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YUCCA MOUNTAIN

SITE CHARACTERIZATION PROJECT

RADIOLOGICAL PROGRAMS

DISTRIBUTION OF NATURAL AND MAN-MADE RADIONUCLIDES IN SOIL AND BIOTA AT YUCCA MOUNTAIN, NEVADA (SCPB: N/A)

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DISCLAIMER

EXECUTIVE SUMMARY

The Radiological/Environmental Field Programs Department (R/EFPD) of the Department of Energy's (DOE) Civilian Radioactive Waste Management System, Management and Operating Contractor (CRWMS, M&O) is conducting a comprehensive radiological monitoring program at Yucca Mountain to determine the existing background radiation. This document describes the soil and biota radiological monitoring activities performed from 1989 through 1995, and summarizes the specific radionuclide concentrations in surface soil, vegetation, and small mammals at the Yucca Mountain site.

Most of the radionuclides detected in Yucca Mountain soils were naturally occurring. They were radionuclides in the uranium-238 (^{238}U) and thorium-232 (^{232}Th) decay series, and potassium-40 (^{40}K). The specific activities for ^{238}U, ^{232}Th and ^{40}K were 0.10 ± 0.04, 0.52 ± 0.19, and 28.48 ± 2.03 pCi/gram dry weight, respectively. In both the ^{238}U and ^{232}Th series, disequilibria between parent and progeny nuclides were observed. Although the specific activities for ^{238}U and ^{232}Th were relatively low, their progeny nuclide concentrations were much higher. Radium-226 (^{226}Ra), a decay product of ^{238}U, had an average concentration of 1.75 ± 0.46 pCi/gram, more than ten times higher than its ascendent, ^{238}U. Radium-228 (^{228}Ra), a decay product of ^{232}Th, had an average concentration of 1.90 ± 0.48 pCi/gram, about four times higher than ^{232}Th. In general, the concentration data of these naturally occurring radionuclides were found to be normally distributed.

Compared to other areas in the United States, as well as around the world, Yucca Mountain soils exhibit relatively high radioactivity. In particular, the ^{40}K content of the soil is exceptionally high at Yucca Mountain, possibly due to the fact that the underlying rocks are predominantly igneous. In nature, igneous rocks are more radioactive than other types of rocks.

In addition to the naturally occurring radionuclides, trace amounts of man-made nuclides were detected in soil samples. The most significant ones were the fallout-derived nuclides, strontium-90 (^{90}Sr) and cesium-137 (^{137}Cs). The average concentration of ^{90}Sr was 0.13 pCi/gram, ranging from below the detection limit to 1.10 pCi/gram. The average concentration of ^{137}Cs was 0.37 pCi/gram, ranging from below the detection limit to 0.97 pCi/gram. Very small amounts of plutonium-239 (^{239}Pu) were also detected in soil samples, and the average concentration was 0.02 pCi/gram, ranging from below the detection limit to 0.14 pCi/gram. Because of the low concentrations, some of the samples contained specific activities lower than the detection limits.

^{90}Sr and ^{137}Cs concentrations in Yucca Mountain soils were found to be lower than those detected in other areas of southern Nevada and Utah that are situated downwind of the Nevada Test Site (NTS). However, the Yucca Mountain data were comparable with the values observed in Area 25 of the NTS.

When ambient gamma exposure rates at Yucca Mountain were calculated using dose conversion factors (DCF) and soil radioactivity data, the average exposure rate was estimated to be 16.7 μrem/hr, or 146 mrem/yr. The calculation also indicated that approximately 1% of the exposure was attributable to the man-made source, ^{137}Cs. The calculated exposure rates were in good agreement with the results measured by pressurized ionization chambers (PICs).

Compared to the United States and worldwide averages, the Yucca Mountain area has relatively high levels of gamma radiation. This is due mainly to high naturally occurring radioactivity in the soils. Relatively high elevations also contribute to the high gamma radiation background.

Deer and cattle forage were collected from both near-field and far-field locations. Only very small amounts of ^{90}Sr, ^{137}Cs, and ^{239}Pu were detected in the samples. The average concentration of ^{90}Sr was 0.04 pCi/gram dry weight, ranging from below the detection limit to 0.94 pCi/gram. The average concentration of ^{137}Cs was 0.014 pCi/gram dry weight, ranging from below the detection limit to 0.087 pCi/gram. These values were lower than those reported for areas downwind of the NTS in southern Nevada and Utah. The average concentration of ^{239}Pu was 0.005 pCi/gram dry weight, ranging from below the detection limit to 0.087 pCi/gram. Statistical tests indicated that the concentrations of these three nuclides in the near-field samples were not significantly different from those in far-field samples.

The soil-to-plant transfer ratios for ^{90}Sr, ^{137}Cs, and ^{239}Pu were estimated to be 0.31, 0.04, and 0.25, respectively. The values for ^{90}Sr and ^{137}Cs fall within the ranges published in the NCRP 76 report. The ratio for ^{239}Pu, however, is much higher than the value reported by the NCRP.

Two species of small mammals, Merriam's kangaroo rats (*Dipodomys merriami*) and long-tailed pocket mice (*Chaetodipus formosus*) were collected as indicator species for characterizing existing radionuclide levels and monitoring any potential contribution from site characterization activities. Only very small amounts of ^{90}Sr and ^{137}Cs were found in the samples, which averaged 0.04 and 0.02 pCi/gram ash weight, respectively. Due to the limited sample size, critical organs or tissues were not analyzed separately, thus, these data had limited value for dosimetry purposes. However, the low concentrations of ^{90}Sr and ^{137}Cs reflected the findings observed in soil and vegetation samples. These numbers were much lower than those observed in areas downwind of the NTS in southern Nevada and Utah.

In summary, available radiological data suggest that the radioactivity reported at Yucca Mountain is relatively high because of high concentrations of naturally occurring radionuclides in the soil. No evidence of above-normal man-made radiation levels was found at Yucca Mountain. In fact, this study demonstrates that Yucca Mountain soil and biota contain lower concentrations of fallout radionuclides, such as ^{90}Sr and ^{137}Cs, than other areas in southern Nevada and Utah.

Analysis of the available data has identified several areas requiring further study. For soil programs, more samples taken at more frequent intervals are necessary for trending analysis. More importantly, data on the vertical distribution of radionuclides in soil must be acquired for dose assessment. For biota programs, which include vegetation and small mammals, more data are needed for statistical uncertainty analysis. It is also recommended that the critical organs or tissues of animal samples be analyzed separately in future studies.

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1.0 INTRODUCTION

The Radiological/Environmental Field Programs Department (R/EFPD) of the Department of Energy's (DOE) Civilian Radioactive Waste Management System, Management and Operating Contractor (CRWMS, M&O) is conducting a comprehensive radiological monitoring program of the environs at Yucca Mountain to determine the existing background radiation. This document describes the soil and biota monitoring activities performed from 1989 through 1995, and summarizes specific radionuclide concentrations in surface soil, vegetation, and small mammals at the project site.

1.1 Background

In 1982, the Nuclear Waste Policy Act (NWPA) was enacted into law. This federal law, which was amended in 1987, addresses the national issue of geologic disposal of high-level nuclear waste generated by commercial nuclear power plants, as well as defense programs during the past few decades. As required by the law, the DOE's Yucca Mountain Site Characterization Project (YMP) is conducting studies to determine if the site is suitable for the nation's first high-level nuclear waste repository.

1.2 Site Description

The area known as the "Yucca Mountain site" is situated on the southwestern boundary of the Nevada Test Site (NTS) and includes adjoining lands administered by the U.S. Air Force (USAF) and the Bureau of Land Management (BLM). The site is located in Nye County, Nevada, approximately 160 km (100 mi) northwest of the city of Las Vegas (DOE, 1994).

Located in the southern Great Basin of the Basin and Range Province, the regional setting of the Yucca Mountain site may be generally characterized as consisting of linear mountain ranges separated by intervening valleys with ephemeral streams and rivers. The area ranges from the Mojave Desert to the south (at elevations below 1,220 m or 4,000 ft) through a transition zone (sometimes called the transition desert) which extends beyond the northern boundary of the site to the cooler and wetter Great Basin Desert (elevations above 1,552 m or 5,000 ft). The soils are generally rocky or sandy and dry. The major topographical feature of the site is Yucca Mountain itself, a long north-to-south aligned volcanic ridge with an elevation of 1,494 m (4,900 ft). The mountain slopes steeply westward to Crater Flat (elevation 1,189 m or 3,900 ft) and gradually eastward to Jackass Flats (elevation 1,097 m or 3,600 ft). Five sizeable washes cross the site east of Yucca Mountain, the largest being Fortymile Wash which drains to the Amargosa Valley (DOE, 1994).

The vegetation at Yucca Mountain is dominated by Mojave desert plant communities below 1,220 m and by transitional plant communities of the Mojave and Great Basin desert floor at higher elevations. Detailed information on vegetation associations are described by Beatley (1976) and Collins and O'Farrell (1982). Despite the number of species found at the site, plant life is generally considered to be sparse, typical of any desert region.

Although as many as 46 mammalian species may occur in the vicinity of the site, the most abundant are rodents, i.e., Merriam's kangaroo rats (*Dipodomys merriami*) and long-tailed pocket mice (*Chaetodipus formosus*), followed by jackrabbits (*Lepus californicus*) and cottontails (*Sylvilagus audubonii*) (Collins et al., 1982). The kangaroo rat and pocket mouse are the two mammalian species sampled for the radiological programs.

1.3 Sources of Radionuclides at Yucca Mountain

Radionuclides in the environment of Yucca Mountain may be classified as either naturally occurring or man-made. Potential sources of man-made radionuclides include: direct releases from past NTS activities or resuspension from other NTS locations; releases from the commercial low-level radioactive waste disposal facility located near Beatty, Nevada; enhanced releases of natural radionuclides resulting from surface-disturbing activities; and worldwide fallout. The primary concern about these radionuclides in the Yucca Mountain environment is the potential for exposure to humans.

Naturally occurring radionuclides generally are either extraterrestrial in origin (i.e., radionuclides produced by cosmic radiation) or terrestrial (i.e., radionuclides present in the earth's crust). Cosmogenic radionuclides are produced in the atmosphere, biosphere and lithosphere by cosmic ray interactions in the atmosphere. The four most important cosmogenic radionuclides are tritium (^{3}H), beryllium-7 (^{7}Be), carbon-14 (^{14}C) and sodium-22 (^{22}Na), and the most important mechanism of human exposure is ingestion.

Terrestrial radionuclides are the very long-lived radionuclides that have existed within the earth since its formation several billion years ago and have not significantly decayed away (Eisenbud, 1987). The most significant of these radionuclides are potassium-40 (^{40}K, half-life of 1.28×10^{9} years), uranium-238 (^{238}U, half-life of 4.47×10^{9} years) and thorium-232 (^{232}Th, half-life of 1.41×10^{10} years). The progeny of the ^{238}U and ^{232}Th series also contribute to terrestrial radiation. Other radionuclides, such as those present in the uranium-235 (^{235}U, half-life of 7.04×10^{8} years) decay series, are less important from a dosimetry point of view, as they contribute little to the total radiation from the natural background (UNSCEAR, 1993).

Because the Yucca Mountain site extends onto the NTS, it is possible that some man-made radionuclides reported within the environs of Yucca Mountain resulted from NTS activities. These man-made radionuclides may also come from worldwide fallout. Although the origin of these nuclides can not be distinguished, the goals of this study are to characterize the existing radiological conditions, to quantify their impacts, if any, and to provide input data for other site characterization tasks.

Numerous fission products can be released into the atmosphere as a result of above-ground nuclear detonations or nuclear reactor accidents. Most of the fission products, however, are relatively short-lived, and are readily detectable in the environment only during and immediately following a detonation or accident. They do not contribute significantly to the dose received by humans (Eisenbud, 1987). For long-term dose assessment purposes, the most significant man-made radionuclides are strontium-90 (^{90}Sr, half-life of 28.5 years) and cesium-137 (^{137}Cs, half-life of 30.0 years) (NCRP 50, 1976; Romney et al., 1983). These nuclides have been closely monitored throughout the world in studies of the impact of atmospheric nuclear weapons testing on the environment. In addition, tritium (^{3}H, half-life of 12.35 years), plutonium-238 (^{238}Pu, half-life of 87.75 years), and plutonium-239 (^{239}Pu, half-life of 2.44 x 10^4 years) may be of concern, as these nuclides were routinely released into the environment as a result of past NTS operations (REECo, 1994).

1.4 Radionuclides of Interest

Radionuclides of interest for the site characterization project are selected based on several criteria (DOE, 1990):

- Significant radionuclides derived from various NTS activities.
- Radionuclides specifically addressed in the long-term release limits of the Environmental Protection Agency's (EPA) criteria for geologic disposal of high level nuclear waste (40 CFR Part 191, Appendix A).

- Radon and radon progeny products, per the 30 CFR Part 57 criteria for worker safety.

- Radionuclides with long half-lives or existing in significant quantities in spent fuel or high-level nuclear waste.

- Naturally occurring radionuclides.

The radionuclides of interest applicable to the soil and biota at the Yucca Mountain site are shown in Table 1.

Table 1. Radionuclides of interest for radiological studies on soil and biota.

	Sources					
		Spent Fuel (c)				
Radionuclides	NTS (a, d)	>0.01%, 10 yrs	>1%, 10,000 yrs	HLW (b)	Naturally Occurring	40CFR191
H-3	X					
Be-7					X	
C-14					X	X
K-40					X	
Fe-55		X				
Co-60		X		X		
Ni-59			X			
Ni-63		X		X		
Sr-89	O					
Sr-90	X	X		X		X
Zr-93				X		
Tc-99			X	X		X
Ru-106		X				
Sb-125		X				
Sn-126						X
I-129						X
I-131	O					
Cs-134		X		X		
Cs-135						X
Cs-137	X	X		X		X
Ce-144		X				
Pm-147		X				
Sm-151		X		X		
Eu-154		X				
Eu-155		X				
Pb-210					X	
Po-210					X	
Ra-226			X		X	X
Ra-228					X	
Th-228					X	
Th-230					X	X
Th-232					X	X
U-233					X	X
U-234			X		X	X
U-235					X	X
U-236						X
U-238	X	X	X		X	X
Np-237						X
Np-239			X			
Pu-238	X	X		X		X
Pu-239	X	X	X			X
Pu-240	X	X	X			X
Pu-241	X	X		X		
Pu-242				X		
Am-241	X	X				X
Am-243			X			
Cm-243		X				
Cm-244		X				

a: NTS=Nevada Test Site.
b: HLW=High Level Waste.
c: Percent of total activity per fuel element.
d: The "O" indicates these radionuclides are not associated with projected Project activities but may be associated with NTS activities and could interfere with projected monitoring activities.

2.0 DATA COLLECTION AND ANALYSIS

Radiological studies and monitoring in the vicinity of the NTS have been conducted since the first series of nuclear weapons testing was initiated. Most of these radiological studies were test-specific, and the available data provided very limited information about the southwest region of the NTS and the general Yucca Mountain area (CRWMS, M&O/SAIC, 1995).

The Radiological Monitoring Plan (RadMP) is the governing document for the radiological monitoring activities of the Yucca Mountain Site Characterization Project. The document specifies the applicable regulations, requirements and guidance that control the collection and use of radiological monitoring data during the various phases of the project (DOE, 1990). The radiological monitoring and data collection activities at Yucca Mountain are intended to characterize the existing radiological background.

In addition, the monitoring data may be useful in supporting the resolution of certain performance and design issues that address repository preclosure radiological safety requirements (DOE, 1988a; DOE, 1988b). The data may also provide valuable information for the preparation of the Environmental Impact Statement (EIS), as well as input data for biosphere dose assessment modeling.

2.1 Soil Sampling Programs

Soil provides an integrating medium that can account for contaminants released to the atmosphere, either directly in gaseous effluent, or indirectly from resuspension of on-site contamination. Hence, soil sampling and analysis may be used to evaluate long-term accumulation trends, and to estimate radionuclide inventory in the environment.

The YMP radiological monitoring grid was defined as a circular area with a radius of 84 km (approximately 50 mi), centered on the north portal of the Exploratory Studies Facility (ESF) with the coordinates of Easting 551135.7, Northing 4078351.6 on the Universal Transverse Mercator (UTM) Projection Grid Zone 11 of the North American continent, as shown in Figure 1. Two fields of interest were defined in this study area: near-field (NF), within a 16 km radius, and far-field (FF), between 16 and 84 km from the center of the radiological monitoring grid.

To date, soil sampling activities have been conducted only in the near-field area. Primary soil sampling locations were selected to coincide with air sampling stations, since the comparability of data may be important in achieving the objectives of the overall environmental sampling programs. Soil samples were also collected from indicator species sampling locations to characterize the conditions to which the indicator species were exposed. In addition, soils were sampled at locations where major surface-disturbing activities would be conducted to support possible decontamination and decommissioning activities.

At each designated sampling location, a Random Number Table (RNT) was used to determine sampling points. An effort was made to avoid areas of unusual wind or precipitation influence when selecting sampling spots. Unless otherwise specified, soil samples were taken from the top 2 cm of undisturbed ground by using a 25 x 25 x 2 cm surface scrape. Multiple sampling points were selected and a composite sample was generated for each location. The soil, once collected, was sieved, dried, and shipped to a qualified vendor for analysis of specific radionuclides. Meanwhile, a sample split was archived for possible use in evaluating anomalous results in the future.

A total of 98 surface soil samples were collected from 1991 through 1995, as shown in Figure 2. These sampling locations were located throughout the near-field to provide preliminary data on soil radioactivity at the Yucca Mountain site.

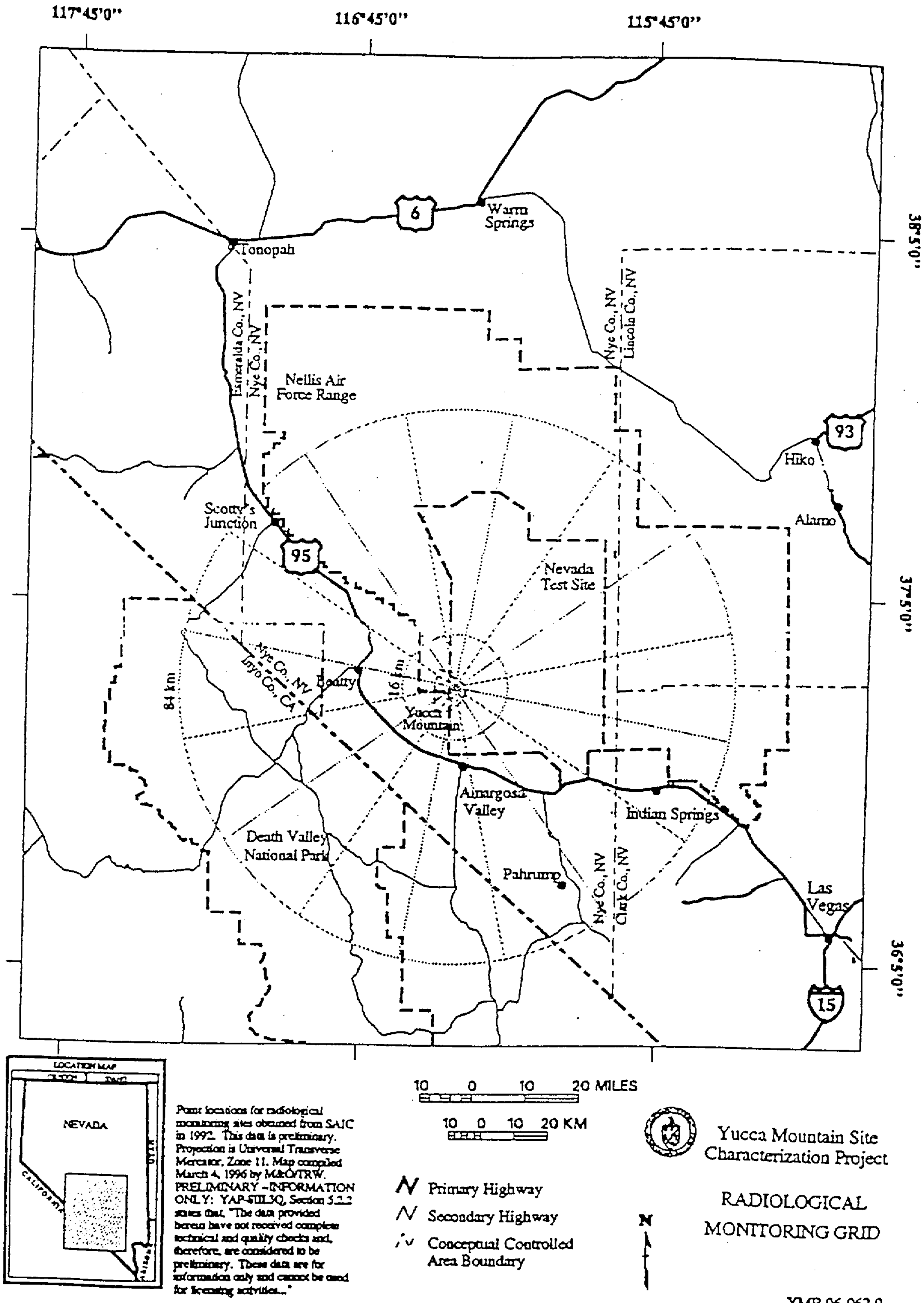
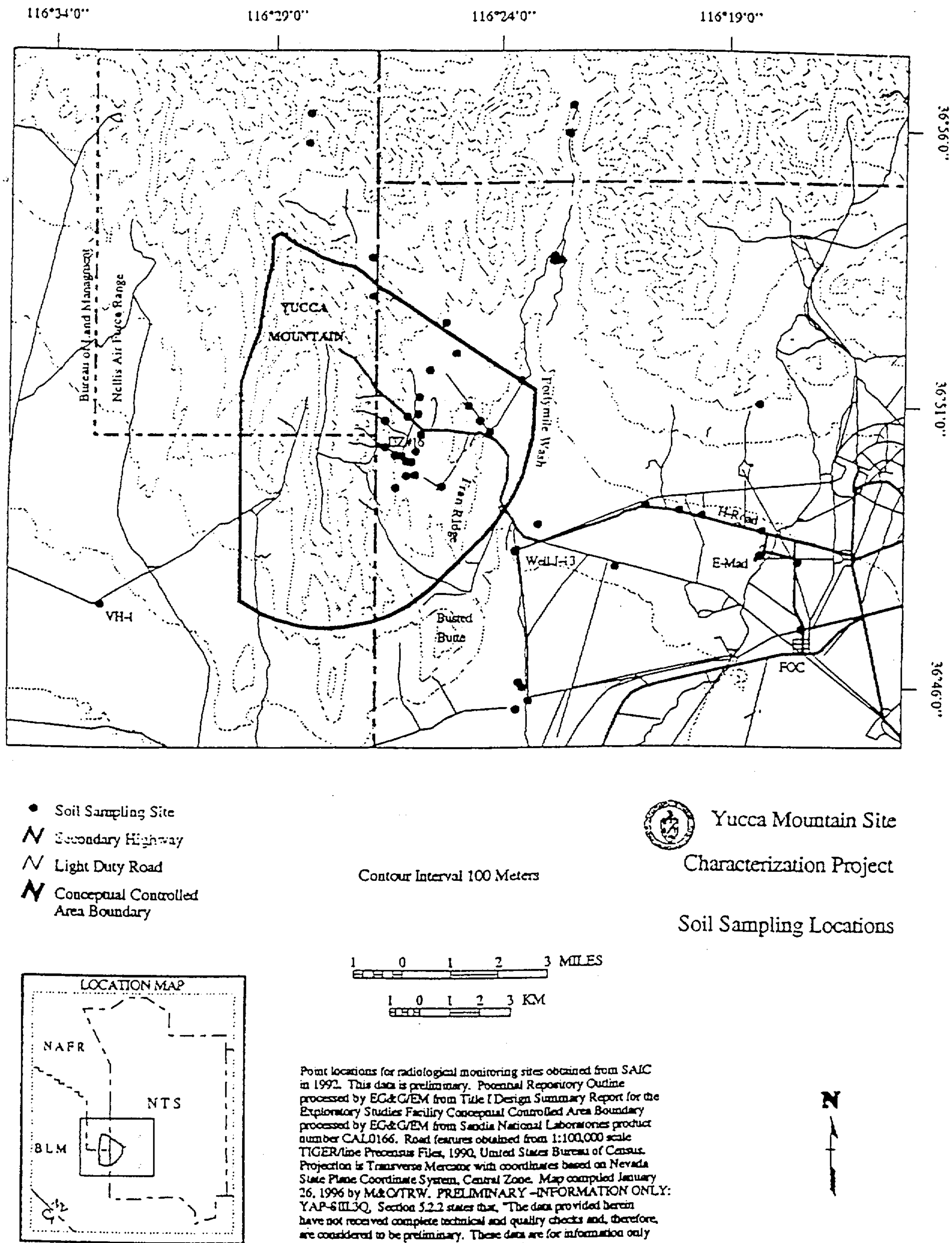


Fig. 1. Location of the Yucca Mountain Site.



Point locations for radiological monitoring sites obtained from SAIC in 1992. This data is preliminary. Potential Repository Outline processed by EG&G/EM from Title I Design Summary Report for the Exploratory Studies Facility Conceptual Controlled Area Boundary processed by EG&G/EM from Sandia National Laboratories product number CAL0166. Road features obtained from 1:100,000 scale TIGER/line Precensus Files, 1990, United States Bureau of Census. Projection is Transverse Mercator with coordinates based on Nevada State Plane Coordinate System, Central Zone. Map compiled January 26, 1996 by M&O/TRW. PRELIMINARY -INFORMATION ONLY: YAP-SIII.3Q, Section 5.2.2 states that, "The data provided herein have not received complete technical and quality checks and, therefore, are considered to be preliminary. These data are for information only and cannot be used for licensing activities..."

Fig. 2. Soil sampling locations.

2.2 Biota Sampling Programs

Biota samples, which included vegetation and small mammal samples, were collected by the Environmental Sciences Department (ESD), and transferred to the R/EFPD for analysis of various radionuclide concentrations. Both plant and animal specimens were used as indicator species to characterize existing radionuclide concentrations in the biosphere environment, as well as to monitor potential pathways for transport of radionuclides to humans.

Mule deer (*Odocoileus hemionus*) occur in low numbers in the vicinity of Yucca Mountain. Because mule deer are a game species and can be hunted on nearby public lands, they represent a potential ingestion pathway to humans. Deer migrate over an area much larger than Yucca Mountain, including portions of the NTS. Therefore, it is impossible to attribute any detectable levels of radionuclides in deer to the Yucca Mountain area. Instead, an indirect method using samples of deer forage species is being used to monitor radionuclide sources (EG&G/EM, 1994).

There are public cattle grazing allotments in the vicinity of the Yucca Mountain project site. Radionuclides present in plants may be consumed by cattle, and, in turn, enter into human food chains. This potential ingestion pathway is being monitored by analyzing specific radionuclide contents in cattle forage collected within the boundaries of these grazing allotments.

A total of 143 forage samples were collected from 39 sampling locations, as shown in Figure 3a, between 1990 and 1995. Specific radionuclide concentrations were analyzed by a qualified vendor.

Two species of small mammals, Merriam's kangaroo rats (*Dipodomys merriami*) and long-tailed pocket mice (*Chaetodipus formosus*), were collected and analyzed for specific radionuclide concentrations because of their generally limited movement

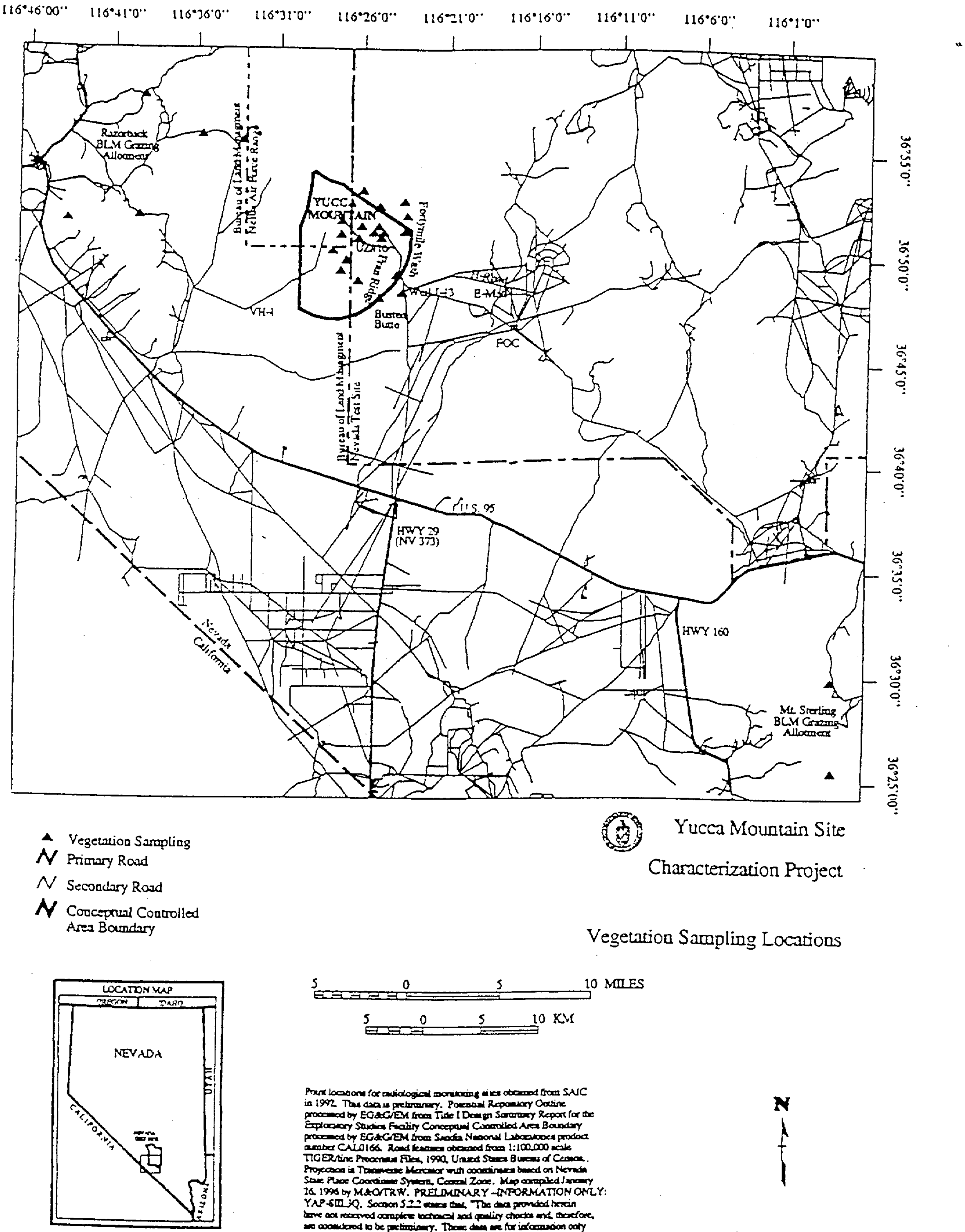


Fig. 3a. Vegetation sampling locations.

within the immediate area of a burrow (small home range), relatively short generation time, and high population densities. A total of 56 samples from 12 established locations, as shown in Figure 3b, were collected between 1989 and 1995. The intact animals were blended and analyzed for radionuclide concentrations. No differentiation was made for analysis between muscle, bone, and gastrointestinal (GI) tract tissues.

2.3 Radiochemical Analysis

Since environmental samples usually contain a very small quantity of radionuclides, detection limits must be taken into consideration when selecting analytical techniques, as well as when interpreting results. In order to positively detect a radionuclide, counting signals produced by the radionuclide must be intensive enough to be distinguished from the instrument background. The detection limit, often referred to as Minimum Detectable Activity (MDA) or Lower Limit of Detection (LLD), is defined as the smallest quantity of radioactivity in a sample that can be detected with some specified degree of confidence (usually 95%). Detection limits depend upon current radiation detector technology, as well as the laboratory procedures used to perform the measurement.

Radiochemical analysis for various radionuclides in soil, vegetation and small mammal samples were performed by a qualified vendor in accordance with approved analytical procedures (Teledyne, 1994). Specific activities for soil and vegetation samples were reported in pCi/gram dry weight, whereas results for animal samples were reported in pCi/gram ash weight. Decay corrections were not applied to any samples.

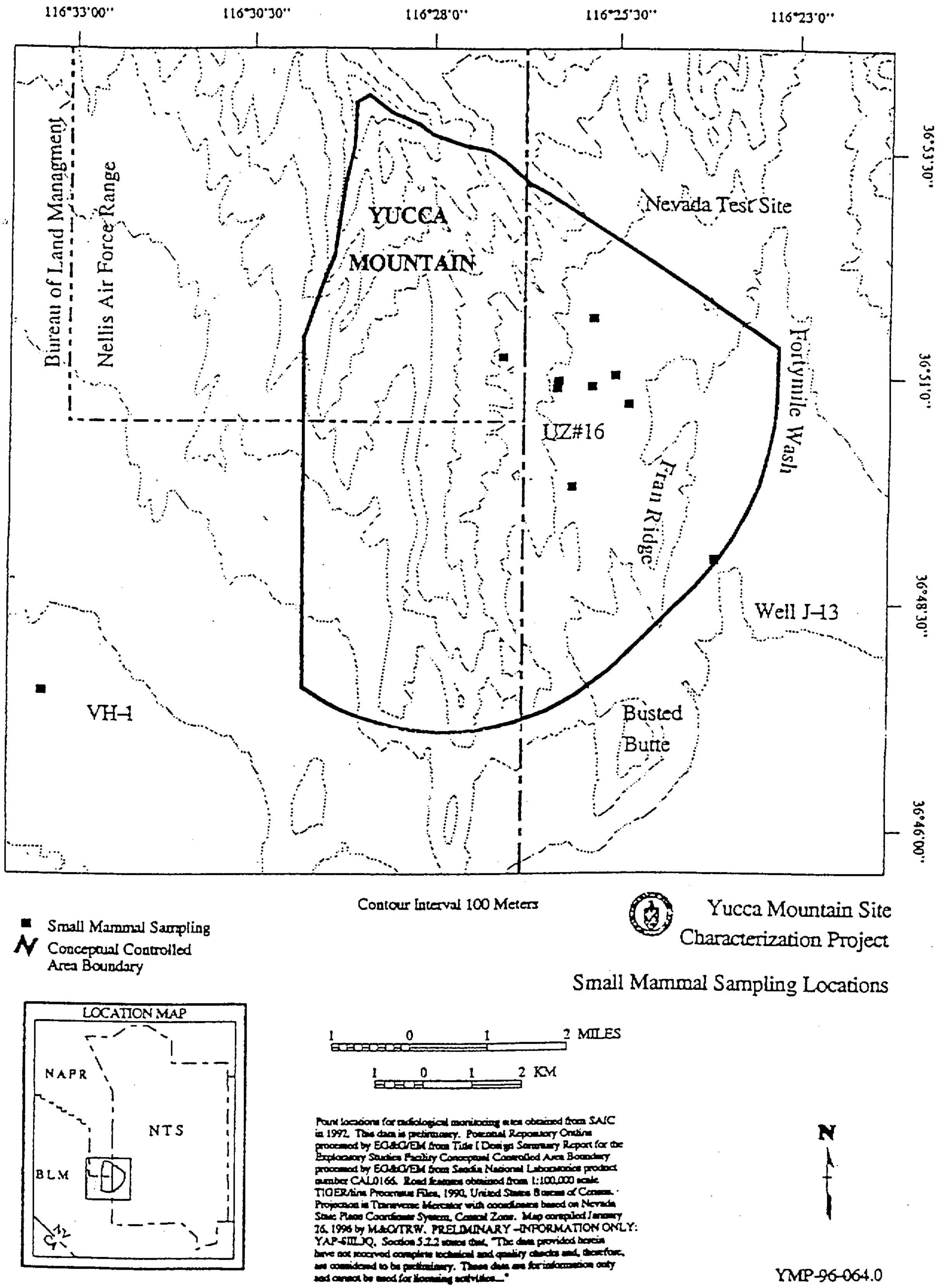


Fig. 3b. Small mammal sampling locations.

3.0 RADIONUCLIDES IN SOIL

Most of the positively identified radionuclides in Yucca Mountain soils were naturally occurring, which included: uranium-234 (^{234}U, half-life of 2.5 x 10^5 years), thorium-230 (^{230}Th, half-life of 8.0 x 10^4 years), radium-226 (^{226}Ra, half-life of 1,620 years), lead-210 (^{210}Pb, half-life of 22 years) and polonium-210 (^{210}Po, half-life of 138 days) from the ^{238}U decay series; radium-228 (^{228}Ra, half-life of 5.8 years) and thorium-228 (^{228}Th, half-life of 1.9 years) from the ^{232}Th series; and ^{40}K. Trace amounts of radionuclides associated with nuclear weapons testing and global fallout, such as ^{90}Sr, ^{137}Cs, cesium-134 (^{134}Cs, half-life of 2.06 years), europium-155 (^{155}Eu, half-life of 4.96 years), and ^{239}Pu, were also found in the soil samples.

3.1 Naturally Occurring Radionuclides

The significant, naturally occurring radionuclides, in terms of abundance and exposure to humans, are those radionuclides in the ^{238}U and ^{232}Th decay chains, and ^{40}K. ^{238}U, ^{232}Th and ^{40}K are primordial radionuclides which were produced when the universe was formed several billion years ago (Eisenbud, 1987). Because of their long half-lives, they have not completely decayed and still exist in the earth's crust in significant quantities. These radionuclides, along with their progeny, account for most of the background radiation to which humans are exposed. Other primordial radionuclides, such as the neptunium series, which originated from the parent element plutonium-241 (^{241}Pu, half-life of 14.4 years), have already decayed to the nearly stable nuclide bismuth-209 (^{209}Bi, half-life of 2 x 10^{18} years).

The amounts of these primordial radionuclides in the earth's crust are a complicated function of an area's geochemical history, and vary greatly between different geographical locations. Igneous rocks tend to contain somewhat higher radioactivity than sandstones and limestones, as shown in Table 2. The natural radioactivity of soil, usually a more direct determinant of radiation level in the ambient environment, depends upon not only the radioactivity of the parent rock but also upon the soil formation and transport processes that were involved. In the course of rock weathering and soil formation, chemical and biochemical interactions influence the distribution patterns of these primordial radionuclides, as well as of all the radionuclides created by the radioactive decay of these elements (NCRP 76, 1984; Myrick et al., 1983).

Table 2. Average radium, uranium, thorium and potassium contents in various rocks[a]

Type of rock	^{226}Ra (pCi/g)	^{238}U (pCi/g)	^{232}Th (pCi/g)	^{40}K (pCi/g)
Igneous	1.3	1.3	1.3	22
Sedimentary				
Sandstones	0.7	0.4	0.7	8.8
Shales	1.1	0.4	1.1	22
Limestones	0.4	0.4	0.1	2.2

a Adopted from UNSCEAR, 1958.

Table 3 summarizes the statistical data for the naturally occurring radionuclides in the surface soil at Yucca Mountain, and compares these data with published data from other areas around the world. At Yucca Mountain, ^{238}U and ^{232}Th concentrations in soil are relatively low. Their progeny, however, have much higher specific activities. The statistics also indicate that the specific activity of ^{40}K is exceptionally high at Yucca Mountain, compared to national and worldwide averages. The high natural radioactivity in soil reflects the fact that the underlying rock at Yucca Mountain, which is generally a type of igneous (volcanic tuff), is more radioactive. Also, the disequilibria between the parent radionuclides and their decay products imply the complexity of the soil formation and transport processes.

Table 3. Statistical data for and comparison of naturally occurring radionuclides in Yucca Mountain surface soils.

	Activities (pCi/g dry wt.)							
	^{238}U	^{226}Ra	^{210}Pb	^{210}Po	^{232}Th	^{228}Ra	^{228}Th	^{40}K
Yucca Mountain								
Average (1 SD)	0.10 (0.04)	1.75 (0.46)	1.27 (0.29)	1.09 (0.35)	0.52 (0.19)	1.90 (0.48)	1.79 (0.62)	28.48 (2.03)
Range	0.002 - 0.22	0.77 - 3.25	0.70 - 1.90	0.52 - 2.00	0.17 - 0.92	1.13 - 2.66	0.95 - 6.27	18.50 - 34.50
Skewness	0.16	-0.80	0.77	0.33	0.37	0.22	3.25	-1.03
Kurtosis	-0.07	1.50	-1.17	-1.20	-1.31	-1.65	23.60	6.11
Test for Normality								
Kolmogorov D	0.0694	0.054	0.1189	0.0854	0.0686	0.1203	0.1141	0.1228
Prob > D	> 0.15	> 0.15	> 0.15	> 0.15	> 0.15	< 0.0214	< 0.01	< 0.01
Distribution	Normal	Normal	Normal	Normal	Normal	----	Normal[a]	Normal[a]
Nevada[b]								
Average (1 SD)	1.3 (0.65)	1.5 (0.72)			1.5 (1.6)			
Typical Range	0.74-1.8	0.89 - 2.0			0.62 - 3.0			
United States[c]								
Average (1 SD)	1.0 (0.83)	1.1 (0.48)			0.98 (0.46)			10
Typical Range	0.12 - 3.8	0.23 - 4.2			0.10 - 3.4			2.7 - 18.9
Worldwide[d]								
Average (1 SD)	0.66	0.79			0.65			10
Typical Range	0.33 - 1.32	0.49 - 1.98			0.22 - 1.31			3.3 - 20

a. The null hypothesis (normal distribution) is not rejected if the one extreme value is excluded, as shown in Fig. 7(b) and 7(d), respectively.
b. Myrick et al., 1983.
c. UNSCEAR, 1988.
d. NCRP 50, 1976.

3.1.1 Uranium Series

The uranium series originate with ^{238}U, as shown in Figure 4. Among the radionuclides in the ^{238}U decay chain, ^{226}Ra and its progeny are responsible for a major fraction of the dose received by humans from naturally occurring internal emitters. Through alpha decay, ^{226}Ra becomes radon (^{222}Rn), an inert gas with a half-life of 3.8 days. The decay of radon is followed by a series of short-lived alpha and beta emitting progeny. After six decay steps, ^{210}Pb is produced, which has a half-life of 22 years. This nuclide decays through bismuth-210 (^{210}Bi) to produce ^{210}Po, an alpha-emitting nuclide with a half-life of 138 days, which decays to stable lead-206 (^{206}Pb). Since ^{226}Ra is an alpha emitter, it does not add directly to the gamma activity of the environment, but does so indirectly through its gamma-emitting descendants.

While radioactive equilibrium between ^{238}U and ^{226}Ra exists in many surface soils in the United States, large deviations from equilibrium are also observed due to the different geochemical properties of uranium and radium compounds (Myrick et al., 1983). Departure from equilibrium occurs even more readily for those ^{238}U decay products beyond ^{222}Rn because of the escape of gaseous radon from the soil matrix (NCRP 76, 1984).

A total of 98 near-field surface soil samples were collected and analyzed between 1991 and 1995. The average specific activities for ^{238}U and its major decay products, ^{226}Ra, ^{210}Pb and ^{210}Po, were 0.10 ± 0.04 (1 SD), 1.75 ± 0.46, 1.27 ± 0.29, and 1.09 ± 0.35 pCi/gram dry weight, respectively. Apparently, radioactive disequilibria in the uranium decay chain existed in the surface (top 2 cm) of Yucca Mountain soil, as the decay products, ^{226}Ra, ^{210}Po and ^{210}Pb, were present in concentrations one order of magnitude higher than their ascendent, ^{238}U. This enrichment is probably due to some very complex physical and chemical processes. The complexity of the redistribution mechanism is beyond the scope of this report. It is, however, very important to understand the equilibrium ratio in order to make the correct assumptions for dose assessment modeling.

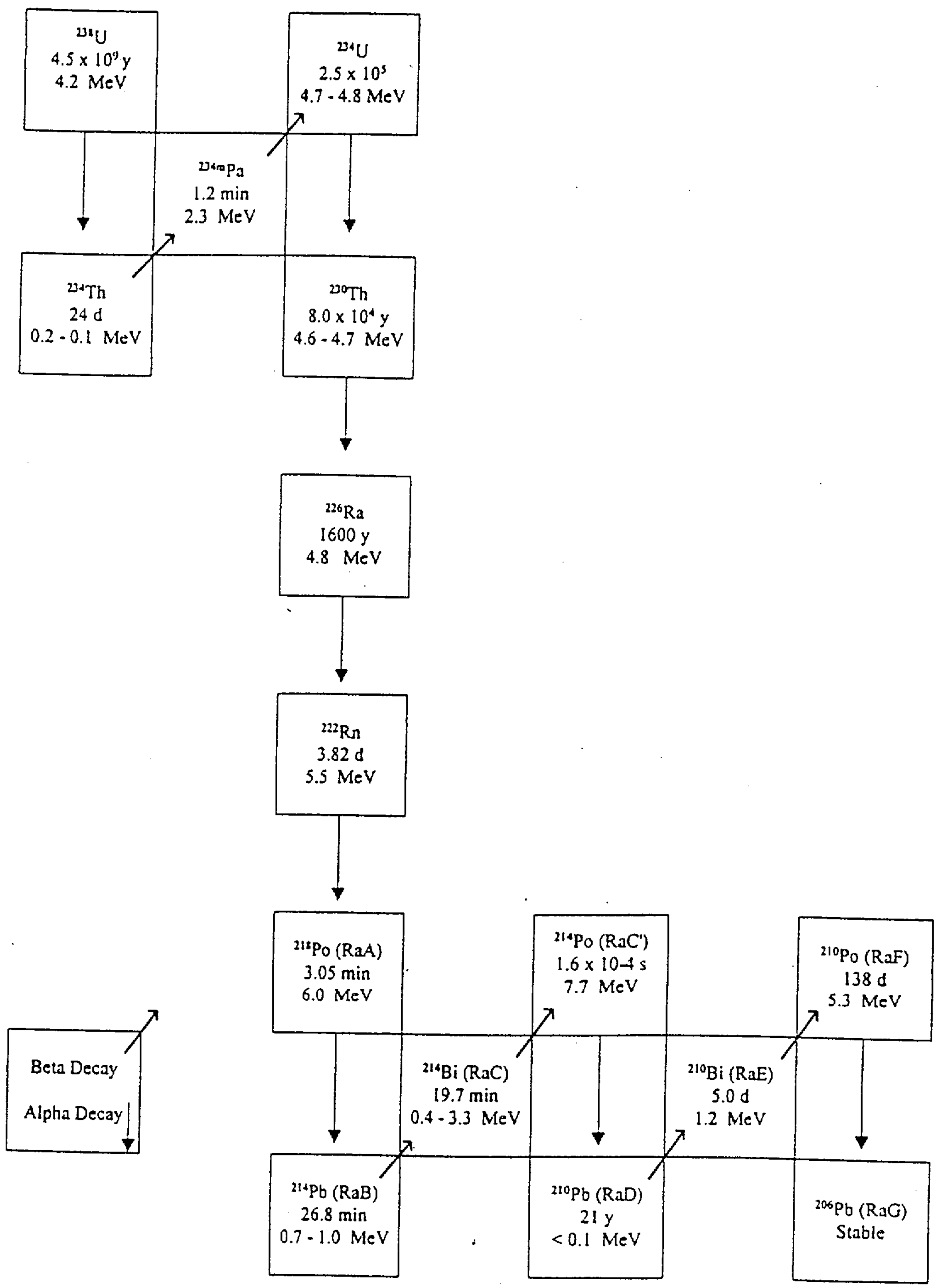


Fig. 4. Principal decay scheme of the uranium series.

Compared with literature values reported from other places around the world, as shown in Table 3, Yucca Mountain soils contain less ^{238}U. However, taking the disequilibrium factor into account, the overall radioactivity from the uranium series is at the high end of the worldwide distribution spectrum.

Figure 5 depicts the distributions of ^{238}U, ^{226}Ra, ^{210}Pb and ^{210}Po observed in Yucca Mountain soils. The bar charts show the distributions of the measurement data, whereas the bell-shaped curves are the hypothesized normal distribution curves constructed from the sample means and standard deviations. Each chart shows good agreement between the empirical data and the theoretically calculated normal distribution.

In addition, Kolmogorov's normality test (Stephens, 1974; SAS, 1993) was performed to test whether the data were from a normal distribution. The null hypothesis was that the data came from a normal distribution, and the p-value (Prob > D) was used to determine whether to reject the null hypothesis. The p-value, also referred to as the *probability value* or *observed significance level*, is the probability of obtaining a D statistic greater than the computed D statistic when the null hypothesis is true. The smaller the p-value, the stronger the evidence against the null hypothesis. The computed p-values for ^{238}U and its decay products, as shown in Table 3, are all larger than 0.15. Therefore, there was no reason to conclude that these data were not normally distributed.

3.1.2 Thorium Series

The thorium decay series start with ^{232}Th, as shown in Figure 6. The characteristics of the thorium series are different from those of the uranium series in a number of respects:

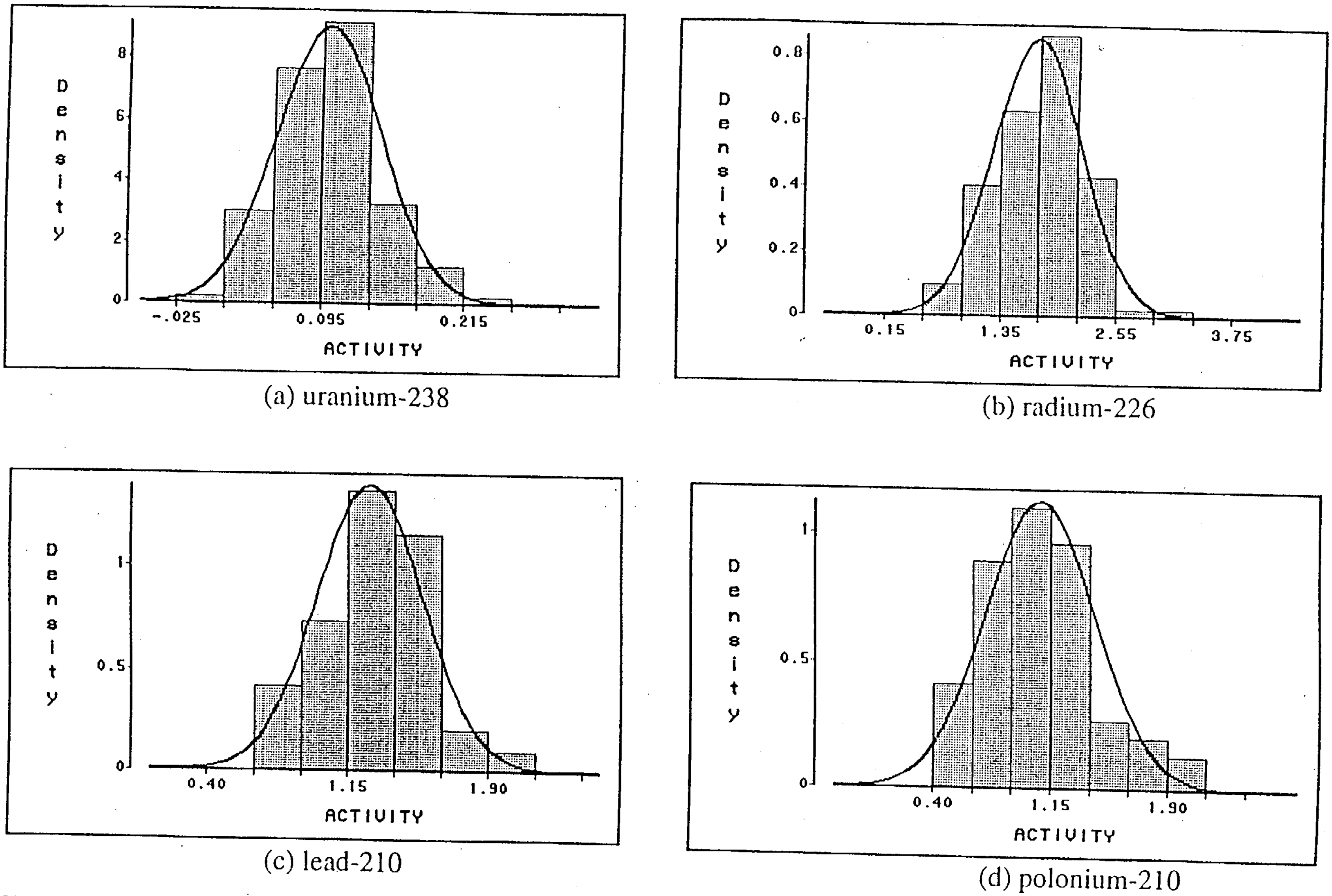


Fig. 5. Frequency distributions of specific soil activities (pCi/g dry wt.) of (a) uranium-238, (b) radium-226, (c) lead-210 and (d) polonium-210. The curve lines are normal distribution curves constructed from sample means and standard deviations.

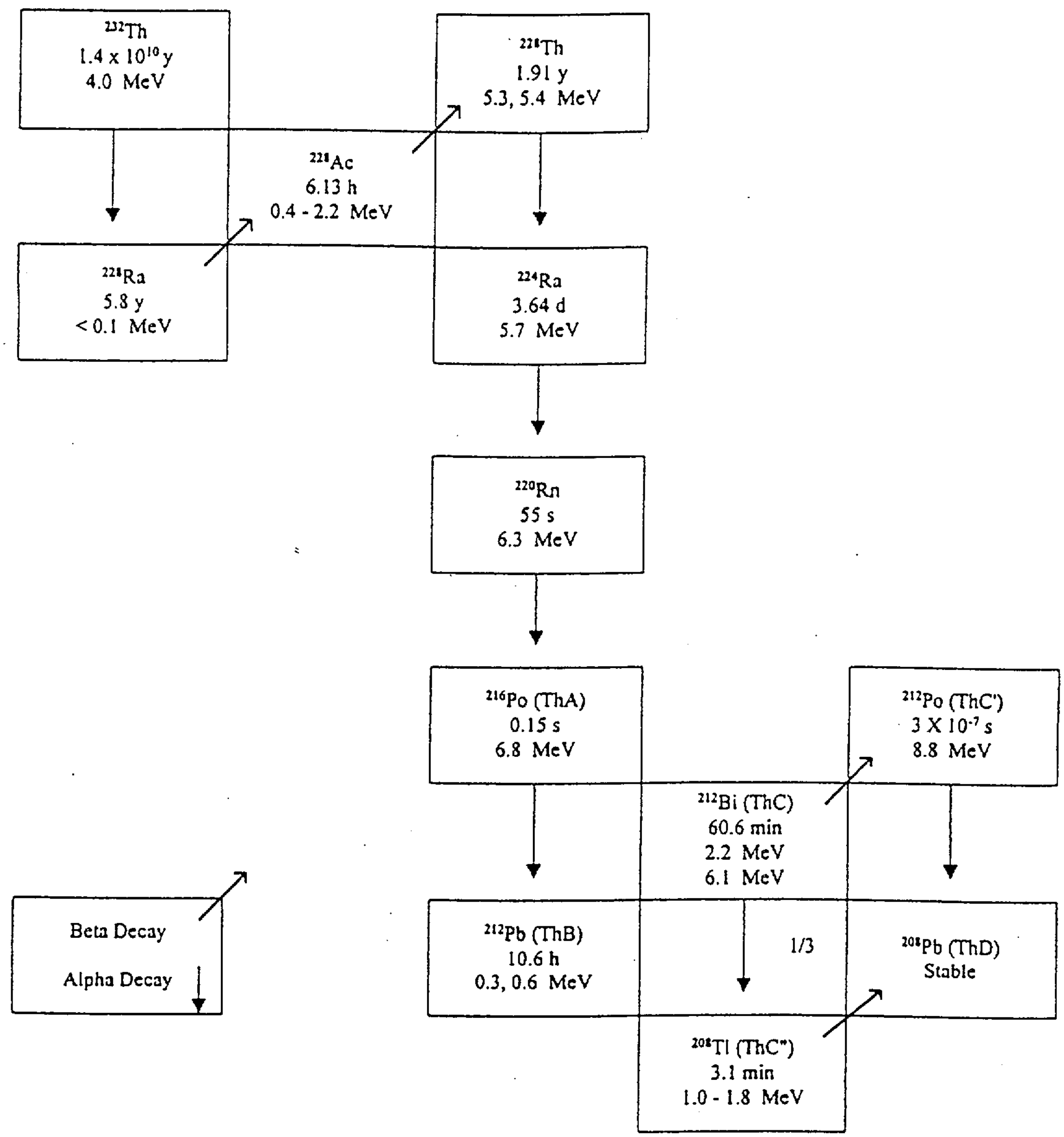
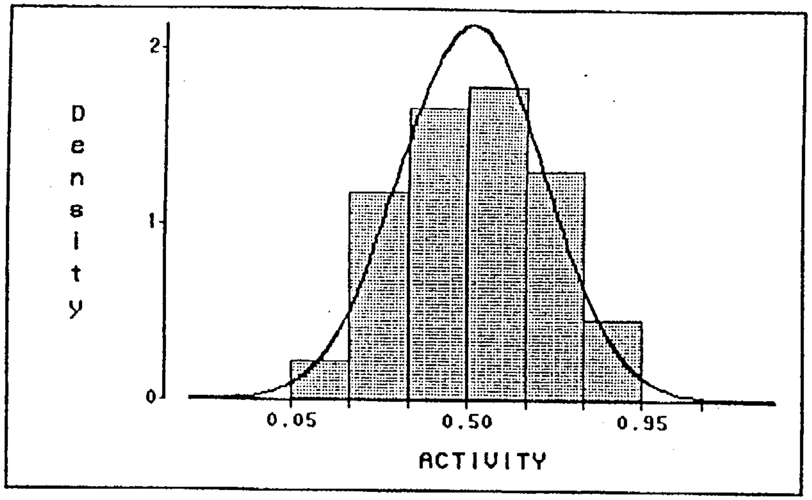


Fig. 6. Principal decay scheme of the thorium series.

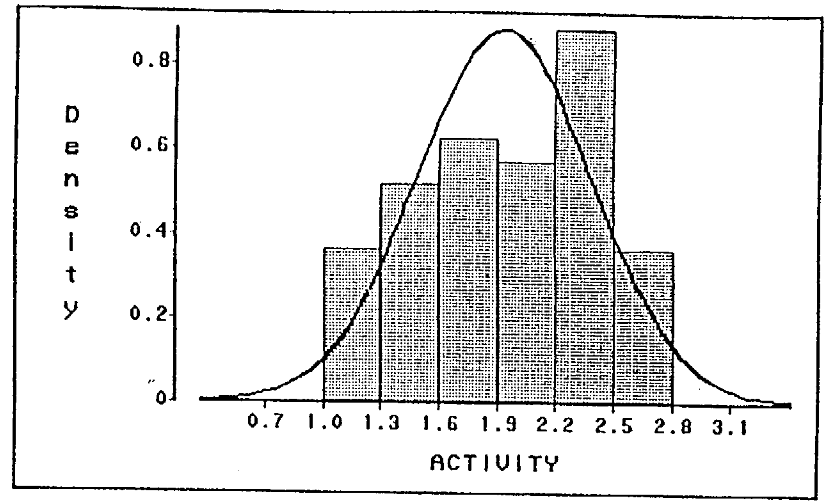
- ^{228}Ra has a much shorter half-life than ^{226}Ra (5.8 years compared to 1,620 years).
- ^{228}Ra is a beta emitter that decays to alpha-emitting ^{228}Th, with a half-life of 1.9 years. ^{228}Th, in turn, decays through a series of alpha emitters including the noble gas ^{220}Rn (thoron), which has a half-life of only 54 seconds, compared to 3.8 days for Rn-222 (radon). Because of its short half-life, thoron has less opportunity than radon to diffuse into the atmosphere from the matrix in which it is formed.
- In the ^{228}Ra chain, there is no long-lived "stopping" nuclide comparable to ^{210}Pb (half-life of 22 years). The longest-lived nuclide beyond ^{228}Th is ^{212}Pb, with a half-life of 10.6 hours. The dosimetry and radiochemistry of the thorium series tend to be complicated by these characteristics (Eisenbud, 1987).

Thorium, like uranium, exists in rocks and soils in various amounts. Igneous rocks contain higher concentrations of thorium than do limestones and sandstones, as shown in Table 2. Soils derived from igneous rocks tend to contain higher specific radioactivities. At Yucca Mountain, the average concentrations of ^{232}Th and its decay products, ^{228}Ra and ^{228}Th, were 0.52 ± 0.19 (1 SD), 1.90 ± 0.48, and 1.79 ± 0.62 pCi/gram dry weight, respectively. Radioactive disequilibria between ^{232}Th and its progeny were also observed in the surface soils at Yucca Mountain. The ^{228}Ra and ^{228}Th contents were three to four times higher than their originator, ^{232}Th.

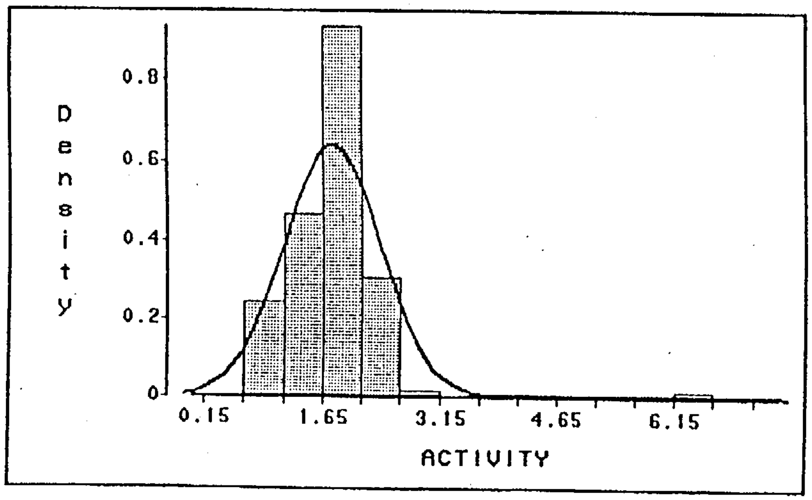
The ^{232}Th content in Yucca Mountain soils is relatively low compared to values reported from other areas around the world, as shown in Table 3. However, the specific activities of its progeny, ^{228}Ra and ^{228}Th, are much higher than that of ^{232}Th. The distributions of the ^{232}Th series are similar to those of the ^{238}U series, as shown in Figure 7. The normality test results using Kolmogorov's D statistics are listed in Table 3. The p-value (> 0.15) for ^{232}Th data shows that the data are normally



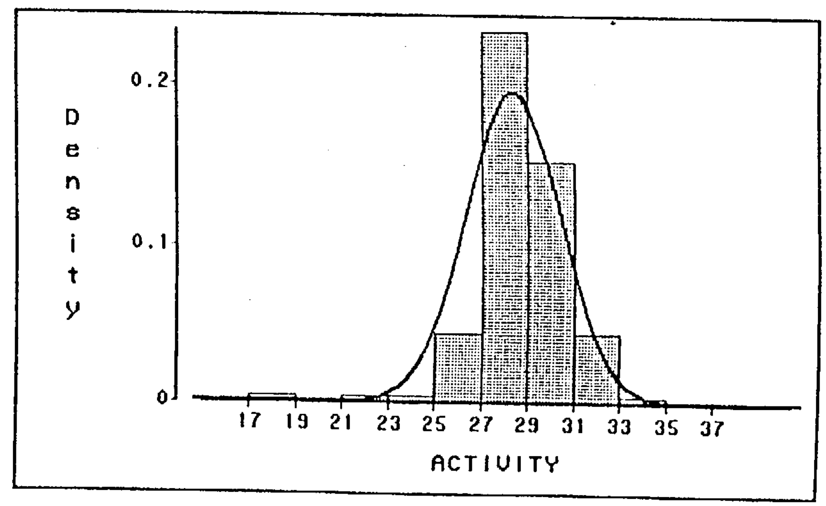
(a) thorium-232



(b) radium-228



(c) thorium-228



(d) potassium-40

Fig. 7. Frequency distributions of specific soil activities (pCi/g dry wt.) of (a) thorium-232, (b) radium-228, (c) thorium-228 and (d) potassium-40. The curve lines are normal distribution curves constructed from sample means and standard deviations.

distributed. Although the *p*-value for ^{228}Ra suggests that the data are not normally distributed, the evidence to reject the null hypothesis (i.e., normal distribution) is not strong, as indicated by the *p*-value of 0.0214. The weak evidence for rejecting the null hypothesis is also reflected in Figure 7, in which the empirical data do not show a significant departure from the hypothesized normal curve. It is clear that the data for ^{228}Th are not normally distributed, as the *p*-value is less than 0.01. However, if the one extreme data point (out of 98 total data points), as shown in Figure 7, is excluded from the normality test, the *p*-value would be 0.15. In other words, without the one outlier data point, the ^{228}Th data are normally distributed.

3.1.3 Potassium-40

Of the three naturally occurring potassium isotopes, only ^{40}K is radioactive. It is a beta and gamma emitter, and the relative abundance of ^{40}K in potassium is about 0.01%.

The average specific activity of ^{40}K in surface soils at Yucca Mountain was 28.48 ± 2.03 pCi/gram dry weight, as shown in Table 3. This value is substantially higher than those reported for other areas of the United States and around the world. This may be due to the fact that the underlying rock in Yucca Mountain is rich in potassium (DOE, 1988b). The high concentration of ^{40}K, in addition to its contribution to internal dose, is a major contributor to the ambient gamma radiation in the Yucca Mountain environment (see section 3.4 for details).

Although the normality test for ^{40}K showed strong evidence against the null hypothesis (i.e., normal distribution), the conclusion was different when one extreme data point (out of 98 total data points) was excluded from the test. Without the outlier, the ^{40}K data were normally distributed. Figure 7 illustrates the distribution of ^{40}K in Yucca Mountain soils. The extreme value on the far left side of the distribution has a value of 18.50 pCi/gram.

3.2 Man-made Radionuclides

3.2.1 Strontium-90

^{90}Sr has a half-life of 28 years, and is a chemical analogue of calcium. It is one of the significant radionuclides in fallout that delivers dose to humans through food contamination. Studies conducted shortly after World War II identified ^{90}Sr as the most hazardous radionuclide in fallout and concluded that there was a limit to the amount of ^{90}Sr that could be disseminated, above which bone cancer would be caused to develop in the world's population (Eisenbud, 1987).

As expected, small amounts of ^{90}Sr were found in surface soils at Yucca Mountain. The average concentration of ^{90}Sr was 0.13 pCi/gram, ranging from below the MDA to 1.10 pCi/gram. A total of 67 out of 98 results were above the MDA, which had an approximate value of 0.04 pCi/gram.

A survey was conducted at the NTS and its downwind areas in southern Nevada and Utah in 1980, and reported an average ^{90}Sr concentration in surface soil (top 2.5 cm) of 4.43 pCi/gram dry weight, with a range of 1.3 to 21.1 pCi/gram (Romney et al., 1983). The comparison, after making decay corrections, suggests that the concentration of ^{90}Sr in surface soils at Yucca Mountain soil is substantially lower than those in other parts of the NTS and downwind areas. However, a study conducted by the Desert Research Institute (DRI) in 1989 reported that the average ^{90}Sr concentration in surface soils in Area 25 of the NTS was 0.19 pCi/gram (DOE, 1989), very similar to that detected at Yucca Mountain after taking decay into account.

Although the data collected in this study do not provide any information about the vertical distribution of ^{90}Sr in soil, Romney's study found that ^{90}Sr remained primarily within the top 5-cm layer of undisturbed soil. Table 4 lists the statistical data for ^{90}Sr in Yucca Mountain surface soils, as well as the comparisons with published data.

Table 4. Statistical data for and comparison of man-made radionuclides in Yucca Mountain surface soils.

	Activities (pCi/g dry wt.)				
	^{90}Sr	^{137}Cs	^{134}Cs	^{155}Eu	^{239}Pu
Yucca Mountain					
Average	0.13	0.37	0.07	0.18	0.02
Median	0.10	0.36	0.08	0.19	0.01
Range	Below MDA - 1.10	Below MDA - 0.97	Below MDA - 0.13	Below MDA - 0.35	Below MDA - 0.14
MDA	0.04	0.08	0.04	0.13	0.01
Southern Nevada and Utah[a]					
Average	4.43	2.22			
Range	1.3 - 21.1	1.3 - 3.9			
NTS, Area 25[b]					
Average	0.19[c]	0.35			
Range		Below MDA - 0.64		Below MDA (< 0.38)	

a. Two sampling locations were within the NTS, and five were in the downwind direction in southern Nevada and Utah (Romney et al., 1983).
b. DOE, 1989.
c. Estimated from ^{90}Sr : ^{137}Cs = 0.55.

3.2.2 Cesium-137

^{137}Cs is another important fallout-derived nuclide in soil. It has a 30-year half-life, compared to 28 years for ^{90}Sr, and is produced somewhat more abundantly than ^{90}Sr in nuclear detonations (about 1.6 Ci ^{137}Cs per Ci of ^{90}Sr) (Eisenbud, 1987). Cesium is an analogue of potassium. When ingested by humans, about 80% is deposited in muscle and about 8% in bone (UNSCEAR, 1969).

Of a total of 98 near-field surface soil samples analyzed, 93 had specific activities above the MDA, which had an approximate value of 0.08 pCi/gram. The average concentration of ^{137}Cs in Yucca Mountain surface soils was 0.37 pCi/gram, ranging from below the MDA to 0.97 pCi/gram. This value is far below the 2.22 pCi/gram average concentration detected at the NTS and its downwind areas (Romney et al., 1983), but is similar to the level of 0.35 pCi/gram reported for Area 25 of the NTS (DOE, 1989). Table 4 lists the data for these comparisons.

3.2.3 Cesium-134

^{134}Cs is a beta and gamma emitter with a half-life of 2.06 years. It is an activation product produced in nuclear reactors. A unique characteristic of this nuclide is that it is not a naturally occurring radionuclide, nor is it associated with nuclear weapons testing activities. Usually, it is an indicator of a nuclear reactor accident.

At Yucca Mountain, 88 out of 98 samples had specific activities greater than the MDA. The approximate value of the MDA for the radioanalytical analysis was 0.045 pCi/gram, while the average concentration of ^{134}Cs was 0.071 pCi/gram, ranging from below the MDA to 0.13 pCi/gram. Since this nuclide is present in spent fuel, further study is needed to determine existing levels and the origin of this radionuclide at the site.

3.2.4 Europium-155

^{155}Eu is a fission product with a half-life of 4.96 years. It is a less important nuclide in terms of dose to humans since it is a low energy beta and gamma emitter with a relatively short half-life. This nuclide, however, is present in spent fuel, and the soil analysis indicates that an average ^{155}Eu concentration of 0.18 pCi/gram already exists in the Yucca Mountain surface soil, ranging from below the MDA (approximately 0.13 pCi/gram) to 0.35 pCi/gram. Of the 98 soil samples analyzed, 77 had specific activities greater than the detection limit.

^{155}Eu concentrations in surface soils in Area 25 of the NTS were measured by the DRI (DOE, 1989), as shown in Table 4. Because all of the DRI measurement results were below the detection limit, which was 0.38 pCi/gram at that time, the upper limit (<0.38) was reported. In comparison, the ^{155}Eu content of Yucca Mountain soils is similar to the level found in Area 25. Because of the low detection limit, many positive detections were reported among the Yucca Mountain soil samples, but all analytical results were less than 0.38 pCi/gram.

3.2.5 Plutonium-239

^{239}Pu (half-life of 2.41 x 10^4 years) is produced in thermal reactors by neutron irradiation of ^{238}U. It is also used in nuclear weapons and as fuel for fast reactors. Approximately 325 kCi of ^{239}Pu have been distributed worldwide from nuclear weapons testing (Hardy, 1974; Eisenbud, 1987). In addition to the worldwide sources, small amounts of ^{239}Pu are released into the environment as a result of routine NTS activities (REECo, 1994).

^{239}Pu poses very little external exposure threat to humans, as it emits very low energy beta and gamma radiation with small intensities. The major dosimetry concern regarding this nuclide is internal alpha exposure when inhaled or ingested.

Contaminated soil is a potential source of resuspension, as well as uptake by plants, which could introduce the nuclide into food chains.

Only trace amounts of ^{239}Pu were detected in Yucca Mountain soils. The average concentration was 0.02 pCi/gram, ranging from below the MDA to 0.14 pCi/gram. Of the 98 near-field soil samples analyzed for ^{239}Pu, 57 yielded results above the MDA (approximately 0.01 pCi/gram).

3.3 Uncertainty Analysis

The uncertainty reported with each individual analytical result only accounts for the counting error. Counting error, which arises from the random nature of radioactive decay, is not the only source of uncertainty in the analytical result. Every step, from sample collection, handling, and preparation, to counting, may introduce error or uncertainty into the final result. In order to obtain an estimate of the overall uncertainty for the radionuclide concentrations reported in this study, duplicate samples were analyzed and the difference between the duplicates was reviewed.

Ten soil samples were collected from a 60-ft^2 area at a near-field location. These samples were collected, processed, and analyzed under the same procedures, but treated separately. It was expected that the radionuclides in such a small area would be uniformly distributed. Therefore, any differences in analytical results were attributed to the overall uncertainty.

Table 5 summarizes the uncertainty for the radionuclides analyzed. The mean value, μ, is the average concentration for a radionuclide, and σ is the corresponding standard deviation. The coefficient of variation (c.v.), σ/μ, expressed as a percentage, is an indicator of the overall relative error or uncertainty for the reported analytical result.

Table 5. Uncertainty analysis results.

Nuclide	Average, pCi/gram μ	Standard Deviation σ	Coefficient of Variation(c.v.) σ/μ
Ag-110m	-1.39E-04	1.23E-02	8846.0%
Am-241	5.60E-03	4.13E-03	73.8%
Be-7	4.67E-02	6.60E-02	141.2%
C-14	-1.70E-01	2.25E-01	132.1%
Ce-141	2.06E-03	1.08E-02	524.1%
Ce-144	-9.66E-02	6.52E-02	67.5%
Co-57	-1.13E-02	5.72E-03	50.7%
Co-58	-3.18E-03	9.16E-03	287.8%
Co-60	2.16E-04	1.47E-02	6811.5%
Cr-51	-1.48E-01	7.44E-02	50.4%
Cs-134	3.79E-02	1.22E-02	32.3%
Cs-137	1.04E-01	7.25E-02	69.6%
Eu-152	-5.12E-01	8.56E-02	16.7%
Eu-154	-1.77E-02	2.78E-02	157.1%
Eu-155	1.03E-01	4.53E-02	43.8%
Fe-59	-1.68E-03	3.26E-02	1939.4%
I-129	-3.23E-02	2.87E-02	88.9%
I-131	-2.04E-03	1.33E-02	653.9%
K-40	2.82E+01	1.79E+00	6.4%
Mn-54	8.62E-03	6.84E-03	79.4%
Mo-99	4.55E-02	3.84E-02	84.4%
Nb-95	1.74E-02	1.32E-02	75.7%
Np-237	2.07E-03	2.74E-03	132.6%
Pu-238	5.11E-03	8.70E-03	170.2%
Pu-239	3.04E-03	2.81E-03	92.5%
Pu-241	1.00E+00	7.24E-01	72.0%
Ra-226	1.14E+00	3.15E-01	27.5%
Ra-228	1.30E+00	8.26E-02	6.4%
Ru-103	-4.51E-03	5.58E-03	123.9%
Ru-106	4.37E-02	8.80E-02	201.1%
Sb-124	1.56E-03	1.30E-02	834.2%
Sb-125	3.07E-03	1.66E-02	541.8%
Sn-126	1.96E-03	7.76E-03	395.6%
Sr-90	1.40E-02	4.43E-02	315.9%
Tc-99	-6.72E-02	2.03E-01	302.9%
Th-228	1.07E+00	8.14E-02	7.6%
U-234	6.41E-02	1.64E-02	25.6%
U-235	2.66E-03	4.05E-03	152.2%
U-238	6.11E-02	2.65E-02	43.4%
Zn-65	2.20E-02	4.74E-02	215.7%
Zr-95	1.87E-02	2.65E-02	141.6%

Generally, when radioactivity of a sample is low, counting statistics are the predominant contributor to the overall uncertainty. In contrast, when a sample is more radioactive, counting error is reduced dramatically, and the errors introduced by other sources, such as sample collection and processing, become more significant to the overall uncertainty.

The 6.4% coefficient of variation for ^{40}K, the most abundant radionuclide in Yucca Mountain soils, indicated very good reproducibility. In other words, good quality control was practiced during the entire process of sample collection and analysis. Other naturally occurring radionuclides, ^{238}U, ^{232}Th and their decay products, had fairly good reproducibility because of their relative abundance in the soil and good quality control during the analysis. The coefficients of variation for ^{238}U, ^{234}U, ^{226}Ra, ^{228}Th, and ^{228}Ra were 43.4%, 25.6%, 27.5%, 7.6%, and 6.4%, respectively. The man-made radionuclides, ^{134}Cs, ^{137}Cs, and ^{155}Eu, were also repeatedly detected in this study. Their coefficients of variation were 32.3%, 69.6% and 43.8%, respectively. Other radionuclides, however, had enormous coefficients of variation or uncertainties, which again indicated that the quantity of these nuclides in the soil was too small to be reliably detected.

3.4 External Exposure Dose Assessment

3.4.1 Calculation of Ambient Gamma Radiation from Soil Radioactivity

External exposure from radionuclides in the soil and radionuclides deposited on the ground is one of the major pathways by which the human body is irradiated in the biosphere environment. Gamma radiation is the only concern in this pathway since other types of radiation, such as alpha and beta, can not penetrate far enough through soil, the soil-air interface, or air to enter the human body.

Models and databases for estimating distributions of radioactivity in soil and their associated external doses above ground have been presented in the literature (Beck, 1972; Kocher, 1985), and are widely used in environmental dose assessment. Theoretically, the gamma dose rate in air above ground can be calculated by the following general equation:

$$H(t) = \sum (\chi_i(t) * \mathrm{DCF}_i), \qquad (1)$$

where $H(t)$ is the external dose rate at time t; $\chi_i(t)$ is the source concentration of the ith photon-emitting radionuclide at time t; and DCF_i is the dose rate conversion factor, or dose rate factor, for the ith nuclide. The DCF is defined as the dose rate per unit source concentration in soil, which depends on the distribution of nuclides in soil and the energy of the photons emitted by the nuclide. For radionuclides deposited on the ground surface, the DCF depends on the height of the receptor location above the ground. However, for radionuclides in soil, the DCF is usually insensitive to the height of the receptor location above ground for heights of about 10 m or less (Beck, 1968). This is because air has little shielding effect on gamma radiation if the distance is short, but soil, on the other hand, may significantly block out gamma radiation emitted from a source underneath the ground surface. Studies show that sources more than 150 cm below the ground surface contribute little to the dose rate in air. It is usually assumed that Equation (1) is used to calculate the dose rate at 1 m above ground.

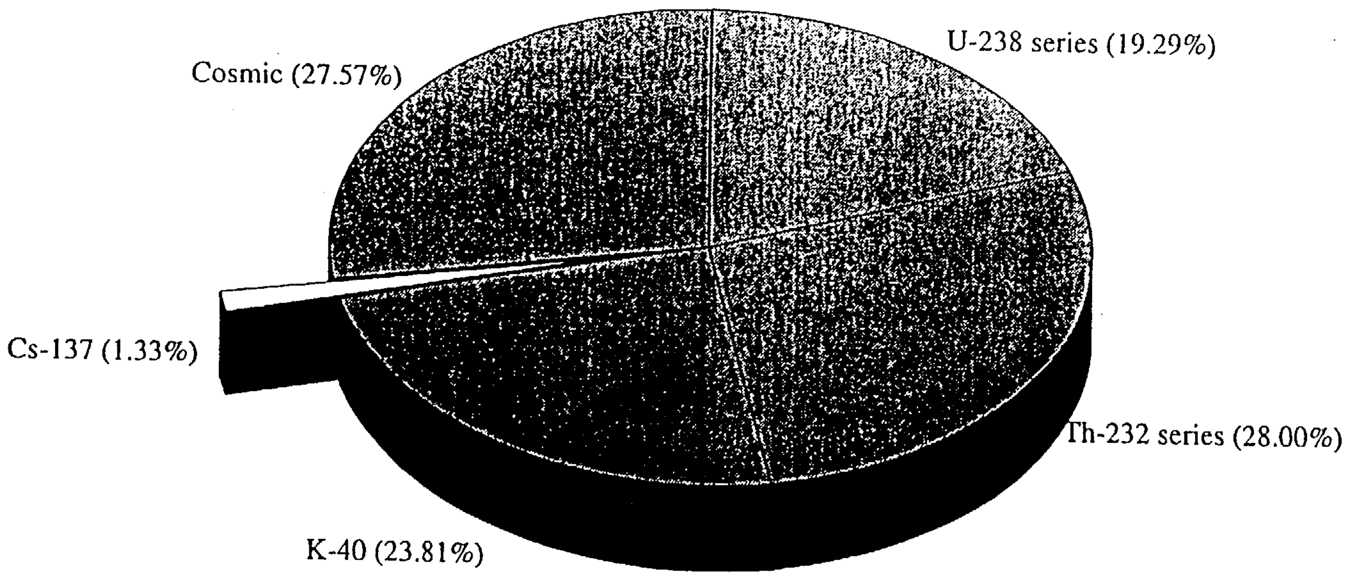
Both naturally occurring and man-made radionuclides are present in the environment at Yucca Mountain. The distribution of these two categories of nuclides, however, could be quite different, thus affecting their contributions to the ambient gamma radiation. Previous study showed that in undisturbed areas, the naturally occurring radionuclides, ^{238}U, ^{232}Th and their decay products, and ^{40}K, are uniformly distributed such that infinite depth and lateral extent exposure geometry can be assumed.

However, the man-made radionuclides from fallout or redeposition from resuspension are exponentially decreased with depth (Beck, 1968). Although these assumptions have been generally well accepted for environmental dose assessment, no site-specific data relative to the vertical distribution of radionuclides in soil were collected. These assumptions are therefore subject to further verifications.

The DCFs used in this report were provided in the RESRAD User's Manual (ANL, 1993). RESRAD is an environmental dose assessment computer code for implementing the DOE's residual radioactive material guidelines, which are incorporated into DOE Order 4500.5 and the proposed 10 CFR 834. The algorithm used for calculating the DCFs in RESRAD was originally developed by Kocher and Sjoreen (1985) and Chen (1991).

Figure 8 reveals the components of the total ambient gamma exposure at Yucca Mountain. The terrestrial portions of the gamma exposure are estimated on the basis of underlying soil radioactivity; cosmic radiation is estimated on the basis of elevation of the sampling locations (UNSCEAR, 1993). It is noted that approximately 99% of the gamma exposure is attributed to the natural sources, and the man-made source ^{137}Cs accounts for about 1% of the gamma radiation at Yucca Mountain.

Ambient gamma radiation at Yucca Mountain is relatively high compared to national and worldwide averages, as shown in Table 6. The high gamma exposure is partly due to the high elevation of the site, but more significantly, to the high primordial radioactivity in Yucca Mountain soils. The man-made source, ^{137}Cs from fallout, contributes little to the gamma background at the site.



Total = 16.7 urem/hr (146.2 mrem/yr)

Fig. 8. Components of ambient gamma exposure at Yucca Mountain, Nevada.

Table 6. Estimated annual external gamma dose rates from natural sources.

Source of Irradiation	Dose Rate, mrem/year: Yucca Mountain		Dose Rate, mrem/year: United States	Dose Rate, mrem/year: Worldwide Normal Background Areas[c]	
Cosmic rays	40.1		27[a]	35.5 (30.1)	
Ionizing component		31.6			30 (28)
Neutron component		8.5			5.5 (2.1)
Cosmogenic radionuclides					
Primordial radionuclides					
K-40	34.8		13.1[b]	15 (12)	
Rb-87					
U-238 series:	28.2		15.8[b]	10 (9)	
U-238 → U-234		0.01			
Th-230					
Ra-226		28.18			
Rn-222 → Po-214					
Pb-210 → Po-210		0.01			
Th-232 series:	40.9		19.3[b]	16 (14)	
Th-232					
Th-228 → Ra-228		16.15			
Th-228 → Ra-224		24.78			
Rn-220 → Tl-208					
Total (rounded)	144		75	80 (65)	

a. Source: BEIR V, 1990.
b. UNSCEAR, 1993.
c. Source: UNSCEAR, 1982; UNSCEAR, 1988. Estimates from UNSCEAR 1982 report are given in parentheses.

3.4.2 Verification of Dose Calculation

To ensure the validity of the dose calculation, the theoretical method was compared with the experimental results. Two Pressurized Ionization Chambers (PICs) have been installed at the near-field locations, NF6 and NF87, to continuously measure gamma exposure rates since 1992. Exposure rates measured by the PICs confirm that the theoretical calculations were in good agreement with the empirical data, as shown in Table 7. Overall, the difference between the calculation and the measurement was about 6%.

Table 7. Comparison between calculated and measured exposure rates at two near-field locations.

Location	Average Exposure Rate, μrem/hr	
	Theoretically Calculated	Measured by PIC
NF6	18.2	18.6 ± 0.32 (1 SD)
NF87	15.3	17.0 ± 0.46 (1 SD)

4.0 RADIONUCLIDES IN BIOTA

4.1 Radionuclides in Vegetation

Soil nourishes the terrestrial ecosystem. Radionuclides in soil can be transported to plants by root uptake or through direct external foliar deposition, and, in turn, enter into food chains.

Mule deer have been observed in the vicinity of Yucca Mountain. Since mule deer are a game species, the pathway, soil → deer forage → deer, can be a potential exposure pathway to human beings. Therefore, monitoring radionuclide contents in deer forage provides important data for understanding this exposure pathway. A total of 143 deer forage samples were collected from 32 sampling locations in the near-field between 1990 and 1995.

In addition to deer, cattle graze on public grazing allotments near the Yucca Mountain project site. Radionuclides in plants consumed by cattle can also enter into the human food chain. Therefore, radionuclide levels in forage are important input data for assessing exposure to humans through ingestion. A total of seven cattle forage sampling locations were established in 1993, five of them in the Razorback grazing allotment and two in the Mt. Sterling allotment, and 14 samples were collected and analyzed. The Razorback allotment, which is the closest allotment to Yucca Mountain, is located 12 to 28 km northwest of the ESF. The Mt. Sterling allotment is 52 to 68 km southeast of the ESF. Most of the cattle forage samples were collected in the far-field areas.

4.1.1 Strontium-90

Strontium is a chemical analogue of calcium. It becomes part of the pool of calcium in the biosphere once it is generated, and is a major part of the total radioactive dose to bone and bone-marrow from world-wide fallout. The ^{90}Sr content of plants can be due either to direct uptake from soil or to foliar deposition. No effort was made to differentiate between the two transport mechanisms in this study, since the forage will be used as an indicator for the potential ingestion pathway, soil → forage → deer or cattle → humans.

As shown in Table 8, the average ^{90}Sr concentration in deer forage at Yucca Mountain was found to be 0.04 pCi/gram dry weight, ranging from below the MDA (approximately 0.05 pCi/gram) to 0.94 pCi/gram. Of the 143 deer forage samples analyzed, only about one fifth of the samples contained ^{90}Sr levels higher than the MDA. This average value was much lower than the results of the survey conducted by Romney in southern Nevada and Utah in 1980 (Romney et al., 1983), in which an average concentration of 0.16 pCi/gram dry weight was reported. After decay correction, this value would be 0.12 pCi/gram by 1993, the midpoint of our study period.

Cattle forage had ^{90}Sr contents similar to those of deer forage. The average value was 0.03 pCi/gram, ranging from below the MDA to 0.09 pCi/gram dry weight. The Student's t-test indicated that there was no significant difference between the data for deer and cattle forage. The Student's t-test also suggested that there was no significant difference in ^{90}Sr levels in plants between near-field and far-field locations.

Soil-to-plant transfer coefficient, or soil-to-plant concentration ratio (CR), is a parameter which projects how a radionuclide migrates in the biosphere environment. As its name implies, this parameter is defined as the ratio of radionuclide concentration in plants to the radionuclide concentration in soils. It is intended to reflect only plant uptake from soil via roots, although the effects of deposition of nuclides on plant surfaces following fallout or resuspension from soil may also contribute to the experimental values (NCRP 76, 1984).

At Yucca Mountain, the soil-to-plant concentration ratio for ^{90}Sr was estimated to be 0.31, which falls within the reported range, 0.12 to 23, in NCRP 76 (1984). Since no far-field soil data were collected, soil-to-plant ratio was estimated for the near-field only.

Table 8. Comparison of ^{90}Sr concentrations in forage at Yucca Mountain with those at the NTS and downwind areas.

	YMP Study		NTS and Downwind[a]
Activity, pCi/g dry wt.	Deer Forage	Cattle Forage	Deer Forage
Average	0.04	0.03	0.16
Median	0.02	0.03	0.10
Range	BDL[b] - 0.94	BDL - 0.09	0.05 - 0.3
MDA	0.05	0.05	----

a. NTS and downwind areas in southern Nevada and Utah (Romney et al., 1983).
b. Below detection limit.

4.1.2 Cesium-137

Unlike strontium, cesium is so tightly bound by soil that root uptake is slight, and foliar absorption is therefore the main portal of entry of ^{137}Cs to the food chains (Eisenbud, 1987). Deer forage samples collected at Yucca Mountain contained very small amounts of ^{137}Cs, as shown in Table 9. A total of 143 samples were collected and analyzed, and less than 10% of the samples yielded results greater than the detection limit (approximately 0.04 pCi/gram). The average concentration was 0.014 pCi/gram dry weight, and the highest concentration was 0.087 pCi/gram. This average was also lower than the results of the survey conducted by Romney in southern Nevada and Utah in 1980, in which an average of 0.046 pCi/gram was reported (Romney et al., 1983). After decay correction, this value would be 0.033 pCi/gram by 1993, the midpoint of our study period.

Similarly, the ^{137}Cs content of cattle forage samples was very low. The average concentration of ^{137}Cs was 0.019 pCi/gram, ranging from below the MDA to 0.066 pCi/gram. The Student's *t*-test also confirmed that there was no significant difference in ^{137}Cs levels in plants between the near-field and far-field.

Cesium is a congener of potassium. Previous studies have shown that the uptake of cesium from soil is inversely proportional to the potassium content in soil (NCRP 76, 1984). Because Yucca Mountain soils are high in potassium and low in ^{137}Cs, as reported in previous sections of this report, it was not surprising to detect low ^{137}Cs concentrations in plants.

Table 9. Comparison of ^{137}Cs concentrations in forage at Yucca Mountain with those at the NTS and downwind areas.

	YMP Study		NTS and Downwind[a]
Activity, pCi/g dry wt.	Deer Forage	Cattle Forage	Deer Forage
Average	0.014	0.019	0.046
Median	0.011	0.017	0.040
Range	BDL[b] - 0.087	BDL - 0.066	0.02 - 0.06
MDA	0.04	0.04	----

a. NTS and downwind areas in southern Nevada and Utah (Romney et al., 1983).
b. Below detection limit.

The soil-to-plant transfer ratio for ^{137}Cs was estimated to be 0.038, which falls into the range of 1.4×10^{-3} to 5.7×10^{-1} reported in NCRP 76 (1984). It is noted that the transfer ratio for ^{137}Cs is about one order of magnitude smaller than that for ^{90}Sr.

4.1.3 Plutonium-239

A total of 143 deer forage samples were analyzed for ^{239}Pu. Less than 10% of the samples yielded results greater than the detection limit, which had an approximate value of 0.02 pCi/gram for the analysis. The average concentration of ^{239}Pu in forage was 0.005 pCi/gram dry weight, ranging from below the MDA to 0.087 pCi/gram.

Cattle forage samples, collected in the far-field, contained slightly more ^{239}Pu than deer forage samples collected in the near-field, as shown in Table 10. The difference, however, was not statistically significant.

The soil-to-plant transfer ratio for ^{239}Pu was estimated to be 0.25, much higher than the range of 9.6×10^{-6} to 8.5×10^{-4} reported in NCRP 76 (1984). This exceptionally high soil-to-plant transfer ratio may be due to the fact that most of the analytical results for soil and forage were below the detection limits, which may have introduced large uncertainties into the measurement data. Another possible explanation is that the ^{239}Pu in forage results from direct foliar deposition rather than from root uptake. Further study is needed to clarify this transfer ratio before it can be used as a parameter for modeling the biosphere.

4.2 Radionuclides in Small Mammals

Two small mammal species, Merriam's kangaroo rats (*Dipodomys merriami*) and long-tailed pocket mice (*Chaetodipus formosus*) were collected as indicator species to characterize existing radionuclide levels and monitor any potential releases due to site characterization activities.

Table 10. ^{239}Pu concentrations in forage at Yucca Mountain.

Activity, pCi/g dry wt.	YMP Study	
	Deer Forage	Cattle Forage
Average	0.005	0.009
Median	0.001	0.003
Range	BDL[a] - 0.087	BDL - 0.182
MDA	0.02	0.02

a. Below detection limit.

In addition to some naturally occurring radionuclides, such as ^{14}C and ^{40}K, small amounts of ^{137}Cs and ^{90}Sr were positively detected in these species. Although it is known that ^{90}Sr is a bone-seeking nuclide, whereas most ^{137}Cs is deposited in muscles, no effort was made to count bone and muscle tissues separately. Ten to 20 kangaroo rats or long-tailed pocket mice, collected at the same time and location, were pooled together to obtain sufficient mass for radiochemical analysis. As the entire body, including gastrointestinal (GI) tract and its contents, were included in the analysis, the reported values could be a partial reflection of the trace amounts of radionuclides present in the forage or soil ingested by the animals. To study the behavior of a specific radionuclide in the biosphere environment, target organs and tissues of indicator species should be analyzed separately.

4.2.1 Strontium-90

The average ^{90}Sr concentration in small mammals at Yucca Mountain was found to be 0.04 pCi/gram ash weight, ranging from below the MDA (approximately 0.02 pCi/gram) to 0.47 pCi/gram ash weight. Of the 56 samples analyzed, approximately half of them contained ^{90}Sr levels higher than the MDA.

4.2.2 Cesium-137

The average concentration of ^{137}Cs was 0.02 pCi/gram ash weight, ranging from below the MDA (approximately 0.02 pCi/gram) to 0.08 pCi/gram ash weight. Forty-eight out of the 56 samples analyzed yielded specific ^{137}Cs activities greater than the detection limit, or MDA.

In Table 11, ^{90}Sr and ^{137}Cs concentrations in small mammals at Yucca Mountain are compared with the concentrations of these nuclides in similar small mammal species collected in southern Nevada and Utah, including the NTS area. These comparisons indicate that small mammals at Yucca Mountain contain much less ^{90}Sr and ^{137}Cs than those collected from the areas downwind of the NTS in southern Nevada and Utah. Although the comparisons may not be statistically meaningful, they are consistent with previous findings that soil and forage at Yucca Mountain contain less fallout-derived radioactivities than those in the areas downwind of the NTS in southern Nevada and Utah.

Table 11. ^{90}Sr and ^{137}Cs concentrations in small mammals at Yucca Mountain and other areas in southern Nevada and Utah.

	^{90}Sr			^{137}Cs		
Activity	Yucca Mountain	South Nevada and Utah[a]		Yucca Mountain	South Nevada and Utah[a]	
(pCi/g ash wt.)		Bone	GI Tract		Muscle	GI Tract
Average	0.04	3.72	2.16	0.02	0.30	1.44
Median	0.02	3.6	1.7	0.02	0.3	2.1
Range	BDL[b] - 0.47	1.4 - 5.7	0.9 - 3.9	BDL - 0.08	0.1 - 0.6	0.2 - 2.3

a. NTS and its downwind areas in southern Nevada and Utah (Romney et al., 1983).
b. Below detection limit.

5.0 QUALITY ASSURANCE

Program management controls were applied to ensure a level of quality commensurate with regulatory requirements and industry standards. The validity of the data collected was ensured by qualified personnel implementing the requirements of specially developed procedures.

The conventional quality aspects of the programs were monitored through an active audit and surveillance program to ensure proper quality assurance.

Controls to ensure data quality were initiated and maintained through the following practices:

- Documented personnel training and qualification prior to work
- Technical procedure review before approval for use
- Procedure compliance policy for work performance
- Regular calibration of the data collection instruments used for monitoring, sampling, analysis, and counting
- Mandatory documenting of nonconforming or deficient conditions potentially affecting data quality, together with a structured corrective-action process
- Appropriate data review prior to data reduction, analysis and reporting

Records management and document control were completed in compliance with appropriate procedures. All data packages were reviewed and validated in accordance with approved R/EFPD procedures.

6.0 SUMMARY AND CONCLUSIONS

Data collected to date by the YMP radiological programs describe the existing radiological characteristics of the Yucca Mountain site. As presented in this document, the monitoring data are useful for determining existing levels of man-made radionuclides in soil, as well as in biota at Yucca Mountain. The soil data also serve to illustrate why Yucca Mountain has a relatively high ambient gamma background.

In addition, the radiological monitoring data provide necessary input for biosphere dose assessment modeling. In fact, the external exposure dose assessment reported in this document shows the feasibility of using the monitoring data for dose assessment. However, the collection of radiological data needs to be continued in order to fully understand the radiological characteristics at the Yucca Mountain site, and to provide the information necessary for biosphere dose assessment activities. Specifically, the following data are recommended for acquisition in future studies:

Soil Studies

Since soil samples have not been collected in far-field locations, several far-field soil samples should be collected to determine the radiological conditions in the environment surrounding the Yucca Mountain site, specifically in the Amargosa Valley and Crater Flat areas. Efforts to collect far-field soil samples should coincide with the vegetation studies, especially within the cattle grazing allotments where the potential ingestion by beef cattle represent a potential exposure pathway to humans via beef consumption.

There are no data available on the vertical distribution of radionuclides in soils at Yucca Mountain. Since this information is important for environmental dose assessment, soil profiles should be studied in the near future.

Currently, trending analysis is infeasible due to insufficient data points. Therefore, repeated samples should be collected at established monitoring locations more frequently in order to conduct trending analysis.

Vegetation Studies

The soil-to-plant transfer ratio is an important parameter in understanding how radionuclides are transported in the biosphere. More soil and vegetation data are essential in order to obtain a better estimation of this transfer ratio, and, more importantly, to evaluate precision (i.e., statistical uncertainty) associated with the results.

Small Mammal Studies

Because each nuclide has a different biochemical characteristic, it is recommended that the bone, tissue, and GI tracts of the small mammal species be analyzed separately for specific radionuclide concentrations in order to obtain more meaningful and comparable data for dosimetry studies.

LIST OF ACRONYMS

BDL	Below Detection Limit
BLM	Bureau of Land Management
CFR	Code of Federal Regulations
CR	Concentration Ratio
CRWMS	Civilian Radioactive Waste Management System
DCF	Dose Conversion Factor
DOE	Department of Energy
DEI	Desert Research Institute
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ED	Environmental Sciences Department
ESF	Exploratory Studies Facility
FF	Far-Field
GI	Gastrointestinal
LAD	Lower Limit of Detection
M&O	Management and Operating
MDA	Minimum Detectable Activity
NCRP	National Council on Radiation Protection and Measurement
NF	Near-Field
NTS	Nevada Test Site

LIST OF ACRONYMS (Cont'd)

NWPA	Nuclear Waste Policy Act
pCi/gram	PicoCuries per Gram
PIC	Pressurized Ionization Chamber
RadMP	Radiological Monitoring Program
R/EFPD	Radiological/Environmental Field Programs Department
RNT	Random Number Table
SD	Standard Deviation
USAF	U.S. Air Force
UTM	Universal Transverse Mercator
YMP	Yucca Mountain Site Characterization Project

GLOSSARY

Background radiation - Radiation in the environment from cosmic rays and naturally radioactive elements.

Cosmic radiation - Ionizing radiation of extraterrestrial origin.

Curie (Ci) - A basic unit used to describe the rate of radioactive disintegration. One curie is equal to 37 billion disintegrations per second.

Data validation - A systematic process for reviewing a body of data against a set of criteria, to provide assurance that the data are adequate for their intended use.

Far-field locations - Monitoring stations more than 16 km from the Exploratory Studies Facility on the Yucca Mountain site.

Fast reactor - A reactor in which the average neutron energy is characteristic of the high energy neutrons released in a nuclear fission reaction. Fast reactor produces more fissionable materials than it is consumed.

Gamma ray - A photon or radiation quantum emitted spontaneously by a radioactive substance.

Near-field locations - Monitoring stations within 16 km of the Exploratory Studies Facility on the Yucca Mountain site.

Picocurie (pCi) - One trillionth of a curie.

Pressurized ionization chamber (PIC) - An instrument used to measure ambient gamma radiation by measuring the current produced when radiation ionizes gas in the chamber.

Primordial radionuclides - Those radionuclides which were formed or present at the origin of the earth and which account for most of the ambient gamma radiation from terrestrial sources.

Radiation dose - The quantity of energy from incoming radiation that is absorbed by a medium.

Radiation exposure - The total electrical charge produced by ionizing radiation per unit mass or volume of air.

Radionuclide - An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation.

Source term - The quantity of radioactive materials released to the biosphere.

Specific activity - Sample activity per unit mass, e.g., pCi/gram.

Terrestrial radiation - The portion of ambient background radiation that is emitted from naturally occurring radioactive materials in the earth.

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