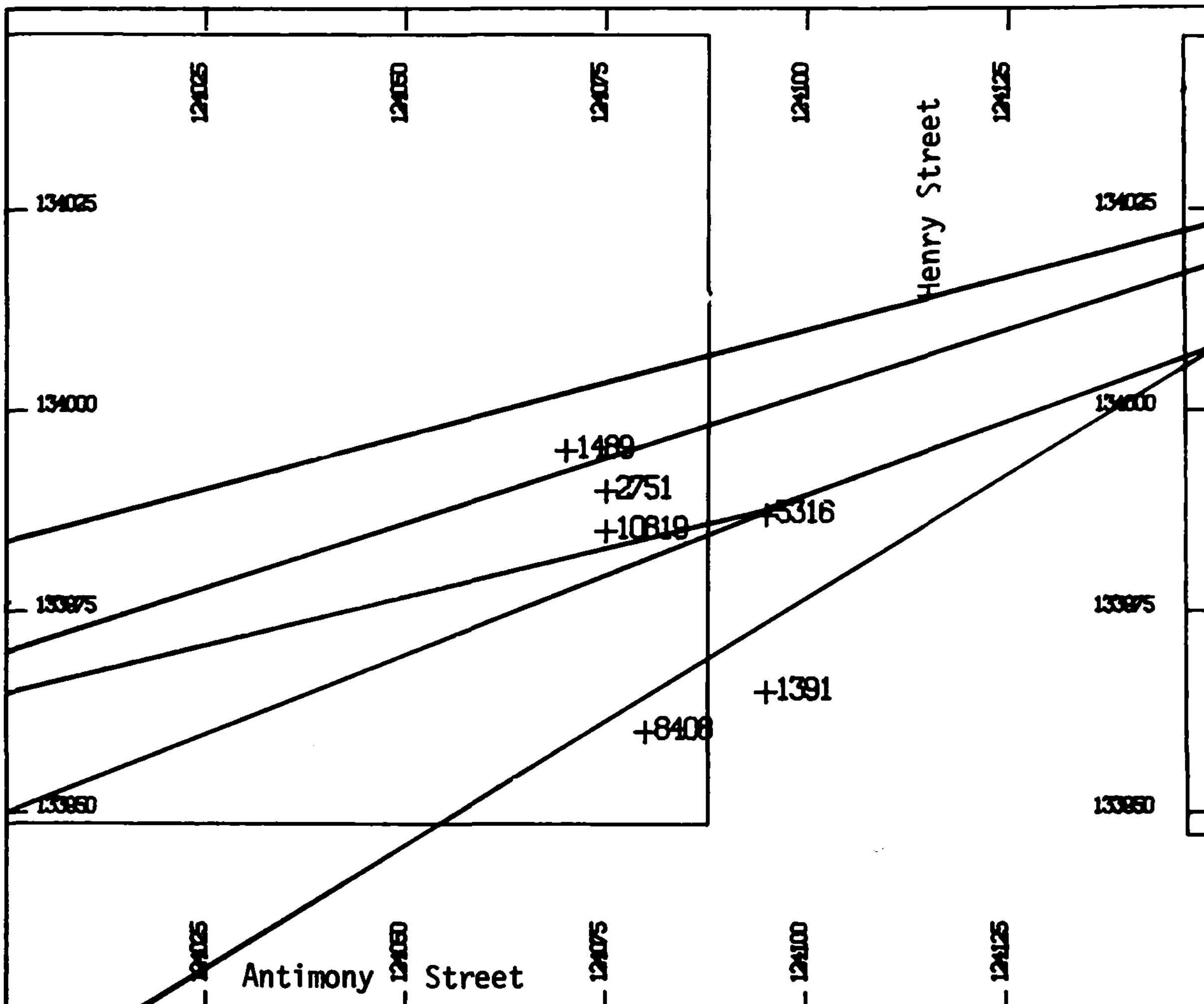


SCALE 1" = 30. ' (TE 11/24/80-7/15/82)

BOUNDARY			BOUNDARY
EAST = 126260.00	0 30		NORTH = 130400.00
WEST = 126065.00	FEET		SOUTH = 130200.00
______ = Veins			+ = Measurement Sites

FIGURE 5-28

RADON SOIL GAS CONCENTRATIONS (pCi/l) AT MEASUREMENT SITES TRAVERSING MINERALIZED VEINS - GOLD AND JACKSON STREETS



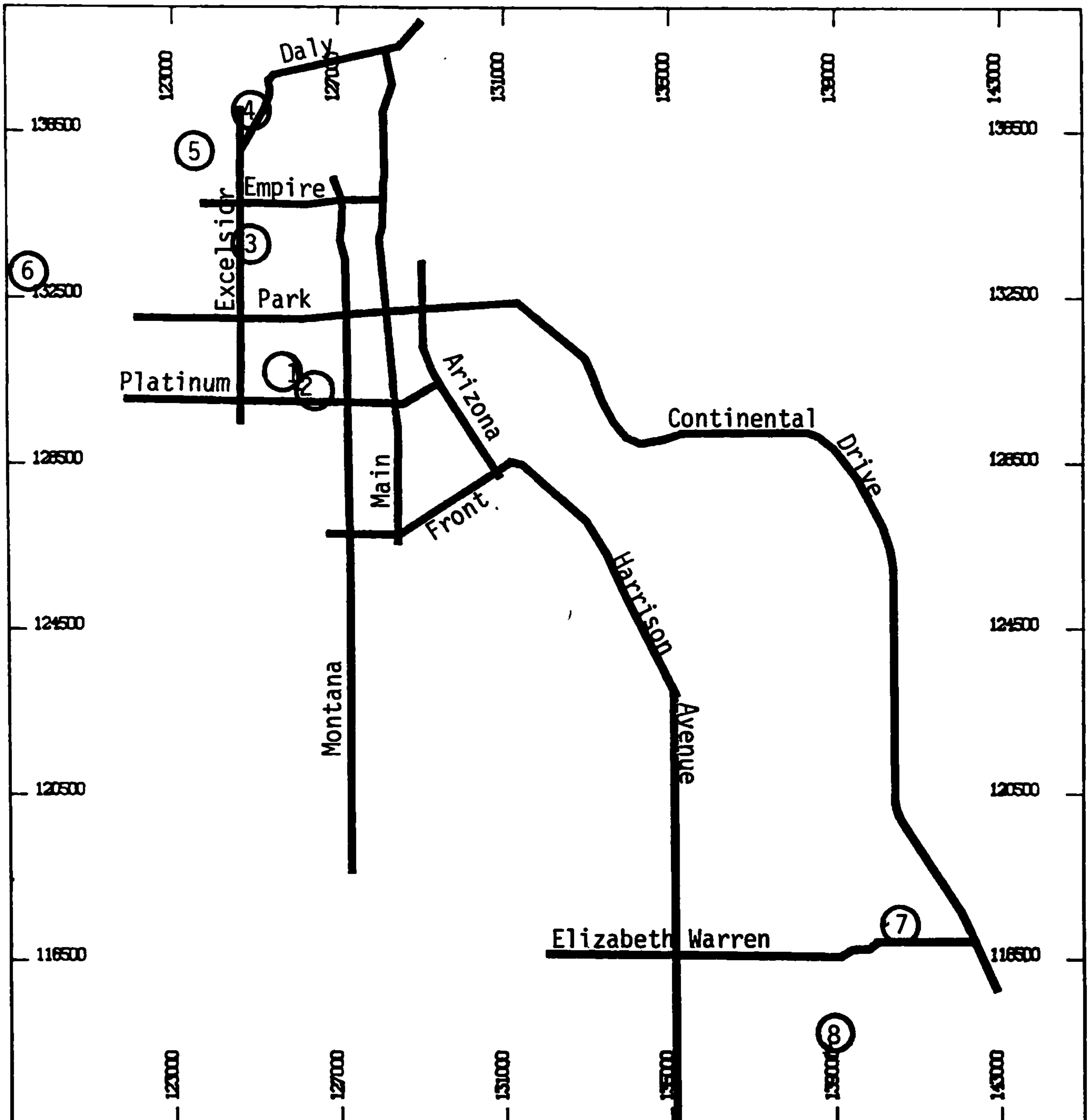
SCALE 1" = 25. ' (TE 11/24/80-7/15/82)

BOUNDARY				BOUNDARY		
EAST	-	124150.00	0 — 25 FEET	NORTH	-	134050.00
WEST	-	124000.00		SOUTH	-	133925.00

——— = Veins + = Measurement Sites

FIGURE 5-29

RADON SOIL GAS CONCENTRATIONS (pCi/l) AT MEASUREMENT SITES TRAVERSING MINERALIZED VEINS - HENRY AND ANTIMONY STREETS



SCALE 1" = 4000.

BOUNDARY				BOUNDARY	
EAST	= 145000.00	0	4000	NORTH	= 139500.00
WEST	= 119000.00	FEET		SOUTH	= 112500.00

FIGURE 5-30

ROCK AND SOIL COLLECTION SITES
FOR RADON EXHALATION TESTS

TABLE 5-3

COMPARATIVE RADON EXHALATION MEASUREMENTS
OF BUTTE AREA ROCK AND SOIL SAMPLES

Sample No.	Sample Location	Sample Type	Radon Exhalation Rate ($pCi/m^2/min$)
1	Jackson & Gold Sts.	Aplite	520
2	Jackson & Gold Sts.	Vein Material	1663
3	Antimony & Henry Sts.	Vein Material	2615
4	Walkerville Drive	Aplite	727
5	Emmett & Missoula Sts.	Aplite	1001
6	West Junior High Sch.	Aplite	602
7	Columbus & East Lake Streets	Alluvium	301
8	100 Star Lane	Alluvium	151
9	Homestake Lake	Quartz Monzonite	305
10	Homestake Pass	Quartz Monzonite	169

Building Materials

Building materials were evaluated to determine if they were a source of radon in structures. Activated charcoal canisters were obtained from the EPA Eastern Environmental Radiation Facility (EERF) in Montgomery, Alabama, to measure radon exhalation rates from these materials. The following building materials were evaluated:

1. Concrete
2. Conventional concrete blocks
3. Concrete blocks containing slag from smelting operations
4. Bricks (red and white)
5. Gypsum board
6. Plaster

Radon exhalation measurements were performed by making an air-tight seal between the activated charcoal canister and the material to be tested using duct tape. The canister was attached to the material being tested from 48 to 96 hours. During each measurement, additional canisters were simultaneously placed to measure ambient radon. Following each measurement, the canisters were sealed to prevent further radon exposure, and were returned to the EERF for analysis by gamma spectroscopy.

The ambient radon measurements during each test were higher than the measurements made with the canisters which were sealed to the material being evaluated, thus eliminating building materials as suspect sources.

Dissolved Radon in Water

Butte city water supplies originate from surface water sources; however, these water supplies were measured to determine dissolved radon content. In addition, springs and private water supplies outside the city were measured. Liquid scintillation vials were obtained from the EERF for sample collection. A measured volume of each water sample was injected into duplicate scintillation vials and returned to the laboratory for analysis.

Data obtained from analyses of Butte water samples for dissolved radon content are presented in Table 5-4. As seen in Table 5-4, the dissolved radon concentrations in the Butte surface water supplies are so low that they cannot be accurately measured. Groundwater supplies in the Butte area are elevated in dissolved radon content but not to the point where they are considered as a significant source of indoor radon.

Radon Measurements in Underground Sewers

It is possible that the entry route of radon into some structures is through unsealed service entries or through plumbing fixtures having dry traps or no traps at all. For this reason, measurements of radon concentrations in underground sewers were made.

Samples were collected by lowering an intake tube through manhole cover ventilation holes to a depth of six to eight feet and drawing air from this intake tube through a 500 ml scintillation cell. This method of sample collection was preferred to removing the manhole cover, since it prevented abnormal air circulation at the point of sampling.

Measurements were made at 41 locations throughout the city as shown in Table 5-5. Measurements ranged from lows of less than 1 pCi/l to a high of more than 400 pCi/l. Generally the highest radon concentrations were measured in areas demonstrating high indoor radon concentrations. The highest measurements were again found in the northwest part of the city.

Structures have not been evaluated to determine the degree of radon entry through unsealed service entries or through dry-trapped or untrapped plumbing fixtures. The radon concentrations measured in underground sewers does demonstrate the need to evaluate service entrances as potential routes of radon entry into structures.

Radon In Natural Gas Supplies

The radon content of natural gas was measured to determine if unvented gas appliances contribute significantly to indoor radon concentrations. The radon content of natural gas in Butte averaged 14 pCi/l. Thus, the natural gas contribution to indoor radon concentrations is negligible.

TABLE 5-4

DISSOLVED RADON CONCENTRATIONS IN WATER SOURCES IN THE BUTTE AREA

Sample Location	Sample Number	Dissolved Radon Concentration (pCi/l + 2 sigma)*		
Butte Water Co., 129 W. Galena (Big Hole River Supply)	1	- 4	±	1359%
	2	12	±	455%
Blaine Elementary School (Moulton Reservoir Supply)	1	- 6	±	905%
	2	69	±	79%
Hawthorne Elementary School (Basin Creek Reservoir Supply)	1	- 38	±	141%
	2	- 49	±	111%
Hoeffner's Pump Station (Anaconda) - 3 wells (55-70 feet)	1	510	±	13%
	2	464	±	14%
Private Residence (Lost Creek) private well (55 feet)	1	2913	±	3%
	2	2938	±	3%
Private Residence (Roosevelt Drive), private well (115 feet)	1	3346	±	2%
	2	3277	±	2%
Spring Water from Source 1000 Block between Zarelda and Lexington Streets	1	4029	±	2%
	2	4110	±	2%

*There is a 95 percent assurance that the true value lies between the reported value ± 2 sigma.

TABLE 5-5

RADON CONCENTRATIONS IN
BUTTE UNDERGROUND SEWERS

Date	Location	Radon (pCi/l)
12/3/80	Excelsior & 17th	0.2
	Excelsior & 15th	0.8
	Excelsior & 11th	0.4
	Excelsior & Missoula	12.6
	Thornton between Pine & Walnut	0.8
	Thornton between Continental & Pine	0.3
	Stuart between Pine & Walnut	1.1
	Garfield between Silver Bow & Locust	2.1
12/10/80	Blacktail & 4 Mile Vue	2.6
	Blacktail & 4 Mile Vue	0.4
	Elizabeth Warren & Bartoletti Prop.	1.1
	KOA & Kaw	72.0
	George & Silver Bow Creek	84.7
12/11/80	Farragut & Yale (west)	59.4
	Farragut & Yale (east)	3.1
	Hill & Evans (SW)	4.9
	Hill & Evans (east)	5.9
	Hill & Evans (NW)	5.2
	Lexington & Majors	105.1
	Oregon (W) & Silver Bow Creek (N)	105.0
12/18/80	US-10 & Hamblin Heights	52.4
1/14/81	Excelsior & Woolman (SE)	110.5
	Excelsior & Woolman (SW)	283.4
	Caledonia & Excelsior (W)	403.8
	Emmett & Park	1.5
	Mercury (S) between Girard & Emmett	1.1
	Silver & Emmett	16.1
	Silver between Emmett & Girard	12.6
	Gold between Emmett & Girard	22.1
	Platinum between Emmett & Girard	1.3
	Girard between Platinum & Steele	1.9
1/16/81	Waukesha & Emmett	125.6
1/15/81	Woolman & Emmett	10.4
	Galena & Clark	20.9
	Silver & Colorado	167.1
1/16/81	Colorado & Aluminum	219.8
1/15/81	Nevada & 1st	1.0
	Atlantic & 1st	20.0
	Monroe & Wall	7.6
	Lafayette & Irene (SE)	0.8
	Hannibal & Hancock	1.8

6. CONCLUSIONS

Radon Sources

Phosphate slag

Phosphate slag produced near Butte by the Stauffer Chemical Company is elevated in radium-226 content. However, tests have confirmed that radon exhalation from the slag is not a significant health concern. The radium content of the slag is essentially the same as that of the phosphate ore, but the slag exhales less than one percent as much radon as the ore.

Outside Air

Monthly averages of radon in ambient air ranged from low of about 0.25 pCi/l at the Hebgen Park Station to a high of 5.86 pCi/l at the Hornet Street Station. Ambient air is not responsible for the high radon and radon progeny concentrations measured in homes; however, when radon concentrations are high, the contributions from the ambient air should be considered when measuring indoor radon and radon progeny concentrations.

The high ambient radon concentrations measured in Butte show the need to consider ambient radon when standards are developed that relate to maximum permissible concentrations of indoor radon or radon progeny. The average outside radon concentration (3.25 pCi/l) measured at the Hornet Street Station, when drawn into a structure, produces a radon progeny concentration of 0.010 WL at an equilibrium of 32 percent (the average integrated measurement equilibrium for the 20 study homes). If the equilibrium should increase to 45 percent, as measured in some homes, the ambient contribution to the indoor radon progeny concentration would be 0.015 WL.

Soil

The radium-226 content of soil in the Butte area ranges from about one to three picocuries per gram. The radium in the soil undoubtedly contributes to indoor radon concentrations; however, except for the Skyway Park area, sources other than soils are thought to be responsible for the high indoor radon concentrations observed in the Butte area. Soil is believed to be the most substantial source of radon in Skyway Park; however Skyway Park is not as severely impacted by elevated indoor radon concentrations as is northwest Butte.

Surface Geology

Radon soil gas measurements made in rhyolite were generally less than 100 pCi/l. Indoor radon and radon progeny concentrations measured in structures built on rhyolite were low. Rhyolite is not considered a source of Butte's indoor radon problem.

It was difficult to determine the rock types at the radon soil gas measurement sites; however, radon soil gas measurements in aplite and quartz monzonite appeared to be about the same as the average for Butte as a whole. Measurements in aplite in Walkerville were about twice the levels measured in aplite near the West Junior High School. This measurement difference probably results from the structure of the aplite because radon exhalation tests on aplite from these locations did not show a substantial difference.

Radon exhalation measurements made on mineralized vein material, aplite, quartz monzonite and alluvium show the vein material exhales substantially more radon than do other rock and soil samples tested. Tests on aplite indicate that the aplite exhales approximately three times the radon that is exhaled from quartz monzonite and alluvium.

Fractures and mineralized veins are the surface geology features believed to be the cause of the most severely elevated indoor radon concentrations. Radon soil gas measurements over fractures and over mineralized veins were often five to ten times higher than the average concentrations measured in the Butte area. Gamma radiation measurements at mineralized veins also are often an order of magnitude higher than measurements of surrounding rocks.

Other Measurements

Measurements of radon in natural gas, dissolved radon in water, and radon exhalation rates from common building materials showed that they make no significant contribution to the indoor radon concentrations in Butte.

Summary

Ambient air, soils and surface geology all contribute to the indoor radon problem in Butte. It is believed that homes constructed over major fractures or mineralized veins are the most severely affected. Aplite and quartz monzonite and soils also contribute to the problem, but to a lesser extent. It is possible that ambient air is a significant source of indoor radon during certain atmospheric conditions in structures having no other substantial source of radon.

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