LEGIBILITY NOTICE

ORNL/TM--11067

DE90 004917

Health and Safety Research Division

Nuclear and Chemical Waste Programs
(Activity No. AH 10 15 01 0; NEAH002)

INVESTIGATION OF BACKGROUND RADIATION LEVELS AND GEOLOGIC UNIT PROFILES IN DURANGO, COLORADO

G. H. Triplett
W. L. Foutz*
L. R. Lesperance**

*Oak Ridge Associated Universities
**Formerly employed by Oak Ridge Associated Universities

Date Published: November 1989

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The authors wish to thank Dave Witt for his assistance in interpretations and review, Mike Puglisi and John Zutman for drafting assistance, and Caroline Griffith for compilation of data and her patience and efficiency in typing this manuscript.

Thanks are also expressed to Chris Muhr, David Smuin, and Luke Owen for sampling and Richard Knott for his assistance in establishing the Durango conversion table and review.

Gratitude is expressed to Betty Ellis for her assistance in obtaining unpublished archived soil sample data collected in connection with earlier studies.

Special appreciation is due to Dr. Craig Little for his assistance and advice during the course of the project.

ABSTRACT

As part of the Uranium Mill Tailings Remedial Action (UMTRA) Project, Oak Ridge National Laboratory (ORNL) has performed radiological surveys on 435 vicinity properties (VPs) in the Durango area. This study was undertaken to establish the background radiation levels and geologic unit profiles in the Durango VP area.

During the months of May through June, 1986, extensive radiometric measurements and surface soil samples were collected in the Durango VP area by personnel from ORNL's Grand Junction Office. A majority of the Durango VP surveys were conducted at sites underlain by Quaternary alluvium, older Quaternary gravels, and Cretaceous Lewis and Mancos shales. These four geologic units were selected to be evaluated. The data indicated no formation anomalies and established regional background radiation levels. Durango background radionuclide concentrations in surface soil were determined to be 20.3 ± 3.4 pCi/g for ^{40}K, 1.6 ± 0.5 pCi/g for ^{226}Ra, and 1.2 ± 0.3 pCi/g for ^{232}Th. The Durango background gamma exposure rate was found to be 16.5 ± 1.3 μR/h. Average gamma spectral count rate measurements for ^{40}K, ^{226}Ra and ^{232}Th were determined to be 553, 150, and 98 counts per minute (cpm), respectively. Geologic unit profiles and Durango background radiation measurements are presented and compared with other areas.

Field data collected during VP surveys from 1983 to 1985 were compiled from 250 locations. Based on these measurements, a formula was derived to convert from thousand counts per minute (kcpm) measured with a gamma scintillator to microroentgens per hour (μR/h). The conversion formula for Durango was determined to be

$$y = 5.28 + 1.55x$$

where

y = exposure rate in μR/h,

x = count rate in counts per minute × 1000.

INTRODUCTION

PURPOSE

In 1978, Congress passed PL 95-604, the Uranium Mill Tailings Radiation Control Act (UMTRCA), which authorized the Department of Energy (DOE) to remediate the 24 inactive uranium mill tailings sites nationwide, along with their associated vicinity properties (VPs). (VPs are those sites, both publicly and privately owned, that are potentially contaminated with radioactive material originating from inactive uranium mills.) Environmental Protection Agency standards must be exceeded for a VP to be eligible for remediation. As part of the Uranium Mill Tailings Remedial Action (UMTRA) Project, Oak Ridge National Laboratory (ORNL) has performed radiological surveys on 435 VPs in the Durango area. This study was undertaken to establish background radiation levels and geologic unit profiles in the Durango VP area.

To provide baseline measurements against which to compare VP readings, extensive background radiometric measurements and surface soil samples were collected during May and June of 1986 in the Durango VP area by personnel from ORNL's Grand Junction Office. Results of these measurements and comparative analyses are presented.

Field data measurements collected during the Durango VP surveys from 1983 to 1985 were evaluated along with measurements taken on the Durango tailings pile in 1985. These measurements were used to determine the conversion table for scintillator count rate measurements (in thousand counts per minute) to gamma exposure rates (in microroentgens per hour) for the Durango area.

LOCATION AND HISTORY OF OPERATIONS

The Durango mill tailings site is located just southwest of Durango with the Animas River on the east, Lightner Creek on the north, and Smelter Mountain on the southwest. Originally, a lead smelter was operated from 1880 to 1930 on the site. Slag from that operation underlies much of the mill area (Allen and Strong 1984). During World War II, the federal government established the Metals Reserve Company to purchase strategic materials needed for the war effort. In 1942, the U.S. Vanadium Corporation designed and built a mill on the site to supply vanadium. From 1943 to 1946, vanadium tailings were reprocessed to recover uranium for the Manhattan Project. The mill was closed from late 1946 until 1949, when the Vanadium Corporation of America (VCA) leased the plant, reopened it, and signed a contract to sell uranium to the Atomic Energy Commission (AEC). The mill continued to operate until 1963 and was purchased during that time by VCA (Haywood et al. 1980). Ore containing an average concentration of 0.29% uranium and 1.60% vanadium was obtained from mines in the Uravan Mineral Belt (Ford, Bacon and Davis 1977).

From 1949 to 1963, 1.6 million tons of ore was processed. In 1967, VCA merged with Foote Mineral Company. During 1976 and 1977, Ranchers Exploration and Development Corporation of Albuquerque, New Mexico, purchased the site. Two parcels on it were deeded to the Colorado Highway Department and the La Plata Electric Company (Ford, Bacon and Davis 1977). The site was subsequently purchased by Hecla Engineering and sold to the state of Colorado in December 1986. Tailings have been moved and are currently being stabilized five miles west of the site in Bodo Canyon as a remedial action under the UMTRA project. Completion is scheduled for September 1990 (Turner 1987).

SCOPE OF STUDY

The background study area encompasses approximately 3800 acres of LaPlata County in southwest Colorado (Fig. 1). Formations sampled were limited to the four on which most of the VPs were located, namely, the Cretaceous Mancos and Lewis shales and the Quaternary gravels and alluvium.

METEOROLOGY

Durango is located at the boundary between plateaus and mountains so the climate is milder and drier than the normal mountain climate, but more humid than the adjacent plateau climate (Maxwell 1977). The annual average precipitation is 48 cm, and average annual snowfall is 165 cm. The coldest month is January with an average high temperature of 4 °C, an average low of −12 °C, and a mean of −4 °C. July is the hottest month, with an average high temperature of 29 °C, an average low of 10 °C, and a mean of 19 °C.

A meteorological monitoring site was located by DOE in the southern part of the study area near the intersection of U.S. Highway 160-550 and U.S. Highway 160 West. It showed the predominant wind direction to be west-northwest down the Animas River 41% of the time. Atmospheric conditions are stable 30% of the time, extremely unstable 14% of the time, and neutral more than 30% of the time. Wind speeds are equal to or less than 10 miles per hour approximately 94% of the time (DOE 1984). These conditions have resulted in windblown tailings in both directions along the canyon around the tailing piles.

GEOLOGY

GEOLOGIC SETTING

Durango is situated in the Animas River valley south of the Central San Juan Mountains in southwestern Colorado. It occupies a site near the hingeline between the glaciated, volcanic terrain of the San Juan Mountains to the north and the broad, stable San Juan Basin section of the Colorado Plateau physiographic province to the south.

The stratigraphic record in this region is remarkably complete with the only major unconformity existing between Cambrian and Devonian time. Sedimentary rocks deposited from the Devonian Period to Eocene Epoch are evident from Molas Pass, 40 miles north of Durango, south to the New Mexico border, 18 miles south of Durango. Tertiary deposits younger than Eocene are all of igneous origin and range from volcanic ash-flow tuff to intrusive porphyritic quartz monzonite. Quaternary

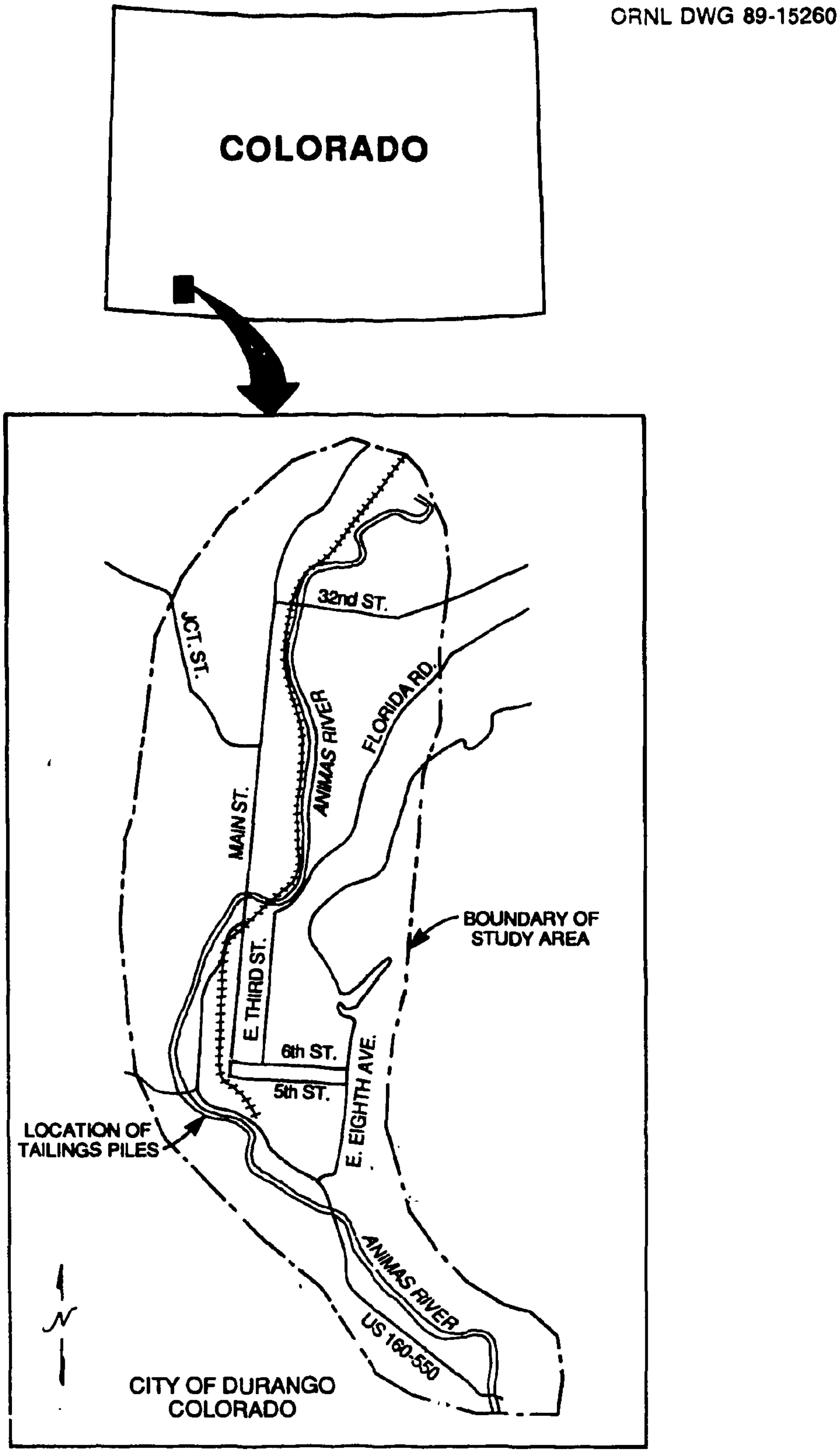

Fig. 1. Index map showing location of Durango background study area.

deposits are widespread, consisting of glacial drift, outwash gravels, landslide debris, and alluvium (Atwood and Mather 1932).

DESCRIPTION OF ROCK UNITS

Outcrops in the study area are all of Cretaceous age, as shown in the stratigraphic column in Fig. 2. The sandstone units (Pictured Cliffs, Cliffhouse, Menefee, Point Lookout, Mesa Verde) are cliff or hogback formers and are differentiated on Fig. 2. Because of the surface distance between sandstone outcrops and VP areas, the influence of the sandstone outcrops on background radiation levels in the study area is not significant; consequently, they were not sampled for radionuclide concentration and are omitted from further discussion.

A geologic map depicting soil sample locations is presented in Fig. 3. Geologic units sampled for radionuclide concentrations are the Lewis Shale, Mancos Shale, two alluvial units associated with terraces, and the floodplain of the Animas River (Steven et al. 1977).

Two shale units which outcrop in the study area, Mancos Shale (Km) and Lewis Shale (Kl), are valley formers due to their lower resistance to erosion and are the surface formations dominating the study area. The Mancos is predominantly a dark-gray marine shale. Lower units of the Mancos Shale are thin-bedded calcareous shale and argillaceous limestone with abundant pelecypod fossils in some locations. Upper units are calcareous shale and argillaceous limestone with scattered argillaceous sandstone at the base. The Mancos commonly weathers to flat plains or low rounded hills with soft papery shale talus slopes. Lewis Shale is dark-gray clay shale with rusty weathering concretions in the lower unit and thin-bedded sandstone stringers near the top (Fig. 4). The Lewis and Mancos shale formations are very similar in appearance and composition (Atwood and Mather 1932).

Five types of surficial deposits are found in the study area: (1) alluvium, (2) Quaternary landslide debris, (3) alluvial fan deposits, (4) terrace gravels, and (5) glacial drift, which consists mostly of terminal moraines located north and east of the study area.

Alluvial deposits described above have been separated into two groups for the purposes of this study since those deposits may influence background radiation levels in the study area. Group one, Quaternary alluvium (Qal), consists of types 1, 2, and 3, and comprises most of the surface soil and subsurface material above bedrock in VP areas. Group two, Quaternary terrace gravel (Qg), consists of types 4 and 5. Qal covers most of the lower elevations of the Animas River valley, where the floodplain roughly defines the extent of Qal deposits (Fig. 3). Qal samples taken for analysis consist mostly of soil and poorly sorted sandy gravels.

Figure 5 illustrates the relationship of terrace gravels to Lewis Shale near Bodo Canyon. Samples taken from terrace gravel deposits consist of coarse gravel from decomposed volcanic, intrusive, and sedimentary rocks. Vicinity properties covered by terrace gravel (Qg) are located on low terraces northeast of Durango and near the mouth of Bodo Canyon, south of Durango (Fig. 6). The terrace gravels (Qg) and Quaternary alluvium (Qal) are not evident in this photograph. Terrace gravels are

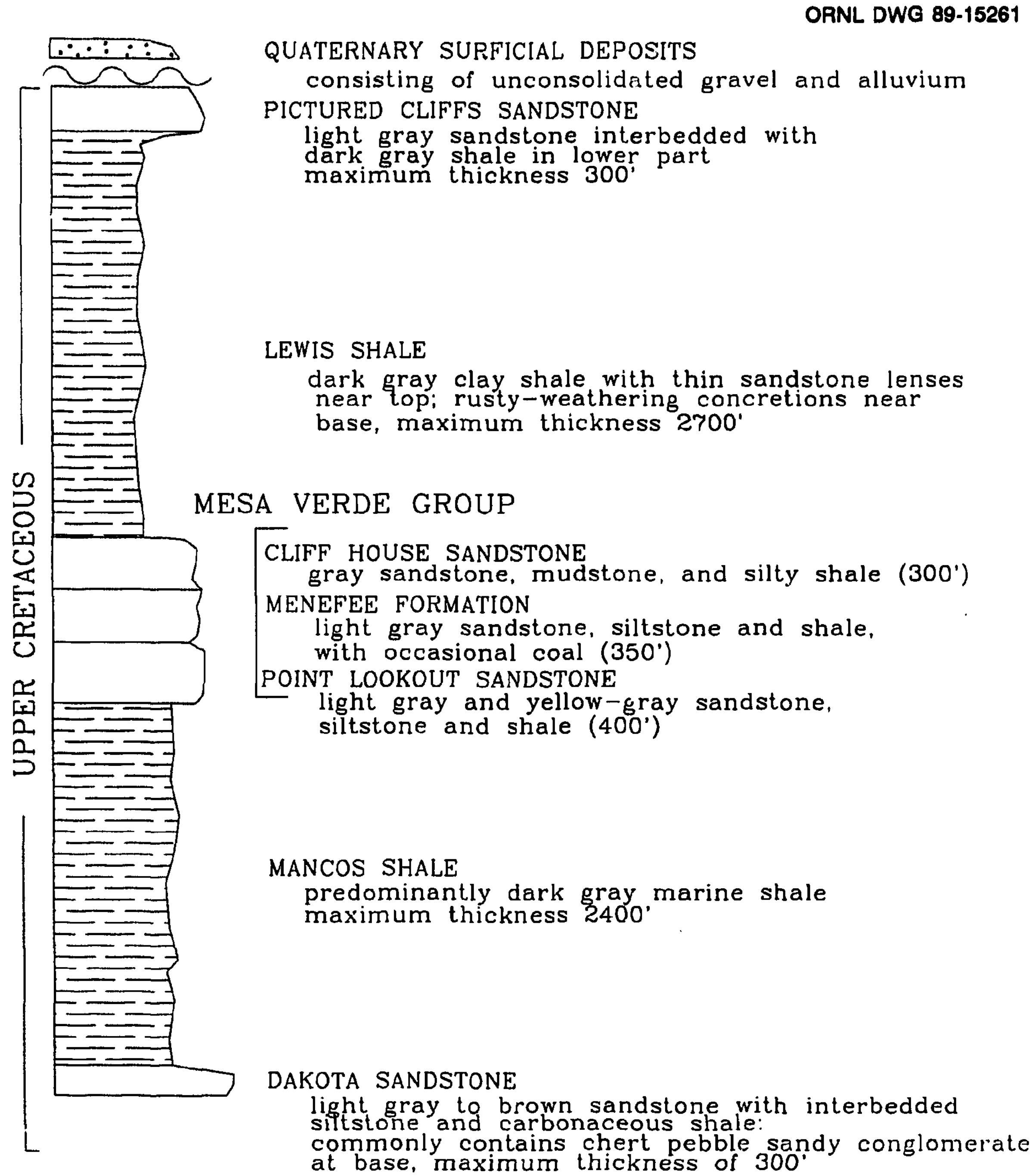

Fig. 2. Stratigraphic column of rock outcrops in Durango background study area.

ORNL DWG 89-15262

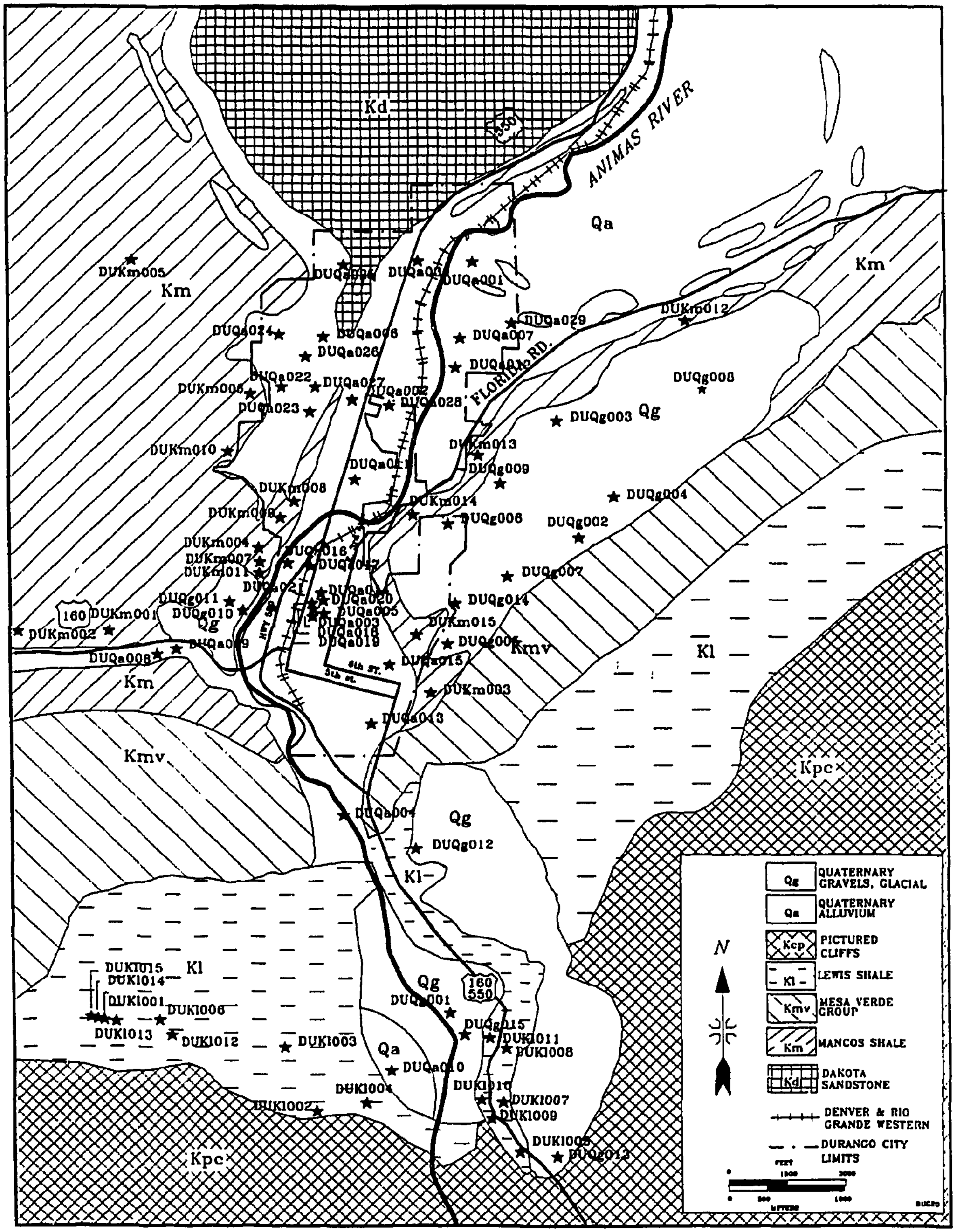

Fig. 3. Generalized surface geology surrounding Durango, Colorado, with Durango Background Study soil sample locations indicated.

ORNL PHOTO 5768-89

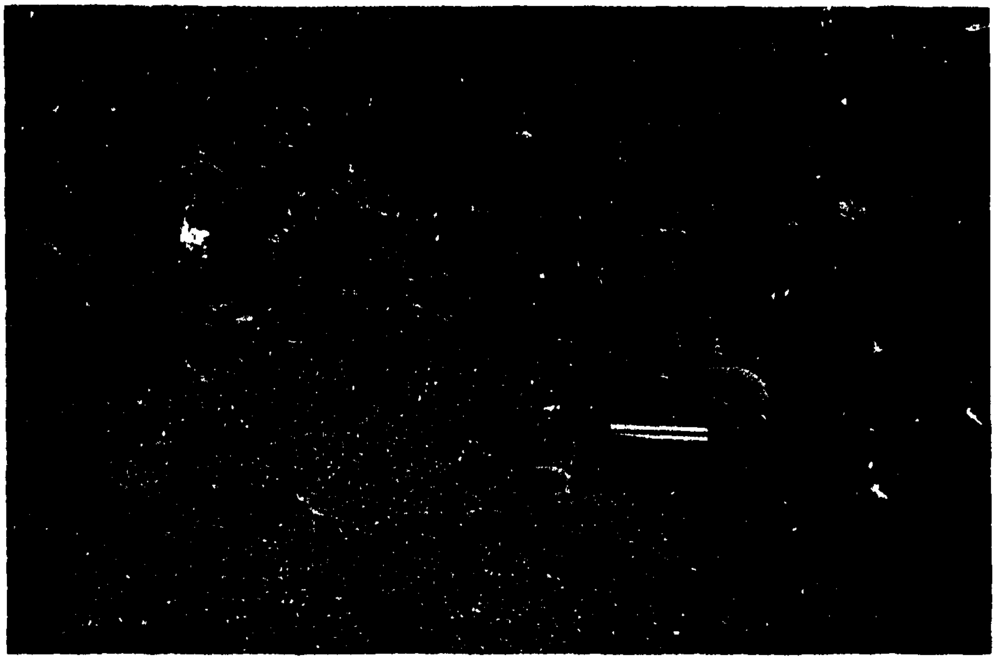

Fig. 4. Cretaceous Lewis Shale outcrop showing weathering concretions in lower unit and thin-bedded sandstone stringers in upper unit.

ORNL PHOTO 5769-89

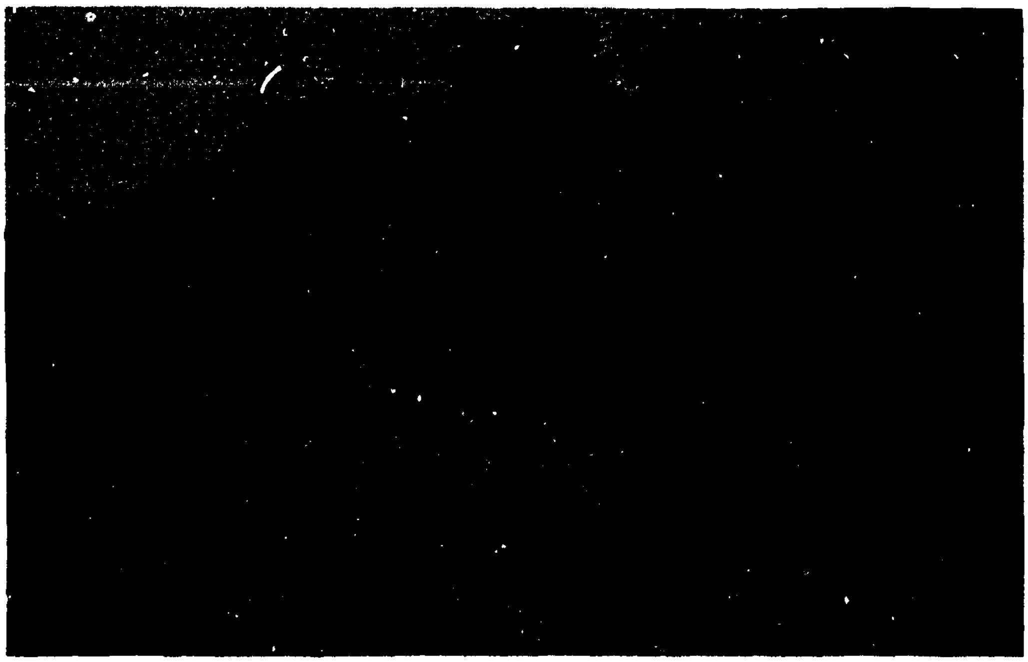

Fig. 5. Quaternary terrace gravels at contact with Lewis Shale showing poorly sorted gravel, boulders, and some stratification.

ORNL PHOTO 5770-89

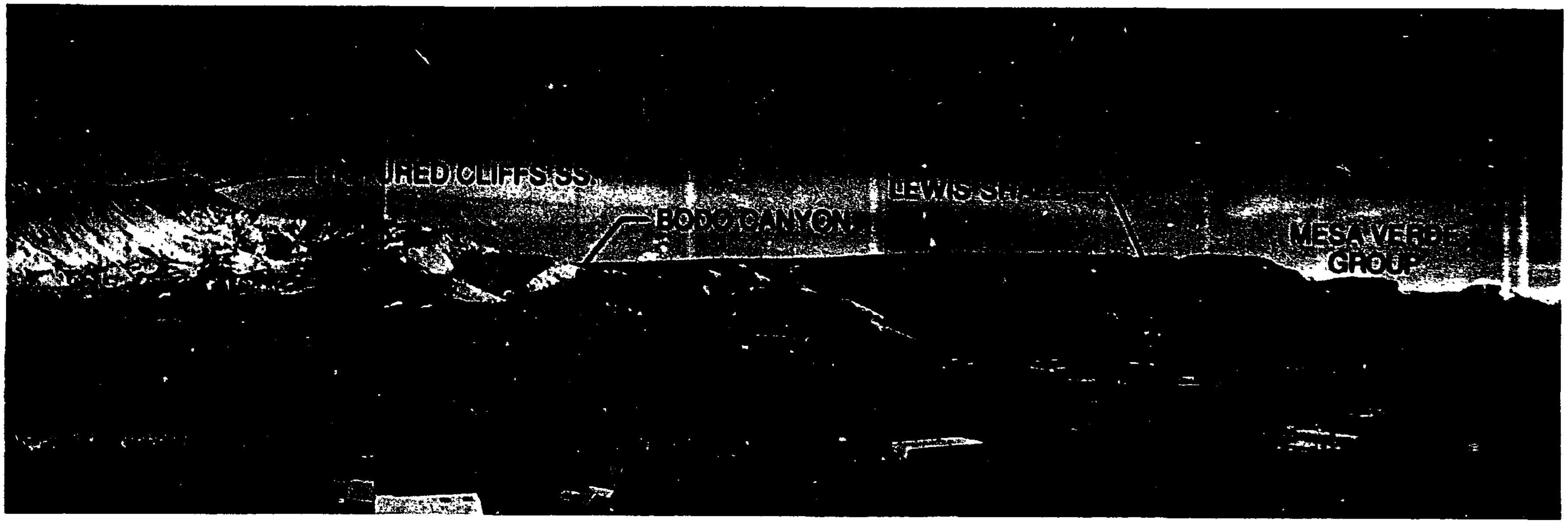

Fig. 6. View looking west across Animas River toward Bodo Canyon showing geologic contacts.

glacial outwash deposits composed of poorly sorted sandy gravel containing boulders up to 3 m in size in places and occasionally showing some degree of stratification.

FIELD PROCEDURES

SAMPLE SITE LOCATIONS

The goal of the survey was to determine gamma spectral and gamma rate meter measurements, to estimate concentrations of ^{40}K, ^{226}Ra, and ^{232}Th in surface soil, and to define the geologic profile of the four major geologic units in the Durango VP survey area. Background is defined by the averages of all the data obtained.

Because windblown tailings elevate the gamma exposure rate over background values, areas where windblown tailings are known to exist were avoided for the study. Also, just south of Animas City Mountain a natural outcrop of Dakota Sandstone known to bear uranium ore in some areas is present and causes slightly higher gamma readings (Hilton 1981). No samples were taken from this formation due to the limitation of the study to the four geologic units in which most of the vicinity property surveys were conducted.

Quaternary alluvium, Quaternary gravels, Lewis Shale, and Mancos Shale were the geologic units sampled in the Durango vicinity. Fifteen sample sites each were located on the Lewis Shale, Mancos Shale, and Quaternary gravels; 30 sample sites were located on the Quaternary alluvium (Fig. 3). Because alluvium is derived from surrounding geologic units, it is more difficult to characterize radiologically than other stratigraphic units which possess more distinctive lithic features. Alluvium represents a greater percentage of the exposed surface in the Durango vicinity relative to the other geologic units and consequently was sampled more frequently than other units. All sample locations were within a 2-mile radius of Durango. Sampling sites were located at accessible public areas along roadways.

RADIOLOGICAL MEASUREMENTS

Gamma rate meters (Appendix A) were field checked daily in an area with background gamma exposure rates and in accordance with existing calibration procedures (Little et al. 1986). Battery condition and count rate in thousand counts per minute (kcpm) were recorded. Next, a depleted uranium source was placed on the gamma rate meter probe, and the elevated value was registered. Finally, the net value was calculated by subtracting the background (kcpm) from the source (kcpm). Any net value which was raised more than 20% of the mean indicated a need for maintenance.

At each sample site, a field-checked gamma rate meter was used to detect gamma radiation in thousand counts per minute at ground level, at 15 cm above the soil surface (Fig. 7), and at 15 cm below the soil surface when the soil sample had been removed.

At each sample location, gross counts and net counts for ^{40}K, ^{226}Ra, and ^{232}Th were determined with a gamma ray spectrometer (Fig. 8). The portable gamma ray spectrometer (Appendix A) was calibrated daily as specified in the technical manual (Geometrics Exploranium 1977). The radium/thorium ratio for each geologic unit in this

ORNL PHOTO 5771-89

Fig. 7. Field surveyor taking gamma-ray exposure measurements with scintillator at 15 cm above soil surface.

ORNL PHOTO 5772-89

Fig. 8. Field surveyor taking gamma-ray spectrometer measurements.

study was determined to be less than 2, indicating no contamination. In areas of contamination, excess radium is present. A ratio of greater than 3 has been found to indicate the presence of tailings and/or ore (Witt 1986).

The gamma exposure rate in microroentgen per hour was determined by a pressurized ionization chamber (PIC) (Fig. 9 and Appendix A). The PIC was calibrated as specified in the operation manual (Reuter-Stokes 1981). PIC readings were used to determine the conversion factor between thousand counts per minute and microroentgen per hour for the rate meter.

Surface soil samples were collected from the top 15 cm of soil. Approximately 500 g of soil per sample was collected. A gamma rate meter was used to take a reading at 15 cm below the soil surface. Subsurface gamma measurements were taken to ensure that no buried radioactive sources that might influence the results of the study were present. Each soil sample was recorded and geologically described by color, texture, and permeability. Each soil sample was assigned an identification number, packaged in a foil pan and plastic bag, and transferred to the ORNL soils laboratory at Grand Junction. In the soils laboratory, samples were dried in a 43 °C oven for 12 h, weighed, crushed to 1/4-in.-diam or smaller, canned, and stored for 14 days for radon in-growth before being analyzed using a NaI(Tl) gamma spectrometry system (Little et al. 1986).

RESULTS OF RADIONUCLIDE ANALYSES

Results of the laboratory analyses for ^{40}K, ^{226}Ra, and ^{232}Th concentrations in surface soil are presented in Appendix B. The "Unit Sampled," along with the "Sample No.," can be used to find the soil sample on the soil sample location map in Fig. 3. A summary of background data sets of the laboratory analysis for the individual geologic units is presented in Table 1. This includes measurements taken for each unit, and the average, standard deviation, and minimum and maximum values.

Figure 10 is a graphical representation of the distribution of laboratory analytical values for ^{40}K, ^{226}Ra, and ^{232}Th concentrations in surface soil for each geologic unit and the Durango background. The Student's *t* distribution was performed on this data and showed no significant differences between the units within a 95% confidence interval (Daniel 1984). This similarity allowed all the samples from all four units to be averaged to create the Durango background.

Two samples, Qa1008 and Qa1009, bordered the windblown area around the pile and were among 13 samples with a ^{226}Ra concentration greater than 2.0 pCi/g. Six of these 13 samples were taken in the Mancos Shale, which is known to contain minor elevated concentrations of uranium in this area. The Mancos Shale was deposited in a benthonic-marine environment where minor concentrations of uranium are syngenetically precipitated by organic material (Theis 1981). The Lewis Shale, deposited in a similar environment, had one sample with a ^{226}Ra concentration greater than 2.0 pCi/g. The remaining six samples with elevated concentrations were from Quaternary gravels and alluvium, which are not favorable host rocks for uranium. These higher values are probably random sampling fluctuations related to the fact that twice as many samples were taken from the alluvium as from the other units or to the heterogeneous nature of the alluvium.

ORNL PHOTO 5773-89

Fig. 9. Field surveyor taking PIC measurements.

Table 1. Background concentration data sets for individual geologic units and summary (Durango background)

Unit sampled	Number of samples analyzed		Radionuclide concentrations in surface soils (pCi/g) ^{40}K	^{226}Ra	^{232}Th
Qal	30	Ave.	20.6	1.6	1.1
		Sdv.	2.5	0.5	0.3
		Min.	16.9	0.8	0.5
		Max.	26.5	3.3	1.6
Qg	15	Ave.	19.3	1.3	1.0
		Sdv.	2.4	0.4	0.2
		Min.	14.9	0.9	0.7
		Max.	22.8	2.6	1.3
Kl	15	Ave.	22.7	1.4	1.4
		Sdv.	4.4	0.3	0.3
		Min.	15.6	1.0	0.9
		Max.	27.5	2.4	1.8
Km	15	Ave.	18.5	1.8	1.2
		Sdv.	3.2	0.7	0.3
		Min.	13.7	0.9	0.8
		Max.	26.6	3.1	2.0
	Durango background				
	75	Ave.	20.3	1.6	1.2
		Sdv.	3.4	0.5	0.3
		Min.	13.7	0.8	0.5
		Max.	27.5	3.3	2.0

ORNL DWG 89-15263

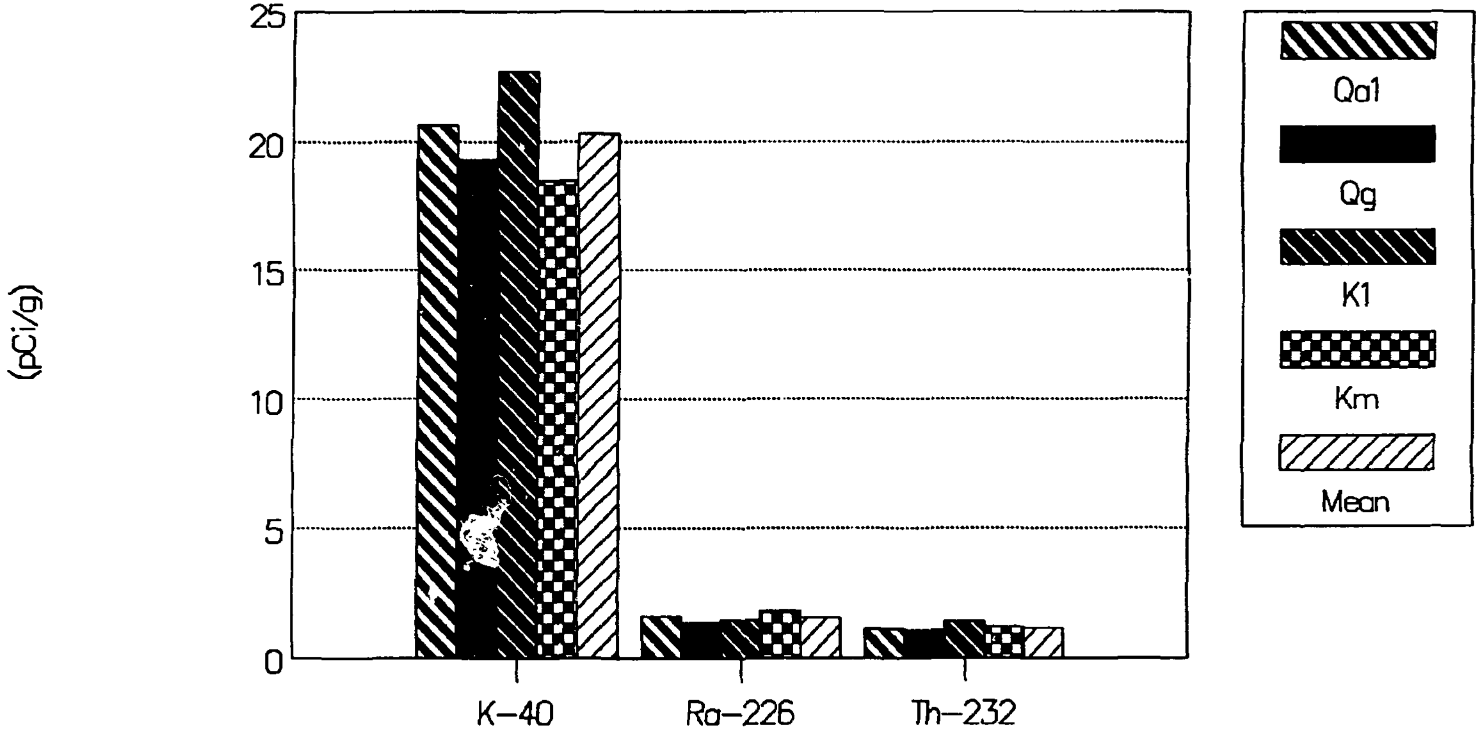

Fig. 10. Elemental concentrations in various geologic units.

Durango background concentrations for ^{40}K were determined to be 20.3 ± 3.4 pCi/g; for ^{226}Ra, 1.6 ± 0.5 pCi/g; and for ^{232}Th, 1.2 ± 0.3 pCi/g.

RESULTS OF THE IN SITU GAMMA RATE METER AND GAMMA SPECTROMETER MEASUREMENTS

Results of in situ gamma rate meter and gamma spectrometer measurements are presented in Appendix C. Identification of each sample is provided for correlation with the location map in Fig. 3. Background data sets for individual geologic units, including a background summary, are presented in Table 2. Also presented is a statistical summary for each unit including number of measurements taken, average, standard deviation, and minimum and maximum values.

Figures 11 to 13 are graphical representations of the distribution of average gamma spectrometer in situ data for each geologic unit and the Durango background. The Student's t test was performed on this data and indicated ($P > 0.05$) that there were no significant differences between each geologic unit. This allowed all samples to be averaged to create the Durango background.

Durango background for gamma exposure rates is 16.5 ± 1.3 μR/h. In situ gamma spectrometer measurement averages are: 5073 for total cpm, 553 cpm for ^{40}K, 150 cpm for ^{226}Ra, 98 cpm for ^{232}Th, and 1.53 for radium/thorium ratio.

COLORADO POTASSIUM BACKGROUND LEVELS

The Off-Site Pollutant Measurements Group of the Health and Safety Research Division at ORNL measured background radiation levels across the United States from 1975 to 1979 (Myrick et al. 1981). Concentrations of ^{226}Ra and ^{232}Th in surface soil samples from the 1975 to 1979 study were used for comparison to the Durango measurements. However, no ^{40}K values for Colorado were found in the published literature to be used for a regional comparison to the Durango measurements. Potassium concentrations in surface soil were determined during the 1975 to 1979 study but were not published. Colorado ^{40}K unpublished soil sample data, with corresponding external gamma radiation level at 1 m above the surface, were retrieved from archives of the earlier study and found to be 18.6 pCi/g. This was determined from 31 soil sample locations with an external gamma radiation measurement represented by X and a corresponding ^{40}K concentration in surface soil represented by Y (Appendix D). The correlation coefficient between these 31 data pairs is 0.59 (Table 3), which is significant at $P < 0.05$.

REGIONAL DIFFERENCES

A comparison of the Durango background laboratory soil analyses with Grand Junction, Colorado, the state of Colorado, and the United States is depicted for ^{40}K, ^{226}Ra, and ^{232}Th in Fig. 14. The values are shown in Table 4. The mean Durango soil concentrations for ^{40}K, ^{226}Ra, and ^{232}Th of 20.3, 1.6, and 1.2 pCi/g fall within the average

Table 2. Background data sets of in situ measurements for individual geologic units and summary (Durango background)

Unit sampled	No. analyzed		Exposure rate (μR/h)	Total counts (cpm)	1.46-MeV ^{40}K (cpm)	1.76-MeV ^{226}Ra (cpm)	2.62-MeV ^{232}Th (cpm)	Ra/Th ratio
Qal	30	Ave.	15.8	5028.0	523.8	138.4	89.6	1.5
		Sdv.	0.9	1426.9	93.4	31.8	19.9	0.4
		Min.	14.0	3710.0	379.0	89.0	49.0	0.9
		Max.	18.8	11010.0	893.0	254.0	148.0	2.8
Qg	15	Ave.	16.0	4584.7	520.9	141.3	92.9	1.5
		Sdv.	0.7	372.7	62.3	18.6	10.0	0.3
		Min.	15.0	3820.0	417.0	111.0	77.0	1.0
		Max.	17.2	5210.0	625.0	178.0	107.0	2.3
Kl	15	Ave.	17.6	5650.0	649.3	162.3	115.6	1.4
		Sdv.	1.3	903.8	104.6	18.5	18.1	0.2
		Min.	14.0	4300.0	476.0	119.0	75.0	1.2
		Max.	19.0	7840.0	781.0	193.0	140.0	2.0
Km	15	Ave.	17.0	5073.3	548.9	169.5	101.3	1.7
		Sdv.	1.2	447.4	48.5	34.3	18.4	0.5
		Min.	14.0	4330.0	484.0	121.0	67.0	1.0
		Max.	19.0	5990.0	635.0	247.0	133.0	2.8
				Durango background				
		Ave.	16.5	5073.0	553.0	150.0	98.0	1.5
		Sdv.	1.3	1065.0	95.0	30.0	20.0	0.4
		Min.	14.0	3710.0	379.0	89.0	49.0	0.9
		Max.	19.0	11010.0	893.0	254.0	148.0	2.8

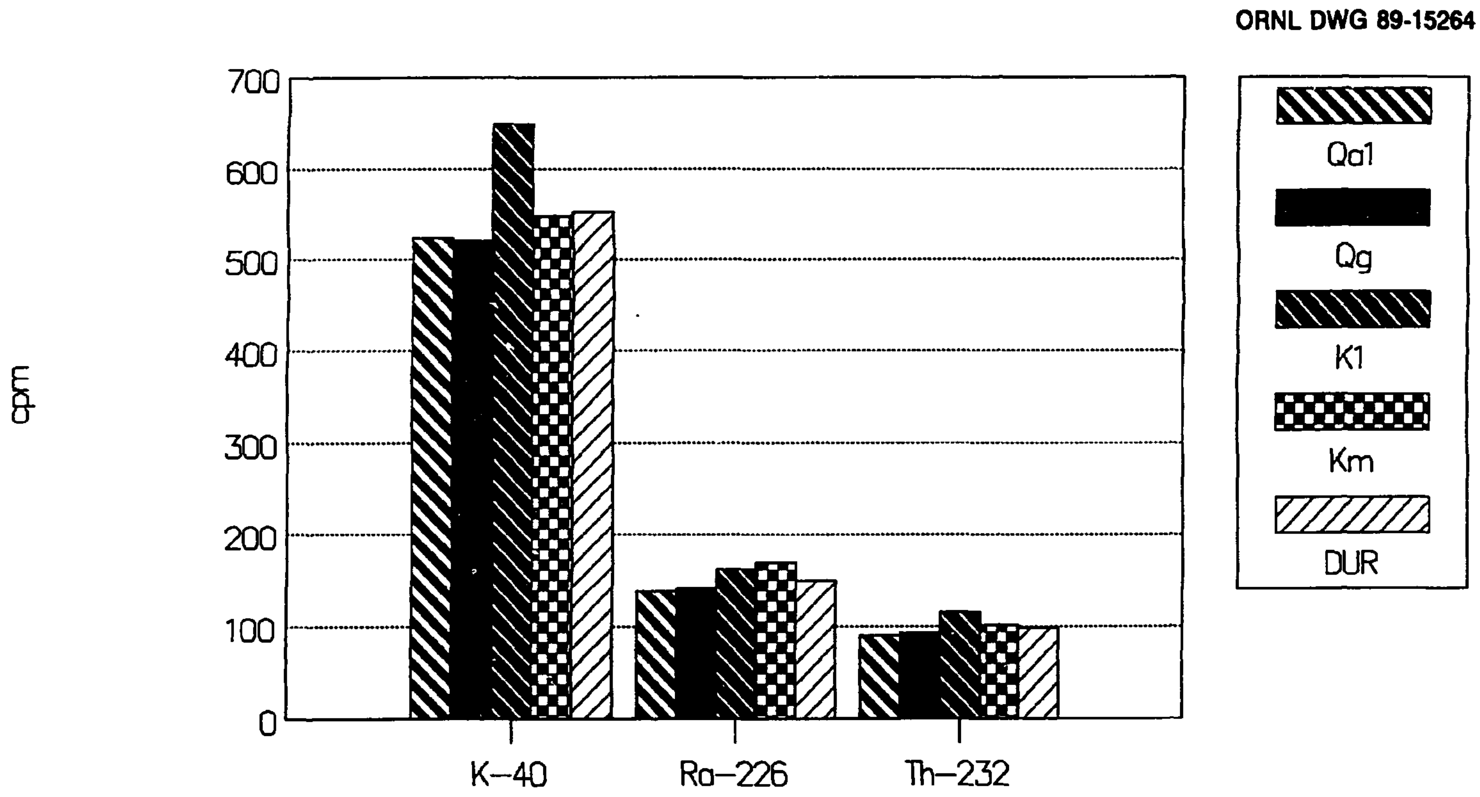

Fig. 11. In situ spectrometer readings for various geologic units.

ORNL DWG 89-15265

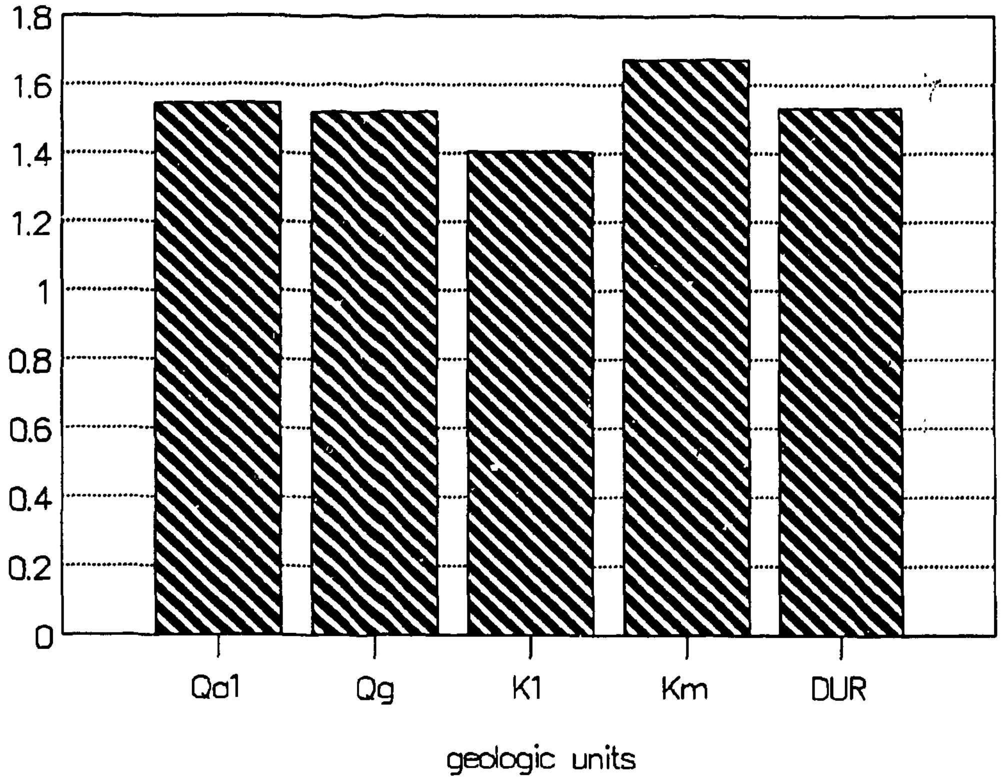

Fig. 12. Background Ra/Th ratio in situ.

ORNL DWG 89-15266

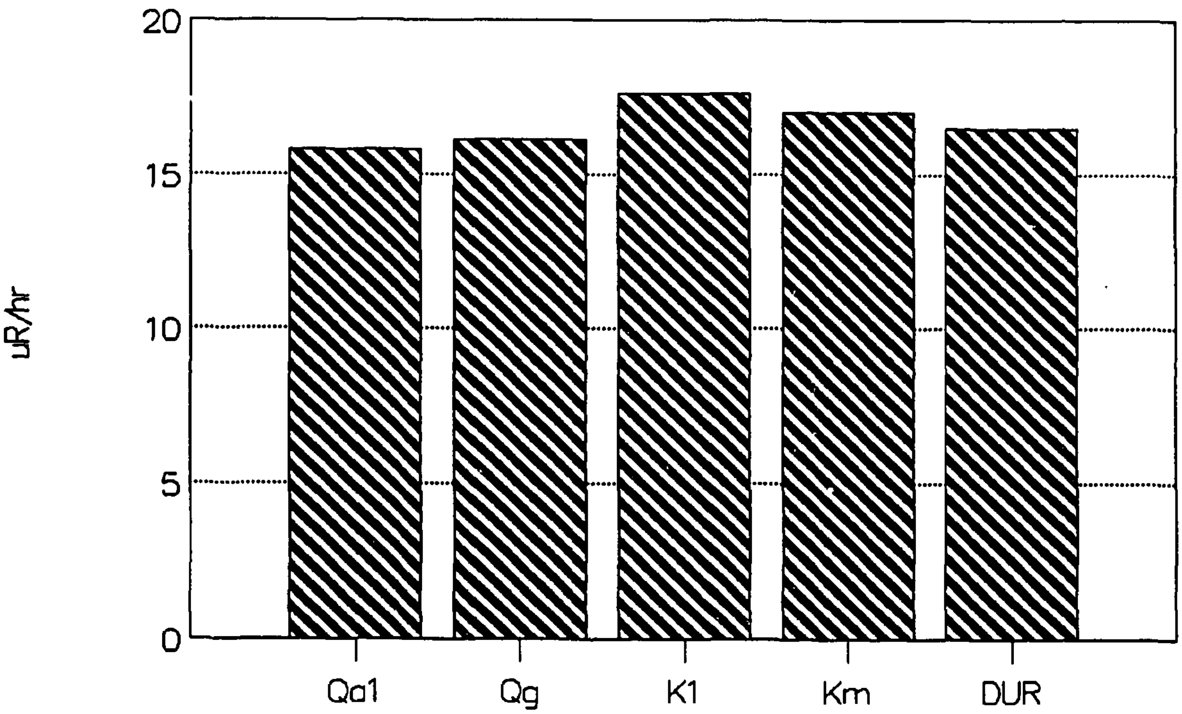

Fig. 13. Background gamma exposure rates in microroentgens per hour.

Table 3. Correlation analysis for background measurements using gamma exposure rate as independent variable

Dependent variable	Slope	Intercept	Number of observations	Correlation coefficient (r)
		Durango vicinity property area		
Lab ^{40}K concentration	1.25	−0.18	75	0.46[a]
Lab ^{226}Ra concentration	0.09	0.14	75	0.20
Lab ^{232}Th concentration	0.11	−0.58	75	0.46[a]
Lab ^{40}K + lab ^{226}Ra concentration	1.33	−0.04	75	0.50[a]
Lab ^{40}K + lab ^{232}Th concentration	1.35	−0.76	75	0.48[a]
Lab ^{226}Ra + lab ^{232}Th concentration	0.19	−0.44	75	0.42[a]
Lab ^{40}K + lab ^{226}Ra + lab ^{232}Th concentration	1.44	−0.62	75	0.51[a]
		State of Colorado		
Lab ^{40}K concentration	0.64	9.42	31	0.59[a]

[a]Significant correlation at $P < 0.05$.

ORNL DWG 89-15267

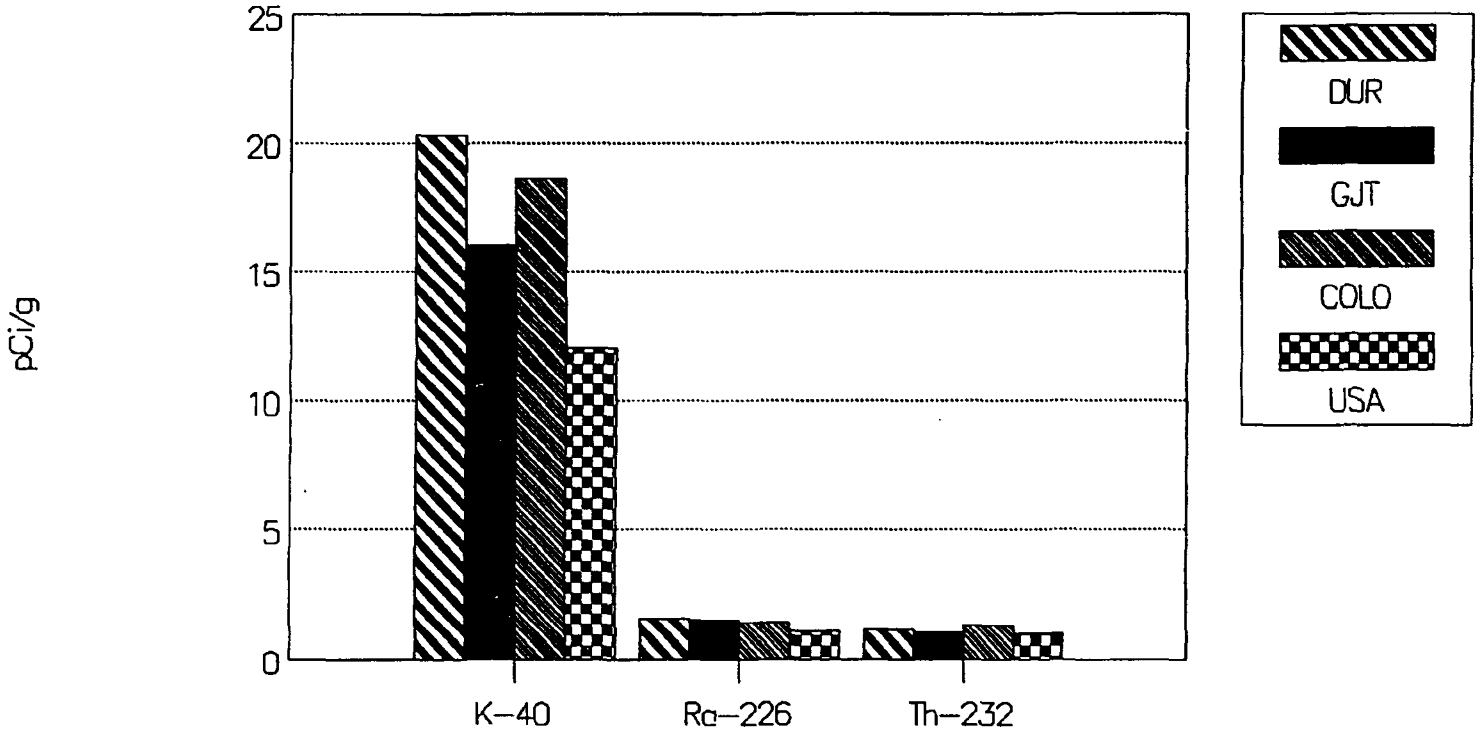

Fig. 14. Isotopic concentrations in geologic units.

Table 4. Isotopic concentration in soil samples from several regions

	^{40}K (pCi/g)	^{226}Ra (pCi/g)	^{232}Th (pCi/g)
Durango	20.3	1.6	1.2
Grand Junction[a]	16.0	1.5	1.0
Colorado	18.6[b]	1.4[c]	1.3[c]
United States	12.0[d]	1.1[c]	1.0[c]

[a]Smith 1985.
[b]Appendix D.
[c]Myrick et al. 1981.
[d]NCRPM 1975.

ranges, but are slightly higher than the mean values, for all observed values other than soil concentration values for ^{232}Th in Colorado and for ^{40}K in the United States. Durango's mean value for ^{232}Th (1.2 pCi/g) is slightly lower than that for Colorado (1.3 pCi/g). The mean ^{40}K value for Durango (20.3 pCi/g) is higher than that for the United States (12.0 pCi/g). The parent rock, soil formation, and transport processes involved affect the radioactivity of the soil (Myrick et al. 1981). In Durango, the Lewis and Mancos shales, which were deposited in the same environment as minor concentrations of uranium, are present. In addition, the Quaternary gravels samples had rocks of igneous origin which are known to be high in ^{40}K. These factors are reflected in the slightly higher mean Durango surface soil concentrations. A comparison of the Durango background external gamma exposure measurements with Grand Junction, Colorado, the state of Colorado, and the United States is presented in Fig. 15. Values are shown in Table 5. The mean external gamma exposure rate of 16.5 μR/h in Durango is higher than that for all other regions observed, but within the range for all but the United States. As discussed earlier, many components influence external gamma exposure rate, and Durango is located in the area of the United States with the highest range of external gamma exposure rates (Myrick et al. 1981).

STATISTICAL ANALYSES

A linear regression and correlation analysis was performed using average external gamma exposure rates as the independent variable and the laboratory results for all possible combinations of the three radionuclides as the dependent variable. The correlation coefficient (r) is a measure of the closeness of fit of the regression equation to the sample data. If the regression line is a perfect fit, r will be equal to 1. In the Durango VP area, r ranged from 0.20, for gamma exposure rate vs laboratory analysis of ^{226}Ra, to 0.50 for gamma exposure rate vs laboratory analyzed ^{40}K plus laboratory analyzed ^{226}Ra (Table 3). Appendix D presents data from which the state of Colorado's average potassium and gamma exposure rates were derived. Included in the data are the number of samples analyzed and the average, standard deviation, minimum, and maximum values. All of the correlations presented in Table 3 were significant at the 95% confidence level, except the laboratory analyzed ^{226}Ra concentration, which indicated a lower correlation of exposure rate with ^{226}Ra concentration. There is no apparent reason for this finding.

DURANGO CONVERSION CURVE

A conversion table (Appendix E) for converting gamma scintillator count rates (kcpm) to exposure rates (μR/h) was derived in May 1985. This was based on 250 data pairs of gamma scintillator measurements at 15 cm and a corresponding Reuter-Stokes PIC measurement taken at the same location.

Field data collected during vicinity property surveys in Durango from July 1983 until May 1985 were compiled from 214 locations. Gamma scintillator measurements ranged from 4 to 80 kcpm. However, approximately 70% of these measurements were obtained in the background range of 4 to 6 kcpm. In order to have a broader range and more

ORNL DWG 89-15271

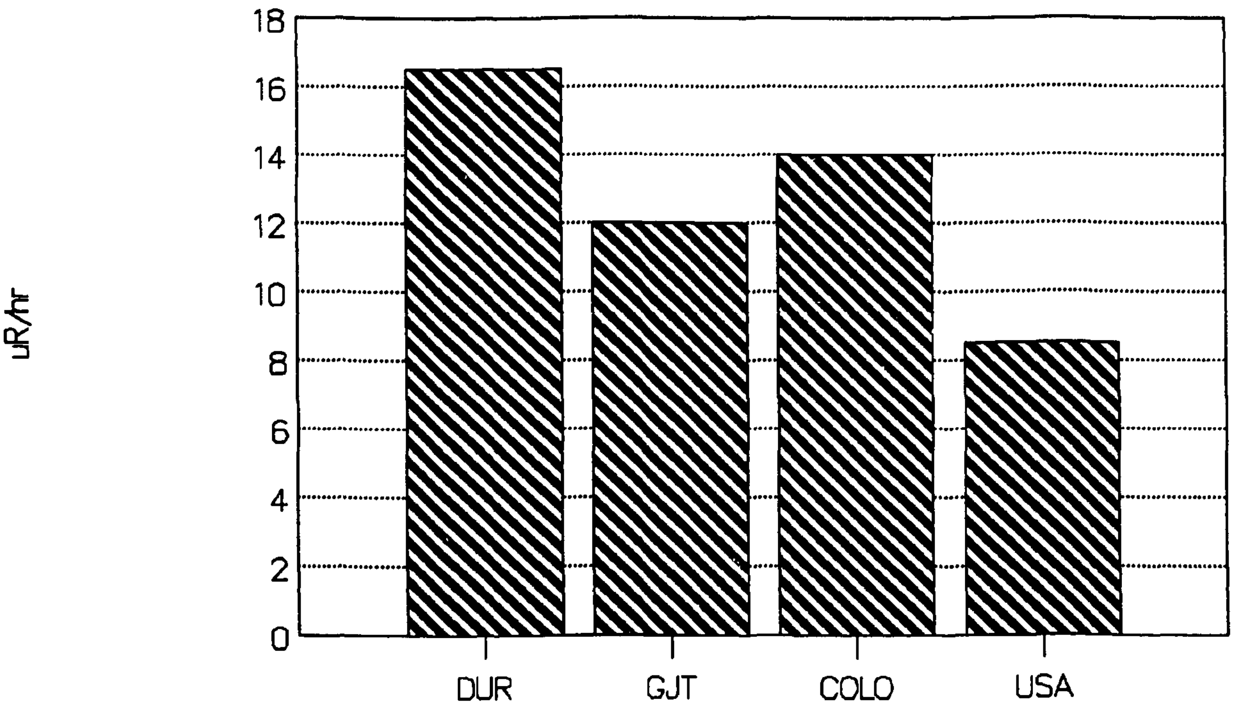

Fig. 15. Gamma exposure rate (background).

Table 5. Background external gamma exposure rates from several regions

	Range (μR/h)	Mean (μR/h)	Standard deviation
Durango, Colorado	15—18	16.5	± 1.3
Grand Junction, Colorado[a]	10—14	12	± 4
State of Colorado[b]	4—24	14	± 10
United States[b]	4—13	8.5	± 4.1

[a]Smith 1985.
[b]Myrick et al. 1981.

data points in the upper end of the range, 36 more measurements ranging from 55 to 320 kcpm were taken at locations on the tailings pile in May 1985. Operational specifications for the flux range of the Reuter-Stokes PIC is 1 to 500 μR/h. This was the determining factor for the high end of the measurements range. In order to predict values of microroentgen per hour corresponding to given values of thousand counts per minute, 250 data pairs were analyzed by linear regression.

A linear regression and correlation analysis was performed using external gamma exposure rates obtained in thousand counts per minute by the gamma rate meter as the independent variable (x) and in microroentgen per hour by the PIC as the dependent variable (y). Data pairs from 250 locations had a linear relationship expressed by the following equation:

$$y = a + bx$$

where

y = measurements in μR/h,

a = point at which the line crosses the y axis, or slope intercept,

b = amount by which the line changes per unit change in x, or the slope,

x = measurement in kcpm.

The conversion formula for Durango, based on these 250 data pairs, is $y = 5.28 + 1.55x$. The correlation coefficient is 0.98, indicating a regression line approaching a perfect fit (1.0).

SUMMARY

Extensive radiometric measurements and surface soil samples were collected in the Durango VP area by personnel from ORNL's Grand Junction Office in conjunction with the UMTRA Project. Assessment of the data indicated no unit anomalies and established the regional background radiation levels and geologic profiles in the study area. Concentrations in surface soil are 20.3 ± 3.4 pCi/g for ^{40}K, 1.6 ± 0.5 pCi/g for ^{226}Ra, and 1.2 ± 0.3 pCi/g for ^{232}Th. Concentrations of ^{40}K, ^{226}Ra, and ^{232}Th measured for each formation were found to correlate significantly at the 95% confidence level.

Durango background gamma exposure rates ranged from 15 to 18 μR/h. In situ gamma spectrometer measurement averages were 553 cpm for ^{40}K, 150 cpm for ^{226}Ra, and 98 cpm for ^{232}Th, with a radium/thorium ratio of 1.53.

Regional comparisons demonstrated that radionuclide measurements, and therefore gamma exposure rates, are higher in the Durango study area. This is due to the presence of gravels, igneous rocks, and the Lewis and Mancos shales.

Linear regression and correlation analyses were performed between average external exposure rate and the laboratory results for radionuclide concentrations in surface soil. Correlation coefficients (r) ranged from 0.20 to 0.50 (Table 3). This indicated significant correlations at $P < 0.05$ for all radionuclides and radionuclide concentrations combinations except ^{226}Ra.

A conversion formula for converting gamma scintillator counts rates to gamma exposure rates in microroentgen per hour was derived. This was based on 250 data pairs, gamma scintillator measurements (kcpm) at 15 cm and a corresponding Reuter-Stokes PIC measurement (μR/h) taken at the same location.

The conversion formula for Durango was determined to be $y = 5.28 + 1.55x$ where y = exposure rate in microroentgen per hour and x = count rate in counts/minute × 1000 (kcpm). This conversion formula is being used for all UMTRA surveys in Durango.

Background measurements and the conversion formula can be utilized in the Department of Energy's program to remediate the mill tailings sites and associated VPs in Durango. In addition, these measurements should be considered background in Durango for studies in any of the geologic units profiled.

REFERENCES

Allen, J.W., and D. Strong. 1984. *Radiologic Characterization of the Durango, Colorado, Uranium Mill Tailings Remedial Action Site,* GJ-15, Bendix Field Engineering Corporation, Grand Junction, Colorado.

Atwood, W.W., and K.F. Mather. 1932. *Physiography and Quaternary Geology of the San Juan Mountains, Colorado,* Geological Survey Professional Paper 166, U.S. Department of the Interior.

Daniel, W.W. 1984. *Essentials of Business Statistics,* Houghton Mifflin Company, Boston.

Department of Energy. 1984. *Remedial Action at the Former Vanadium Corporation of America Uranium Mill Site, Durango, La Plata County, Colorado,* Vols. 1 and 2, DOE/EIS-011D, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Ford, Bacon and Davis, Utah, Inc. 1977. *Engineering Assessment of Inactive Uranium Mill Tailings, Durango Site, Durango, Colorado,* GJT-6, Salt Lake City.

Geometrics Exploranium. 1977. "Gamma Ray Spectrometer, Model GJ-410," in *Technical Manual: Operation,* Vol. I, Geometrics, Inc., Toronto.

Haywood, F.F., et al. 1980. *Radiological Survey of the Inactive Uranium-Mill Tailings at Durango, Colorado,* ORNL-5451, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Hilton, L.K. 1981. *An Aerial Radiological Survey of the Durango, Colorado, Uranium Mill Tailings Site,* EP-U-003, EG&G Survey Report, Las Vegas.

Little, C.A. et al. 1986. *RASA/UMTRA Procedures Manual,* ORNL/TM-9902, Sections 10.2-10.4, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Maxwell, J.C. 1977. *Uranium Hydrogeochemical and Stream Sediment Reconnaissance in the San Juan Mountains, Southwest, Colorado,* LA-6651-MS, Los Alamos Scientific Laboratory of the University of California, Los Alamos, New Mexico.

Myrick, T.E., et al. 1981. *State Background Radiation Levels: Results of Measurements Taken During 1975-1979,* ORNL/TM-7343, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

NCRPM. 1975. National Council on Radiation Protection and Measurements. *Natural Background Radiation in the United States,* NCRP Report No. 45, Washington, D.C.

Reuter-Stokes. 1981. "RSS-111 Environmental Radiation Monitor (P.I.C.)," *Operational Manual, RSS-111 Area Monitor System,* Cleveland.

Smith, G.D. 1985. *Background Exposure Rates and ^{226}Ra Concentrations in Surface Soils in Grand Junction, Colorado,* Department of Radiology and Radiation Biology, Colorado State University, Fort Collins, Colorado.

Steven, T.A., et al. 1977. Geologic Map of the Durango Quadrangle, Southwestern Colorado: U.S.G.S. Map I-764, Scale 1:250,000.

Theis, N.J., et al. 1981. *National Uranium Resource Evaluation, Durango, Quadrangle,* GJQ-011 (81), Bendix Field Engineering Corporation, Grand Junction, Colorado.

Turner, J.E., M-K Ferguson Environmental Assessment and Verification Manager. 1987. Personal communication.

Victoreen, Inc. 1979. "Gamma Ratemeter," in *Instruction Manual for Model 490, Thyac III,* Cleveland.

Witt, D.A. 1986. "Memo: Preliminary Results of Gamma Spectral Data, March 10, 1986," Oak Ridge National Laboratory, Grand Junction, Colorado.

APPENDIX A: INSTRUMENTATION

GAMMA RATE METER

The gamma survey meter consisted of a Victoreen portable pulse count rate meter, Model 490, Thyac III, in conjunction with a gamma scintillation probe using a 1.25- × 1.50-in. sodium iodide crystal (Model 489-55) coupled with a photomultiplier tube (Victoreen 1979).

PORTABLE GAMMA RAY SPECTROMETER

The Geometrics Exploranium Gamma Ray Spectrometer Model GR-410 is a differential, four-channel spectrometer, designed for field use in determining ^{226}Ra (as ^{214}Bi, using an energy window peak of 1.76 MeV gamma), thorium (as ^{208}Tl, using an energy window peak of 2.62 MeV gamma), and potassium (as ^{40}K using an energy window peak of 1.46 MeV gamma) mineral content. A sodium iodide thallium-activated crystal incorporated with a photomultiplier tube through high-speed differential pulse height analyzers determines total count (all energy between 0.5 and 3.0 MeV). The radium-thorium ratio is then determined to distinguish the amount of background gamma exposure rate created by the radionuclides radium and thorium.

PRESSURIZED IONIZATION CHAMBER

The Reuter-Stokes RSS-111 Environmental Radiation Monitor, also known as a pressurized ionization chamber or PIC, is a gamma exposure monitoring system designed to measure and record low-level exposure rates such as natural background radiation. The PIC is used to determine the conversion factor between thousand counts per minute and microroentgen per hour for the rate meters.

APPENDIX B: RADIONUCLIDE CONCENTRATIONS IN SURFACE SOIL SAMPLES

Unit sampled	Sample No.	^{40}K (pCi/g)	^{226}Ra (pCi/g)	^{232}Th (pCi/g)
Qal	001	20.10 ± 1.9	1.13 ± 0.3	1.31 ± 0.3
Qal	002	23.40 ± 2.4	1.25 ± 0.3	0.54 ± 0.3
Qal	003	19.50 ± 1.9	2.09 ± 0.3	1.02 ± 0.3
Qal	004	24.60 ± 2.4	1.45 ± 0.3	1.54 ± 0.3
Qal	005	19.90 ± 1.9	1.92 ± 0.3	0.85 ± 0.3
Qal	006	17.00 ± 1.6	1.03 ± 0.3	0.55 ± 0.3
Qal	007	23.70 ± 2.3	1.55 ± 0.3	0.82 ± 0.3
Qal	008	17.10 ± 1.6	3.30 ± 0.3	0.98 ± 0.3
Qal	009	18.90 ± 1.8	2.44 ± 0.3	1.03 ± 0.3
Qal	010	23.80 ± 2.3	1.63 ± 0.3	1.27 ± 0.3
Qal	011	20.50 ± 2.0	1.68 ± 0.3	1.01 ± 0.3
Qal	012	20.60 ± 2.0	1.47 ± 0.3	0.89 ± 0.3
Qal	013	24.30 ± 2.3	1.15 ± 0.3	1.57 ± 0.3
Qal	014	19.30 ± 1.8	2.13 ± 0.3	1.07 ± 0.3
Qal	015	22.00 ± 2.1	1.25 ± 0.3	0.94 ± 0.3
Qal	016	22.40 ± 2.2	1.28 ± 0.3	1.20 ± 0.3
Qal	017	19.80 ± 1.9	1.37 ± 0.3	0.90 ± 0.3
Qal	018	19.90 ± 1.9	2.83 ± 0.3	1.09 ± 0.3
Qal	019	20.50 ± 2.0	1.68 ± 0.3	1.30 ± 0.3
Qal	020	23.70 ± 2.3	1.62 ± 0.3	1.33 ± 0.3
Qal	021	19.20 ± 1.8	1.30 ± 0.3	0.98 ± 0.3
Qal	022	19.90 ± 1.9	1.69 ± 0.3	1.43 ± 0.3
Qal	023	18.20 ± 1.7	1.90 ± 0.3	1.16 ± 0.3
Qal	024	20.90 ± 1.7	1.46 ± 0.3	1.14 ± 0.3
Qal	025	19.10 ± 1.8	1.39 ± 0.3	1.11 ± 1.7
Qal	026	17.90 ± 1.7	1.44 ± 0.3	0.95 ± 0.3
Qal	027	18.60 ± 1.8	1.41 ± 0.3	0.89 ± 0.3
Qal	028	18.20 ± 1.7	0.76 ± 0.3	0.94 ± 0.3
Qal	029	16.90 ± 1.6	1.02 ± 0.3	0.99 ± 0.3
Qal	030	26.50 ± 2.6	1.41 ± 0.3	1.54 ± 0.3
Qg	001	20.00 ± 1.9	0.94 ± 0.3	0.79 ± 0.3
Qg	002	22.80 ± 2.2	1.10 ± 0.3	1.31 ± 0.3
Qg	003	20.30 ± 1.9	1.42 ± 0.3	1.00 ± 0.3
Qg	004	21.40 ± 2.1	1.13 ± 0.3	0.92 ± 0.3
Qg	005	22.20 ± 2.1	1.75 ± 0.3	1.08 ± 0.3
Qg	006	20.70 ± 2.0	1.72 ± 0.3	1.08 ± 0.3
Qg	007	19.70 ± 1.9	1.14 ± 0.3	1.29 ± 0.3
Qg	008	20.00 ± 1.9	1.19 ± 0.3	1.34 ± 0.3
Qg	009	20.60 ± 2.0	1.08 ± 0.3	1.13 ± 0.3
Qg	010	14.90 ± 1.4	1.03 ± 0.3	0.76 ± 0.3

APPENDIX B (continued)

Unit sampled	Sample No.	^{40}K (pCi/g)	^{226}Ra (pCi/g)	^{232}Th (pCi/g)
Qg	011	19.30 ± 1.9	2.64 ± 0.3	0.90 ± 0.3
Qg	012	18.20 ± 1.7	1.20 ± 0.3	1.13 ± 0.3
Qg	013	17.30 ± 1.7	1.39 ± 0.3	0.79 ± 0.3
Qg	014	15.40 ± 1.5	1.27 ± 0.3	0.70 ± 0.3
Qg	015	16.20 ± 1.5	0.96 ± 0.3	1.07 ± 0.3
Kl	001	16.00 ± 1.5	1.11 ± 0.3	1.03 ± 0.3
Kl	002	26.80 ± 2.6	2.42 ± 0.3	1.61 ± 0.3
Kl	003	25.80 ± 2.5	1.23 ± 0.3	1.13 ± 0.3
Kl	004	21.90 ± 2.1	1.39 ± 0.3	1.34 ± 0.3
Kl	005	16.50 ± 1.6	1.47 ± 0.3	0.87 ± 0.3
Kl	006	25.30 ± 2.5	1.40 ± 0.3	1.84 ± 0.3
Kl	007	27.00 ± 2.6	1.42 ± 0.3	1.50 ± 0.3
Kl	008	27.50 ± 2.7	1.53 ± 0.3	1.27 ± 0.3
Kl	009	22.90 ± 2.2	1.59 ± 0.3	1.34 ± 0.3
Kl	010	26.50 ± 2.6	1.02 ± 0.3	1.64 ± 0.3
Kl	011	25.10 ± 2.4	1.70 ± 0.3	1.53 ± 0.3
Kl	012	15.60 ± 1.5	1.14 ± 0.3	1.02 ± 0.3
Kl	013	16.40 ± 1.5	1.24 ± 0.3	1.46 ± 0.3
Kl	014	22.50 ± 2.2	1.31 ± 0.3	1.56 ± 0.3
Kl	015	25.40 ± 2.5	1.57 ± 0.3	1.53 ± 0.3
Km	001	26.60 ± 2.6	2.12 ± 0.3	1.23 ± 0.3
Km	002	18.50 ± 1.8	1.04 ± 0.3	1.09 ± 0.3
Km	003	17.70 ± 1.7	1.06 ± 0.3	1.09 ± 0.3
Km	004	20.80 ± 2.0	1.61 ± 0.3	1.35 ± 0.3
Km	005	20.10 ± 1.9	1.28 ± 0.3	1.34 ± 0.3
Km	006	14.60 ± 1.4	2.21 ± 0.3	0.81 ± 0.3
Km	007	15.20 ± 1.4	1.99 ± 0.3	0.92 ± 0.3
Km	008	18.10 ± 1.7	2.44 ± 0.3	1.30 ± 0.3
Km	009	15.80 ± 1.5	3.12 ± 0.3	0.91 ± 0.3
Km	010	13.70 ± 1.3	1.91 ± 0.3	1.03 ± 0.3
Km	011	20.90 ± 2.0	0.88 ± 0.3	1.63 ± 0.3
Km	012	19.10 ± 1.8	1.03 ± 0.3	1.97 ± 0.3
Km	013	19.50 ± 1.9	2.24 ± 0.3	1.10 ± 0.3
Km	014	17.00 ± 1.6	2.90 ± 0.3	0.87 ± 0.3
Km	015	19.80 ± 1.9	1.28 ± 0.3	1.27 ± 0.3

APPENDIX C: IN SITU GAMMA SPECTROMETER AND GAMMA RATE METER MEASUREMENTS

Unit sampled	Sample No.	Exposure rate (μR/h)	Total counts (cpm)	1.46-MeV ^{40}K (cpm)	1.76-MeV ^{226}Ra (cpm)	2.62-MeV ^{232}Th (cpm)	Ra/Th ratio
Qal	001	15.0	11010	893	254	148	1.70
Qal	002	17.0	6440	495	137	92	1.50
Qal	003	16.0	6160	512	150	97	1.50
Qal	004	17.0	4380	516	114	91	1.30
Qal	005	16.0	5780	470	129	92	1.40
Qal	006	15.0	3760	379	119	93	1.30
Qal	007	16.0	4540	526	104	99	1.00
Qal	008	16.0	5980	515	144	69	2.10
Qal	009	16.7	6260	531	155	72	2.20
Qal	010	17.0	6760	588	175	106	1.65
Qal	011	15.0	3710	456	110	67	1.60
Qal	012	14.0	5410	480	127	73	1.70
Qal	013	18.8	6070	720	171	133	1.30
Qal	014	16.0	4530	511	142	96	1.50
Qal	015	15.6	4410	492	98	108	0.91
Qal	016	16.1	4680	566	133	105	1.20
Qal	017	15.6	4560	560	139	100	1.40
Qal	018	16.1	4370	453	149	78	1.90
Qal	019	15.7	4710	527	164	93	1.80
Qal	020	15.0	4380	503	133	85	1.60
Qal	021	14.4	3890	520	96	63	1.50
Qal	022	15.5	4320	466	153	85	1.80
Qal	023	15.5	4170	449	146	74	1.90
Qal	024	16.0	5010	594	156	106	1.50
Qal	025	16.1	4430	472	136	49	2.80
Qal	026	16.0	4500	493	158	81	2.00
Qal	027	16.0	4330	489	155	86	1.80
Qal	028	14.0	3780	466	102	77	1.30
Qal	029	15.0	3790	464	89	76	1.20
Qal	030	16.0	4720	607	114	93	1.20
Qg	001	16.0	4700	533	137	95	1.40
Qg	002	17.0	4830	625	145	103	1.40
Qg	003	15.0	3820	417	112	100	1.00
Qg	004	16.0	4690	570	142	100	1.40
Qg	005	16.7	4780	470	148	91	1.60
Qg	006	16.1	4590	487	142	80	1.80
Qg	007	16.1	4320	485	139	106	1.30
Qg	008	16.1	4130	452	134	89	1.50
Qg	009	15.0	4410	522	121	81	1.50
Qg	010	15.0	4050	437	111	83	1.40

APPENDIX C (continued)

Unit sampled	Sample No.	Exposure rate (μR/h)	Total counts (cpm)	1.46-MeV ^{40}K (cpm)	1.76-MeV ^{226}Ra (cpm)	V	Ra/Th ratio
Qg	011	17.1	5210	536	175		2.30
Qg	012	17.2	4930	574	178	[illegible]	1.80
Qg	013	16.0	4630	522	147	94	1.60
Qg	014	15.8	4870	584	143	107	1.30
Qg	015	16.1	4810	600	145	86	1.10
Kl	001	16.0	4300	542	119	89	1.30
Kl	002	19.0	7840	725	193	117	1.60
Kl	003	18.0	5020	605	144	106	1.40
Kl	004	17.0	4970	573	170	103	1.70
Kl	005	17.1	4930	486	142	106	1.40
Kl	006	17.6	5940	694	184	130	1.40
Kl	007	19.0	6610	771	178	130	1.40
Kl	008	19.0	6230	781	169	126	1.30
Kl	009	17.0	5610	692	162	105	1.60
Kl	010	18.0	5920	724	160	129	1.20
Kl	011	17.6	5820	706	159	126	1.30
Kl	012	14.1	4490	476	149	75	2.00
Kl	013	17.1	5250	541	167	117	1.40
Kl	014	18.1	5490	653	162	140	1.20
Kl	015	18.9	6330	771	176	135	1.30
Km	001	18.0	4670	530	140	108	1.30
Km	002	16.0	4330	508	132	87	1.50
Km	003	17.0	5350	613	143	112	1.30
Km	004	19.0	5510	593	202	95	2.00
Km	005	14.0	4670	495	212	129	1.00
Km	006	18.0	5140	535	185	93	2.00
Km	007	16.1	4790	484	185	67	2.80
Km	008	16.4	4760	548	166	88	1.88
Km	009	18.0	5990	564	247	110	2.20
Km	010	16.0	4600	484	154	90	1.70
Km	011	17.6	5620	618	203	120	1.70
Km	012	17.2	5090	520	143	133	1.10
Km	013	16.7	4980	552	155	78	2.00
Km	014	17.0	5300	554	202	100	2.00
Km	015	18.0	5300	635	176	109	1.60

APPENDIX D: STATE OF COLORADO LAB ^{40}K VALUES

X (μR/h)	Y (pCi/g)	
15.00	19.00	
15.00	18.00	
10.00	13.30	
8.10	15.00	
6.30	4.90	
7.10	8.40	
9.90	16.50	
12.00	20.00	
13.00	15.00	
13.00	16.00	
22.00	20.00	
21.00	17.00	
19.00	18.20	
16.00	23.00	
13.00	18.90	
15.00	26.00	
18.00	18.80	
15.00	22.30	
15.00	18.80	
16.00	23.80	
9.30	19.00	
10.00	18.80	
15.00	24.60	
11.00	19.00	
11.00	19.00	
11.00	14.00	
14.00	4.20	
19.00	28.10	
34.00	28.60	
17.00	25.00	
14.00	23.30	
444.70	576.50	Sum
14.35	18.60	Ave
28.16	33.25	Var
5.31	5.77	Sdv
6.30	4.20	Min
34.00	28.60	Max

Number of Observations: 31

APPENDIX E: DURANGO CONVERSION TABLE

Thousand counts per minute (kcpm)	Microroentgen per hour (μR/h)
1.0	6.8
1.5	7.6
2.0	8.4
2.5	9.2
3.0	9.9
3.5	10.7
4.0	11.5
4.5	12.3
5.0	13.0
5.5	13.8
6.0	14.6
6.5	15.4
7.0	16.1
7.5	16.9
8.0	17.7
8.5	18.5
9.0	19.2
9.5	20.0
10.0	20.8
10.5	21.6
11.0	22.3
12.0	23.9
13.0	25.4
14.0	27.0
15.0	28.5
16.0	30.1
17.0	31.6
18.0	33.2
19.0	34.7
20.0	36.3
21.0	37.8
22.0	39.4
23.0	40.9
24.0	42.5
25.0	44.0
26.0	45.6
27.0	47.1
28.0	48.7
29.0	50.2
30.0	51.8

APPENDIX E (continued)

Thousand counts per minute (kcpm)	Microroentgen per hour (μR/h)
31.0	53.3
32.0	54.9
33.0	56.4
34.0	58.0
35.0	59.5
36.0	61.1
37.0	62.6
38.0	64.2
39.0	65.7
40.0	67.3
41.0	68.8
42.0	70.4
43.0	71.9
44.0	73.5
45.0	75.0
46.0	76.6
47.0	78.1
48.0	79.7
49.0	81.2
50.0	82.8
51.0	84.3
52.0	85.9
53.0	87.4
54.0	89.0
55.0	90.5
56.0	92.1
57.0	93.6
58.0	95.2
59.0	96.7
60.0	98.3
61.0	99.8
62.0	101.4
63.0	102.9
64.0	104.5
65.0	106.0
66.0	107.6
67.0	109.1
68.0	110.7
69.0	112.2
70.0	113.8

APPENDIX E (continued)

Thousand counts per minute (kcpm)	Microroentgen per hour (μR/h)
71.0	115.3
72.0	116.9
73.0	118.4
74.0	120.0
75.0	121.5
76.0	123.1
77.0	124.6
78.0	126.2
79.0	127.7
80.0	129.3
81.0	130.8
82.0	132.4
83.0	133.9
84.0	135.5
85.0	137.0
86.0	138.6
87.0	140.1
88.0	141.7
89.0	143.2
90.0	144.8
91.0	146.3
92.0	147.9
93.0	149.4
94.0	151.0
95.0	152.5
96.0	154.1
97.0	155.6
98.0	157.2
99.0	158.7
100.0	160.3
101.0	161.8
102.0	163.4
103.0	164.9
104.0	166.5
105.0	168.0
106.0	169.6
107.0	171.1
108.0	172.7
109.0	174.2
110.0	175.8

APPENDIX E (continued)

Thousand counts per minute (kcpm)	Microroentgen per hour (μR/h)
111.0	177.3
112.0	178.9
113.0	180.4
114.0	182.0
115.0	183.5
116.0	185.1
117.0	186.6
118.0	188.2
119.0	189.7
120.0	191.3
121.0	192.8
122.0	194.4
123.0	195.9
124.0	197.5
125.0	199.0
126.0	200.6
127.0	202.1
128.0	203.7
129.0	205.2
130.0	206.8
131.0	208.3
132.0	209.9
133.0	211.4
134.0	213.0
135.0	214.5
136.0	216.1
137.0	217.6
138.0	219.2
139.0	220.7
140.0	222.3
141.0	223.8
142.0	225.4
143.0	226.9
144.0	228.5
145.0	230.0
146.0	231.6
147.0	233.1
148.0	234.7
149.0	236.2
150.0	237.8

APPENDIX E (continued)

Thousand counts per minute (kcpm)	Microroentgen per hour (μR/h)
151.0	239.3
152.0	240.9
153.0	242.4
154.0	244.0
155.0	245.5
156.0	247.1
157.0	248.6
158.0	250.2
159.0	251.7
160.0	253.3
161.0	254.8
162.0	256.4
163.0	257.9
164.0	259.5
165.0	261.0
166.0	262.6
167.0	264.1
168.0	265.7
169.0	267.2
170.0	268.8
171.0	270.3
172.0	271.9
173.0	273.4
174.0	275.0
175.0	276.5
176.0	278.1
177.0	279.6
178.0	281.2
179.0	282.7
180.0	284.3
181.0	285.8
182.0	287.4
183.0	288.9
184.0	290.5
185.0	292.0
186.0	293.6
187.0	295.1
188.0	296.7
189.0	298.2
190.0	299.8

APPENDIX E (continued)

Thousand counts per minute (kcpm)	Microroentgen per hour (μR/h)
191.0	301.3
192.0	302.9
193.0	304.4
194.0	306.0
195.0	307.5
196.0	309.1
197.0	310.6
198.0	312.2
199.0	313.7
200.0	315.3