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RADON AND RADON DECAY PRODUCT CONCENTRATIONS IN NEW MEXICO'S URANIUM MINING AND MILLING DISTRICT

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EXECUTIVE SUMMARY

Elevated radiation levels associated with uranium mining and milling activities have been of concern in recent years. Reports concerning uranium mill tailings in Grand Junction, Colorado and Salt Lake City, Utah have demonstrated that increased concentrations of airborne radioactivity occur in areas surrounding tailings piles. In addition, uranium mine releases of radioactivity have been shown to be of concern not only to mining personnel but to indigenous populations through the venting of particulates and radioactive radon-222 gas. Increased risk of lung cancer among uranium miners exposed to high concentrations of radon gas and its radioactive decay products has been documented. While elevated radon and radon decay product concentrations are much lower in the areas surrounding uranium mines and mills, the New Mexico Environmental Improvement Division (NMEID) remains concerned about potential health hazards to the public health resulting from exposures to radiation from uranium mining and milling activities.

In 1977, the New Mexico Legislature appropriated $100,000 to the NMEID for a "program to prevent or abate harm to the environment from radiation or chemicals directly or indirectly caused by mine spoil piles and mine stock piles and tailings from uranium mills..." To support this legislative mandate a one year monitoring study was undertaken to determine (1) sources of high concentrations of airborne radioactivity in uranium producing areas, (2) background radioactivity levels as well as levels associated with milling facilities and mines, (3) if New Mexico standards are being exceeded, (4) potential future problem areas in view of the then-rapid expansion of the uranium industry and (5) the need for further regulation development and remedial action. This study was later extended an additional year.

Specifically, the two year NMEID program collected and measured over 1700 individual outdoor radon air samples from 33 sites, and documented radon decay product concentrations inside buildings and homes at 18 locations in the Grants Mineral Belt. Radon and radon decay product data were analyzed statistically and compared with both background and current state and federal standards. External radiation exposure rates were also measured at all radon and radon decay product sampling locations.

Radon concentration measured near uranium milling facilities not located near uranium mines were not found to exceed New Mexico Radiation Protection Regulations (NMRPR) for an individual. These regulations exclude all contributions from natural background. In general, these levels were also below the more restrictive standard for a population which is one-third of the standard for an individual. Several values, however, were close to or above the population limit. Consequently, monitoring should continue in housing developments and small communities near uranium facilities to verify that these more restrictive radiation standards for a population continue to be met in the future. In addition, since only radon was considered in making this assessment, monitoring results from all other existing exposure pathways must be included to determine overall compliance with regulatory limits.

Uranium mines are not subject to the NMRPR. For purposes of comparison, however, the NMRPR concentration limits were used as health guidelines to gauge ambient radon concentrations resulting from activities including mining.

Since background must be subtracted from the measured radon concentrations, estimates of net concentration are difficult to make because of the technical problem of determining radon background in the heavily developed Ambrosia Lake area. The estimates presented are believed to be realistic based on background measurements made elsewhere and on the results of computer modeling.

Measured radon concentrations in air near uranium mines were found to be above radon health guidelines based on the NMRPR for an individual member of the public at three of nine locations in the Ambrosia Lake region in the Grants Mineral Belt. Radon levels at these three locations were roughly twice the concentration limit for one year of the study. The total radon inventory was partitioned based on estimates of the fraction of the radon from natural background, uranium mining and milling. It was estimated that 80% of the total radon released per year at Ambrosia Lake came from mining activities, 4% from milling activities and 16% from natural background sources.

While elevated radon concentrations indicate the potential for excessive exposure to radiation and the necessity for future monitoring activities, actual radiation exposures depend on a number of factors. These factors include meteorological conditions, building materials, proximity to radiation sources, air exchange rates in nearby structures and duration of exposure. Indoor radon decay product measurements show that radiation exposures could range from near background to above health guidelines. However, due to the difficulty in estimating above background radon decay product levels indoors, it is difficult to determine if health guidelines have been exceeded. Because of the existing potential for exposure to radon decay products indoors, industry has made a concerted effort to remove as many residences from Ambrosia Lake as possible. The population has decreased from approximately 100-150 residents at the time of this study to less than five in 1985.

For the purposes of planning and regulation development, the lifetime risk of a radiation induced cancer death was estimated for a hypothetical individual who is exposed to the measured radon levels at Ambrosia Lake. This estimate was made to evaluate the need for regulation of environmental impacts from uranium mining.

The lifetime risk of premature lung cancer was one chance in 1000 to one chance in 10,000 per year of exposure for the average two-year Ambrosia Lake radon concentration of 4.0 pCi/l. The corresponding risk for 6.4 pCi/l, the highest yearly average measured in the NMEID study, was one chance in 600 to one chance in 6000 per year of exposure. Measured background radon concentrations averaged approximately 0.5 pCi/l and corresponded to a lifetime risk of one chance in 8000 to one chance in 80,000 per year of exposure.

Since unlicensed sources have been shown to contribute the majority of radon compared to all other sources, modification of the New Mexico Radiation Protection Regulations to include uranium mining must be considered. In addition, every effort should be made to avoid future siting of mine vents near populated areas. If this situation occurs, radon levels should be continuously monitored at all critical locations. Clearly, it would be inadvisable to locate any future housing in areas determined to be borderline or in excess of radiation protection limits. It should be further recognized that documentation of background levels in areas of proposed uranium extraction is critical to the NMEID for protection of the public health through its regulatory authority and that a clear definition of "background" be stated in the radiation regulations.

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1.0 INTRODUCTION

1.1 BACKGROUND INFORMATION

Elevated radiation levels associated with uranium mining and milling have been extensively studied in recent years (1-7, 10). A series of reports (2, 4, 5) on mill tailings in Grand Junction, Colorado, and Salt Lake City, Utah, demonstrated that increased concentrations of airborne radioactivity occur in areas surrounding tailings piles. Uranium mine release of radioactivity has been estimated to exceed that of mills (8, 25). These findings, coupled with results of studies (6, 7, 9) of increased mortality rate of uranium miners exposed to pre-1960 high concentrations of airborne radioactivity indicate that such sources of radioactive materials should be carefully controlled in order to adequately protect the public health. After 1960 more stringent regulations were adopted to control concentrations.

The principal contaminant is radon-222*, an inert, radioactive gas with a half-life of 3.8 days. Radon is a member of the uranium-238 decay chain, and is, therefore, generated along with other members of the chain, in uranium ore. Since radon is an inert gas, it is capable of leaving the ore and entering the atmosphere, depending on a number of factors including atmospheric pressure, ore moisture content and physical and chemical treatment of ore. Decay of released radon in the atmosphere produces radioactive decay products ("radon daughters" or "radon progeny"), that can be inhaled and become attached to bronchial epithelial surfaces of the respiratory tract.

Subsequent radioactive decay of these decay products attack human respiratory tissues through direct ionization and excitation of the constituent atoms and molecules, and through the formation of free radicals (10). The increased risk of lung cancer among individuals, such as uranium miners, that have been exposed to high radon and radon decay product concentrations have been extensively documented (6, 7). Lung cancers observed among uranium miners due to radon decay product inhalation arise primarily in the lower bronchi of the tracheo-bronchial region near the lung (42). Therefore, the biological tissue at risk is considered to be the basal cells of the bronchial epithelium (43, 44, 45) and the primary health threat from radon exposure is from the inhalation of radon decay products.

1.2 USEPA RECOMMENDATIONS

The New Mexico Environmental Improvement Division (NMEID) has been concerned about the potential health hazards that these radiation exposures represent. In November 1975, at the request of the NMEID, a team from the U.S. Environmental Protection Agency's (USEPA) Las Vegas Facility measured radon and radon daughter concentrations in the Grants Mineral Belt Area, the center of the State's uranium mining and milling industry. Results of this program indicated that radon levels in the Ambrosia Lake region, an area heavily developed with both uranium mining

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*In this report, "radon" will refer to radon-222 and "radium" to radium-226 unless otherwise indicated.

and milling, could be delivering doses to lung tissue of people in the area that range from near background to above health guidelines. The USEPA made five recommendations based on their preliminary survey of radon and radon progeny:

1. Sources of the high concentrations should be identified.
2. Local background radon concentrations should be measured.
3. Pre-operational monitoring of proposed mine and mill sites should be performed to determine baseline levels of radioactivity.
4. A long term (one year or more) sampling program should be established to measure seasonal variations and determine annual averages of airborne concentrations of radioactive materials for comparison with State and Federal regulations.
5. Radiation dose to potentially exposed populations should be evaluated.

1.3 NMEID STUDY OBJECTIVES

In the 1977 session of the New Mexico Legislature, a bill was passed which appropriated $100,000 to the NMEID to fund a "program to prevent or abate harm to the environment from radiation or chemicals directly or indirectly caused by mine spoil piles and mine stock piles and tailings from uranium mills. . . " (11) It was stated that this program should include "a description of the problem" and "identification of sources of radiation or chemical waste directly or indirectly resulting from uranium mining and milling activities . . ." In order to carry out the objectives of the Legislative Act, an on-going air monitoring program was installed in the Grants Mineral Belt. This program established a data base in order to:

1. Determine background and facility associated radiation levels for the area.
2. Identify sources of high airborne concentrations of radioactivity.
3. Determine if New Mexico Regulations are being violated.
4. Establish a reference level from which trends in concentrations can be documented in any future monitoring scheme.
5. Provide recommendations for any necessary changes in state laws and regulations.

As noted earlier, the health hazard associated with radon comes from the inhalation of the radon decay products, rather than the radon itself. Since people spend most of their time indoors, radon decay product concentrations in buildings are needed to determine exposures. These concentrations depend not only on the radon concentration, but also on factors such as ventilation rates, internal air circulation, and presence of other aerosols.

Because radon decay product concentrations depend on so many variables, it is difficult to estimate indoor levels due to emissions from nearby uranium mines or mills. In addition, if sampling is limited to the location of existing buildings, radon transport and the associated radiation exposure may not be adequately determined. At the time this study was performed the uranium industry was in rapid expansion. Uranium mines were being constructed near the towns of

Crownpoint and San Mateo. At the same time housing projects were being proposed for areas near uranium facilities. Since these mines were not yet operating and houses not yet built, it was not possible to measure indoor radon decay product levels from the mine and mill emissions. Yet the potential radiological impacts of these mine and mill activities needed to be evaluated in order to avoid future unwarrented radiation exposures.

In this study, outdoor radon levels were measured in order to determine if a potential radiation problem existed from mine or mill emissions. Outdoor radon concentrations were used as an upper limit for indoor radon decay product concentrations that could result from mine and mill emissions. This limit however, would exclude radon from other sources such as building materials. Indoor radon decay product concentrations were then estimated from outdoor radon concentrations by assuming various degrees of equilibrium. Radon decay product concentrations were measured in a limited number of structures in the area to estimate current exposure levels. Of the 18 structures in which measurements were made, eight were frame houses, five were trailers, two were adobe homes, one was a rock house, one was a block house, and one was a sheet metal building. External radiation levels were also measured and reported.

This report discusses the results of two years of monitoring radon and radon decay product levels around the Anaconda, Homestake Mining Company (HMC) and Kerr-McGee uranium mills, as well as the Ambrosia Lake uranium mining area.

Monitoring results were analyzed using statistical tests. Conclusions and recommendations based on a comparison of the data with New Mexico Radiation Protection Regulations (NMRPR) are presented in the final sections of this report, as well as the associated estimates of lung cancer risk resulting from exposure to measured radiation levels.

2.0 RADIOLOGICAL HEALTH CRITERIA

This report uses standards given in the New Mexico Radiation Protection Regulations (NMRPR) for evaluating results of the measurements program (12). These standards, contained in Part Four of the regulations, are based on recommendations made by international and national radiation advisory committees, such as the Federal Radiation Council (FRC), International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP) (14, 29, 30). These regulations are compatible (and in the case of standards, nearly identical) with those of the U.S. Nuclear Regulatory Commission (USNRC) (13). Regulations governing radon released by New Mexico licensees to unrestricted areas fall into four areas:

1. Exposure To An Individual (NMRPR 4-160.A.). Radon levels to which individuals may be exposed cannot exceed 3 pCi/l in excess of background. Levels may be averaged for periods not to exceed one year.

2. Exposure To A Population. (NMRPR 4-160.E.). If a suitable sample of the population is exposed to a licensee's effluent, then the concentration limit is reduced to 1 pCi/l above background. Again, levels may be averaged for periods not to exceed one year. The regulation does not define "suitable sample."

   The intent of this regulation as originally conceptualized in the Federal Radiation Council's Report Number One (14), is to ensure that all members of a population receive less than the maximum exposure permitted to an individual. Because exposures will vary among individuals, the FRC assumed that the maximum exposure would not exceed three times the average exposure. The FRC further advised that prudent use of the population limit be applied when sensitive elements of a population such as children are exposed. Therefore, unless all individual exposures are determined, the more restrictive population limit must be invoked.

3. As Low As Reasonably Achievable (NMRPR 4-100.B.). Radon releases to unrestricted areas should be kept to as low a level as is resonably achievable, even though the effluent limits given in 1. and 2. above may be met. The intent of this regulation is to emphasize that any unnecessary radiation exposure should be avoided if possible. Even though a licensee may not be violating concentration limits, he should still make every reasonable effort to reduce his release of radon.

4. Working Levels (NMRPR Footnote 3, Appendix A). Radon decay product levels can be substituted for radon concentration limits. The radon limit of 3 pCi/l would be replaced by one thirtieth of a working level (WL)*.

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*A working level is any combination short-lived radon-222 daughters, polonium-218, lead-214, bismuth-214 and polonium-214 in one liter of air, without regard to the degree of equilibrium that will result in the ultimate emission of 1.3×10^5 MeV of alpha particle energy.

The NMRPR apply to licensees (holders of radioactive material licenses) and registrants (individuals registered to use radiation producing machines) of the State of New Mexico. Any facility, such as uranium mills, ion-exchange plants, and in-situ leach facilities, producing refined uranium is therefore required to have a license. However, uranium mining is not included**, and is specifically exempted from the licensing requirement under NMRPR 3-110.B. Therefore, while these standards were applied to all areas monitored in this study to evaluate health risks, they apply in a legal, regulatory sense only to radon coming from licensed facilities and not from exempted uranium mines. When the standards are compared to radon and radon decay product levels primarily due to uranium mine operations, the standards are referred to as "health guidelines" to underscore their non-regulatory use. This will be further discussed in Section 5.2.

**Occupational radiation exposure of uranium miners is regulated by the Mine Safety and Health Administration of the U.S. Department of Labor

3.0 METHODS AND PRESENTATION OF DATA

3.1 METHODOLOGY

Air concentrations of radon and radon decay products were measured both at sites near uranium mines and mills and at background locations. External radiation measurements were also made at each location. This section describes the equipment, procedures, and sampling design used in this study.

3.1.1 Sampling and Analysis Techniques

Radon: Rn-222 was sampled using a modification of the method described by Sill, et. al. (15). Air was pumped over a 48 hour period at a rate of 10-20 ml/minute into bags, constructed out of material resistant to radon leakage. The method differed from that described by Sill in two respects: tedlar rather than mylar bags were used in the sampling, and several of the pumps were battery operated pulse pumps rather than the modified aquarium pumps used by Sill. Samples were taken every two weeks. After collection, a fraction of the sampled air was filtered into a scintillation cell. These commercially-obtained cells, similar to the design described by George, et al. (16), consisted of a 1.4 liter cylindrical chamber coated on the inside with zinc sulfide. This material scintillates or emits a pulse of light when struck by an alpha particle. The light pulses from each cell were counted for fifty minutes by a photomultiplier tube and scaler. The radon concentration in the sampled air from each scintillation cell was then calculated using the measured counting rate, corrected for system background, and a calibration factor previously determined for each cell.

A final calculation used measured radon concentrations to determine the average radon concentration during the two-day sampling period. Measured values were corrected for radioactive decay that occurred between the time of sampling and time of measurement by extrapolating back to the midpoint of the sampling period.

Samples were counted a minimum of two and a half hours after the sample was introduced into the scintillation cell. This allowed the radon in the samples to come into equilibrium with its short-lived decay products, effectively increasing the alpha counting rate by about a factor of three.

Radon Decay Products: Radon decay product concentrations were measured inside trailers, buildings and homes at eighteen locations in the Grants Mineral Belt. On the average a one week sample was taken every two months at each location. Concentrations were measured using radon progeny integrating sampling units (RPISU), provided by the U.S. Environmental Protection Agency (USEPA). These units consisted of an air pump, a filter and two TLD (thermoluminescent dosimeter) chips. One chip counted all types of radiation coming from the filter, while the other was sufficiently shielded so that alpha radiation coming from radon daughters on the filter were not detected. Subtracting the two TLD chip exposures after analysis permitted the determination of short-lived alpha activity mainly attributable to radon decay products. All TLD readings and working level calculations were performed by the USEPA's Office of Radiation Programs, Las Vegas Laboratory.

External Radiation: Measurements of external radiation were made with a pressurized ionization chamber. This device consisted of a chamber filled with argon gas at 25 atmospheres of pressure. The instrument measured both cosmic and terrestrial penetrating radiation, including any gamma levels coming from sources such as naturally occurring radioactivity in rocks, soil, uranium ore or tailings.

3.1.2 Selection of Sampling Locations

Figure 3.1 shows the location of the sampling sites and the type of sample collected at each site. Thirty-three locations were sampled for radon, eighteen for radon decay products and thirty-three for external gamma. Of the thirty-three sites where radon was monitored, twenty-nine had sampling performed over a two-year period. All other radon monitoring was performed over a single year.

Radon sampling sites were located at (1) points of expected maximum concentration (2) nearby populated areas and (3) background locations that were either distant or upwind from radiation sources. Aerial photos of the mills, taken by the USEPA at the request of the NMEID, were used to identify potential locations.

Points of expected maximum radon concentration for uranium mine/mills were estimated from meteorological data and standard graphs and tables giving the position of expected maximum values at ground level for Xu/Q, where X is the pollutant concentration, Q is its emission rate, and u is the mean wind speed, as a function of stability class and height of emission (17). Modifications of these estimates were introduced when necessary for the following reasons:

1. Having area rather than point sources for tailings piles.

2. Aerodynamic downwash of radon coming off tailings piles.

3. Mountainous terrain.

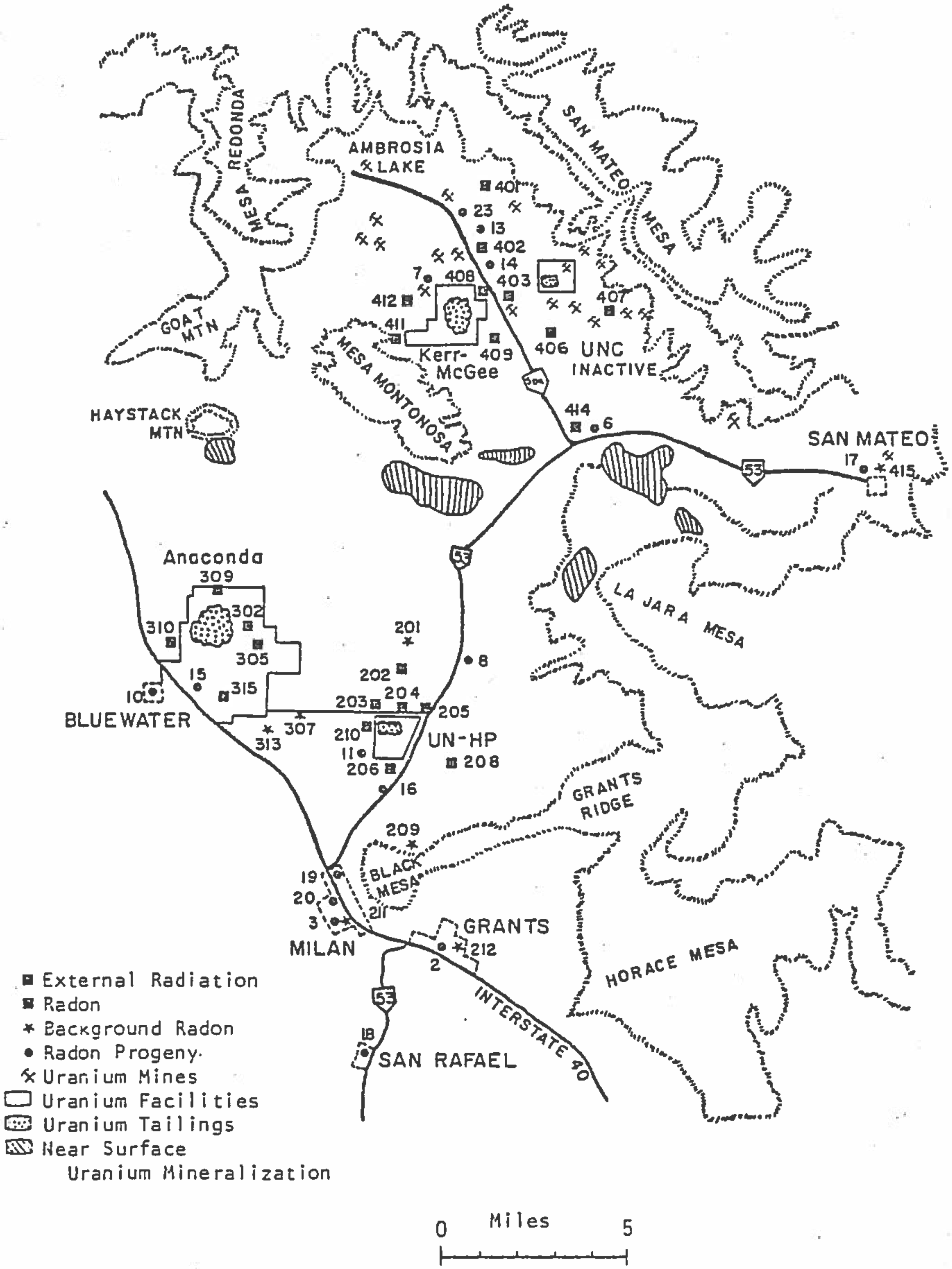

Figure 3.1 Sampling Locations and Station Numbers

Because of the comparatively low height of tailings piles (maximum heights of 20 to 25 meters), the expected location of maximum concentration was less than one kilometer from the source for all stability classes. The first correction, which involved using a virtual point source further upwind, had the effect of reducing this distance even more. In most cases this meant that stations intended to monitor the highest off-site concentrations needed to be located as close to facility boundaries as possible. General criteria used in selecting radon sampling locations were as follows:

1. Choosing the one or two prevailing wind directions from meteorological information available at the time of program design and consideration of local topography. The principal wind directions were out of the northwest at Anaconda, and out of the northwest and south-southwest at HMC.

2. Placing monitors in the predominant downwind directions at boundary locations (or at times at the point of expected maximum concentrations on the mill property), another one-half mile downwind from the first, and a third one mile downwind from the second.

3. Placing a fourth and possibly a fifth monitor at the boundary line (or point of maximum expected concentration) at one quarter to one half mile on either side of the first monitor.

4. Establishing one or two background stations distant from the mill.

5. Locating a station at the boundary line in a predominately upwind directing from the mill.

6. Placing a station at the home of the closest resident.

This scheme located from two to six stations in areas of maximum concentration. In addition, approximately three stations were located at more than a mile and a half from any mine/mill radon source to determine background concentrations for the area. The middle stations described in (2) helped to indicate how radon concentrations varied with distance from the source.

The above strategy was generally followed in selecting sampling sites, not only for the sampling reported here, but also for sampling being conducted in other areas. However, several exceptions occurred, most notably in the Ambrosia Lake region, where the sampling scheme was modified to include locations near mines.

In choosing downwind locations, particular consideration had to be given to night time meteorology. Radon concentrations typically increase through the nigh, and reach a peak just before sunrise when the most stable wind conditions dominate. After sunrise, increasing atmospheric mixing dilutes radon concentrations so that lower levels are usually observed during the day. Wind directions associated the highest radon concentrations, therefore, are usually those occurring during the night. These wind directions are not necessarily those associated with higher velocity winds found during the afternoon, and are usually greatly influenced by local topography.

Radon decay product monitoring was limited to areas where indoor sampling locations were available in the selected study zones. This sampling was used to obtain a measure of the actual radiation exposure being incurred by members of the public. Sampling locations were chose to obtain measurements in areas of possible elevated indoor radon decay product inhalation exposure and in background locations.

External radiation levels were measured at all radon monitoring stations. There locations included background sites, areas of expected elevated gamma levels and residences located close to monitored facilities. Also, external radiation was measured, both inside and outside, at radon decay product stations.

3.2 RESULTS

3.2.1 Outdoor Radon Monitoring

Mean values for all radon samples were determined at each sampling location by calculating averages for the first year (April, 1978 to March, 1979) and second year (April, 1979 to March, 1980).

These values, along with their standard deviations, standard errors and number of samples, are presented in Tables 3.1 and 3.2. In addition to individual stations, results are presented for groups of stations at background locations and areas of expected maximum concentrations near the Anaconda and HMC mills as well as at Ambrosia Lake. Standard deviations were calculated from the samples themselves, and thus they reflect the variation of radon concentrations due to environmental causes such as weather or ground moisture, as well as analytical variation due to measurement techniques.

At two locations, a sampling procedure was followed to determine the components of variance of the measurement program. The results of this sampling are given in Appendix A.

In Figures 3.2 and 3.3, radon concentrations measured at each location are displayed on a map of the area for each year studied. Patterns of the concentrations measured during the first and second year of sampling are readily apparent. Radon concentrations measured in the Ambrosia Lake area are higher than those at other monitored sites for both years that monitoring took place. In the Ambrosia lake area, the highest measured values tended to group along the centerline of the Ambrosia Lake valley, reflecting the drainage of air towards the southeast. Atmospheric modeling by Droppo and Glissmeyer (49) have subsequently predicted that the highest concentrations would occur several miles west of the centerline. However, radon measurements were not taken in this location to confirm model predictions. Elevated values were observed at station 414, which is located some 3-4 miles from the nearest active mine or mill, but is situated in the drainage pattern. However, elevated radon values at 414 may also be due in part to nearby outcrops of mineralized rock, as noted by other authors (10).

During both years of monitoring, stations which were not near mine vents but located close to and downwind from the HMC and Anaconda tailings piles were observed to have higher radon values than those located in the same direction but farther away. For example, stations 203, 204 and 205, north of the HMC pile, are higher than station 202 which is higher that station 201. The same effect can be observed, but not as markedly, around Anaconda toward the southeast. Station 307 placed halfway between the HMC and Anaconda tailings piles, registered background radon levels both years. This suggests that the two mills are fairly well isolated from each other in that radon emissions from one mill do not appreciably affect radon levels around the other. Radon levels at HMC, Anaconda and background locations did not change significantly from the first to second year. However, a large increase in radon was observed at Ambrosia Lake for the second year. Implications of this increase will be discussed in Section 5.1.

3.2.2 Indoor Radon Decay Product Monitoring

Results of working level measurements taken in buildings in the Grants area are given in Table 3.3, along with a description of the type of building in which the sampling took place. Figure 3.4 shows these averages on a map of the area. Values ranged from 0.0029 to 0.0393 working levels for all structures sampled.

3.2.3 External Radiation

External radiation levels at each location, measured with a pressurized ionization chamber, are given in Table 3.4. These values are also presented on an area map in figure 3.5. External radiation levels ranged from 11.1 to 93.1 micro-R/hr.

The towns of Milan and Grants had levels of 11.1 and 13.0 micro-R/hr or approximately 97.2 and 113.9 mrem/y. These values are at background levels for New Mexico and the western U.S. in general. However, elevated values were observed nearby tailings piles. For example, 93.1 micro-R/hr near the HMC pile is approximately 8 times the background rate for external exposure.

TABLE 3.1 First Year Radon Averages by Station (pCi/l)

Station	Mean	Standard Deviation	Standard Error	Sample Number	P(Normal)[a]	P(Log-Normal)[a]
201	1.12	1.15	.28	17	LT.01	.268
202	1.32	.99	.22	20	.164	.783
203	1.92	1.26	.28	20	LT.01	LT.01
204	2.01	1.35	.34	16	LT.01	.456
205	1.55	1.14	.28	17	LT.01	.154
206	1.18	1.05	.24	19	LT.01	.830
208	1.10	.97	.27	13	.049	.428
209	.72	.69	.16	18	.01	.357
210	1.55	1.31	.30	19	.01	.074
211	.44	.46	.10	20	.01	.822
212	.36	.45	.10	21	.01	.064
302	1.37	.70	.16	19	.354	.877
305	.76	.68	.16	19	.034	.354
307	.63	.73	.18	17	.01	.588
309	.30	.29	.07	19	.18	0.521
310	.41	.49	.12	17	.01	.827
313	.48	.37	.08	20	.017	.056
315	.57	.55	.12	22	LT.01	.837
401	1.02	.25	.06	20	.764	.108
402	3.15	1.66	.35	22	.548	.168
403	3.47	1.87	.42	20	LT.01	.540
406	2.96	1.85	.44	18	.566	LT.01
407	2.01	1.11	.26	18	.043.	520
408	4.12	3.03	.66	21	.188	LT.01
409	3.59	3.32	.76	19	LT.01	.388
411	.91	.55	.13	19	.477	.081
412	4.23	4.56	1.27	13	LT.01	.427
414	1.50	1.17	.27	19	.037	.469
500	.13	.08	.05	3	.640	.975
501	.10	.03	.02	3	.154	.122
502	.10	.05	.03	3	.05	.069
Background[b]	.57	.69	.06	122	LT.01	GT.15
Selected Bkg[c]	.42	.34	.07	25	LT.01	.746
Ambrosia Lake[d]	3.20	2.53	.24	110	LT.01	.023
Anaconda[e]	1.06	.75	.12	38	LT.07	LT.01
HMC[f]	1.83	1.24	.17	53	LT.01	LT.01

(a) Probability that a normal/log-normal distribution would have a test statistic larger than that calculated for the data at each station. If the value is less than 0.05 the distribution is not normal/log-normal using the 95% level of significance.

(b) Composed of all samples taken at stations 201, 209, 211, 212, 307, 313, 500, 501, 502.

(c) 25 samples chosen at random from all individual background samples.

(d) Pooled sampled taken at stations 402, 403, 406, 407, 409, 412.

(e) Pooled samples taken at stations 302, 305.

(f) Pooled samples taken at stations 203, 204, 205.

TABLE 3.2 Second Year Radon Averages by Station (pCi/l)

Station	Mean	Standard Deviation	Standard Error	Sample Number	P(Normal)[a]	P(Log-Normal)
201	.81	.75	.17	20	.011	.544
202	.89	.78	.17	21	LT.01	.320
203	1.51	1.11	.24	22	LT.01	.409
204	1.89	1.00	.21	23	.357	.826
205	1.12	.83	.18	22	LT.01	.631
206	.93	.83	.19	20	.015	.210
208	.84	.64	.14	20	.016	.917
209	.79	.57	.12	23	.072	.167
210	1.41	1.35	.31	19	.015	LT.01
211	.71	.81	.17	23	LT.01	.249
212	.61	.59	.14	18	.042	.266
302	.78	.50	.11	21	.404	.097
305	.95	.76	.17	21	LT.01	.976
307	.55	.53	.12	21	LT.01	.024
309	.21	.13	.03	21	.386	LT.01
310	.36	.28	.06	20	.156	.061
313	.47	.51	.11	23	LT.01	.536
315	.49	.37	.08	24	.030	.048
401	1.18	.43	.10	19	.303	0.12
402	6.40	3.28	.66	25	LT.01	.914
403	5.70	2.23	.50	20	.213	.096
406	3.40	2.00	.44	21	.096	LT.01
407	3.23	1.55	.32	23	.773	.035
408	5.77	3.59	.77	22	.470	.246
409	5.43	3.58	.75	23	.360	LT.01
411	1.10	.78	.16	24	.193	.051
412	3.74	2.53	.52	24	.330	LT.01
414	1.69	1.23	.26	22	.050	.436
415	.14	.22	.05	19	LT.01	.482
500	.15	.12	.03	16	.806	.675
501	.17	.13	.03	15	.087	.381
502	.14	.10	.03	9	LT.01	.456
Background[b]	.50	.58	.04	187	LT.01	GT.15
Selected Bkg[c]	.53	.73	.15	25	LT.01	.546
Ambrosia Lake[d]	4.66	2.89	.25	136	.091	LT.01
Anaconda[e]	.87	.64	.10	42	LT.01	.407
HMC[f]	1.51	1.02	.12	67	LT.01	GT.15

(a) Probability that a normal/log-normal distribution would have a test statistic larger than that calculated for the data at each station. If the value is less than 0.05 the distribution is not normal/log-normal using the 95% level of significance.

(b) Composed of all samples taken at stations 201, 209, 211, 212, 307, 313, 415, 500, 501, 502.

(c) 25 samples chosen at random from all individual background samples.

(d) Pooled samples taken at stations 402, 403, 406, 407, 409, 412.

(e) Pooled samples taken at stations 302, 305.

(f) Pooled samples taken at stations 203, 204, 205.

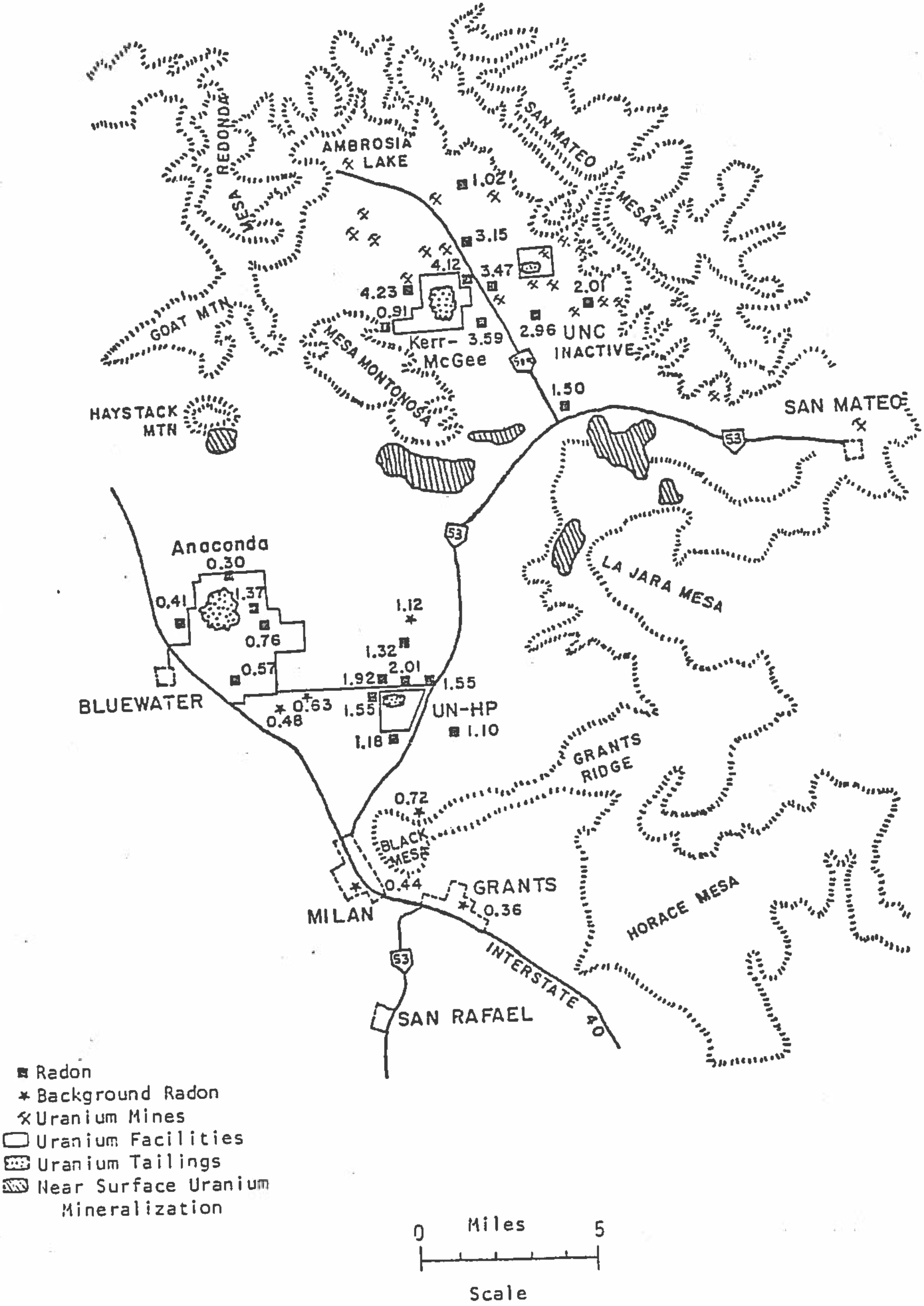

Figure 3.2 First Year Radon Averages By Station

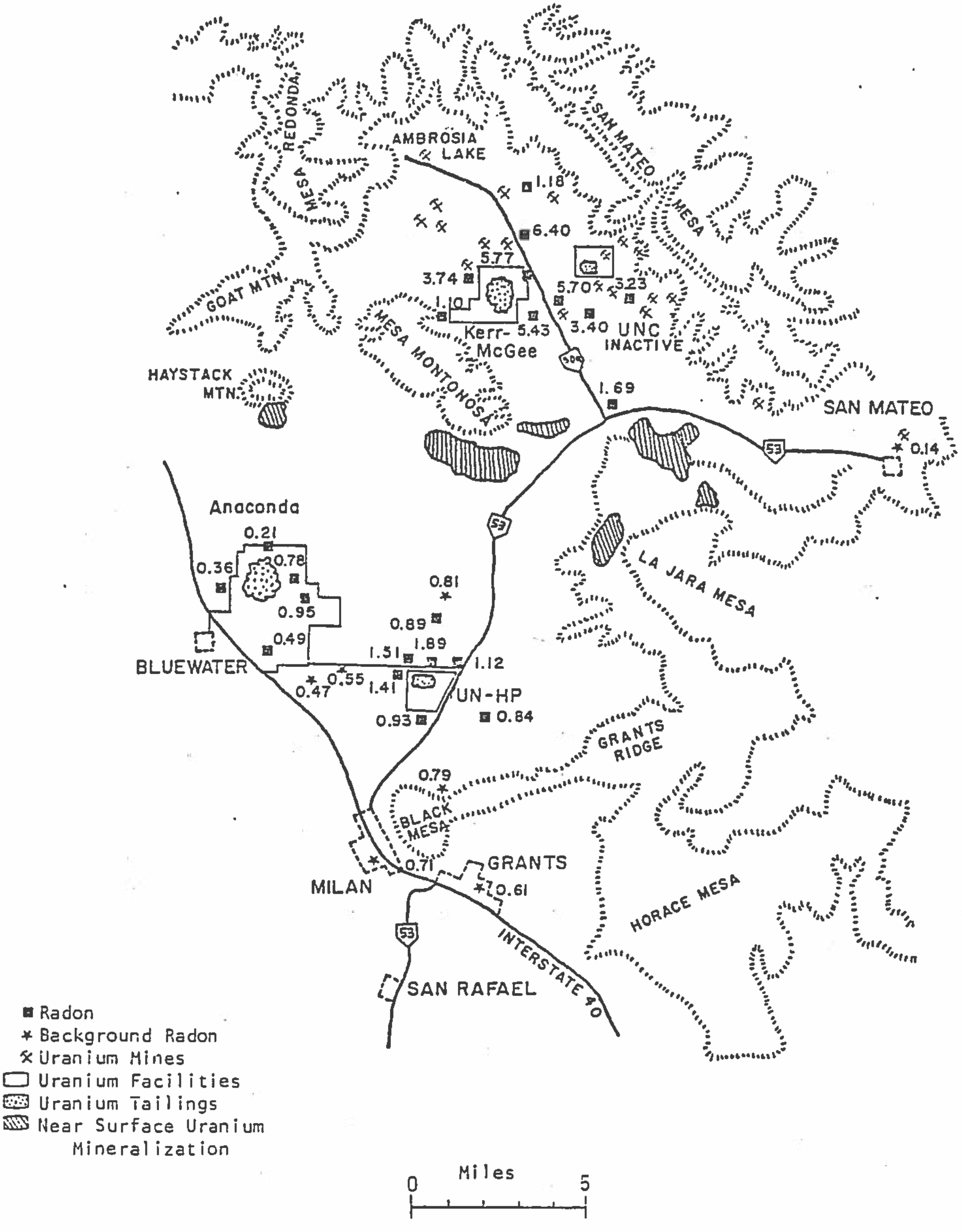

Figure 3.3 Second Year Radon Averages By Station

TABLE 3.3 Average Working Level Measurements

Station	WL[a]	S.D.[b]	N	Building Type	Heating[c] Cooling	Type of Foundation
1	.0119	.0053	11	Adobe Hs.	W	Crawl Space
2	.0049	.0019	17	Frame Hs.	G,AC	Slab
3	.0117	.0061	10	Frame Bldg.	G,AC	Slab
6	.0082	.0027	6	Frame Hs.	G	Slab
7	.0173	.0087	7	Trailer	AC	
8	.0084	.0039	6	Trailer	G,AC 2	
10	.0054	.0028	7	Rock/Stucco	W	Slab
11	.0116	.0052	6	Frame Hs.	G	Crawl Space
13	.0085	.0030	5	Trailer		
14	.0131	.0046	6	Trailer		
15	.0061	.0021	7	Block Hs.	G	Crawl Space
16	.0085	.0034	7	Sheet Metal Warehouse	G,AC	Slab
17	.0037	.0014	6	Frame Hs.	G,W	Crawl Space
18	.0103	.0039	6	Adobe Hs.	W	Crawl Space
19	.0098	.0066	5	Frame Hs.	G	Crawl Space
20	.0067	.0066	5	Frame Hs.	G	Slab
21	.0029	.0008	5	Trailer	G,AC	
23	.0393	.0200	4	Frame/Stucco	G, AC	Crawl Space

(a) A working level (WL) is defined in part 4, Appendix A of the NMEID radiation regulations as any combination of short-lived radon-222 daughters in one liter of air, without regard to the degree of equilibrium, that will result in the ultimate emission of 1.3 E5 MeV of alpha particle energy.

(b) S.D. = Standard Deviation.

(c) W = wood, G = gas, AC = air conditioning.

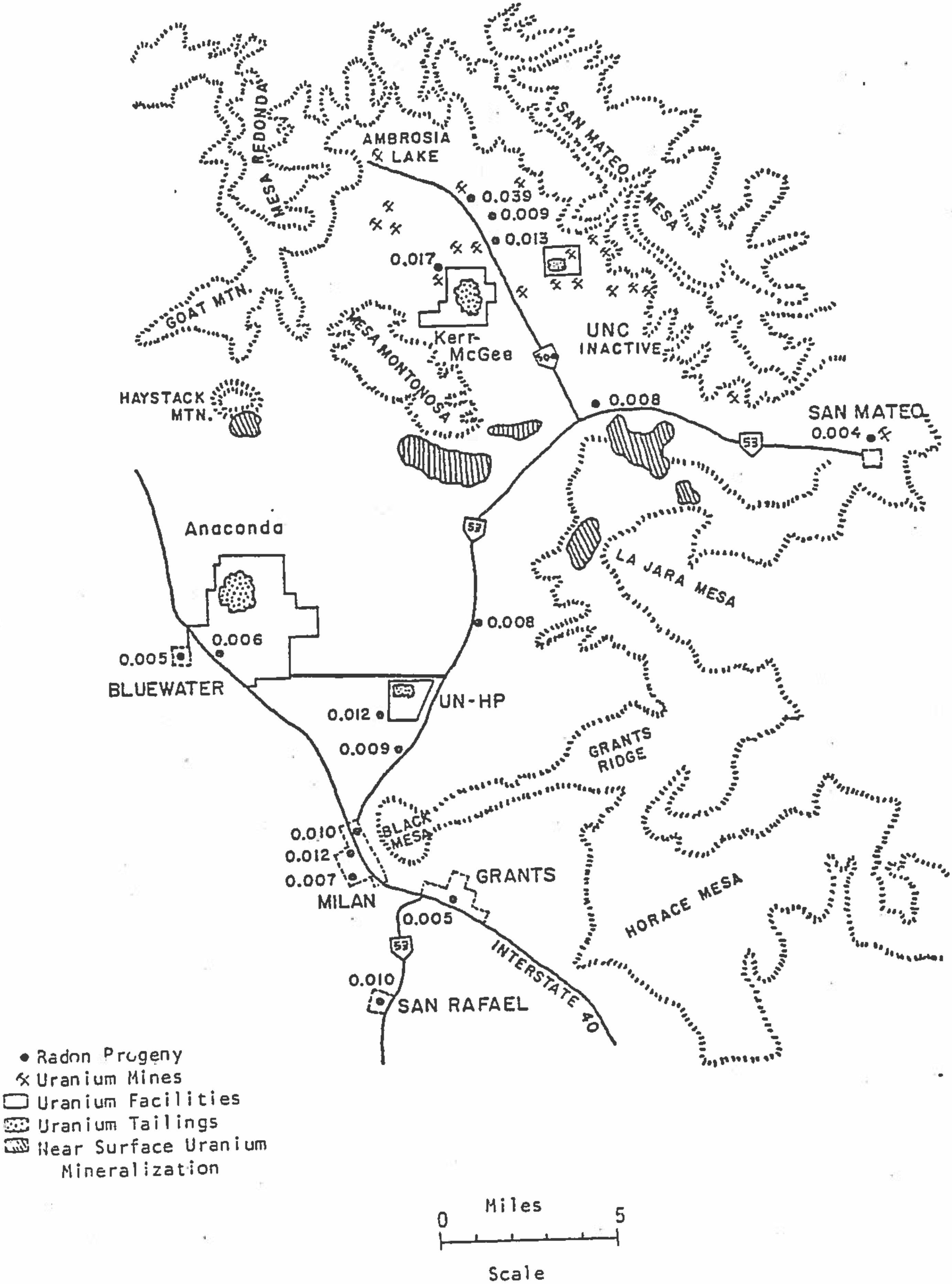

Figure 3.4 Average Radon Progeny Concentrations

TABLE 3.4 External Radiation Levels

STATION	EXPOSURE RATE (micro-R/hr)
201	11.7
202	18.4
203	71.3
204	93.2
205	27.5
206	12.5
208	15.8
209	13.8
210	15.8
211	11.1
212	13.0
302	91.6
305	15.8
307	13.0
309	11.1
310	11.6
313	14.0
315	13.5
401	15.8
402	27.5
403	19.0
405	71.6
406	13.7
407	26.6
408	30.1
409	20.0
411	15.7
412	15.7
414	16.3
415	15.4
500	14.0
501	12.0

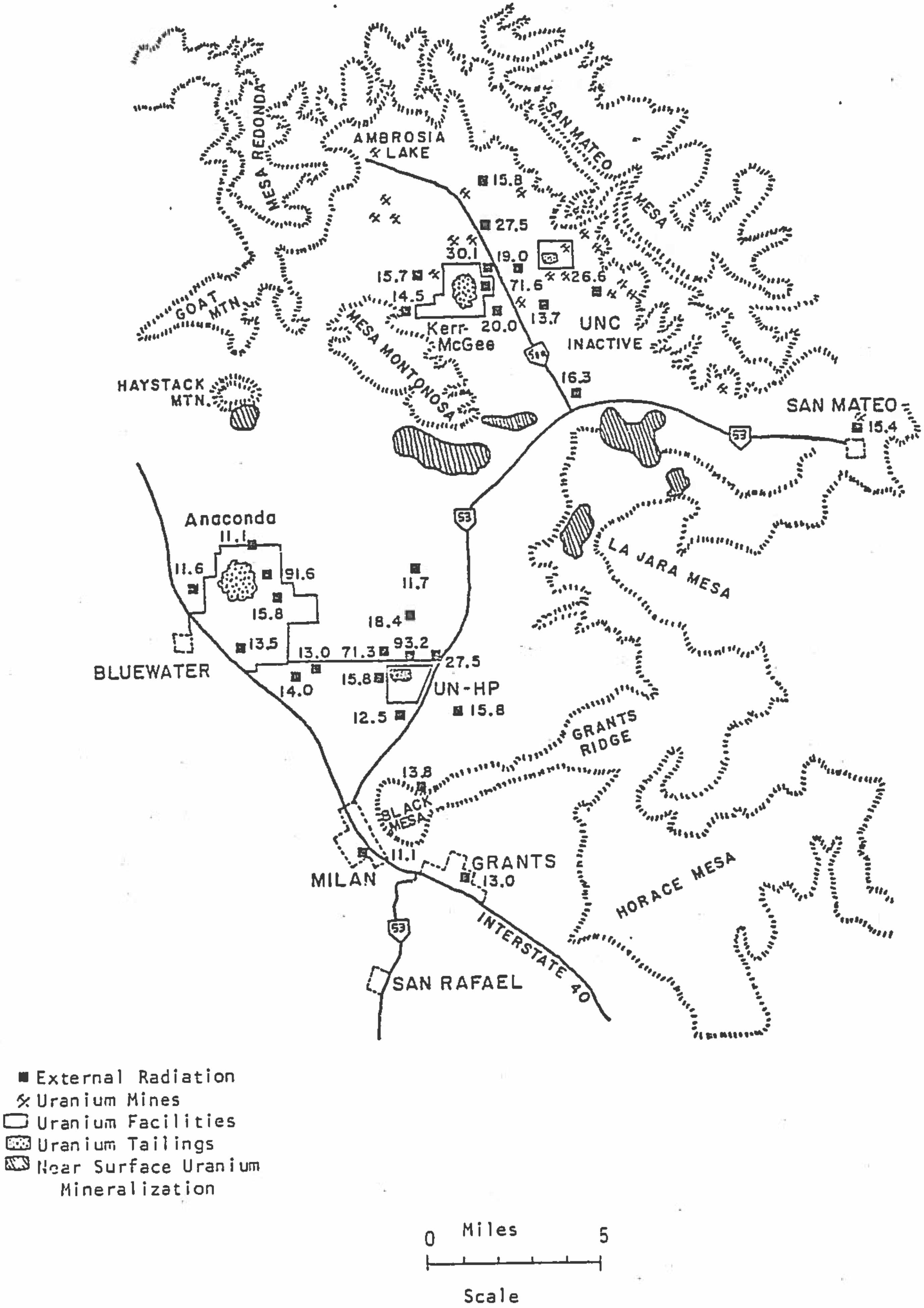

Figure 3.5 External Radiation Levels

4.0 TREATMENT AND EVALUATION OF DATA

Results from the radon, radon decay product and external radiation monitoring data sets were used to address the following questions:

1. Is there a statistically significant difference between radon levels measured at either Ambrosia Lake or near any monitored mills, and those measured at background locations?
2. Are New Mexico Radiation Protection Regulations being violated?
3. What is the additional radiation exposure if any, that may accrue to an individual living at Ambrosia Lake or near any of the monitored uranium mills?
4. Does this additional radiation exposure (if any), or increased radon level, represent an unacceptable health risk?

New Mexico Radiation Protection Regulations, as well as recommendations by international and national radiation advisory bodies such as the ICRP and NCRP, require that radiation dose due to human activity be assessed relative to natural background radiation (12, 18, 19). In following these recommendations, both background and facility-associated radon and radon decay product levels were taken into account in evaluating radiation exposures and resulting health risks.

Annual mean concentrations and their standard errors were calculated by year at each site. Concentrations at background stations were then compared with those measured at Ambrosia Lake and near monitored mills. Radiation exposures were calculated for observed differences above background. These differences and calculated radiation exposures were then compared to radiation protection standards given in Part 4 of the NMEID Radiation Protection Regulations. Finally, using measured radon and radon decay product levels, estimates of risk due to lung cancer mortality were calculated.

4.1 STATISTICAL METHODS USED TO EVALUATE THE DATA

Statistical tests were performed using the computer program Statistical Analysis System (SAS) to describe the data and determine if any measured differences were statistically significant (31). Hypothesis testing was performed for parametric and nonparametric tests comparing radon measurements at each mine/mill station with those at background, or comparing several stations grouped together (20). A test statistic was calculated for each test and the probability (P) that identical populations would yield a test statistic greater than that calculated for the data sets being compared was determined. If P was less than 0.05, it was concluded that the two populations were not identical at the 95% confidence level and the tested hypothesis was rejected at this level.

Non-parametric tests were used extensively. These tests were chosen as a result of considering whether the radon data followed a normal or a log-normal distribution. A Kolmogorov-Smirnov test for normality and log-normality was performed on the data from each sampling site for each year of sampling (21). P-values for these tests are shown in Tables 3.1. and 3.2.

As can be seen from Tables 3.1 and 3.2, the data favor, although not conclusively, the log-normal distribution. Fifty-one of the 63 tests (81%) had a P (log-normal) value greater than 0.05, while only 27 (43%) had a P (normal) greater than 0.05. While this indicates that the individual station distributions may have the same general log-normal shape, the failure rate is slightly greater than what one might expect. It was therefore felt more appropriate to use non-parametric tests, which are slightly less powerful than parametric tests, but do not require any distributional assumptions.

Two types of non-parametric tests were used to compare data. A Kruskal-Wallis test (non-parametric one-way analysis of variance) determined if data collected at several different stations could be shown to come from the same population. This test indicated, for example, if radon data taken at different background stations were from distinct populations or not.

The second non-parametric test used was the Wilcoxon rank sum test. This test determined if data taken from two locations, such as background and Ambrosia Lake, were from the same population.

In addition to non-parametric tests, a t-test was also performed to provide a comparison with a more generally used test. Even though the t-test is parametric, it is known to be robust in handling non-normal data (20, 40, 41).

4.2 BACKGROUND RADIATION LEVELS

4.2.1 Radon

Measurements were taken in the Grants Mineral Belt at ten locations believed to be relatively unaffected by emissions from monitored facilities. Values measured at these stations were used to estimate the natural radon environment prior to uranium development. Average background radon concentrations were found to be 0.57 ± 0.06 pCi/l and 0.50 ± 0.04 pCi/l for the first and second year of monitoring. Measurements taken near uranium facilities were then compared with background levels in order to see if any statistically significant increase in radiation levels had occurred. Background radon stations were located at Grants (station 212), Milan (211), San Mateo (415), Crownpoint (500 and 501), Bluewater Lake (502), and at four sampling sites 1.5 miles from a uranium facility (201,209, 307 and 313), as shown on Figure 3.1.

A Kruskal-Wallis test was performed with a null hypothesis that no difference existed between radon concentrations at background locations. The test result gave a probability less than 0.001, and therefore the null hypothesis was rejected. The data indicated that there were statistically significant differences in background radon concentrations measured at various locations within the Grants Mineral Belt. An inspection of the data showed that station 201 was consistently elevated above other stations, while stations 415, 500, 501 and 502 were consistently below the average. Omitting these five stations from the Kruskal-Wallis test raised the test probability to 0.08, indicating that the remaining stations came from the same population at the 95% confidence level. The question of which background stations should be used in this study is an important one. Radiation protection practices, as noted earlier, are based on a comparison of facility radiation levels with background.

If background concentrations are overestimated, then a greater proportion of higher levels measured near uranium mines and mills would be incorrectly attributed to natural causes rather than to the facility. On the other hand, underestimating background would cause the incorrect conclusion that mine and mill contributions to total radon levels are greater than they actually are.

Collected data has shown that there are significant differences in concentrations between locations in data set A. This presents a difficult situation in applying radiological health standards, which require that background be subtracted from levels measured in mine/mill areas. However, some assumption about background needed to be made. In the absence of pre-operational background data, and in view of the impossibility of obtaining background radon levels at each specific monitoring site, data set (A) described below was felt to represent a reasonable estimate of background concentrations. In order to account for the objection that a uranium mining area might be expected to have background radon concentrations higher than background levels found in other areas, a second data set (B) giving a maximum estimate of background was also used for duplicate testing. The two background data sets were:

A. Stations 201, 209, 211, 212, 307, 313, 415, 500, 501 and 502.

B. Data taken only from the highest background location, station 201.

Data from (A) was considered to give the best estimate of background and is used in the main body of this report. However, the highest observed radon values were sufficiently elevated so that the conclusions reached in this study were warranted even if one were to purposely bias the background data to the highest values recorded. Tests against the values of station 201, discussed in Appendix B, indicated that areas in Ambrosia Lake were still considerably elevated even above this relatively high background estimate.

The mean value of the stations in Group A was used for background in this report since it had the advantages of 1) being measured during the same time as the other stations, 2) including background measurements at these undistrubed locations (with which it is in statistical agreement) as well as at locations nearer the areas of concern and 3) being measured with the same technique as the mine/mill stations.

For making statistical tests between background and mine/mill locations, 25 samples were randomly selected from background data set (A) for each year so that the two populations would have roughly the same number of samples. Descriptive statistics from these selected background samples are given in Tables 3.1 and 3.2.

A Wilcoxon test was performed on the 25 selected background samples from year one and year two. The resulting probability was 0.183, indicating that the first and second year samples came from the same populations.

There is some evidence that background could be lower than used here. As shown before, the data in background set A were not from the same population. This could indicate that the lower stations were at background while the others were impacted by industry. Furthermore, the assumption that background conditions exist beyond a distance of 1.5 miles from a uranium facility may not be valid.

Several investigators have measured background radon concentrations in undisturbed areas of the Grants Mineral Belt far removed from any industrial impacts. These values are shown in Table 4.1. The average and standard error of the mean for all values was 0.19 ± 0.02 pCi/l.

TABLE 4.1 Background Radon Concentrations in Undisturbed Areas of the Grants Mineral Belt

Area Location	N	Mean and Standard Error (pCi/l)
Phillips Nose Rock Site (46)	11	0.25 ± 0.05
Exxon L-Bar In-Situ Site (47)	16	0.25 ± 0.08
Gulf Mill Site (48)	20	0.21 ± 0.02
Town of San Mateo (NMEID)	19	0.14 ± 0.05
Town of Crownpoint (NMEID)	37	0.15 ± 0.02
Bluewater Lake (NMEID)	12	0.13 ± 0.03

Using a lower background value would raise the previously borderline stations over the limit. A case in point is station 210 which, with a background of 0.19 pCi/l, would be raised to 1.36 and 1.22 pCi/l above background for years one and two (see Section 4.4).

Determining background levels at Ambrosia Lake is a difficult task which cannot be accomplished with direct measurements due to previous uranium mining and milling in the area. Hence, must measure background in outlying areas with similar geological structure and apply those levels to Ambrosia Lake. Because of this difficulty, we have conservatively used 0.5 pCi/l as background in this report. Additional monitoring is undisturbed areas will be used to further evaluate this important problem.

An attempt was made during the summer of 1982 to determine "background" in Ambrosia Lake during a mine shutdown. This study showed that mean radon concentrations did not decrease significantly during the shutdown. However, the study proved inconclusive for several reasons. During the shutdown period, both Kerr-McGee and HMC mines were down for two weeks, but not at the same time. Furthermore, even though no ore was produced, many of the vents ran for several hours per day and some vents operated for 100 percent of the shutdown period. Without normal venting of radon, high levels would continue to build up in the underground mine. Therefore, even though the percentage of venting was reduced, high concentrations of radon would have been discharged into the atmosphere. Since no measurements of vent emissions were taken, radon discharges could not be substantiated. In addition, other sources such as tailings piles mine spoils and windblown tailings continued to release radon and, therefore, measurement of true background still could not have been achieved (see Appendix C).

4.2.2 Indoor Radon Decay Products

Determination of representative background concentrations of radon decay products proved to be a difficult problem which is still being addressed by field monitoring.* Most complications stem from the large number of variables that affect indoor radon decay product levels. Radon decay product levels are not only affected by outdoor radon entering a building, but also by radon emitted from sources close to or inside the structure, such as building materials, type of heating and cooling, insulation and the underlying soil or foundation (22). In addition, occupational practices in the use of the building are significant factors in that they influence ventilation rates and therefore determine the length of time available for radon to form decay products.

At some background locations monitored in this study, factors other than outside radon concentrations dominated radon decay product concentrations. For example, a structure with an average of 0.0119 working levels was an adobe home constructed in an area far removed from uranium mining and milling activities. The highest value of 0.0393 WL which was 220% higher than the next highest value, was measured in the only non-trailer from Ambrosia Lake and was surrounded by mine vents. This value lies outside the 95% confidence interval for all other stations. The mean and standard error for data from all stations during both years at Ambrosia Lake was 0.020 ± 0.007 WL (n = 4). All background stations averaged 0.007 ± 0.001 WL (n = 11).

4.2.3 External Radiation

The external gamma exposure rate was taken at each radon location to see if there was a correlation between the two. The correlation coefficient between the second year radon values and the external gamma values was 0.11. Using only background stations, the correlation was 0.50, while the mine/mill stations had a correlation of -0.03. It is clear from inspecting the gamma data that stations with high values are close to tailings piles. It is not so clear with radon, however, because there are other factors that affect radon more than external gamma, such as mine vents and meteorology. This could account for the low correlation coefficients observed.

The external radiation data taken at the radon sampling locations were broken up into four groups and a one way analysis of variance (ANOVA) performed. The four groups were: (1) background stations, (2) those within one half mile of a tailings pile, (3) those within one half mile of a mine vent but not within one half mile of tailings pile and (4) those located further than one half mile from either a vent or pile but not designated as a background location. The ANOVA test yielded an F value of 21.2, which exceeds F (.01, 3, 29) = 4.54. Therefore, the four means were found not to belong to the same population. The four means and standard errors were 13.12 ± 0.40, 62.53 ± 12.88, 25.80 ± 2.39 and 14.65 ± 0.58 micro-R/hr, respectively.

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*We are indebted to Mr. Richard Douglas formally of the USEPA Office of Radiation Protection Las Vegas Facility for analyses of the radon progeny samples, as well as the gamma data at each radon progeny sampling site.

4.3 STATISTICAL ANALYSIS OF RADON LEVELS FROM MAJOR REGIONS

For purposes of testing, this data was pooled into three groups:

1. Ambrosia Lake (stations 402, 403, 406, 407, 409 and 412).

2. Anaconda (stations 302 and 305). (Note: Both of these stations were located on Anaconda property in restricted areas).

3. Homestake Mining Company (HMC) (stations 203, 204 and 205). (Note these stations are not located in the HMC restricted area. While a public road passes between these stations and the tailings pile, long-term occupancy obviously does not occur.)

These groups corresponded to areas of expected elevated levels of radon gas as described in June, 1977 NMEID report, Airborne Radioactivity Monitoring Program for the Grants Mineral Belt (23). Data was grouped in this way in order to illustrate general characteristics of certain geographical regions. However, for the purpose of health evaluations, only radon concentrations at a single location need be compared with background (12).

Kruskal-Wallis tests were performed on each of these three data sets to see if the hypothesis that no difference exists between the populations sampled at each location within the group could be rejected. The results are given in Table 4.2.

TABLE 4.2 Probability That Radon Levels From Grouped Stations Came From the Same Population

Location	Year One	Year Two
Ambrosia Lake	0.010	0.182
Anaconda	0.763	0.007
HMC	0.011	0.190

These results indicated that, in general, none of the three areas could always be characterized by a single population of radon concentrations. As a result, stations were not grouped together but were tested individually against background. Results of these tests are discussed in Section 4.5.

4.4 COMPARISON OF BACKGROUND WITH MINE/MILL LEVELS

Mean radon concentrations are given by year and station number in Table 3.1 and 3.2. Using average background values of 0.57 ± 0.06 and 0.50 ± 0.04 for the first and second year of sampling, the amount of measured radon that exceeded background was calculated at each station and listed in Table 4.3. It is again noted that radon concentrations at Ambrosia Lake are compared to NMRPR concentration limits only as health guidelines and not as regulatory requirements, because uranium mine effluents are not regulated under the NMRPR.

These results shown in Table 4.3. represent the best estimates of the differences between radon values at radon values at each station and background as measured by the sampling program. The results indicate that it is probable that the individual concentration limit of 3 pCi/l was exceeded at stations 408, 409 and 412 in the first year and at stations 402, 403, 408, 409 and 412 in the second year. In addition, since a population lived in the vicinity of stations 206, 210, 315, 402, 403 and 414, the 1 pCi/l population limit may be applied at these locations* (see Section 2.0 concerning radiological health criteria for the populations). The 1 pCi/l standard, if applicable, was exceeded at stations 402 and 403 in the first year and at stations 402, 403 and 414 in the second year. The average of six stations at Ambrosia Lake exceeded this limit for both years, indicating that locating a "suitable sample the population" in the Ambrosia Lake area is unadvisable for radiological health reasons.

Subtraction of background radon concentrations indicated that radon limits were exceeded in Ambrosia Lake. No locations were found to exceed the 3 pCi/l limit around Anaconda** or HMC. The 1 pCi/l population limit was not exceeded around these two mills, although the difference at station 210 was very close to this limit in both the first year (0.98 pCi/l) and the second year (0.90 pCi/l). At two locations, stations 203 and 204, the concentrations exceeded 1 pCi/l above background, but the population limit did not apply since no one was living in the area.

Clearly, it would be inadvisable to locate any future housing development in the vicinity of stations 203 and 204 because of these elevated levels.***

In making this assessment, only radon concentrations have been considered since other radionuclide analyses have not been completed. However, radioactive airborne particulates have been monitored and will be evaluated in light of the radon results to determine overall compliance with regulation limits.

A related question is, now that the best estimate of how much radon levels at a particular location exceed background levels, what is the statistical significance of these results? This will be discussed in the next section.

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*Since the study was completed, the population at Ambrosia Lake has dropped substantially. The 1 pCi/l limit no longer applies to stations 402, 403 and 414.

**Both stations at Anaconda were inside the restricted area where the 3 pCi/l limit does not apply. It was shown at these two locations close to the tailings pile, even the more strict off-site limit of 3 pCi/l was not exceeded.

***Residential development in this area is very unlikely to occur since HMC has acquired land extending to one half mile north of its tailings pile.

TABLE 4.3 Measured Radon Concentrations in Excess of Background at Each Mine/Mill Station

	First Year		Second Year	
Station	Radon Difference[a]	Standard Error of Difference[b]	Radon Difference	Standard Error of Difference
202	.75	.23	.39	.17
203	1.35	.29	1.01	.24
204	1.44	.35	1.39	.21
205	.98	.29	.62	.18
206	.61	.25	.43	.19
208	.53	.28	.34	.15
210	.98	.31	.91	.31
302	.80	.17	.28	.12
305	.19	.17	.45	.17
309	-.27	.09	-.29	.05
310	-.16	.13	-.14	.07
315	0.00	.13	-.01	.09
401	.45	.08	.68	.11
402	2.58	.36	5.90	.66
403	2.90	.42	5.20	.50
406	2.39	.44	2.90	.44
407	1.44	.27	2.73	.32
408	3.55	.66	5.27	.77
409	3.02	.76	4.93	.75
411	.34	.14	.60	.16
412	3.66	1.27	3.24	.52
414	.93	.28	1.19	.26
Ambrosia Lake	2.63	.25	4.16	.24
Anaconda	.49	.75	.37	.11
HMC	1.26	.18	1.01	.13

(a) Background values, taken from Tables 3.1, and 3.2, are .57 ± .06 and .50 ± .04 for the first and second year, respectively.

(b) The standard error of the difference, SE (Station - BKG) was calculated from $SE(Station-BKG) = (SE(Station)^2 + SE(BKG)^2)^{\frac{1}{2}}$ (24)

4.5 STATISTICAL ANALYSIS OF BACKGROUND AND MINE/MILL LEVELS

As discussed in Section 4.1, a Wilcoxon test was used to compare background stations with stations near uranium mines and mills. This non-parametric test, equivalent to the Mann-Whitney test, operates on a ranking of the data values, rather than the values themselves. It is only slightly less powerful than the t-test, which was the parametric test used to confirm Wilcoxon results. The test procedure consisted of the following steps:

1. A background data set of 25 samples was chosen by random selection from the total background data set of 122 samples for year one.

2. 3 pCi/l was added to each selected background sample.

3. The results of selected background plus 3 pCi/l were then tested against the sample results at each mine/mill station. The tested hypothesis was that the station and selected background + 3 pCi/l were from the same population. If the probability P was less than 0.05, it was concluded that the mine/mill station was not from the same population as background +3pCi/l. If in addition the mean was higher than background +3 pCi/l, then it was concluded that the 3 pCi/l limit was exceeded at the 95% confidence level. These stations are indicated by footnotes in Table 4.4. If P was greater than 0.05, the data was considered inconclusive since the desired level of significance was not achieved.

4. Steps two and three were repeated for 1 pCi/l, instead of 3 pCi/l, added to the selected background data set.

5. Steps two and three were repeated for just the sample results.

6. This procedure was repeated for the second year of sampling using the selected background data for that year. Results are shown in Table 4.4 and presented grahically in Figures 4.1 and 4.2.

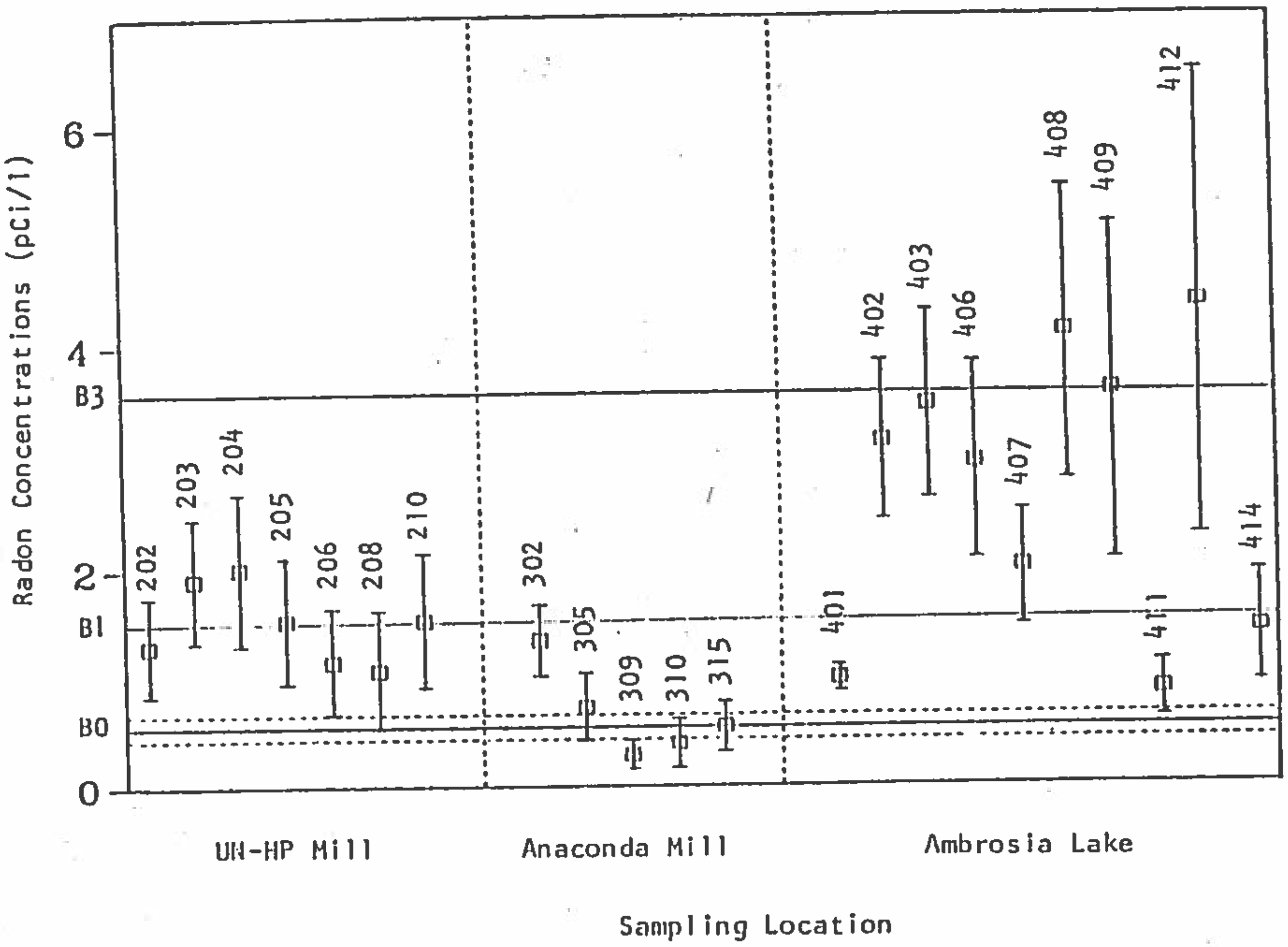

Figure 4.1 95% Confidence Intervals For First Year Radon Data. B0 = Background (Dotted Lines Show 95% Confidence Intervals), B1 = One pCi/l Limit Above Background and B3 = Three pCi/l Limit Above Background.

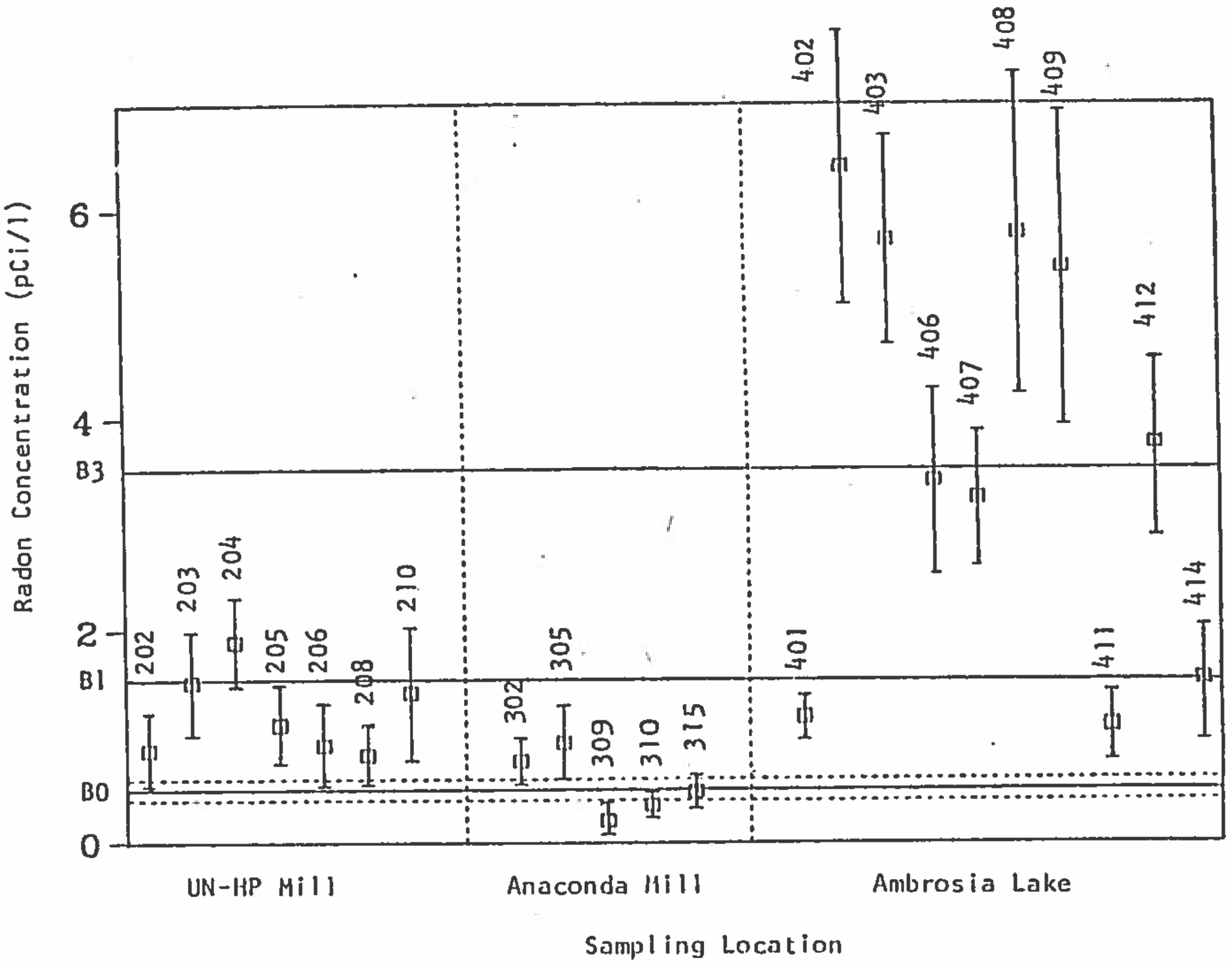

Figure 4.2 95% Confidence Intervals For Second Year Radon Data. B0 = Background (Dotted Lines Show 95% Confidence Intervals), B1 = One pCi/l Limit Above Background and B3 = Three pCi/l Limit Above Background

TABLE 4.4 Wilcoxon Test Probability Values Comparing Radon Concentrations at Mine/Mill Stations with Background[a] and Concentration Limits

	Year One			Year Two		
Station	+3pCi/l	+1pCi/l	+0	+3pCi/l	+1pCi/l	+0
202	LT.01	.215	LT.01	LT.01	LT.01	LT.01
203	LT.01	.120	LT.01	LT.01	.121	LT.01
204	LT.01	.067	LT.01	LT.01	.083	LT.01
205	LT.01	.048[c]	LT.01	LT.01	LT.01	LT.01
206	LT.01	.013	LT.01	LT.01	LT.01	.013
208	LT.01	.024	.017	LT.01	LT.01	LT.01
210	LT.01	.415	LT.01	LT.01	.128	LT.01
302	LT.01	.187	LT.01	LT.01	LT.01	LT.01
305	LT.01	LT.01	.078	LT.01	LT.01	LT.01
315	LT.01	LT.01	.238	LT.01	LT.01	.076
401	LT.01	LT.01	LT.01	LT.01	.088	LT.01
402	.194	LT.01[c]	LT.01	LT.01[b]	LT.01[c]	LT.01
403	.091	LT.01[c]	LT.01	LT.01[b]	LT.01[c]	LT.01
406	.082	LT.01[c]	LT.01	.456	LT.01[c]	LT.01
407	LT.01	.078	LT.01	.459	LT.01[c]	LT.01
408	.207	LT.01[c]	LT.01	.022[b]	LT.01[c]	LT.01
409	.472	.013[c]	LT.01	.052	LT.01[c]	LT.01
411	LT.01	LT.01	LT.01	LT.01	.031	LT.01
412	.345	LT.01[c]	LT.01	.239	LT.01[c]	LT.01
414	LT.01	.203	LT.01	LT.01	.436	LT.01

a) The background data set consisted of 25 samples randomly selected from 122 year one samples (for year one) and the 187 year two samples (for year two) collected at stations 201, 209, 211, 212, 307, 313, 415, 500, 501 and 502.

b) These stations are significantly higher than background +3 pCi/l. Unmarked significant stations are less than background +3 pCi/l.

c) These stations are significantly higher than background +1 pCi/l. Unmarked significant stations are less than background +1 pCi/l. Significant stations in the background +0 column are greater than background.

TABLE 4.5 t-Test[a] Probability Values Comparing Radon Concentrations at Mine/Mill Stations With Background[b] and Concentration Limits

	Year One			Year Two		
Station	+3pCi/l	+1pCi/l	+0	+3pCi/l	+1pCi/l	+0
202	LT.01	.337	LT.01	LT.01	LT.01	.060
203	LT.01	.047[d]	LT.01	LT.01	.473	LT.01
204	LT.01	.052	LT.01	LT.01	.083	LT.01
205	LT.01	.326	LT.01	LT.01	.042	LT.01
206	LT.01	.183	LT.01	LT.01	LT.01	.051
208	LT.01	.138	.014	LT.01	LT.01	.072
210	LT.01	.337	LT.01	LT.01	.363	LT.01
302	LT.01	.396	LT.01	LT.01	LT.01	.087
305	LT.01	LT.01	.029	LT.01	LT.01	.034
315	LT.01	LT.01	.123	LT.01	LT.01	.409
401	LT.01	LT.01	LT.01	LT.01	1.027	LT.01
402	.236	LT.01[d]	LT.01	LT.01[c]	LT.01[d]	LT.01
403	.445	LT.01[d]	LT.01	LT.01[c]	LT.01[d]	LT.01
406	.158	LT.01[d]	LT.01	.288	LT.01	LT.01
407	LT.01	.019[d]	LT.01	.197	LT.01	LT.01
408	.149	LT.01[d]	LT.01	LT.01[c]	LT.01[d]	LT.01
409	.409	LT.01[d]	LT.01	.010[c]	LT.01[d]	LT.01
411	LT.01	LT.01	LT.01	LT.01	.026	LT.01
412	.490	.033[d]	LT.01	.348	LT.01	LT.01
414	LT.01	.381	LT.01	LT.01	.298	LT.01

(a) One tailed t-test; It was assumed that the variances were unequal.

(b) The background data set consisted of 25 samples randomly selected from the 122 year one samples (for year one) and from the 187 year two samples (for year two) collected at station 201, 209, 211, 212, 307, 313, 415, 500, 501 and 502.

(c) These stations are significantly higher than background +3 pCi/l. Unmarked significant stations are less than background +3 pCi/l.

(d) These stations are significantly higher than background +1 pCi/l. Unmarked significant stations are less than background +1 pCi/l. Significant stations in the background +0 column are greater than background.

In addition, a t-test was performed on the data, following the same steps as were used for the Wilcoxon test. The results are listed in Table 4.5 and were in good agreement with results from the Wilcoxon test, lending support to statistical conclusions reached in evaluating the radon data. The following observations were made:

Year One

1. At no location was the 3 pCi/l limit* statistically proven to be exceeded at the 95% confidence level i.e., those with probabilities of less than 0.05 had means less than 3 pCi/l plus background. Station 403, 408, 409 and 412 had means higher than the limits, but could not be statistically proven to exceed the limit for a one year period.

2. The 1 pCi/l limit was exceeded at stations 402, 403, 406, 408, 409 and 412 at the 95% confidence level i.e., they came from a different population than background + 1 pCi/l and had a higher mean. However, this limit only applies to stations 402 and 403, where populations were present.

Year Two

1. The 3 pCi/l limit was exceeded at stations 402, 403 and 408 at the 95% confidence level.

2. The 1 pCi/l limit was exceeded at stations 402, 403, 406, 407, 408, 409 and 412 at the 95% confidence level. However, this limit only applies to stations 402 and 403, where populations were present.

3. All mine/mill stations shown, with the exception of stations 309, 310 and 315, were significantly above background at the 95% confidence level of significance.

4. The overall two year average of 4.0 pCi/l in Ambrosia Lake exceeded the 3 pCi/l limit.

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*The phrase "3 pCi/l limit" means 3 pCi/l plus background and refers to a health guideline since mine emissions are excluded from NMRPR.

5.0 DISCUSSION

5.1 RADON CONTRIBUTIONS FROM MINE, MILL AND NATURAL SOURCES

Results in Section 4.4 showed that not only were many stations above background as defined in Section 4.2.1 (p. 26), but three also exceeded background + 3 pCi/l for at least one year. Five others exceeded background + 1 pCi/l. As shown in Section 4.5, these limits were exceeded at the 95% confidence level.

The degree to which background was exceeded was associated with the extent to which an area was developed by the uranium industry. Stations at Ambrosia Lake, with eighteen active uranium mines, one active and one inactive uranium mill, were higher than those around either of the comparatively isolated Anaconda or HMC mills.

A related question, discussed earlier, is whether this increase at Ambrosia Lake is due to the mines/mills themselves or to the presence of natural underground ore bodies. This issue could only have been completely resolved by adequate radon monitoring prior to any uranium mining. This monitoring could not have been performed at the appropriate time. Therefore, in this study, background levels were estimated from measurements at locations outside of the Ambrosia Lake area. These measurements were considered to be representative of background at Ambrosia Lake. Some indication of the importance of mines and mills at Ambrosia Lake, as compared with background radon produced by undisturbed uranium ore bodies and native soils , can be gained by consideration of radon source terms, or the amount of radon produced per year by various sources. Battelle Pacific Northwest Laboratory (PNL) measured radon from mine vents at Ambrosia Lake (25). Calculations based on their results estimated that some 122,000 curies of radon were emitted per year from mine vents. Approximately 4500 curies per year come from other mine sources, such as ore storage piles or mine waste piles.

In addition to measuring mine vent emissions, Battelle has modeled radon concentrations in Ambrosia Lake from these emissions (49). They stated that ". . . mine vents are the major influence on the computed radon concentrations. The tailing piles contribute to, but do not control the computed radon patterns." Therefore, regardless of what background is, mine vents are capable of producing elevated radon concentrations in the Ambrosia Lake area, which approximate concentrations measured by NMEID.

Annual radon releases from the two uranium mills in the Ambrosia Lake area were estimated by the PNL group to be 6200 curies. Total radon emissions from uranium mines and mills at Ambrosia Lake were 132,700 curies.

These emission rates can be compared with those expected from natural background. For the 50 square mile (1.3×10^8 m^2) area comprising Ambrosia Lake to equal the 132,700 curies/year produced by mines and mills, the average emanation rate would have to be 32.4 pCi/m^2-sec and have radium-226 concentrations of approximately 32 pCi/gram. This calculation uses USNRC's emanation estimate of 1.0 pCi of radon/m^2-sec for each pCi of Ra-226/gram in soil. Normal soil radon emanation values for New Mexico range from 0.5 to 2.0 pCi/m^2-sec, well below that needed for soil radon flux at Ambrosia Lake to compare with mine/mill radon emissions (26). Nor have the elevated radium-226 soil concentrations been observed in undisturbed Ambrosia Lake soil. Background samples taken by Ford, Bacon and Davis at Ambrosia Lake ranged from 1 to 5 pCi/g of radium-226 (27). Oak Ridge National Laboratory samples ranged from 0.72 -2.7 pCi/g of radium-226 in New Mexico. Their nationwide average was 0.23 - 4.2 pCi/g (39). This suggests that radon emanating from soil is much less than that from mines and mills.

In addition, surface soils at Ambrosia Lake have been surveyed for radium-226 content by the Surveillance and Assessment Section of the NMEID in 1981 at all existing radon sampling stations. A range of 1 to 19 pCi/g was observed with a mean and standard error of 6.0 ± 2.0 pCi/g. It was also observed that soils in close proximity to the Kerr-McGee facility or mine vents were elevated above those taken at undisturbed sites. Therefore, it was concluded that the mean radium-226 value of 6.0 pCi/g reflected uranium extraction contributions such as wind blown tailings. This soil concentration is well below that required to account for mine/mill emissions of 132,700 curies/year. It would produce only 24,500 curies/year using the USNRC relation of 1.0 pCi/m^2-sec for each pCi/g of Ra-226 in soil (26). In addition, soils were collected in 1983 at 16 locations across Ambrosia Lake from the soil surface and at a depth of 12 inches. The surface soil mean and standard error was 13.5 ± 6.6 pCi/g for Ra-226 while soils at depth averaged 0.57 ± 0.08 pCi/g. Radium-226 soil concentrations at depth agree well with surface measurements taken in remote undisturbed areas of the Grants Mineral Belt.It was estimated that of the total curies of radon released per year from Ambrosia Lake (157,200 curies), approximately 16% was due to soil emanation, 80% to mine emissions and 4% to milling activities.

It has been suggested that low grade ore outcrops and underground ore bodies may be contributing to the elevated radon concentrations measured in this study. However, most sizeable outcrops are located three or four miles south and west of Ambrosia Lake, while the mined ore bodies are several hundred feet underground (28). This indicates that contribution from natually occurring sources of radon would not increase the radon concentrations to the extent observed.

One additional observation resulted from a test comparing first and second year pooled radon values for Ambrosia Lake and the HMC/Anaconda milling areas. For Ambrosia Lake, a P value of less than 0.01 indicated a significant difference between the first and second year data at the 95% confidence level. A similar test on the pooled HMC and Anaconda data, on the other hand, gave P =0.240. This showed that the first and second year sample results for HMC/Anaconda data were not significantly different. If high radon values at Ambrosia Lake came from high background values rather than mine/mill emissions, then background would have had to increase significantly to account for the higher measured values in the second year (for example, compare 3.15 pCi/l versus 6.40 pCi/l at station 402 for the first and second years, respectively.). However, the fact that no significant difference in background radon concentrations was observed in the HMC/Anaconda areas from the first year of sampling to the second, suggested that the increased radon was not due to background, but to mine/mill emissions.

Consideration of source terms and radon monitoring results suggest that (1) Uranium mines are the primary cause of elevated radon concentration in Ambrosia

Lake and (2) Active uranium mills emitted radon at detectable levels above background close to tailings piles, but are not important contributors compared to mines. Both isolated mills, Anaconda and HMC, had appreciably lower radon concentrations than the combined mines and mills at Ambrosia Lake.

5.2 COMPARISON OF RADON LEVELS WITH NMEID RADIATION REGULATIONS

New Mexico Radiation Protection Regulations (NMRPR) apply to holders of radioactive material licenses. At present, uranium mines are not licensed by the NMEID (NMRPR 3-110.B.) and are not subject to these regulations. This situation leaves the principal source of airborne radioactivity without regulatory control.

It has been shown that the 3 pCi/l health guideline was exceeded at Ambrosia Lake. This indicated that the potential exists for an individual member of the public to receive a dose in excess of recommended limits if he were to spend a large fraction of his time in the area. Limited working level measurements showed that actual exposures were below or approximately equal to the 0.033 WL plus background standard. However, most Ambrosia Lake measurements were made in trailers which would not adequately reflect actual levels if permanent structures were placed in the area. The only non-trailer showed the highest levels of any structure measured in this study. Recent measurements, made in this Post Office before it was torn down, averaged 0.043 WL with individual measurements ranging up to 0.23 WL. This average is in close agreement with the previous value of 0.039 WL. Both measurements were taken primarily in the fall, winter and spring months.

As discussed in Section 5.3, doses from exposure to radon depend on the degree of equilibrium between radon and its decay products, since this determines the working level value. Indications of the actual exposures incurred by individuals living in Ambrosia Lake are given by averages of indoor working level measurements made during the course of the radon sampling program. These averages, shown in Table 3.3, range in Ambrosia Lake from 0.009 WL to 0.039 WL. The three lowest values were found in trailers, while the highest value was found in a building. This could reflect differences in building materials or ventilation rates (air exchange rates). High radon concentrations at Ambrosia Lake do not indicate that individuals living in that area necessarily incurred large radiation doses. Well ventilated structures, such as the two trailers at stations 13 and 14, had near background average working level values. However, a structure with a low air exchange rate could potentially have a working level value, and corresponding radiation exposure in excess of recommended limits.

The regulatory limit of 3 pCi/l above background for radon was not exceeded by any licensee (uranium mill) at monitored locations during these two years of sampling. There is a question whether the limit of 1 pCi/l above background is being exceeded south of HMC in a populated area. If so, it is a borderline situation and the conservatism to protect public health that is inherent in these limits indicates that there is not an immediate public health hazard. It is possible, however, that when other exposure contributions are taken into account, such as inhalation of windblown particulate material, some action will need to be taken in these borderline situations.

While licensees are required to comply with effluent limits (NMRPR 4.160.A.) they also have the regulatory responsibility to maintain releases of radioactive material to unrestricted areas to as low a level as is reasonably achievable (ALARA). This requirement is presently being observed by uranium mills who have instituted various operational procedures designed to reduce emissions. Anaconda, for example, routinely maintained its tailings area wet, a practice which could be responsible for the reduction in radon at station 302 from the first to second year of sampling. HMC has obtained control of the area north of its tailings pile, thus restricting any development of this region. These actions are in accordance with the ALARA principle, and encouraged by the Radiation Protection Bureau.

5.3 ESTIMATE OF RADIATION EXPOSURE

Radon data was used to estimate the annual exposure to the bronchial epithelium due to constant exposure to these levels. The exposure was calculated according to the following procedure: (1) The annual average radon concentrations at a particular location were multiplied by .005 to obtain the annual average working level at 50% equilibrium and (2) The annual average working level was multiplied by 51.5 in order to obtain the number of working level months (WLM) of exposure. The final result was exposure in working level months that an individual would receive if he lived at a location 100% of the time for an entire year and inhaled radon at the measured level in 50% of equilibrium with its decay products. The 50% equilibrium value is supported by data from the Ambrosia Lake Post Office. Outdoor radon was measured at 6.4 pCi/l. At 50% equilibrium, this becomes 0.032 WL which correlates well with the measured value of 0.039 WL.

Exposures to the bronchial epithelium, shown in Table 5.1 were based on outdoor radon measurements. They represented estimates of exposures to individuals from sources outside occupied buildings. The total exposure must also include indoor radon sources such as building materials, natural gas and well water. These other factors could increase the total exposures reported. Practices associated with the use of these buildings can also effect radon exposures. In this calculation, it was assumed that radon was at 50% equilibrium with its short-lived decay products. However, a decrease in the air exchange rate would increase this equilibrium ratio and the corresponding exposure. At 100% equilibrium, for example, all exposure estimates in Table 5.1 would be doubled. On the other hand, increased air exchange rates would decrease the estimated exposure. A determination of the actual exchange rates on a building-by-building basis would be needed to present accurate radon exposures for specific cases. However, since excessive working level values have been measured, continued monitoring by the Surveillance and Assessment Section of the Radiation Protection Bureau is justified.

TABLE 5.1 Average Annual Radiation Exposures to the Bronchial Epithelium[a]

	First year		Second year	
Station	Average Radon Level (pCi/l)	Exposure Rate(WLM/y)	Average Radon Level (pCi/l)	Exposure Rate (WLM/y)
201	1.12	.29	.81	.21
202	1.32	.34	.89	.23
203	1.92	.49	1.51	.39
204	2.01	.52	1.89	.49
205	1.55	.40	1.12	.29
206	1.18	.30	.93	.24
208	1.10	.28	.84	.22
209	0.72	.19	.79	.20
210	1.55	.40	1.41	.36
211	0.44	.11	.71	.18
212	0.36	.09	.61	.16
302	1.37	.35	.78	.20
305	0.76	.20	.95	.24
307	0.63	.16	.55	.14
309	0.30	.08	.21	.05
310	0.41	.10	.36	.09
313	0.48	.11	.47	.12
315	0.57	.15	.49	.13
401	1.02	.26	1.18	.30
402	3.15	.81	6.40	1.65
403	3.47	.89	5.70	1.47
406	2.96	.76	3.40	.88
407	2.01	.52	3.23	.83
408	4.12	1.06	5.77	1.49
409	3.59	.92	5.43	1.40
411	.91	.23	1.10	.28
412	4.23	1.09	3.74	.96
414	1.50	.39	1.69	.44
415	-	-	.14	.04
500	.13	.03	.15	.04
501	.10	.02	.17	.04
502	.10	.02	.14	.04
Background	.57	.15	.50	.13
Selected Bkg.	.42	.11	.53	.14
Ambrosia Lake	3.20	.82	4.66	1.20
Anaconda	1.06	.27	.87	.22
HMC	1.83	.47	1.51	.39

(a) These estimates assume that an individual was exposed for 100% of the time during an entire year to radon concentrations measured at a given station, and that the radon is in 50% equilibrium with its daughters.

5.4 ESTIMATE OF LUNG CANCER RISK

The risk of a premature death due to radiation induced lung cancer can be estimated if one knows the level of radon to which the individual is exposed. There is a range of risk estimates published in the literature, ranging from 100 to 1000 premature deaths/lifetime/10^6 man-WLM (26,33-38). If the highest yearly average radon level measured in Ambrosia Lake (6.4 pCi/l) is used, then a cancer mortality of approximately one chance in 600 to one chance in 6000 per year of exposure is obtained. Measured background radon concentrations averaged approximately 0.50 pCi/l and would correspond to a risk of one chance in 8,000-80,000 per year of exposure. The two year average Ambrosia Lake radon concentration of 4 pCi/l resulted in a lifetime risk of one chance in 970-9700 per year of exposure. The risk of lung cancer due to radon exposure at monitored areas other than Ambrosia Lake is one chance in 2500-25,000 per year of exposure using the highest average observed radon concentration in a populated area (1.55 pCi/l).

TABLE 5.2 Lifetime Risk Estimates of Premature Lung Cancer Deaths[c]

Reference	Estimate[a]	Lifetime Probability of Lung Cancer Death Per Year of Exposure[b]
Evans (37)	100	1/9700
NCRP (33)	130	1/7500
Jacobi (35)	100-500	1/9700-1/1900
UNSCEAR (36)	200-450	1/4900-1/2200
USNRC (26)	360	1/5500
BEIR III (38)	850	1/1100
USEPA (51)	860	1/2300
Archer (34)	1000	1/970

(a) Risk estimates for lung cancer per year of exposure are in units of premature deaths per million person-WLM.

(b) This assumes exposure to 4.0 pCi/l of radon at 50% equilibrium with its daughters. This level is the average concentration of radon at Ambrosia Lake over the two year sampling period.

(c) Both the UNSRC and USEPA use 25 WLM/y-WL instead of the 51.5 WLM/y-WL used in this report.

5.5 SUMMARY OF CONCLUSIONS

1. Radon concentrations measured near uranium milling facilities not located near uranium mines were found not to exceed radiation standards for an individual. Most concentrations were also below the more restrictive standards for a population. However, several HMC values were close to or numerically (but not statistically) above the 1 pCi/l plus background limit by assuming the background values given in Section 4.2.1.

2. Active uranium milling facilities emitted radon at detectable levels above background close to tailings piles, but are not important contributors compared to mines. Anaconda and HMC were both isolated from mines and had lower radon concentrations than Ambrosia Lake which has mine and mill radon sources.

3. Ambient radon concentrations in air sampled near uranium mines were found to exceed the health guidelines based on NMRPR for an individual member of the public at three of nine locations during the second of two years of sampling in Ambrosia Lake. While these elevated radon concentrations indicated the potential for radiation exposures in excess of recommended limits and the necessity for future monitoring activities, actual exposures ranged from near background to above health guidelines. Average exposures in Ambrosia Lake were about three times the average for all background stations (0.020 WL vs. 0.007 WL).

   These exposures depend on a number of factors, including meteorological conditions, proximity to radiation sources, air exchange rates in private homes or buildings, and the fraction of time such buildings are occupied. Conclusions regarding exposure comparisions to health guidelines are tentative, however, due to the difficulty in establishing background radon progeny levels indoors.

4. Six of 18 annual average radon concentrations taken in Ambrosia Lake over two years were numercially above the 3 pCi/l health guideline, but could not be proven to exceed this standard statistically due to the inherent degree of variability in the data which ranged from -0.062 pCi/l to 18.35 pCi/l for all Ambrosia Lake stations.

5. Although determination of background in contaminated areas is difficult and may be affected by additional industrial impacts, background radon concentrations were determined to be 0.5 pCi/l in this study. However, a number of investigators including the NMEID Surveillance and Assessment Section have measured background radon concentrations in remote undisturbed locations within the Grants Mineral Belt. The average of these sites was 0.19 pCi/l.

6. From our determination of background levels of radon, the monitoring data indicate that uranium mines are the primary cause of elevated radon concentrations in Ambrosia Lake.

7. Using measured radon and radon progeny concentrations, lifetime risk estimates of premature death due to radiation induced lung cancer were calculated per year of exposure. A range of risk estimates (Section 5.4)

was used for both an average two-year Ambrosia Lake radon concentration (4.0 pCi/l) and the highest yearly average value (6.4 pCi/l). The average value of 4.0 pCi/l corresponds to a lifetime risk of one chance in 970-9700 for a premature lung cancer death per year of exposure while the highest average value represented a risk of one chance in 600-6000 per year of exposure. Measured background radon concentrations used in this study averaged approximately 0.50 pCi/l and corresponds to a lifetime risk of one chance in 8000-80,000 per year of exposure. An average background radon concentration (see Table 4.1) for undisturbed areas of the Grants Mineral Belt (0.19 pCi/l) corresponds to a risk of one chance in 20,000-200,000 per year of exposure.

6.0 RECOMMENDATIONS

The NMEID radiation monitoring programs have measured radon concentrations at three of nine locations in the Ambrosia Lake area that exceed recommended health guidelines for exposure of individuals. High radon concentrations are associated with uranium mine emissions since concentrations around uranium mills far removed from mining activities are well below the individual limits and in only a few cases are near the population limit. As a result of this study, we recommend:

1. Since uranium mines have been shown to release significant amounts of radon, regulation of mine effluents must be considered.

2. Evaluation of all pertinent radionuclide emissions at restricted area boundaries should be continued for mills in close proximity to population centers to assure that the sum of all fractional MPC's does not exceed unity on an annual basis (NMRPR Part 4, Appendix A, Note 1).

3. It is inadvisable to locate future housing in areas determined to be borderline or in excess of radiation protection limits. Monitoring should continue in such areas as uranium facilities to verify that standards continue to be met in the future.

4. Future siting of mine vents near population centers should be discouraged. Where mine vents are located near occupied structures, radon levels should be monitored to assure that concentration limits in NMRPR are not being exceeded.

5. "Background", as used in NMRPR Part 4, Appendix A, is not clearly defined in that it could refer to either natural background levels, or to natural background plus contributions from other industrial activities. This term should be unambiguously defined to refer only to natural background.

6. Radiological background levels should be established at all future impacted areas of uranium development as required in NMRPR 3-300.0.

7. Footnote 3 to Part 4, Appendix A currently permits working level measurements at boundaries of restricted areas to be substituted for radon measurements. Allowing outdoor measurements of working levels does not protect public health adequately. For example, air with radon, freshly emitted from a tailings pile, at 6 pCi/l may be at just 10% of equilibrium, or 0.006 WL, when crossing into an unrestricted area, and thus comply with the regulation limit of 0.03 WL. However, if that air were to enter a nearby home and allowed to come to equilibrium, the radon daughter concentration could conceivably be as high as 0.06 WL. The regulation should be amended to avoid this from occurring by requiring that working level limits must be met in all nearest residences in addition to meeting radon concentration limits.

   Furthermore, the regulations make no mention of replacing the radon population limit of 1 pCi/l with 0.01 WL. This situation should be rectified.

8. Further radiological monitoring is necessary to adequately determine accurate yearly radon averages, document relative contributions of radioactive particulate emission impacts and define overall risks imposed on indigenous populations, individual members of the public and the environment. Further radon monitoring is of particular interest due to the observed difference in radon concentrations between the two years of sampling in the Ambrosia Lake area. This difference resulted from either varying meteorological conditions or radon emission rates or both.

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APPENDIX A: QUALITY CONTROL

Both random and systematic errors were monitored during the course of the sampling program. An assessment of these results is presented in this appendix.

A.1 RANDOM ERRORS

A nested sampling strategy was followed at stations 405 and 315, chosen to represent areas of high and low radon concentrations, respectively, in order to measure the components of variance of the measurement procedure.

At station 405, three samplers were placed side-by-side. Two of these samplers had electric-powered pumps, while the third was battery-powered. Three samples were then collected every sampling period. Two aliquots of air were taken from each sample, and each aliquot was counted twice. Twelve radon concentrations were thus obtained for each sampling period. This procedure corresponded to a four stage nested sampling design. The variance associated with each stage was then calculated using standard analysis of variance techniques. The four stages considered were:

1. Samples were collected every two weeks, giving the variance associated with the natural variation of radon concentrations in time.
2. Sampling with three side-by-side radon samplers measured the variances due to pump characteristics and field sampling procedures.
3. Taking two aliquots of each sample measured the variance due to the use of scintillation cells and calibration factor determination.
4. Counting each aliquot twice determined the variance due to counting statistics and instrument variability.

The above procedures were followed at station 405 for one year. During the second year stage 3 was eliminated. At station 315 the procedure was the same, but stage 3 was not included during the two years of sampling at that site.

Results of the sampling are given in Table A.1. They indicate that the largest contribution to the overall variance is the natural variability of radon concentrations with time.

TABLE A.1 Sources of Variance Associated with Radon Sampling

		STATION 405[a]		STATION 315[a]	
Stage	Source	Variance Component	Percent	Variance Component	Percent
	Total	14.85	100.0%	.229	100.0%
1	Time	13.26	89.3%	.197	86.1%
2	Samplers	1.21	8.1%	.018	8.0%
3	Aliquots	0.30	2.0%	----	----
4	Counts	0.08	0.5%	.015	5.9%

(a) The mean radon concentration at station 405 was 6.18 pCi/l and at station 315 was 0.52 pCi/l.

Variances, and therefore uncertainties, associated with sampling and analysis procedures were only 10% of that due to natural variability. Counting and aliquot variance at station 315 was 5.9% of the total, while at station 405 it was 2.5%. This is due to the familiar increase in counting errors observed when samples of low activity are analyzed. For a sample analysis giving a result of n counts, the corresponding sampling error is $n^{\frac{1}{2}}$. The percentage error is $n^{\frac{1}{2}}/n = n^{-\frac{1}{2}}$. As n becomes small for low activity samples, this percentage increases, as was observed in comparing results for stations 315 and 405.

Our conclusion was that no significant random error, due to the measurement procedure, was introduced by the sampling program. Most of the variability observed was due to that already naturally present in the real variation with time of radon levels at one location.

A.2 SYSTEMATIC ERRORS

Systematic errors were continually checked by frequent calibration of instruments. Radium-226 standards were obtained from both the EPA laboratory in Las Vegas and from the National Bureau of Standards. Scintillation cells were individually calibrated using this standard directly or using previously calibrated cells.

Individual calibration factors were obtained for all scintillation cells. However, it was observed that the calibration factors were clustered around 5 CPM/pCi/l of radon. The average of all calibration factor measurements was 4.86 ± 0.49. Thus any systematic drift of calibration factors would amount to only a 10-20% error due to the stability of these factors.

Instrument variation was checked by frequent counting of a scintillation cell containing a 100 pCi radon standard. Plotting, on semi-logarithmic paper, the radon concentration versus time after obtaining the standard, indicated any potential instrument malfunction.

A further check in systematic error was the simultaneous measurement of radon concentrations at stations 403, 412 and 206 with commercially obtained continuous radon monitors and tedlar bag samplers. Use of the continuous samplers provided an independent check on systematic errors of the tedlar bag method. Results are summarized in Table A.2.

Table A.2 A Comparison of Radon Measurements Using Continuous And Tedlar Bag Samplers

	STATION 403		STATION 412		STATION 206	
Date	Continuous Sampler[a]	Tedlar Bag	Continuous Sampler[b]	Tedlar Bag	Continuous Sampler[c]	Tedlar Bag
03/05/79			3.293	3.679		
03/19/79			1.396	1.409		
06/11/79			4.777	4.034		
06/18/79					0.493	0.890
06/25/79	2.714	6.231	3.148	3.623		
07/03/79					1.082	1.743
07/09/79	7.877	8.503	3.832	3.112		
07/23/79			4.125	3.597		
07/30/79					0.814	0.926
08/06/79			3.634	3.607		
08/13/79					0.213	0.239
08/27/79					0.471	0.912
09/04/79			5.962	5.332		
09/17/79			2.628	3.588		
10/01/79			7.423	9.772		
10/09/79					1.922	2.436
10/15/79	8.757	9.360	7.137	7.353		
10/29/79	4.581[d]	3.288	1.101	1.570		
11/05/79					0.703[d]	1.402
11/13/79			7.158	6.702		
11/26/79					0.560[d]	0.741
12/03/79	7.328	7.351	6.975	6.056		
12/10/79					1.586	1.170
12/17/79	7.549	7.597	7.345	7.290		
01/07/80					0.349[d]	0.368
01/14/80	3.567	6.159	0.515	0.508		
03/10/80	2.385	2.578	1.397	0.452		
03/24/80	2.535	3.057				
04/07/80			3.715	4.309		
Mean	5.255	6.014	4.198	4.222	0.819	1.083
Standard Error	0.867	0.830	0.522	0.592	0.175	0.206

(a) It was not known exactly how much instrument background to subtract from raw numbers of the continuous samplers. Therefore, the highest possible background without incurring negative numbers was used.

(b) Continuous sampler was located 100 yards from Station 412.

(c) Continuous sampler was located one quarter mile from station 206.

(d) 24 hour samples.

Three one-way analysis of variance tests were then performed on the data in Table A.2 with a null hypothesis that both continuous and tedlar bag sampling methodologies were indistinguishable (i.e. radon data from both types of samplers belonged to the same population) at the 95% confidence level.

TABLE A.3 One-Way Analysis of Variance Results Comparing Radon Sampling Methodologies

Station	N	F	P(x)
403	18	0.40	0.344
412	36	0.0009	0.976
206	20	0.95	0.343

As the statistical analysis in Table A.3 showed, the null hypothesis could not be rejected at the 95% confidence level. F values required to reject the hypothesis were 4.49, 4.13 and 4.41 for stations 403, 412 and 206 respectively (i.e. P(x) values must all be less than 0.05). Therefore, we concluded that results from both sampling methodologies were indistinguishable.

One further check on systematic errors was the comparison of data from stations 302, 309 and 315 with data taken by Argonne National Laboratory at or very near to the same sampling locations (32). Argonne data was collected with a continuous radon monitor, while the NMEID data was collected for two days every two weeks. The data is summarized in Table A.4.

TABLE A.4 A Comparison of Argonne and NMEID Yearly Averages for Radon

Argonne Station	pCi/l	NMEID Station	First Year pCi/l	Second Year pCi/l
103	1.57	302	1.37 ± .16	.78 ± .11
102	.53	309	.30 ± .07	.21 ± .03
103	.77	315	.57 ± .12	.49 ± .08

The above data are yearly averages. However, Argonne's data is from July 1977 through July 1978, and the NMEID's data is from April 1978 through April 1979, and April 1979 through April 1980. The downward trend from 1977 to 1980 can be attributed to Anaconda tailings management procedures and/or changing meteorological conditions. There was a short period of time in 1978 when the sampling periods did overlap for two of the stations, although Argonne sampled continuously while EID sampled two days every two weeks. Table A.5 summarizes this overlap.

Table A.5 Simultaneous Argonne and NMEID Radon Measurements During 1978 (pCi/l)

Month	Argonne Station 103	EID Station 302
April	.838	1.127
May	.891	1.412
June	.902	.691
July	1.070	1.858
Average	.925	1.293

Month	Argonne Station 102	EID Station 309
April	.274	.303
May	.211	.273
June	.238	--
Average	.241	.283

APPENDIX B: STATISTICAL ANALYSIS OF STATION 201 WITH MINE/MILL RADON CONCENTRATIONS

As discussed in Section 4.2.1, statistical tests were also performed using background data Set B (station 201). The results, shown in Table B.1, indicate that the conclusions reached in the main body of the report are still valid even if a high background level of radon is used.

TABLE B.1 Wilcoxon Test Probability Values Comparing Radon Concentrations at Mine/Mill Stations With Background Data Set B (Station 201) and Regulatory Limits

	YEAR ONE			YEAR TWO		
Station	+3pCi/l	+1pCi/l	+0	+3pCi/l	+1pCi/l	+0
202	LT.01	.011	.126	LT.01	LT.01	.407
203	LT.01	.153	LT.01	LT.01	.012	LT.01
204	LT.01	.300	LT.01	LT.01	.495	LT.01
205	LT.01	LT.01	.053	LT.01	LT.01	.068
206	LT.01	LT.01	.352	LT.01	LT.01	.419
208	LT.01	LT.01	.458	LT.01	LT.01	.289
210	LT.01	.028	.091	LT.01	.042	.085
302	LT.01	.011	.025	LT.01	LT.01	.333
305	LT.01	LT.01	.148	LT.01	LT.01	.177
315	LT.01	LT.01	.017	LT.01	LT.01	.121
401	LT.01	LT.01	.051	LT.01	LT.01	LT.01
402	.021	.013[b]	LT.01	LT.01[a]	LT.01[b]	LT.01
403	LT.01	LT.01[b]	LT.01	LT.01[a]	LT.01[b]	LT.01
406	.021	.078	LT.01	.278	LT.01[b]	LT.01
407	LT.01	.271	LT.01	.181	LT.01[b]	LT.01
408	.373	.021[b]	LT.01	.044[a]	LT.01[b]	LT.01
409	.120	.155	LT.01	.067	LT.01[b]	LT.01
411	LT.01	LT.01	.487	LT.01	LT.01	.091
412	.168	.071	LT.01	.430	LT.01[b]	LT.01
414	LT.01	.019	.114	LT.01	.173	LT.01

(a) These stations are significantly higher than station 201 +3 pCi/l. Unmarked significant stations are less than station 201 +3 pCi/l.

(b) These stations are significantly higher than station 201 +1 pCi/l. Unmarked significant stations are less than station 201 +1 pCi/l. Significant station in the +0 column are higher than station 201.

APPENDIX C
REVIEW OF INDUSTRY COMMENTS

C.1 INTRODUCTION

In this Appendix we will address comments submitted by industry groups after their review of this report. Comments have also been received from other groups and individuals, including an environmental public interest group, several members of the New Mexico Radiation Technical Advisory Council, and scientists working in the field of radiation health risk assessment. Comments submitted by these other groups and individuals were generally favorable and were included at the discretion of the authors. The comments from industry, however, were unfavorable, and the authors felt that they should explicitly state their reasons why many of industry's criticisms, while they were fully considered, were not included in the final version of the report.

The Environmental Improvement Division (EID) requested that industry review and comment on this report in January, 1982, and May, 1984. The Kerr-McGee Corporation (its New Mexico subsidiary is now Quivira Mining Company) submitted comments in letters to EID dated February 2, 1982 (KM-1 1982) and August 7, 1984 (KM-2 1984). The Uranium Environmental Subcommittee of the New Mexico Mining Association similarly had submittals dated February 4, 1982 (UES-1 1982) and August 20, 1984 (UES-2 1984). These comments, which totaled approximately 60 pages, are not reproduced here because of their length, but they are available for public inspection at the EID offices in Santa Fe.

All comments that were submitted by industry were given full consideration. Most are discussed in this Appendix. Several comments have not been explicitly included here because they were not felt to have direct bearing on the report.

Two industry studies have been cited by Kerr-McGee and the UES as showing that ambient radon background in the Ambrosia Lake area is significantly higher than that used in the report. These are the "Shutdown Study" and the Kerr-McGee background study. Both are discussed below, as well as other comments made by Kerr-McGee and the UES.

C.2 CRITIQUE OF THE "SHUTDOWN STUDY"

BACKGROUND

The EID study measured annual average radon levels at Ambrosia Lake up to 6.4 pCi/l. The average radon level for the area was found to be 4.0 pCi/l for the two-year sampling period. These radon levels would be considered unacceptably high if they were due to human activities and not natural background. The use of 0.5 pCi/l for background radon in this report would attribute the great majority of the radon to uranium mining and milling at Ambrosia Lake.

In order to see if radon levels were affected by uranium mining activity, a sampling study was performed in June, 1982 during a planned two week shutdown of the Kerr-McGee and Homestake Mining Company Ambrosia Lake mines. The assumption was that turning off the mine ventilation systems would eliminate any mine vent radon release, which should be reflected in a dramatic decrease in the ambient radon concentrations.

The shutdown at the Kerr-McGee mines took place from June 14, 1982 to June 27, 1982. Kerr-McGee reports that 43 of its 62 vents (69%) were never turned on during the shutdown. The remaining 19 vents operated for only 5 percent of the shutdown period. None of the vents were on for 100 percent of the time (p.4 KM-2 1984).

Homestake was also shutdown for a two week period, but unfortunately its shutdown did not coincide with the Kerr-McGee period. Homestake shut its mines down from June 28, 1982 to July 11, 1982. Twenty eight of Homestake's 32 vent holes (88%) were never operated during the shutdown. The four remaining vent holes, however, were operated for 100 percent of the shutdown period.

KERR-McGEE RADON MEASUREMENTS

Radon and radon decay product concentrations were measured both by Kerr-McGee and the EID during the two shutdown periods. Kerr-McGee measured radon concentrations at two locations, and radon decay product concentrations at ten locations (Williamson 1983) (see Figure C.1). Statistical analysis of this data was performed by Radian Corporation (Williamson 1983).

Average radon concentrations measured by Kerr-McGee are presented in Table C.1. These concentrations, including those observed during the shutdown periods, are higher than those measured elsewhere in the Grants Mineral Belt area.

The Kerr-McGee radon measurements at two locations showed no statistically significant difference between radon concentrations measured before the shutdown (May 15-June 13), during the Kerr-McGee shutdown (June 14-June 27), during the Homestake Shutdown (June 28-July 11), or after the shutdown (July 12-August 2), with one exception. The post-shutdown radon concentrations at one of their stations were significantly higher than those measured during the previous sampling periods, including the period prior to the shutdown.

Radon levels measured during the two shutdown periods can be seen from the table to be slightly lower than those observed before and after these shutdown periods. As discussed above, however, these small differences were not statistically significant.

EID RADON MEASUREMENTS

The EID also measured radon concentrations during the shutdown period. These measurements were made at the 14 locations in the Ambrosia Lake area shown in Figure C.1. Results of the measurements are given in Table C.2.

The EID data and the Kerr-McGee data are in general agreement, both showing relatively high radon values before, during, and after the shutdown periods. A T-test using the 95% confidence level was used to find statistical differences among radon levels measured before the shutdown, during the Kerr-McGee shutdown, during the HMC shutdown and after the shutdown. In seven cases the radon concentration either before or after the shutdown was significantly higher than the concentration during either the Kerr-McGee or HMC shutdown. In one case, the concentration before the shutdown, was significantly lower than the concentration during the Kerr-McGee shutdown. In the remaining 48 cases there were no significant differences between stations.

DISCUSSION

Both the Kerr-McGee and the EID data indicate that there was little reduction in the radon levels during the shutdown study. The important question, however, is whether it is then valid to conclude that mine vent emissions are negligible compared to natural background at Ambrosia Lake. Two technical issues remain unresolved that preclude this interpretation of these data:

(1). The shutdown study is not representative of a zero radon release situation.

The principal objective of the shutdown study was to measure radon levels when no radon was being released from the mines. Unfortunately, turning off the ventilation system did not guarantee that the radon releases had been significantly reduced. Radon releases may have continued, and probably did continue, due to intermittent use of the ventilation system, and through natural venting.

The use of intermittent ventilation is shown in Table C.3. The table lists the seven Kerr-McGee mines and five Homestake mines involved in the shutdown study. As can be seen from the table, all Kerr-McGee mines had at least one mine vent operating at least twice during the shutdown study, and most mines much more often. The Kerr-McGe mines had at least part of their ventilation systems operating for a period of several hours on an average of over six days during the two week shutdown, or almost once every other day.

In most instances only one or two of the mine vents were operating, and the remaining mine vents were turned off. The total radon release from the mine, however, may be relatively insensitive to the number of mine vents operating. One or two vents operating for several hours could be enough to exchange an appreciable fraction of one air volume of the mine. The great majority of the radon that entered the mine during the preceding time period would be discharged through the mine vent.

Radioactive decay of the radon in the mine between ventilation periods would not significantly change the amount of radon exhausted, since the ventilation periods occurred on an average of once every two days, and the radioactive half-life of radon is 3.8 days.

The main change in radon release due to the mine shutdown is that the radon would be released in a series of pulses -- corresponding to when the ventilation systems were turned on -- rather than a continuous release that normally occurs when the ventilation is operating full time. The quantity of radon that is vented to the atmosphere would not be expected to be drastically different in the two release scenarios.

Little reduction in radon release is also expected for the Homestake mines. The three Homestake mines that were never ventilated were relatively small, and would not be expected to contribute much to the total radon release in any event. The Section 23 and Section 25 mines are larger and were continuously ventilated. Even though this ventilation is only through two vents in each mine, the radon release could be expected to be nearly the same as when the mine was operating. As discussed above, each mine could go through up to several air exchanges per day, and radon diffusing into the mine from the ore would be released with the ventilating air.

An additional complication is that some mines are interconnected. Venting one mine would also include ventilation of the other mine. As an example of this, the Kerr-McGee VH6 and Homestake VH 87W-21N is a common vent serving Kerr-McGee Section 30 mine and Homestake Section 32 mine.

Consequently, we expect only a slight reduction in the radon release during the shutdown study, and not the near zero release rate suggested by industry. We believe that the high radon concentrations observed during the shutdown study are still primarily due to releases from the uranium mines.

In addition to intermittent ventilation, radon releases could occur through natural venting of the mines. A study of uranium mining by the U.S. Environmental Protection Agency gave measured values of natural ventilation in an inactive Ambrosia Lake mine at 75-88 cubic meters/min, and air concentrations of up to 11,000 pCi/l of radon (p. 3-235 USEPA 1983). The EPA quoted a study giving natural ventilation rates in deep mines ranging from 1420 to 4250 cubic meters/min (Peele 1952). There is a potential for continuous radon release from the mines involved in the shutdown study even when their mine vents were completely turned off. However, industry reported using plastic covers for mine vents during non-operational periods. This may have reduced to some extent, radon released via natural venting processes.

(2) Concluding that radon mine vent releases were greatly reduced by the shutdown study conflicts with independent atmospheric modeling performed by Battelle Pacific Northwest Laboratory (PNL).

During 1978-1979, a PNL research group (Jackson 1980) measured radon mine vent emissions from 114 out of an estimated 117 mine vents in the Ambrosia Lake area (p.7 Droppo 1981). The total estimated radon release for the 117 mine vents was 122,000 curies per year. Individual mine vent emissions ranged from 10 curies per year to 8310 curies per year (p.14 Droppo 1981). Because the mine locations were not identified in the Jackson report, we use Jackson's results as reported in the study of Droppo and Glissmeyer.

This radon emission data was used by Droppo and Glissmeyer from PNL to model the radon concentrations in the Ambrosia Lake area (Droppo 1981). They used meteorology data taken at Ambrosia Lake by a research group from the Environmental Protection Agency. Figure C.2 has been reproduced from their report to show isopleths of the radon concentrations derived by modeling radon emissions from mine vents in Ambrosia Lake. The figure also shows the locations of the mine vents and the Kerr-McGee mill tailing pile denoted by the letter B.

Radon levels along the highway where EID stations 402 and 403 were located were in the 3-4 pCi/l range. In sections of the Ambrosia Lake mining area, levels reached 12 pCi/l. Small areas of increased radon were predicted around sources such as mine vents throughout the Ambrosia Lake region.

It is evident from the figure that radon concentrations varied rapidly over short distances, due to the great number of mine vents in the area. Small changes in atmospheric conditions could strongly affect the radon levels observed at a given location. Given the uncertainties in modeling techniques, there is good agreement between the predicted radon concentrations and those observed by the EID's monitoring program. It is important to note that these calculated levels of radon, which are approximately the same as those observed by the EID monitoring program, are entirely due to mine vent and mill emissions, with the mine vents dominating. No contribution from natural background was included in these calculations. The report concludes "...that the computed concentrations from releases from mining and milling activities are of sufficient magnitude to be the major source of the monitored values" (p. 16 Droppo 1981). Droppo and Glissmeyer feel that background is actually low in the Ambrosia Lake area, stating that "...the range of possible background radon concentrations are taken to be from 0.0 up to about 0.5 pCi/l" (p. 16 Droppo 1981) the background radon levels that the EID used in its analysis are slightly above those given by Droppo.

CONCLUSIONS

The shutdown study is supsect because there is no reason to believe that radon emissions from mines were eliminated or greatly reduced during the shutdown. The discussion above shows that most mines did have an appreciable air exchange on an average of once every two days. Given the 3.8 day half-life of radon, we do not believe that the radon emission rate would be greatly reduced by a holdup underground of two days.

The most conclusive evidence for the effectiveness of the shutdown to reduce radon emissions would have been to have monitored the radon emissions. These measurements were unfortunately not taken.

The emission rate measurements and the modeling performed in two PNL studies link the radon concentrations in air measured by the EID with the emissions from the mines. Droppo and Glissmeyer have been able to attribute the high ambient radon concentrations to the mine radon releases. This is strong evidence that the role of natural background in the high ambient radon concentrations is not significant, and that the high radon levels are a result of the mine releases.

C.3 CRITIQUE OF THE KERR-McGEE RADON BACKGROUND DATA

Quivira Mining Company (the Kerr-McGee subsidiary in New Mexico) has reported radon concentrations at 30 locations in the Ambrosia Lake area using Terradex Track-Etch detectors for the time period May 1983 to June 1984. Eighteen of those locations were considered background locations by Kerr-McGee, based on the criteria that they were more than a mile away from either a mine vent or a tailings pile (p.3 KM-2 1984).

Kerr-McGee reports that the average background radon concentration is 2.5 pCi/l (p.3 KM-2 1984). The mean and standard deviation calculated from the Kerr-McGee data for the 18 background stations that was submitted to the EID is 2.43 ± 0.77

for the time period July 1983 to July 1984, in agreement with the company's result.

Review of the Kerr-McGee Data

These data represent a comprehensive scheme to measure the radon levels at Ambrosia Lake. Because of the following reservations, however, we have found these data difficult to evaluate:

(1) The locations that Kerr-McGee chose to measure background are not true background locations in that they could be affected by emissions from Ambrosia Lake. The PNL modeling study described above (Droppo 1981) shows that, for the 1978-1979 emissions rates and meteorology used in that study, many of the Kerr-McGee stations fall within isopleths of radon concentrations in the 0.3 - 1.1 pCi/l range. These levels are exclusive of background; if the 0.5 pCi/l level for background is used, this range becomes 0.8 - 1.6 pCi/l.

Thirteen of the eighteen stations that Kerr-McGee uses to determine background are within the boundaries of the map given in the PNL report that shows their radon isopleths (p. 22 Droppo 1981). The radon concentration for these 13 stations, averaged over the Kerr-McGee data, is 2.49 ± 0.89 pCi/l. This average concentration can be compared with the average value at these 13 locations estimated by interpolation of the radon isopleth lines from the PNL report. The average PNL-modeled radon concentration, due to radon coming from the mine vents, at the 13 Kerr-McGee background locations is 0.5 pCi/l, or 1.0 pCi/l including the 0.5 pCi/l for background.

Radon measurements at the Kerr-McGee stations, although they are affected by mine and mill radon emissions, are below what the modeling would predict by a little more than a factor of two. The modeling does indicate, however, that the Kerr-McGee background stations are well within the area affected by the mine and mill emissions. If meteorological data and radon emission rates were available for the period when Kerr-McGee made its measurements, the agreement may have been better.

(2) Several of the Kerr-McGee stations were near stations previously monitored by the EID. These stations are:

Kerr-McGee Station Number	Kerr-McGee Radon Level (pCi/l)	EID Station Number	EID Radon Level[a] (pCi/l)
R-03	2.29	401	1.02 1.18
R-28	3.34	414	1.50 1.69
R-25	1.22	411	0.91 1.10
R-22	2.39	407	2.01 3.23

[a] Values are given for the first and second year of monitoring.

This table shows shows that the Kerr-McGee measurements are generally higher than those obtained by the EID at comparable stations. This is particularly true at stations R-28 vs 414, which are within 200 m of each other. This difference could be due to different physical conditions such as meteorology and radon emissions rates (the measurements were made 3-4 years apart), or due to different measurement techniques.

The cause of this inconsistency is not well understood and is now being investigated. The EID is now monitoring radon at many of the same points as Kerr-McGee so that two sets of data should soon be available.

(3) The Kerr-McGee data does not include any data point that has an annual average radon level less than 1.22 pCi/l. There is no internal check that the measurement system can measure background levels of radon, which can be as low as 0.2 - 0.5 pCi/l.

(4) Kerr-McGee has not described its measurement or its quality control system. In particular, how reproducible are its radon measurements? The amount of variance due to its measurement technique was not quantified. They did not state which sensitivity Track-Etch film they used, and how the film sensitivity affected their variance. The number of detectors at each sampling location and the exposure times should be specified. Finally, they should describe the procedures employed to ensure that the Track-Etch film was properly stored and not exposed to radon while awaiting deployment in the field or shipping back to Terradex for final readout.

CONCLUSION

The data taken by Kerr-McGee and by the EID are in disagreement at several locations in the Ambrosia Lake area. The EID sampling was in 1978-1980, while the Kerr-McGee sampling was in 1983-1984. This difference in sampling periods may account for some of the difference.

Sampling methods also differed. The EID used tedlar bags and small air pumps, and analyzed each sample within a day after collection using scintillation cells. Kerr-McGee used Terradex Track-Etch detectors, a technique based on counting alpha particle tracks on a photographic emulsion. The analysis was performed by Terradex. The EID data was coincident with a source term and modeling study performed by PNL. The EID and the PNL study are in general agreement.

There has been no parallel study performed at the time that Kerr-McGee made its radon measurements. As a result, it is difficult to resolve the difference between the EID and Kerr-McGee monitoring results. Important questions remain unanswered such as how the meteorological conditions may have affected the radon concentrations at the Kerr-McGee background locations, and how the radon emission rates may have varied.

The authors feel that the background radon level of 0.5 pCi/l at Ambrosia Lake as used in this report has more justification than the 2.5 pCi/l suggested by Kerr-McGee. The reasons for attributing the high radon levels at Ambrosia Lake to mine vent emissions are stronger than their alternatives. Consequently, we see no reason to change the recommendation concerning regulation of uranium mines. We would recommend, however, that this monitoring issue be examined with concurrent field sampling, meteorological monitoring, and radon emission rate measurements.

C.4 RESPONSE TO OTHER COMMENTS MADE BY INDUSTRY

Health Risk Industry has commented that the health hazard from radon is primarily from inhalation of the radon decay products, and not from inhalation of the radon itself. As such, radon decay product measurements at Ambrosia Lake are the relevant measurements to make. Industry states that radon decay product levels are well below the 0.033 WL (above background) required by the New Mexico Radiation Protection Regulations, as shown by industry measurements in outdoor areas.

We fully agree that inhalation of radon decay products is the principal hazard from radon gas. This was discussed at numerous points in the report. It is not acceptable to conclude, however, that outdoor radon decay product measurements are the only meaningful ones for evaluating exposures.

That outdoor measurements show low levels of radon decay products does not imply that indoor levels would also be low. The degree of equilibrium could be very different. For example, Kerr-McGee reports outdoor equilibrium values of 20-30% (p.4 KM-2 1984), which are considerably lower than typical indoor equilibrium levels such as those measured by George and Breslin in New York and New Jersey (George 1978). The New York/New Jersey equilibrium values were approximately 60%. In addition, radon equilibrium values, on which radon decay product concentrations depend, can vary greatly from residence to residence so that some residences can have values considerably greater than 60%.

Outdoor measurement of radon equilibrium values, or of the radon decay product levels, are necessary to evaluate the exposure to individuals while they are outdoors, but are not much use in evaluating exposure to individuals indoors where they spend the majority of their time. Indoor measurements are needed to make this evaluation, if these measurements can be obtained. In some situations, however, such as in planning what potential exposures may occur from a proposed mine activity, these measurements are impossible to make because the activity has not yet been initiated. In this situation, another method based on radon (rather than radon decay product) levels was used.

The goal of this study included evaluating exposures to the residents of Ambrosia Lake, and indoor radon decay product measurements were made in five homes in the area. A second main objective of the program was to evaluate the potential for radiation exposure due to uranium mining and milling, even in areas where uranium mines had been proposed but not yet operated.

At the time that the study was initiated, the uranium industry was rapidly expanding. Mine vent locations were being proposed near populated areas, such as the towns of San Mateo and Crownpoint. In order to assess the potential radiation exposure to the residents of these communities, the radon levels resulting from industry activities had to be studied. Radon indicates just how high the radon daughter levels can get. It indicates the magnitude of the problem under worst-case conditions of full or nearly full equilibrium.

It is not legitimate to measure radon decay product levels in the trailers at Ambrosia Lake and conclude that the levels in the homes at San Mateo or Crownpoint would be similar. There are too many factors involved that affect the degree of equilibrium, including the tightness of the structure and the ventilation rates. Studying the radon levels gives a clearer picture of what the possible decay product levels inside potentially affected homes can be, and therefore presents a sounder basis for the EID to evaluate the need for new regulations.

High Radon Decay Product Level at Ambrosia Lake

The UES claims that the 0.039 WL measured at Ambrosia Lake is due to the use of natural gas for cooking. This measurement is the highest radon decay product measurement made during the two year study. It is over twice as high as the next highest of the five annual averages measured at Ambrosia Lake. The UES presents no evidence for its conclusion as to the cause of the high level, however, such as measurement of the amount of radon in the natural gas. Two reasons are more plausible than the UES's natural gas hypothesis. The building where the measurement was made is a closed frame/stucco structure, which is more airtight than the trailers where the other radon decay product levels were measured. And secondly, this building was the only one of the five at Ambrosia Lake that was monitored during the second year of the study, when the radon levels were up to two times higher than the first year.

The EID Ignored Preoperational Data

The UES has stated (p. 3 UES-2 1984) that the EID did not consider early pre-mining data collected by Anaconda showing anomalies and outcrops or high background areas. The EID would be happy to consider such data if it were made available. This data has been requested by EID and will be reviewed as soon as it is received.

Radon Concentrations Near Mills

The UES states that all radon measured near mills fall within the mills restricted areas, and the 30 pCi/l limit for restricted areas is the appropriate limit, rather than the 3 pCi/l maximum individual limit or the 1 pCi/l population limit (p.4 UES-2).

The region south and southwest of the Homestake Mining Company mill has elevated radon levels in the 0.93 - 1.55 pCi/l range. This is an offsite area having approximately 250 residents. The offsite population limit of 1 pCi/l of radon should apply to this area.

Reason For Mine Venting

The UES indicates that "...the effect of restricting the venting at mines will be to to increase the concentrations underground or to simply close the mines entirely." (p.4 UES-2)

The authors feel that other options are available. These include controlling the land around the mine vents, locating the mine vents in areas at least moderately removed from residences, or increasing the height of the discharge stacks. The EPA quotes a recent study by the U.S. Bureau of Mines that indicates that bulk-heading of mined-out areas may effectively reduce the radon emissions (USEPA 1984), suggesting that this is another method of radon control.

Background Radon Levels In Homes In The United States And At The U.S. Capitol Building.

The UES quoted a calculation made by Dr. Keith Schiager that "...about 2.7% of the American population lives in dwellings with levels above 0.02 WL." (p.24 UES-1 1982) The UES also commented that the radon level measured at the base of the coat rack in the entry way of the U.S. Capitol was 4.7 pCi/1, which would indicate that working levels at Ambrosia Lake "...are less than half of the working levels..." at this location in the Capitol (p. 4 UES-2 1984).

The UES is arguing that because high radon or radon decay product levels due to natural sources are found in the environment, these levels are acceptable for the purposes of public health protection. No regulation of uranium mining is needed since measured radon and radon decay product levels due to uranium mines are on the order of or less than those found in homes or the Capitol building.

The authors disagree with the UES. Indoor exposures to radon decay products has been a health concern for several years, and has been studied by several national advisory bodies, including the National Council on Radiation Protection and Measurements (NCRP). The acceptability of these levels is far from decided.

That a risk is smaller than another risk does not mean that the small risk should be neglected. The authors feel that the uranium industry should be required to maintain standards of environmental protection as high as generally-accepted-as-safe industries.

Use Of the Linear, No-Threshold Hypothesis To Calculate Health Risk

Both Kerr-McGee and UES have criticized the EID's use of the linear, no-threshold hypothesis to calculate health risks at low doses (p. 7 KM-1 1982, p. 4 UES-1 1982). This hypothesis involves a linear extrapolation of health effects observed at high doses to the low dose region, where no health effects have been observed due to the difficulties of measuring risk at low doses.

The UES has commented that the report does not consider "radiation hormesis", which holds that small doses of radiation are beneficial rather than harmful (pp. 26-28 UES-1 1982).

The authors have followed the recommendations of various national and international advisory bodies in using the linear no-threshold hypothesis.

These groups are the International Commission on Radiological Protection (ICRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the NCRP, and the U.S. National Academy of Sciences Committee on the Biological Effects of Ionizing Radiations (BEIR Committee). All these groups recommend the use of the linear, no-threshold hypothesis to estimate cancer risks from alpha radiation. The EID agrees with the recommendations of these Committees in calculating health effects resulting from radon and radon decay product exposure using the linear no-threshold hypothesis. Kerr-McGee and UES correctly comment that health effects at low radiation levels have never been observed; it is also true that it has never been demonstrated that low doses are not harmful. The risk levels predicted for low radiation doses by various models -- including the linear no-threshold hypothesis -- are sufficently low that it is not practical to confirm or disprove them epidemiologically. In the absence of a demonstration of the presence or absence of a harmful effect at low doses, the authors believe it is prudent to base radiation protection regulations on the linear no-threshold hypothesis.

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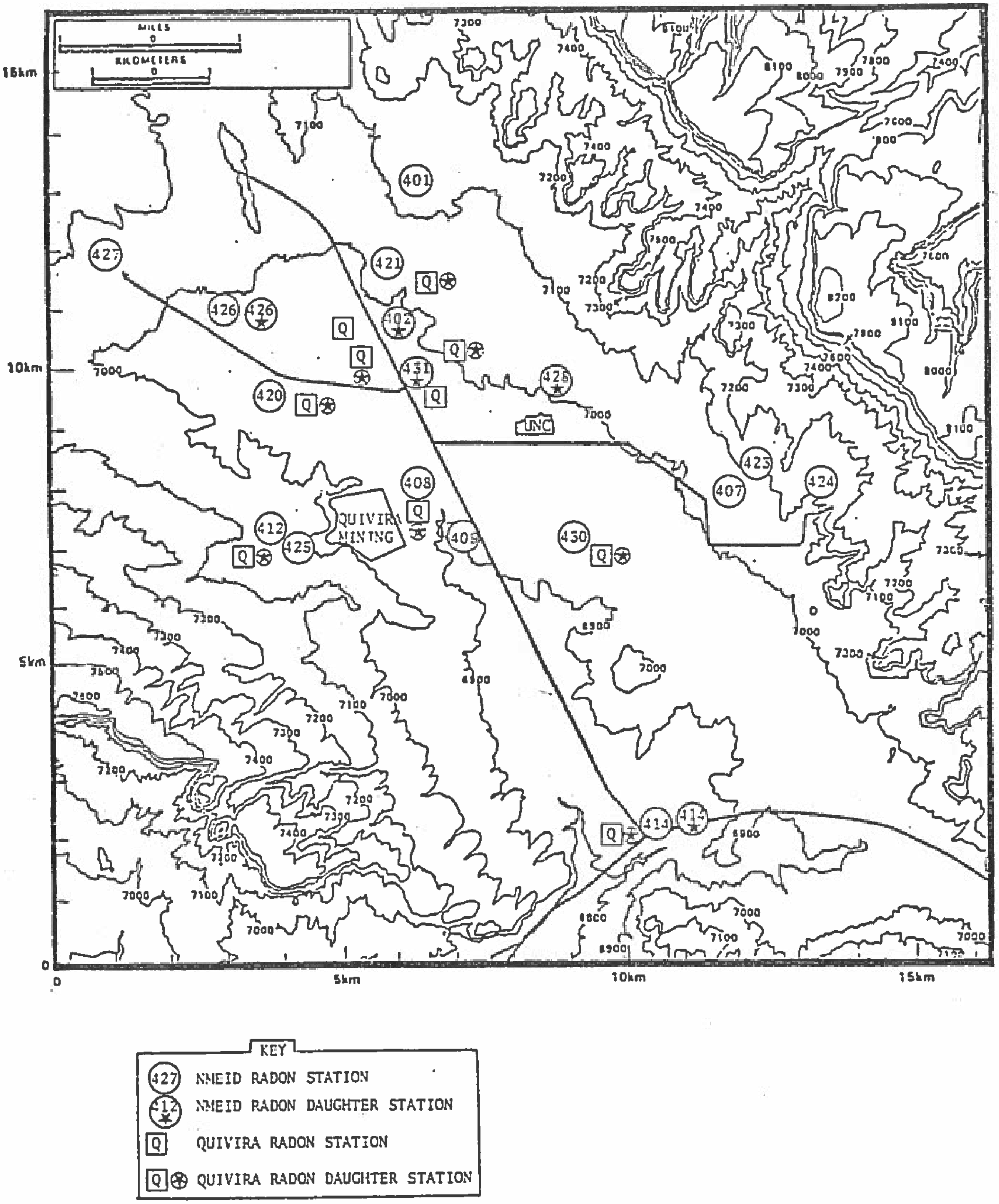

FIGURE C.1. KERR-McGEE AND EID SAMPLING LOCATIONS FOR THE 1982 SHUTDOWN STUDY

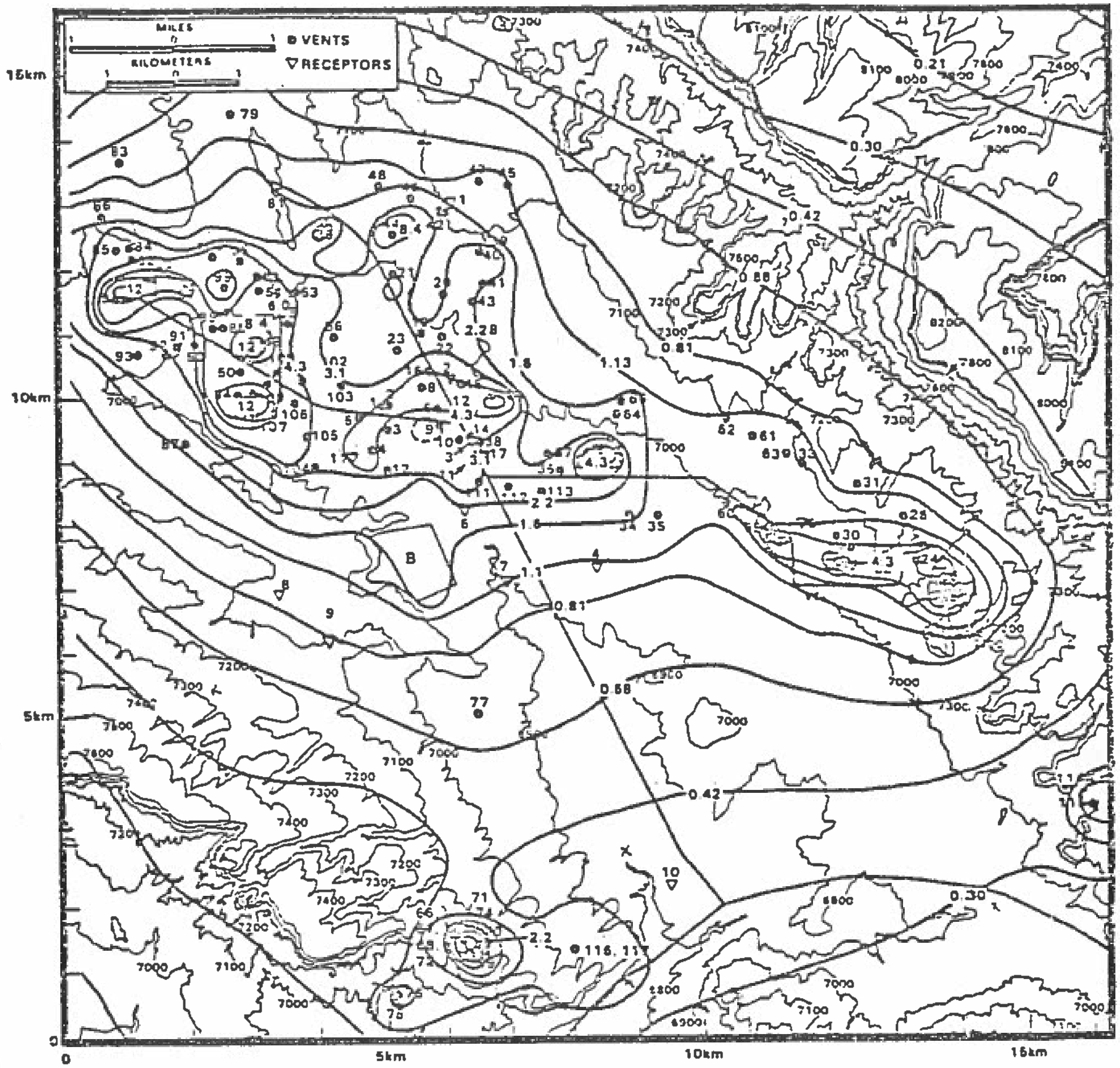

FIGURE C.2. MODELED RADON CONCENTRATIONS FROM MINE VENTS IN AMBROSIA LAKE (pCi/l).

Table C.1 Kerr-McGee Radon Concentrations Taken From the 1982 Shutdown Study(a)

Sampling Period	Date	Radon Concentration (pCi/)l Mine 1	 Mine 2
Before Shutdown	5/15-6/13	4.07 ± 1.13 (9)	5.15 ± 0.59 (6)
During Kerr-McGee Shutdown	6/14-6/27	2.95 ± 1.06 (9)	4.39 ± 1.71 (7)
During Homestake Shutdown	6/28-7/11	3.73 ± 0.93 (10)	4.68 ± 1.19 (5)
After Shutdown	7/12-8/2	6.60 ± 4.19(18)	6.63 ± 1.82 (4)

(a) Data taken from Williamson (1983) are shown as the mean ± standard deviation (sample number)

Table C.2 Radon Concentrations Measured by EID During the 1982 Shutdown Study(a)

Station	Radon Concentration (pCi/l) Before Shutdown	During Kerr-McGee Shutdown	During Homestake Shutdown	After Shutdown
401	0.82 ± 0.38 (5)	0.54 ± 0.30 (2)	0.709 ± 0.098 (2)	1.10 ± 0.67 (2)
402	5.9 ± 1.0 (3)	4.00 ± 0.13 (2)	5.7 ± 1.4 (2)	6.2 ± 3.4 (2)
407	4.2 ± 1.6 (3)	3.04 ± 0.37 (2)	2.0 ± 2.1 (2)	5.06 ± 0.26 (2)
408	3.5 ± 3.3 (3)	5.96 ± 0.83 (2)	1.7 ± 1.6 (3)	7.36 ± 2.7 (2)
409	4.6 ± 4.1 (3)	3.45 ± 0.80 (2)	2.74 ± 0.45 (2)	5.2 ± 1.9 (2)
412	3.30 ± 0.66 (4)	3.2 ± 0.41 (2)	1.97 ± 0.35 (3)	3.7 ± 1.8 (3)
414	1.12 ± 0.98 (3)	1.30 ± 0.26 (2)	1.05 ± 0.47 (3)	1.26 ± 0.65 (2)
420	4.1 ± 2.6 (5)	5.4 ± 2.3 (4)	3.08 ± 0.40 (3)	6.7 ± 2.1 (4)
422	0.28 ± 0.31 (5)	0.31 ± 0.19 (4)	0.41 ± 0.22 (3)	0.34 ± 0.14 (4)
423	0.56 ± 0.88 (5)	1.16 ± 0.54 (4)	1.09 ± 0.84 (4)	1.7 ± 1.1 (4)
424	2.01 ± 0.24 (5)	2.40 ± 0.28 (3)	2.6 ± 1.2 (4)	2.6 ± 0.35 (4)
425	0.99 ± 1.27 (5)	1.20 ± 0.60 (4)	1.04 ± 0.81 (4)	0.738 ± 0.099 (4)
426	5.6 ± 4.2 (5)	6.6 ± 3.0 (4)	1.61 ± 0.96 (4)	4.8 ± 3.7 (4)
427	2.4 ± 1.4 (5)	3.5 ± 1.2 (4)	2.2 ± 1.0 (4)	3.96 ± 0.94 (4)

(a) Results are shown as the mean + standard deviation (number of samples)

TABLE C.3 Ventilation Schedule for the 1982 Shutdown Study (a)

KERR-McGEE MINES								JUNE DATE						
	14	15	16	17	18	19	20	21	22	23	24	25	26[b]	27
Section 17	97	325			440	92	32	144	140			385		
Section 19			5463		1455	3438	813		1205	552		510		
Section 30		1050	289		243		82	636	115		390			
Section 30W		60										50		
Section 33	130				405				110		192			
Section 35	1170	167			128			785	1105	750		320		
Section 36	454	220	300	125	130		310				220			

HOMESTAKE MINES

Section 13 No vents on
Section 15 No vents on
Section 23 2 vents on during entire shutdown (371 hours)
Section 25 2 vents on during entire shutdown (371 hours)
Section 32 No vents on.

(a) Data shows the accumulated total number of minutes per day that individual vents operated for a given mine.

(b) No data availale for June 26 and 27, 1982.