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NEAR-SURFACE MOISTURE AND BIOMASS INFLUENCES
ON THE RELIABILITY OF AERIAL RADIOMETRIC SURVEYS
AS A MEASURE OF NATURAL RADIOELEMENT CONCENTRATIONS

by

J.R. Norwine, D.J. Hansen, D.F. Saunders, and J.H. Galbraith

National Aerial Radiometric Reconnaissance Survey
National Uranium Resource Evaluation Program

Airborne Geophysical Services
Texas Instruments Incorporated
Dallas, Texas 75265

September 28, 1979

Work Performed Under
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Grand Junction, Colorado 81501

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ABSTRACT

Significant differences in aerial radiometric system calibration constants in humid-forested (Portland quadrangle) and desert (Lake Mead test strip) regions indicated the probability of substantial gamma-ray absorption by soil moisture in humid areas (see Part II). A set of test quadrangles was selected to investigate relationships among a group of environmental variables and ratios of whole-quadrangle mean ($\bar{X}$) stream sediment uranium (U) and thorium (Th) contents to corresponding mean aerial radiometric uranium and thorium measurements. It was assumed that stream sediment values might be sufficiently representative of the average surface radioelement concentrations to be used in ground-calibrating the aerial systems.

Preliminary testing (Part I) established strong statistical correlations between the radioelement ratios and moisture and biomass variables. However, it is recognized that moisture and biomass relationships represent a variety of variables affecting the aerial gamma-ray measurements, such as soil formation, including weathering effects. Also, the data suggested that in certain very humid areas placering effects caused the mean thorium and uranium content of stream sediments to be much greater than actual concentrations in the average surface rocks. These effects appeared to be minimal in the arid regions, where the stream sediment data were more representative of the surface materials in general.

These observations prompted a follow-up study using surface-to-aerial ratios based on analyses of surface samples in humid regions and including the stream sediment-to-aerial data ratios only for the relatively arid areas (Part II). Multiple linear regression analyses of the data indicated two-variable models would provide reasonable correction factors for aerial data obtained in humid environments. These variables included:

(1) Annual Moisture Index:

$$\text{Im} = \left(\frac{P}{PE} - 1 \right) 100$$

where

P is mean annual precipitation

PE is mean annual potential evapotranspiration

(2) Biomass of Potential Vegetation (PBIO)

Based on these initial results, a program is recommended to collect representative surface samples of selected formations in a variety of humid environments to provide additional ground calibration data for refining the aerial data correction models.

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PART I
PRELIMINARY TESTING

SECTION I
INTRODUCTION

This report documents some results of the Short-Range Methods Design prepared under Task I-2A of Phase I of Bendix Field Engineering Corporation Subcontract No. 79-300-L. It constitutes a test of portions of the plan for integrating the NURE (National Uranium Resource Evaluation), ARR (Aerial Radiometric Reconnaissance) data, and HSSR (Hydrogeochemical and Stream Sediment Reconnaissance) data with the present DOE (Department of Energy) and BFEC (Bendix Field Engineering Corporation) method of estimating undiscovered uranium resources.

Key approaches in equating ARR and HSSR data to possible undiscovered resources involve attempts to use them as quantitative (or at least semiquantitative) geochemical estimators of the favorability of regions and individual formations as sources or hosts for uranium deposits based on recent studies (Texas Instruments, 1979). This involves comparing each formation with others to detect enrichments or depletions of the natural radioelements with respect to each other, and to their normal abundances in the lithologic types present. Such comparisons require calibration of the aerial gamma-ray spectrometers in terms of equivalent parts per million uranium and thorium and percent potassium in the surface rocks as a function of counts per second as measured at 400-foot altitudes. Calibration is accomplished under desert conditions at the DOE Lake Mead, Arizona, test strip; these data are applicable with reasonable accuracy to other arid or semiarid locations with minimal vegetation cover. In more humid regions, soil moisture and vegetation absorb gamma radiation, resulting in aerial measurements far too low to provide an accurate estimate of the radioelement content of the underlying rocks. Under these circumstances, it is desirable to find an appropriate correction factor with which to adjust the calibration constants to reflect the amounts of soil moisture and vegetative cover. This experiment was devised to test the relationship between selected environmental variables and the absorption of gamma radiation as reflected in regional

KEY TO LOCATION MAP

Quadrangle Number	Quadrangle Name	Quadrangle Number	Quadrangle Name
1	Ardmore	25	Kingman
2	Ashland	26	Knoxville
3	Athens	27	La Junta
4	Augusta	28	Lamar
5	Beeville	29	Las Vegas
6	Bozeman	30	Lawton
7	Charlotte	31	Lovelock
8	Cheyenne	32	Oklahoma City
9	Clinton	33	Plainview
10	Crystal City	34	Portland
11	Denver	35	Pratt
12	Eau Claire	36	Presidio
13	Ekalaka	37	Pueblo
14	Emory Peak	38	Rawlins
15	Enid	39	Rice Lake
16	Glens Falls	40	Scranton
17	Greeley	41	Seguin
18	Green Bay	42	Sherman
19	Greensboro	43	Spartanburg
20	Greenville	44	Tularosa
21	Harrisburg	45	Williams
22	Houston	46	Winnemucca
23	Iron Mountain	47	Winston-Salem
24	Joplin		

Map I. Location of Test Quadrangles

mean ARR thorium and uranium values and mean surface-sample analytical values for the same variables over equivalent regions. Because of the extremely limited available data based on chemical analyses for the uranium and thorium content of surface samples of geological formations, an attempt has been made to use whole-quadrangle mean thorium and uranium values in HSSR data on stream sediments as a measure of the mean radioelement values for all exposed rocks in the quadrangle. These are compared with the corresponding ARR values over a series of test quadrangles to provide an estimate of the relative absorption of the ARR gamma radiation by soil moisture and vegetation. Data availability and time constraints have limited the number of quadrangles for analyses presented here to 46 or fewer. Location of the quadrangles is shown on Map I.

Data from selected quadrangles were analyzed statistically to determine possible relationships of selected environmental factors to the absorption of gamma radiation as evidenced by the differences between uranium and thorium mean values from stream sediment data and those measured by aerial gamma-ray spectrometry.

SECTION II TEST VARIABLES

A. RADIOELEMENT (DEPENDENT) VARIABLES

Two variables (or combinations of variables), shown in Table 2-1, were selected for analysis as dependent variables relative to several environmental variables.

Table 2-1
Radioelement (Dependent) Variables

<u>Label</u>	<u>Variable*</u>	<u>Unit of Measure</u>
THTA	$\text{Th}_{\text{HSSR}}/\text{eTh}_{\text{ARR}}$	Proportion
UHUA	$\text{U}_{\text{HSSR}}/\text{eU}_{\text{ARR}}$	Proportion
LT	$\text{Log}_{10} \text{THTA}$	Log_{10} Proportion
LU	$\text{Log}_{10} \text{UHUA}$	Log_{10} Proportion

* Th_{HSSR}	is stream sediment reconnaissance concentration of thorium in ppm.
U_{HSSR}	is stream sediment reconnaissance concentration of uranium in ppm.
eTh_{ARR}	is aerial radiometric reconnaissance equivalent uranium concentration in ppm (measured as Bi-214).
eU_{ARR}	is aerial radiometric reconnaissance equivalent uranium concentration in ppm (measured as Tl-208).

Values for the HSSR thorium and uranium variables were obtained as whole-quadrangle averages of laboratory analyses of stream sediments from selected sampling locations in the quadrangles. Because stream sediments are products of the hydrogeochemical cycling regimen of each quadrangle, values may reflect placering (enrichment) and other related processes that vary from location to location. Thorium and uranium HSSR data are the most readily available laboratory chemical data that approximate the actual thorium and uranium content of the exposed geological formations. Other than HSSR data, formational chemical analyses are lacking for most quadrangles in the United States.

Values for ARR thorium and uranium may be influenced by absorption of gamma radiation due to atmospheric phenomena such as humidity and temperature inversions as well as by terrestrial features such as biomass, soil moisture, surface water, and soil formation processes. The ARR data are the most readily available radioelement data for the land areas in the priority quadrangles. Because the ARR data measure equivalent thorium (eTh_{ARR}) and equivalent uranium (eU_{ARR}), it is believed that eTh_{ARR} more accurately reflects the actual concentration of thorium in the geological formation than eU_{ARR} reflects the actual concentration of uranium. This is primarily because the critical thorium daughter isotopes decay more rapidly than the uranium daughter isotopes, radium and radon, and have less opportunity to be separated, which would cause disequilibrium in the decay series. Also, uranium is much more leachable in weathering and soil formation, causing the ARR-measured values to be less representative of the bedrock than is the case with thorium.

Ratios between quadrangle mean HSSR data and ARR data are used to reflect the degree of difference between the two measurements, with a value of 1 indicating no difference. Ratios greater than 1 indicate abnormally low ARR values (resulting from interaction of the gamma radiation with physical and biological features of the environment) as well as abnormally high HSSR values due to placer formation of radioactive heavy-mineral concentrates in the stream sediments. Statistical techniques were used to model these interactions using existing data and to obtain adjustment factors that could be used to correct for absorption of the gamma radiation and the resulting discrepancies in HSSR and ARR values, produced in part by the independent environmental variables.

B. ENVIRONMENTAL (INDEPENDENT) VARIABLES

A large number of environmental factors were identified as having the potential to be significant independent variables relative to THTA and UHUA. Nine physical factors, three "geographical factors," and two biological factors were selected to be evaluated as measures or indicators of near-surface gamma-ray absorption. These variables, which were chosen on the basis of likelihood of significant association and availability of data, are shown in Table 2-2.

Table 2-2

Environmental (Independent) Variables

<u>Label</u>	<u>Variable</u>	<u>Unit of Measure</u>
Long	Longitude	Degrees west of Greenwich
Lat	Latitude	Degrees north of equator
Elev	Elevation above mean sea level	Meters
PE	Mean annual potential evapotranspiration	Millimeters
P	Mean annual precipitation	Millimeters
AE	Mean annual actual evapotranspiration	Millimeters
D	Mean annual moisture deficiency	Millimeters
S	Mean annual moisture surplus	Millimeters
R	Mean annual solar radiation	Langleys (lgy)
SA	Mean annual "stagnant air potential"	Days
Im	Annual moisture index	$Im = 100 (P/PE - 1)$
SM	Soil moisture capacity	Centimeters per centimeter
PBIO	Biomass of potential vegetation	Kilogram per square meter
LBIO	Biomass of land-use vegetation	Kilogram per square meter

Values for Long, Lat, Elev, R, and SA were extracted from maps and indices in The National Atlas of the United States of America (USGS, 1970) by grid cells corresponding to the boundaries of the 1:250,000-scale topographic map series of the USGS.

PE, P, AE, D, and S were obtained from tables in the Average Climatic Water Balance Data of the Continents: Part VII, United States (Thornthwaite Associates, 1964) while Im was calculated using the above-listed data and Thornthwaite's revised water balance computation procedure: [$Im = 100 (P/PE - 1)$] (Thornthwaite and Mather, 1955)].

SM, the moisture-holding ("field") capacity of the soil, was calculated by faculty of the Soil and Crop Sciences Department of Texas A&M University (Brown and Thomas, 1979), using the following procedure:

Each test quadrangle was located on a state map, and the county in which it lies was identified. The General Soils Map (Soil Conservation Service) for that county was then obtained and the location of the quadrangle was entered. From the soils map, the texture of the soils in the quadrangle

was assessed. When more than one soil texture was present, the approximate percentages of each texture were obtained. This information was then used in conjunction with Figure 2-1 to yield the average soil moisture-holding values expressed in centimeters. There were several areas for which it was necessary to contact the county SCS office to obtain the needed data orally, because many counties in the United States have no published soil maps. For some states where no county maps were available, needed information was obtainable from a generalized state soils map. (There were several quadrangles for which no information could be obtained, even from the local county SCS soil scientist.)

Figure 2-1. Soil Moisture-Holding Capacity Related to Texture

The two biological factors considered in the analysis were biomass of potential vegetation units (PBIO) and biomass of land-use vegetation units (LBIO).

Average plant biomass from selected 1:250,000 quadrangle areas in the United States was estimated by a two-step process, detailed below, using published biomass estimates (Krebs, 1972; Whittaker, 1975) and potential vegetation and land-use maps from the National Atlas.

Percent composition of map units in each quadrangle was determined in the first step by using a transparent overlay to delineate boundaries of the selected quadrangle area. Relative percent composition for map units in each quadrangle was determined through a dot count using a transparent grid pattern of 729 dots per square inch. Percent composition of each map unit was calculated by counting the number of dots in a given map unit in a quadrangle area and dividing this number by the total number of dots counted for all map units in the quadrangle area. Water and municipal map units were not included in the calculations because no gamma-ray data were obtained for these areas. The resulting quotients for map units were expressed as percentages.

In step 2, map-unit-composition percentages were multiplied by the published biomass estimates for vegetation types similar to the map units. Published estimates of biomass for potential vegetation were from Krebs (1972) and Whittaker (1975). Values were expressed as kilograms per square meter of standing crop. The total biomass for each quadrangle was calculated by summing the products of all map units in the quadrangle area.

Biomass for land-use types was estimated by ranking the land-use map units and assigning biomass values to each type. The values used are presented in Table 2-3. Total biomass for land use was estimated by the procedure just described.

Total biomass estimates for potential vegetation and land use ranged from 1.3 to 40 kilograms and from 2.8 to 30 kilograms respectively for an average 1-square-meter area, assuming biomass distribution to be uniform in the quadrangle area.

Table 2-3

Biomass Estimates Used in Calculating Land-Use Biomass

<u>Biomass Rank</u>	<u>National Atlas Type Number</u>	<u>Land-Use Type</u>	<u>Estimated Standing Crop (kg/m²)</u>
1	7	Forest and woodland, mostly ungrazed	30
2	6	Forest and woodland, grazed	25
3	5	Woodland and forest with some cropland and pasture	20
4	13	Swamp	15
5	9	Open woodland, grazed	10
6	3	Cropland with pasture, woodland and forest	8
7	10	Desert shrubland, grazed	5
8	8	Subhumid grassland and semiarid grazing land	5
9	4	Irrigated land	3
10	2	Cropland with grazing land	3
11	1	Mostly cropland	2
12	14	Marshland	2
13	11	Desert shrubland, mostly ungrazed	1
14	12	Alpine meadow, barrenland, sparse dry tundra	1

For all independent variables, grid cell (quadrangle) values were determined by translating map units or tabular data into a single mean (quantitative) value for each parameter for each grid cell. Such a procedure generates useful values of indeterminate (but certainly less than optimal) reliability, and they must be viewed and utilized on that basis.

Mean values of the environmental variables for each of the 47 test quadrangles are shown in Table 2-4.

Table 2-4
Quadrangle Mean Values

NUMBER	QUAD	ELEV	LONG	LAT	PE	P	AE	D	S	R	SA	IM	SM	PBIO	LBIO	THTA	UHUA	LT	LU
1	ARDMORE	266	97.1	34.1	956	915	841	115	74	415	0	-4.3	12.2	26.8	6.6	0.88	0.84	-0.054	-0.073
2	ASHLAND	217	90.8	46.6	556	856	548	8	308	325	0	54.0	20.8	29.9	26.3	1.15	1.80	0.062	0.255
3	ATHENS	243	83.3	33.9	888	1204	837	51	367	400	35	35.6		35.0	14.4	10.08	7.12	1.003	0.853
4	AUGUSTA	43	81.9	33.4	972	1151	925	47	226	415	20	18.4		35.0	11.9	10.04	7.65	1.002	0.884
5	BEEVILLE	15	97.5	28.4	1118	677	677	441	0	440	0	-39.4	19.0	7.1	3.8		1.79		0.253
6	BOZEMAN	1367	111.3	45.7	587	391	391	196	0	380	5	-33.4		21.8	14.5		1.84		0.264
7	CHARLOTTE	221	80.9	35.2	862	1151	837	25	314	385	45	33.5	16.0	35.4	11.0	5.86	4.98	0.768	0.697
8	CHEYENNE	1869	104.8	41.1	552	374	374	178	0	400	0	-32.2	17.5	8.6	7.2		1.85		0.267
9	CLINTON	427	99.0	35.5	942	680	680	262	0	410	0	-27.8		6.6	2.3	0.90	1.53	-0.047	0.184
10	CRYSTALCITY	198	99.9	28.5	1174	504	504	670	0	450	0	-57.1	18.2	0.7	8.9		1.33		0.123
11	DENVER	1612	104.9	39.8	641	366	366	275	0	410	0	-42.9	17.5	11.9	8.7		3.25		0.512
12	EAUCLAIRE	244	91.5	44.8	627	830	616	11	214	340	0	32.4	20.5	21.3	13.9		1.69		0.228
13	EKALAKA	1142	104.6	45.9	634	330	330	304	0	375	0	-47.9	16.2	7.6	6.4		1.33		0.125
14	EMORYPEAK	2593	103.3	29.2	1116	474	474	642	0	510	0	-57.5	16.7	2.0	6.6	1.03	1.12	0.013	0.049
15	ENID	415	97.9	36.5	876	774	774	102	0	425	0	-11.6	15.8	13.9	4.9	0.91	0.83	-0.040	-0.082
16	GLENSFALLS	107	73.9	42.7	681	930	664	17	266	290	15	36.6		30.7	20.9				
17	GREELEY	1549	104.7	40.4	595	381	381	214	0	400	0	-36.0	9.3	8.9	9.7		2.98		0.475
18	GREENBAY	210	88.1	44.5	610	722	583	27	139	330	0	18.4	17.4	27.1	9.1		2.08		0.318
19	GREENSBORO	271	79.9	36.1	806	1073	783	23	290	380	30	33.1	16.0	35.0	14.7	2.90	2.77	0.463	0.442
20	GREENVILLE	310	82.4	34.8	870	1227	833	37	394	375	40	41.0	15.2	36.3	15.0	6.84	6.38	0.835	0.805
21	HARRISBURG	102	76.8	40.3	722	951	692	30	259	350	30	31.7		40.0	15.8	1.61	1.21	0.206	0.082
22	HOUSTON	12	95.4	29.8	1107	1159	1024	83	135	425	8	4.7	13.0	7.4	2.6	1.53	0.90	0.185	-0.044
23	IRONMOUNTAIN	385	88.0	45.8	554	746	541	13	205	325	0	34.7	21.6	31.5	30.0	1.75	2.23	0.244	0.348
24	JOPLIN	308	94.3	37.1	775	1037	755	20	282	390	5	33.8	18.0	9.9	3.6	0.75	1.07	-0.122	0.030
25	KINGMAN	1015	114.1	35.2	830	277	277	603	0	550	18	-68.5		1.3	3.9	1.01	0.66	0.004	-0.180
26	KNOXVILLE	290	84.0	35.8	898	1206	859	39	347	370	42	34.3		39.7	21.3	3.56	4.25	0.551	0.628
27	LAJUNTA	1115	103.6	38.0	756	399	399	357	0	410	0	-49.6	18.0	1.3	3.9	1.00	1.68	0.000	0.226
28	LAMAR	1110	102.6	38.1	756	399	399	357	0	410	0	-47.2	11.4	1.5	3.4	1.95	2.47	0.290	0.393
29	LASVEGAS	658	115.2	36.1	1127	102	102	1025	0	550	20	-91.0	15.4	4.8	5.1	1.50	0.76	0.175	-0.119
30	LAWTON	348	98.4	34.5	927	802	802	125	0	425	0	-13.5	16.0	4.6	2.8	1.03	1.50	0.014	0.177
31	LOVELOCK	1212	118.5	40.2	679	103	103	576	0	470	60	-84.8		4.0	4.9	0.81	1.11	-0.093	0.045
32	OKLAHOMACITY	390	97.5	35.4	888	810	785	103	25	400	0	-8.8	13.7	22.4	4.8	0.79	1.80	-0.102	0.255
33	PLAINVIEW	1123	101.7	34.2	855	426	426	429	0	450	0	-50.2	11.0	2.5	3.6	1.14	1.00	0.056	0.000
34	PORTLAND	18	70.3	43.7	593	1077	574	19	503	310	5	81.6		26.9	20.6	3.28	3.18	0.516	0.502
35	PRATT	566	98.8	37.6	771	511	511	260	0	410	0	-33.7	20.7	3.3	2.8	1.29	0.92	0.111	-0.036
36	PRESIDIO	857	104.5	29.6	1116	474	474	642	0	510	0	-57.5	18.5	1.4	5.7	1.54	0.99	0.187	-0.005
37	PUEBLO	1414	104.5	38.3	707	303	303	404	0	420	0	-57.1	15.4	13.8	7.2		2.12		0.326
38	RAWLINS	2088	107.3	41.7	550	323	323	227	0	420	15	-41.3	13.8	12.1	8.4		1.57		0.197
39	RICELAKE	372	91.7	45.5	627	830	616	11	214	340	0	32.4	19.0	29.3	19.3	1.75	1.61	0.243	0.207
40	SCRANTON	287	75.7	41.2	663	944	649	14	295	315	25	42.4		31.7	20.9	2.11	1.71	0.324	0.234
41	SEGUIN	240	98.0	29.6	1108	686	686	422	0	430	0	-38.1	13.0	13.1	9.6		1.92		0.283
42	SHERMAN	245	96.6	33.5	977	902	851	126	51	425	0	-7.7	12.0	20.1	4.5	1.01	0.70	0.002	-0.157
43	SPARTANBURG	244	81.9	34.9	853	1218	830	23	388	375	40	42.8	20.0	35.1	14.7	5.72	5.74	0.758	0.759
44	TULAROSA	1480	106.0	33.1	872	276	276	596	0	520	5	-68.3		3.8	8.2		1.18		0.072
45	WILLIAMS	2057	112.2	35.3	590	578	518	72	60	540	10	-2.0	20.0	5.2	9.1	2.75	1.94	0.439	0.289
46	WINNEMUCCA	1310	117.2	40.9	631	217	217	414	0	450	50	-65.6		4.6	4.9	1.17	1.60	0.066	0.204
47	WINSTONSALEM	294	80.2	36.1	812	1127	796	16	331	375	35	38.8	16.0	37.1	18.6	1.98	2.47	0.296	0.392

SECTION III

STATISTICAL ANALYSES

A. METHODS

Statistical techniques used in the data analyses consisted of factor analysis to determine correlation between independent variables, descriptive statistics such as calculation and display of means and variance values, and plots (scattergrams) of one variable against another, and stepwise multiple linear regression analysis to model correlation between dependent and independent variables.

Basic statistics for each variable were generated by the Statistical Analysis System (SAS), a software package distributed by SAS Institute (1976). SAS was also used to perform other statistical procedures that included R-mode factor analysis and stepwise multiple linear regression analysis. The application of R-mode factor analysis permitted the determination of variable redundancy and showed the relationships between pairs and groups of variables.

B. RESULTS AND DISCUSSION

The data shown in Table 2-4 (quadrangle mean values) were subjected to extensive statistical testing to identify meaningful relationships between the independent environmental variables and the dependent radioelement variables. The statistical procedures were generally employed in the following order:

- Calculation of statistics (mean, standard deviation, minimum/maximum values) for the combined test group
- Factor analysis using the Varimax rotation method (SAS, 1976) to determine the degree and nature of interdependence among the independent variables and to obtain simple correlation coefficients (r) between the dependent and each independent variable
- Graphic plots (scattergrams) illustrating the association between specific dependent (radioelement) variables and specific independent (environmental) variables

- Multivariate (stepwise) linear regression (R^2) analyses, the object being an explanatory model in which each dependent variable is "predicted" by an equation based on two or more of the independent variables. If such an equation explained a significant percentage (e.g., 50 percent) of the variance (ratio) between aerial- and ground-recorded concentrations of thorium and uranium, it might be a practical means of "correcting" or reconciling the two sets of data.

The tests were performed in five distinct steps or phases (the types of analyses remained as described in each step):

- Phase I: All test quadrangles (maximum observations = 46, with Glens Falls, N.Y., lacking radioelement data) combined. I.e., the entire sample, representing most of the climatic types found in the United States, was treated as one entity.
- Phase II: Humid-environment quadrangles only were analyzed, defined as those where P (mean annual precipitation) exceeds 900 millimeters per year.
- Phase III: Humid/subhumid-environment quadrangles were studied, where P exceeds 800 millimeters per year.
- Phase IV: Dry-environment quadrangles only, where P is less than 900 millimeters per year.
- Phase V: Arid/semiarid-environmental quadrangles, where P is less than 800 millimeters per year.

The results of these calculations are summarized in the remainder of this section, in the order shown above.

1. Phase I: All Test Quadrangles Combined

Table 3-1 shows the simple statistics, notably the mean and standard deviation, for the amalgamated sample. Dry environments predominated, as illustrated by the means (averages) of moisture index ($\bar{X} = -10.53$) and precipitation ($\bar{X} = 700$ millimeters, or 27.6 inches). The fundamental problem being addressed was also clearly revealed in the means, standard deviations, and maxima of THTA, UHUA, LT, and LU (i.e., all were large enough to indicate inconsistency between aerial and stream-sediment measurements of radioelement concentrations).

Table 3-1
Statistics for 47 Combined Quadrangle Mean Values

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
ELEV	47	699.12765957	653.37021322	12.00000000	2593.00000000
PE	47	805.46808511	185.18484902	550.00000000	1174.00000000
P	47	699.85106383	336.40502639	102.00000000	1227.00000000
AE	47	578.85106383	226.91992255	102.00000000	1024.00000000
D	47	226.61702128	240.89430780	8.00000000	1025.00000000
S	47	121.00000000	151.21306592	0.00000000	503.00000000
R	47	408.93617021	61.92506139	290.00000000	550.00000000
SA	47	11.87234043	16.92517620	0.00000000	60.00000000
IM	47	-10.52765957	43.60999936	-91.00000000	81.00000000
SM	34	16.31764706	3.11598718	9.30000000	21.60000000
TA	46	7.90282609	2.97257962	3.47000000	17.08000000
UA	46	2.07717391	0.62483300	1.14000000	3.51000000
KA	45	1.42666367	0.74408272	0.17000000	2.90000000
TH	34	19.62764706	22.36308453	4.00000000	90.00000000
UH	47	4.57489362	3.76576043	1.31000000	17.10000000
PBIO	47	17.23404255	13.37330691	0.70000000	40.00000000
LBIO	47	10.14893617	6.25444547	2.30000000	30.00000000
THTA	33	2.47309609	2.47919112	0.75431034	10.07338746
UHUA	46	2.20550380	1.67677069	0.66055046	7.65060241
LT	33	0.25321633	0.32280213	-0.12244994	1.00339105
LU	46	0.25403447	0.26643652	-0.18009400	0.83369563

Examination of the matrix of partial correlation coefficients (r) (Table 3-2) revealed that for UHUA and THTA there were four independent variables with r values exceeding 0.50 (Table 3-3). All of these terms were somewhat moisture-related, especially longitude (Long), mean annual precipitation (P), and annual moisture surplus (S). (Longitude is really a proxy measure of moistness, in that mean annual precipitation in the U.S. decreases from east to west.) Furthermore, the plots of factors obtained using the Varimax rotation method revealed a high degree of interdependence among those four factors.

The plots or scattergrams of specific independent variables against each of the factors UHUA and THTA suggested:

- An apparent strong correlation between the radioelement ratios (UHUA and THTA) and measures of moistness, such as P, AE, D, S, and Im, as well as with PBIO. In other words, the wetter the environment, the greater the ratio, indicating a "masking" mechanism such as absorption of the gamma rays by soil moisture and biomass.
- Closer examination of the plots revealed that the above-stated association existed strongly only in the most humid quadrangles. In drier locations [i.e., mean annual precipitation less than 900 millimeters (UHUA) or 800 millimeters (THTA)], it was obscured or nonexistent (Figures 3-1 through 3-4 and A-1 through A-7).

Table 3-2

Correlation Matrix: All Test Quadrangles Combined

	ELEV	LONG	LAT	PE	P	AE	D	S
ELEV	1.00000	0.67570	-0.21170	0.01544	-0.68852	-0.62132	0.59023	-0.56972
LONG	0.67570	1.00000	-0.18351	0.16775	-0.87206	-0.69261	0.75494	-0.86071
LAT	-0.21170	-0.18351	1.00000	-0.86898	-0.07303	-0.30436	-0.27555	0.29124
PE	0.01544	0.16775	-0.86898	1.00000	0.02081	0.23874	0.42123	-0.30717
P	-0.68852	-0.87206	-0.07303	0.02081	1.00000	0.91630	-0.84238	0.80695
AE	-0.62132	-0.69261	-0.30436	0.23874	0.91630	1.00000	-0.78016	0.50288
D	0.59023	0.75494	-0.27555	0.42123	-0.84238	-0.78016	1.00000	-0.66755
S	-0.56972	-0.86071	0.29124	-0.30717	0.80695	0.50288	-0.66755	1.00000
R	0.66864	0.81172	-0.58294	0.50710	-0.65778	-0.48723	0.78172	-0.70114
SA	-0.08345	-0.15291	0.02558	-0.11327	0.16339	-0.03504	-0.04024	0.40432
IM	-0.64226	-0.89963	0.32925	-0.37137	0.89452	0.70031	-0.89330	0.89784
PBIO	-0.64355	-0.85195	0.26917	-0.22230	0.80417	0.60937	-0.71234	0.83695
LBIO	-0.36383	-0.67321	0.60027	-0.52381	0.49404	0.20790	-0.53161	0.75968
THTA	-0.29602	-0.50490	-0.17890	0.08753	0.55894	0.42342	-0.33907	0.58190
UHUA	-0.31670	-0.55775	-0.09470	0.00256	0.60390	0.44588	-0.41479	0.64582

	R	SA	IM	PBIO	LBIO	THTA*	UHUA**
ELEV	0.66864	-0.08345	-0.64226	-0.64355	-0.36383	-0.29602	-0.31670
LONG	0.81172	-0.15291	-0.89963	-0.85195	-0.67321	-0.50490	-0.55775
LAT	-0.58294	0.02558	0.32925	0.26917	0.60027	-0.17890	-0.09470
PE	0.50710	-0.11327	-0.37137	-0.22230	-0.52381	0.08753	0.00256
P	-0.65778	0.16339	0.89452	0.80417	0.49404	0.55894	0.60390
AE	-0.48723	-0.03504	0.70031	0.60937	0.20790	0.42342	0.44588
D	0.78172	-0.04024	-0.89330	-0.71234	-0.53161	-0.33907	-0.41479
S	-0.70114	0.40432	0.89784	0.83695	0.75968	0.58190	0.64582
R	1.00000	-0.04538	-0.81249	-0.71283	-0.68120	-0.19265	-0.31692
SA	-0.04538	1.00000	0.10435	0.39852	0.21706	0.44514	0.48110
IM	-0.81249	0.10435	1.00000	0.83460	0.74312	0.43916	0.50485
PBIO	-0.71283	0.39852	0.83460	1.00000	0.77805	0.55663	0.61796
LBIO	-0.68120	0.21706	0.74312	0.77805	1.00000	0.31327	0.39078
THTA	-0.19265	0.44514	0.43916	0.55663	0.31327	1.00000	0.96058
UHUA	-0.31692	0.48110	0.50485	0.61796	0.39078	0.96058	1.00000

*33 observations

**46 observations

Table 3-3

Selected Simple Correlation Coefficients (r) for Combined Quadrangles

Independent Variable	Dependent Variable	
	UHUA	THTA
Long	-0.53	-0.56
P	0.55	0.60
S	0.60	0.65
PBIO	0.60	0.62

NOTE:

Figure 3-1. Test Quadrangles Combined, UHUA vs IM (A = 1 observation; B = 2 observation, etc.)

Figure 3-3. Test Quadrangles Combined, THTA vs IM (A = 1 observation, B = 2 observations, etc.)

Figure 3-4. Test Quadrangles Combined, THTA vs PBIO (A = 1 observation, B = 2 observations, etc.)

The stepwise linear regression analyses of the combined sample produced models that explained more than 50 percent of the variance between the aerial and hydrologic data, but which were probably affected by the nonlinear moisture constraint explained above. The equations derived were as follows:

$$(1) \text{ UHUA} = 5.78 + 0.02 (S) - 0.03 (SA) - 0.14 (LAT) + 0.069 (PBIO) \\ - 0.009 (PE) - 0.10 (Im) + 0.008 (AE)$$

$$R^2 = 0.62$$

$$(2) \text{ THTA} = -34.74 + 0.02 (S) + 0.57 (LAT) - 0.12 (IM) + 0.001 (ELEV) \\ + 0.016 (AE) + 0.04 (R) - 0.15 (LONG)$$

$$R^2 = 0.59$$

Because the plots and partial r's had suggested the possibility of a logarithmic relationship (Figures 3-5 through 3-8 and A-8 through A-15) between the radioelement ratios and the environmental variables (especially moisture terms), the stepwise regression equations were also run with the logarithm (base 10) of UHUA and THTA as the dependent variables.

$$(3) \text{ LT} = -1.188 + 0.0016 (S) + 0.0026 (R) + 0.007 (PBIO)$$

$$R^2 = 0.59$$

$$(4) \text{ LU} = 0.004 + 0.0009 (S) - 0.0015 (IM) + 0.008 (PBIO)$$

$$R^2 = 0.403$$

These results indicate that for the combined test-quadrangle group the model for the logarithm of the thorium ratio may be superior to that for THTA, but that the model using UHUA is better than that for the logarithm of the ratio UHUA.

Figure 3-5. Test Quadrangles Combined, LU vs IM
(A = 1 observation; B = 2 observations, etc.)

Figure 3-6. Test Quadrangles Combined, LU vs PBIO
(A = 1 observation; B = 2 observations, etc.)

Figure 3-7. Test Quadrangles Combined, LT vs IM
(A = 1 observation; B = 2 observations, etc.)

Figure 3-8. Test Quadrangles Combined, LT vs PBIO
(A = 1 observation; B = 2 observations, etc.)

Map II. Precipitation Boundaries: Aerial Radiometric Surveys

2. Phase II: Moist-Environment Quadrangles Only (P is greater than 900 millimeters)

The need for more intensive scrutiny of the apparent differentiation in the relationship between moisture (and related environmental influences) and magnitude of the radioelement ratios in moist versus dry environments was made evident by the results of Phase I. In Phase II, statistical analyses were performed using only the 15 quadrangles receiving more than 900 millimeters of annual precipitation (see Map II).

In the factor analyses, the matrix of partial r 's (Table 3-4) revealed correlation coefficients exceeding 0.50 for S, PBIO, and P (LT) and D, S, Im, and LBIO (LU).

Table 3-4

Correlation Matrix: Moist-Environment Quadrangles (P > 900 millimeters)

	LT	LU	D	S	R	IM
LT	1.00000	0.96034	-0.37749	0.57827	-0.08950	0.40068
LU	0.96034	1.00000	-0.51498	0.69942	-0.17069	0.51716
D	-0.37749	-0.51498	1.00000	-0.82179	0.70299	-0.83305
S	0.57827	0.69942	-0.82179	1.00000	-0.69920	0.95564
R	-0.08950	-0.17069	0.70299	-0.69920	1.00000	-0.83751
IM	0.40068	0.51716	-0.83305	0.95564	-0.83751	1.00000
PBIO	0.60407	0.64627	-0.41576	0.45675	-0.37162	0.35431
P	0.75454	0.79619	-0.38936	0.58132	0.08171	0.35654
LBIO	0.45385	0.53467	-0.64946	0.73145	-0.79202	0.73446
PE	0.01957	-0.09468	0.69938	-0.64880	0.91816	-0.80810
ELEV	-0.12261	0.03195	-0.09526	0.04052	0.00485	-0.06132
LAT	-0.09944	-0.00976	-0.57578	0.54429	-0.92473	0.73537
	PBIO	P	LBIO	PE	ELEV	LAT
LT	0.60407	0.75454	0.45385	0.01957	-0.12261	-0.09944
LU	0.64627	0.79619	0.53467	-0.09468	0.03195	-0.00976
D	-0.41576	-0.38936	-0.64946	0.69938	-0.09526	-0.57578
S	0.45675	0.58132	0.73145	-0.64880	0.04052	0.54429
R	-0.37162	0.08171	-0.79202	0.91816	0.00485	-0.92473
IM	0.35431	0.35654	0.73446	-0.80810	-0.06132	0.73537
PBIO	1.00000	0.26578	0.76611	-0.30712	0.22595	0.27306
P	0.26578	1.00000	0.24288	0.22948	-0.03043	-0.34239
LBIO	0.76611	0.24288	1.00000	-0.64816	0.10787	0.63878
PE	-0.30712	0.22948	-0.64816	1.00000	-0.09067	-0.96782
ELEV	0.22595	-0.03043	0.10787	-0.09067	1.00000	-0.03858
LAT	0.27306	-0.34239	0.63878	-0.96782	-0.03858	1.00000

Examination of the scattergrams plotting UHUA, THTA, LU, and LT against various moisture and biological terms (Figures 3-9 through 3-16 and A-16 through A-31) indicated a more nearly direct function, especially for LT and LU (e.g., LU with P).

Figure 3-9. Moist-Environment Quadrangles ($P > 900$ millimeters) UHUA vs IM (A = 1 observation; E = 2 observations, etc.)

Figure 3-10. Moist-Environment Quadrangles ($P > 900$ millimeters) UHUA vs PBIO (A = 1 observation; B = 2 observations, etc.)

Figure 3-11. Moist-Environment Quadrangles (P > 900 millimeters) THTA vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-12. Moist-Environment Quadrangles (P > 900 millimeters) THTA vs PBIO (A = 1 observation; B = 2 observations, etc.)

Figure 3-13. Moist-Environment Quadrangles ($P > 900$ millimeters) LT vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-14. Moist-Environment Quadrangles ($P > 900$ millimeters) LT vs PBIO (A = 1 observation; B = 2 observations, etc.)

Figure 3-15. Moist-Environment Quadrangles ($P > 900$ millimeters) LU vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-16. Moist-Environment Quadrangles ($P > 900$ millimeters) LU vs PBIO (A = 1 observation; B = 2 observations, etc.)

The "correction models" generated by the stepwise multiple regression procedure were as follows:

$$LT = 2.27 + 0.016 (PBIO) + 0.02 (P)$$

$$R^2 = 0.74$$

$$LU = 2.44 + 0.17 (PBIO) + 0.02 (P)$$

$$R^2 = 0.84$$

In other words, equations based on only one moisture term (precipitation) and one biological variable (biomass of potential vegetation) explained nearly 75 percent of the variance of LT (the log of the ratio between hydrologic and aerial thorium measurements), and 84 percent of the variance of LU. This suggested that gamma-ray absorption by soil moisture and biomass was a very significant "masking" mechanism in humid environments.

3. Phase III: Humid/Subhumid-Environment Quadrangles Only (P is greater than 800 millimeters)

In Phase III, only the 19 quadrangles receiving more than 800 millimeters mean annual precipitation were tested (see map). Results were similar to those obtained in Phase II, if somewhat less corroborative (Figures 3-17 through 3-24 and A-32 through A-47).

Three environmental variables had simple correlation coefficients in excess of 0.50 with LT and LU: S, PBIO, and P (Table 3-5).

The stepwise multiple regression equations produced the following models:

$$LT = -1.59 + 0.12 (PBIO) + 0.002 (P)$$

$$R^2 = 0.71$$

$$LU = -1.085 + 0.01 (PBIO) + 0.001 (P)$$

$$R^2 = 0.59$$

Figure 3-17. Humid/Subhumid Quadrangles (P > 800 millimeters) UHUA vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-18. Humid/Subhumid Quadrangles (P > 800 millimeters) UHUA vs PBIO (A = 1 observation; B = 2 observations, etc.)

Figure 3-19. Humid/Subhumid Quadrangles (P > 800 millimeters) THTA vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-20. Humid/Subhumid Quadrangles (P > 800 millimeters) THTA vs PBIO (A = 1 observation; B = 2 observations, etc.)

Figure 3-21. Humid/Subhumid Quadrangles ($P > 800$ millimeters) LU vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-22. Humid/Subhumid Quadrangles ($P > 800$ millimeters) LU vs PBIO (A = 1 observation; B = 2 observations, etc.)

Figure 3-23. Humid/Subhumid Quadrangles (P > 800 millimeters) LT vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-24. Humid/Subhumid Quadrangles (P > 800 millimeters) LT vs PBIO (A = 1 observation; B = 2 observations, etc.)

Table 3-5

Correlation Matrix: Humid/Subhumid-Environment Quadrangles
(P > 800 millimeters)

	LT	LU	D	S	R	IM
LT	1.00000	0.92130	-0.40507	0.63794	-0.07918	0.44575
LU	0.92130	1.00000	-0.43658	0.63979	-0.13142	0.46753
D	-0.40507	-0.43658	1.00000	-0.23348	0.76290	-0.88073
S	0.63794	0.63979	-0.23348	1.00000	-0.64877	0.94769
R	-0.07918	-0.13142	0.76290	-0.64877	1.00000	-0.82453
IM	0.44575	0.46753	-0.88073	0.94769	-0.82453	1.00000
PBIO	0.61891	0.61223	-0.56266	0.60197	-0.44318	0.51470
P	0.78026	0.68919	-0.36869	0.65125	0.07951	0.41269
LBIO	0.36274	0.40362	-0.76245	0.71396	-0.84757	0.79820
PE	0.08392	-0.01690	0.69665	-0.50368	0.92080	-0.72654
ELEV	-0.29605	-0.07982	0.10349	-0.26335	0.05156	-0.26973
LAT	-0.18104	-0.09347	-0.58398	0.35775	-0.88217	0.61295
	PBIO	P	LBIO	PE	ELEV	LAT
LT	0.61891	0.78026	0.36274	0.08392	-0.29605	-0.18104
LU	0.61223	0.68919	0.40362	-0.01690	-0.07982	-0.09347
D	-0.56266	-0.36869	-0.76245	0.69665	0.10349	-0.58398
S	0.60197	0.65125	0.71396	-0.50368	-0.26335	0.35775
R	-0.44318	0.07951	-0.84757	0.92080	0.05156	-0.88217
IM	0.51470	0.41269	0.79820	-0.72654	-0.26973	0.61295
PBIO	1.00000	0.41593	0.71609	-0.30173	-0.02978	0.23168
P	0.41593	1.00000	0.15692	0.30642	-0.36391	-0.43513
LBIO	0.71609	0.15692	1.00000	-0.73613	-0.05428	0.71403
PE	-0.30173	0.30642	-0.73613	1.00000	-0.09692	-0.96410
ELEV	-0.02978	-0.36391	-0.05428	-0.09692	1.00000	0.06970
LAT	0.23168	-0.43513	0.71403	-0.96410	0.06970	1.00000

Thus, 71 percent of the variance in the term LT and 59 percent of the variance in LU were explained by mean annual precipitation and biomass of potential vegetation. These R^2 values were considerably below those obtained in Phase II, implying that the inclusion of the subhumid quadrangles (P = 800 to 900 millimeters) weakened the models. Put another way, it may tentatively be concluded that a mean annual precipitation value of 900 millimeters more accurately approximates the boundary between the "humid" region, with apparently significant near-surface gamma-ray absorption and the "dry" region, in which this "masking" process is much weaker.

4. Phase IV: Dry Environment Regions (P is less than 900 millimeters)

Phase IV consisted of statistical tests focusing on quadrangles receiving less than 900 millimeters of mean annual precipitation. Dependent variables were the actual radioelement ratios (UHUA, THTA) rather than LT/LU. (See Figures 3-25 through 3-32 and A-48 through A-63 and Table 3-6.)

Figure 3-25. Dry-Environment Quadrangles (P < 900 millimeters) UHUA vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-27. Dry-Environment Quadrangles ($P < 900$ millimeters) THTA vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-28. Dry-Environment Quadrangles ($P < 900$ millimeters) THTA vs PBIO (A = 1 observation; B = 2 observations, etc.)

Figure 3-29. Dry-Environment Quadrangles ($P < 900$ millimeters) LU vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-30. Dry-Environment Quadrangles ($P < 900$ millimeters) LU vs PBIO (A = 1 observation; B = 2 observations, etc.)

Figure 3-31. Dry-Environment Quadrangles (P < 900 millimeters) LT vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-32. Dry-Environment Quadrangles (P < 900 millimeters) LT vs PBIO (A = 1 observation; B = 2 observations, etc.)

Table 3-6

Correlation Matrix: Dry-Environment Quadrangles
(P < 900 millimeters).

	UHUA	ELEV	AE	IM	D	PBIO
UHUA	1.00000	0.12112	0.09943	0.31902	-0.46540	0.36230
ELEV	0.12112	1.00000	-0.55397	-0.42454	0.19806	-0.37517
AE	0.09943	-0.55397	1.00000	0.64932	-0.57462	0.37091
IM	0.31902	-0.42454	0.64932	1.00000	-0.86431	0.81429
D	-0.46540	0.19806	-0.57462	-0.86431	1.00000	-0.69210
PBIO	0.36230	-0.37517	0.37091	0.81429	-0.69210	1.00000
LAT	0.32532	-0.06002	-0.17606	0.51427	-0.60740	0.65735
S	0.17955	-0.46885	0.28446	0.35537	-0.57329	0.73726
P	0.14671	-0.61219	0.93416	0.85556	-0.68334	0.60026
R	-0.43386	0.40113	-0.40062	-0.73019	0.74921	-0.75345
PE	-0.46255	-0.27599	0.20991	-0.45093	0.67957	-0.49434
LBIO	0.31742	-0.18959	0.11953	0.69346	-0.46957	0.78944
	LAT	S	P	R	PE	LBIO
UHUA	0.32532	0.17955	0.14671	-0.42836	0.46955	0.31742
ELEV	-0.06002	-0.46885	-0.61219	0.40113	-0.27399	-0.18959
AE	-0.17606	0.28446	0.93416	-0.40062	0.20791	0.11953
IM	0.51427	0.35537	0.85556	-0.73019	-0.45093	0.69346
D	-0.60740	-0.57329	-0.68334	0.74921	0.67957	-0.46957
PBIO	0.65735	0.73726	0.60026	-0.75345	-0.49434	0.78944
LAT	1.00000	0.57334	0.06946	-0.69645	-0.83344	0.55544
S	0.57334	1.00000	0.60735	-0.60272	-0.42990	0.83281
P	0.06946	0.60735	1.00000	-0.55623	0.01334	0.40980
R	-0.69645	-0.60272	-0.55623	1.00000	0.55978	-0.55202
PE	-0.83344	-0.42990	0.01334	0.55978	1.00000	-0.45333
LBIO	0.55544	0.83281	0.40980	-0.55202	-0.45333	1.00000

Evaluation of the multiple regression equation developed for the quadrangles in the dry western United States showed that: (1) the models generated were considerably less explanatory: (2) many more independent variables were required in the equation: and (3) the terms P and PBIO were much less important than they were in the humid-environment eastern USA. The equations derived were as follows:

$$\begin{aligned} \text{THTA} = & 9.305 - 0.009 (\text{P}) + 0.002 (\text{PE}) - 0.06 (\text{LAT}) \\ & - 0.008 (\text{S}) + 0.075 (\text{IM}) \end{aligned}$$

$$R^2 = 0.68$$

$$\begin{aligned} \text{UHUA} = & 15.59 + 0.025 (\text{PBIO}) - 0.006 (\text{IP}) - 0.17 (\text{LAT}) \\ & + 0.02 (\text{IM}) - 0.002 (\text{D}) - 0.009 (\text{R}) \end{aligned}$$

$$R^2 = 0.55$$

5. Phase V: Arid/Semiarid-Environment Quadrangles Only (P is less than 800 millimeters)

Phase V calculations, which were based on quadrangles receiving less than 800 millimeters of mean annual precipitation, indicated that (1) features such as elevation, latitude, annual moisture surplus, and radiation played a much greater role (in terms of the ratios THTA and UHUA) in the arid west than they did in eastern humid environments (Figures 3-33 through 3-40 and A-64 through A-79) and (2) correction models derived from multiple regression analysis seem more powerful and useful than those obtained in Phase IV (Table 3-7). These models were as follows:

$$\begin{aligned} \text{THTA} = & -51.03 - 0.009 (\text{ELEV}) + 0.75 (\text{LAT}) + 0.08 (\text{S}) \\ & - 0.43 (\text{IM}) + 0.054 (\text{R}) \end{aligned}$$

$$R^2 = 0.65$$

$$\text{UHUA} = -17.78 + 0.08 (\text{PBIO}) + 0.012 (\text{S}) + 0.04 (\text{R})$$

$$R^2 = 0.66$$

Table 3-7
Correlation Matrix: Arid/Semiarid Quadrangles
(P < 800 millimeters)

	UHUA	ELEV	AE	IM	D	PBIO
UHUA	1.00000	-0.15956	0.31566	0.31982	-0.25503	0.55471
ELEV	-0.15956	1.00000	-0.15183	-0.26865	0.10296	-0.03190
AE	0.31566	-0.15183	1.00000	-0.56311	0.52854	-0.11206
IM	0.31982	-0.26865	-0.56311	1.00000	-0.87050	0.50180
D	-0.25503	0.10296	0.52854	-0.87050	1.00000	-0.51447
PBIO	0.55471	-0.03190	-0.11206	0.50180	-0.51447	1.00000
LAT	-0.27996	0.07081	-0.96428	0.58471	-0.61131	0.15709
S	0.53920	-0.26384	-0.28865	0.94178	-0.80036	0.60364
P	0.72448	-0.35240	0.54079	0.38009	-0.28374	0.43655
R	0.08165	0.04621	0.85996	-0.81132	0.77398	-0.39139
PE	0.19109	-0.09733	0.97244	-0.70492	0.71190	-0.25897
LBIO	0.24660	-0.05335	-0.60658	0.79825	-0.75104	0.70446
	LAT	S	P	R	PE	LBIO
UHUA	-0.27996	0.53920	0.72448	0.08165	0.19109	0.24660
ELEV	0.07081	-0.26384	-0.35240	0.04621	-0.09733	-0.05335
AE	-0.96428	-0.28865	0.54079	0.85996	0.27244	-0.60658
IM	0.58471	0.94178	0.38009	-0.81132	-0.70492	0.79825
D	-0.61131	-0.80036	-0.28374	0.77398	0.71190	-0.75104
PBIO	0.15709	0.60364	0.43655	-0.39139	-0.25897	0.70446
LAT	1.00000	0.30673	-0.49653	-0.83301	-0.96562	0.67078
S	0.30673	1.00000	0.64926	-0.61410	-0.45375	0.71069
P	-0.49653	0.64926	1.00000	0.14361	0.36946	0.14253
R	-0.83301	-0.61410	0.14361	1.00000	0.92400	-0.82929
PE	-0.96562	-0.45375	0.36946	0.92400	1.00000	-0.70308
LBIO	0.67078	0.71069	0.14253	-0.82929	-0.70308	1.00000

Figure 3-33. Arid/Semiarid Quadrangles (P < 800 millimeters) UHUA vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-34. Arid/Semiarid Quadrangles (P < 800 millimeters) UHUA vs PBIO (A = 1 observation; B = 2 observations, etc.)

Figure 3-35. Arid/Semiarid Quadrangles (P < 800 millimeters) THTA vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-36. Arid/Semiarid Quadrangles (P < 800 millimeters) THTA vs PBIO (A = 1 observation; B = 2 observations, etc.)

Figure 3-37. Arid/Semiarid Quadrangles ($P < 800$ millimeter) LJ vs IM (A = 1 observation; B = 2 observation, etc.)

Figure 3-38. Arid/Semiarid Quadrangles ($P < 800$ millimeters) LU vs PBIO (A = 1 observation; B = 2 observations, etc.)

Figure 3-39. Arid/Semiarid Quadrangles ($P < 800$ millimeters) LT vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 3-40. Arid/Semiarid Quadrangles ($P < 800$ millimeters) LT vs PBIO (A = 1 observation; B = 2 observations, etc.)

SECTION IV

SUMMARY AND CONCLUSIONS

The purpose of this preliminary investigation was to determine the relationship between near-surface environmental factors (e.g., soil moisture) and the "discrepancy" in radioelement concentrations as measured by aerial reconnaissance and hydrogeochemical/stream sediment analyses. Furthermore, where such (significant) associations were identified, the aim was to develop quantitative models that could help explain and correct these deviations.

Results of the study indicate that a number of the environmental variables examined, particularly moisture terms, correlate highly with uranium and thorium ratios. Specifically, the following key observations were made:

1. Nationwide (all 47 test quadrangles combined), there was a strong positive correlation between radioelement ratios (hydrogeochemical versus aerial data) and indices of moisture and biomass. These relationships suggest that near-surface gamma-radiation absorption "masks" these concentrations of uranium and thorium from accurate measurement by aerial gamma-ray spectrometry.
2. The above-stated relationship was particularly significant in quadrangles in the humid eastern United States (P is greater than 900 millimeters per year), where stepwise multiple regression equations explained more than 70 percent of the variance in the (log) thorium ratio and more than 80 percent of the variance in the (log) uranium ratio. It should be noted that these models necessitated the use of only two (independent) environmental factors: precipitation (P) and biomass of potential vegetation (PBIO). In such humid regions, data obtained by aerial surveys must be corrected for this absorption effect if they are to be useful measures of radioelement concentrations.
3. The relatively small difference between ARR and HSSR data in the arid/semiarid western United States (P is less than 800 millimeters per year) is:
 - Less amenable to simple explanation through the use of multivariate linear models, although such models do explain approximately 65 percent of the variance in the ratios for uranium and thorium.
 - Apparently related to a broad range of environmental influences, including elevation, latitude, moisture surplus, and solar radiation.

As a rule of thumb, it may be stated that, whereas aerial radio-metric reconnaissance generally provides relatively reliable data in arid regions, such data — if uncorrected — are not trustworthy indicators of radioelement concentrations in humid climatic regions. To be reasonably useful, the latter must be corrected for the effects of gamma-ray absorption and soil formation processes.

The problem of the uncertainties associated with these conclusions should be addressed at this point. The results of this study represent an important advance, but understanding of their true significance is clouded by four uncertainty factors:

- All of the data utilized, environmental and radioelement, were simplified, generalized, reconnaissance-level, fundamentally crude indices. Considerable improvement in the level of resolution, specificity, and reliability of these measurements is possible and needed.
- The relationships among environmental factors are complex and synergistic. This is particularly true of moisture-related variables. Such "influences" as precipitation (P) and biomass of potential vegetation (PBIO), which were each highly correlated with the radioelement ratios, may not be genuine controls in a cause-effect sense at all. Rather, they may be only indicators of the general "humidness" of a quadrangle.
- The varying regional effects of placering of heavy metals in stream sediments are not addressed in this investigation because information is insufficient. It has been demonstrated that the H33R data for such areas as Athens (Georgia) and Denver (Colorado) are anomalously high (relative to actual subsurface radioelement concentrations; see Part II of this report), while those for quadrangles in very silty regions (e.g., the Great Plains) may be too low. Future studies must address and correct for placering and dilution influences.

SECTION V
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PART II FOLLOW-UP STUDY

SECTION I INTRODUCTION

A major finding of the preliminary study was the strong implication that in some of the more humid quadrangles (particularly in the southeastern United States) the HSSR stream sediment data are not a reliable measure of average surface uranium and thorium concentrations. Apparently, there has been considerable placer concentration of the radioactive minerals, resulting in THTA and UHUA values that are anomalously high (i.e., 10) relative to the amount of gamma-ray absorption by soil moisture or vegetation.

It was decided to search for some local surface calibration data based on chemical analysis to compare with the aerial radiometric values and thereby to generate actual measures of the amounts of gamma-ray absorption. Such data were obtained for the Portland, Denver, Pueblo, and Athens quadrangles.

The Portland quadrangle contains the Conway Granite, which has been extensively studied by Richardson (1964). Based on his analyses for thorium and uranium, Texas Instruments (1976) calculated local calibration constants for the aerial radiometric system used in the ARR survey. They are compared in Table 1-1 with constants obtained for an equivalent system over the Lake Mead test strip and were used to calculate THTA' and UHUA' values that reflect actual gamma-ray absorption. The HSSR-derived THTA' and UHUA' values from Table 1-2 are shown in Table 1-1 for comparison.

Phair and Gottfried (1964) published data on the uranium and thorium content of the Pikes Peak Batholith, which is extensively exposed in the Denver and Pueblo quadrangles. These quadrangles are compared with the ARR-derived values for that formation (geoMetrics, 1979) in Table 1-1 along with the corresponding THTA' and UHUA' values.

Table 1-1
Actual and HSSR-Derived Gamma-Ray Absorption Measures

Quadrangle	Calibration Constants (cps/ppm)				HSSR-Derived Values		Actual Values	
	Lake Mead		Local		THTA	UHUA	THTA'	UHUA'
	U	Th	U	Th				
Portland	11.6	5.9	4.15	1.65	3.28	3.18	3.58	2.80
	ARR Values (ppm)		Surface Samples (ppm)					
	U	Th	U	Th				
Denver	3.6	21.6	4.9	25.7	-	3.25	1.19	1.36
Pueblo	3.7	21.0	4.9	25.7	-	2.12	1.22	1.32
Athens	2.47	9.07	5.56	37.8	10.08	7.12	3.83	2.25

Table 1-2
Quadrangle Mean Values

NUMBER	QUAD	ELEV	LONG	LAT	PE	P	AE	D	S	R	SA
1	ATHENS	243	83.3	33.9	888	1204	837	51	367	400	35
2	AUGUSTA	43	81.9	33.4	972	1151	925	47	226	415	20
3	CLINTON	427	99.0	35.5	942	680	680	262	0	410	0
4	DENVER	1612	104.9	39.8	641	366	366	275	0	410	0
5	EMORYPEAK	2593	103.3	29.2	1116	474	474	642	0	510	0
6	GREELEY	1549	104.7	40.4	595	381	381	214	0	400	0
7	KINGMAN	1015	114.1	35.2	880	277	277	603	0	550	18
8	LASVEGAS	658	115.2	36.1	1127	102	102	1025	0	550	20
9	LOVELOCK	1212	118.5	40.2	679	103	103	576	0	470	60
10	PORTLAND	18	70.3	43.7	593	1077	574	19	503	310	5
11	PRESIDIO	857	104.5	29.6	1116	474	474	642	0	510	0
12	PUEBLO	1414	104.5	38.3	707	303	303	404	0	420	0
13	TULAROSA	1480	106.0	33.1	872	276	276	596	0	520	5
14	WILLIAMS	2057	112.2	35.3	590	578	518	72	60	540	10
15	WINNEMUCCA	1310	117.2	40.9	631	217	217	414	0	450	50
NUMBER	QUAD	IM	SM	PBIO	LBIO	THTA	UHUA	LT	LU		
1	ATHENS	35.6	.	35.0	14.4	3.83	2.25	0.583	0.352		
2	AUGUSTA	18.4	.	35.0	11.9	3.83	2.25	0.583	0.352		
3	CLINTON	-27.8	.	6.6	2.3	0.90	1.53	-0.047	0.184		
4	DENVER	-42.9	17.5	11.9	8.7	1.19	1.36	0.075	0.134		
5	EMORYPEAK	-57.5	16.7	2.0	6.6	1.03	1.12	0.013	0.049		
6	GREELEY	-36.0	9.3	8.9	9.7	1.19	1.36	0.075	0.134		
7	KINGMAN	-68.5	.	1.3	3.9	1.01	0.66	0.004	-0.180		
8	LASVEGAS	-91.0	15.4	4.8	5.1	1.50	0.76	0.175	-0.119		
9	LOVELOCK	-84.8	.	4.0	4.9	0.81	1.11	-0.093	0.045		
10	PORTLAND	81.6	.	26.9	20.6	3.58	2.80	0.553	0.447		
11	PRESIDIO	-57.5	18.5	1.4	5.7	1.54	0.99	0.187	-0.005		
12	PUEBLO	-57.1	15.4	13.8	7.2	1.22	1.32	0.088	0.122		
13	TULAROSA	-68.3	.	3.8	8.2	.	1.18	.	0.072		
14	WILLIAMS	-2.0	20.0	5.2	9.1	2.75	1.94	0.439	0.289		
15	WINNEMUCCA	-65.6	.	4.6	4.9	1.17	1.60	0.066	0.204		

N=15

Garvey (1975) presented uranium and thorium analytical data on igneous plutons in the Athens quadrangle, including the Elberton, Danburg, Sparta, and Siloam areas (14 samples). Comparison of his geologic map with that in Geodata (1975) showed a reasonable match between these units and CGR (igneous plutons in the Athens quadrangle) reported by Geodata. The data are compared in Table 1-1.

Examination of the preliminary data and results (in Part I of this report) indicated close similarities between Greeley and Denver quadrangles and between Athens and Augusta as to time of ARR coverage, climate, physiography, and general environmental conditions. Therefore, these two additional quadrangles were included in the follow-up study, using the Denver THTA' and UHUA' values for Greeley and the Athens values for Augusta.

The earlier data (Part I) also indicated that the major effects of placering are restricted to the more humid and severely chemically weathered regions. On this basis, the arid-environment quadrangles in the Basin and Range province were included, using the HSSR-derived values for THTA and UHUA.

SECTION II

STATISTICAL ANALYSES

Table 1-2 summarizes the mean values of the quadrangles selected for study. These were statistically processed as described in subsection III.A (Part I); Table 2-1 presents the means and standard deviations as well as the correlation matrix for the variables. Inspection of the correlation coefficients shows IM (annual moisture index) to be most highly correlated with UHUA and THTA. P (mean annual precipitation), S (mean annual moisture surplus), PBIO (biomass of potential vegetation), and LBIO (biomass of land-use vegetation) are also highly correlated with UHUA and THTA. Figures 2-1 through 2-10 are scattergrams illustrating these correlations. The points representing Portland, Athens, Augusta, Denver, Greeley, and Pueblo are identified on each plot.

The environmental variables most closely related to soil moisture and vegetation are, of course, IM, PBIO, and LBIO. These were chosen for multiple linear regression analysis, which resulted in the following equations:

Best single-variable model for UHUA:

$$\text{UHUA} = 1.88 + 0.0116 (\text{IM}); R^2 = 0.883$$

Best two-variable model for UHUA:

$$\text{UHUA} = 1.76 + 0.0102 (\text{IM}) + 0.0073 (\text{PBIO}); R^2 = 0.890$$

Best three-variable model for UHUA:

$$\text{UHUA} = 1.75 + 0.0101 (\text{IM}) + 0.0072 (\text{PBIO}) + 0.00104 (\text{LBIO}); R^2 = 0.890$$

Best single-variable model for THTA:

$$\text{THTA} = 2.47 + 0.0201 (\text{IM}); R^2 = 0.754$$

Best two-variable model for THTA:

$$\text{THTA} = 1.69 + 0.0443 (\text{PBIO}) + 0.0115 (\text{IM}); R^2 = 0.831$$

Best three-variable model for THTA:

$$\text{THTA} = 1.47 + 0.0423 (\text{PBIO}) + 0.0223 (\text{LBIO}) + 0.0099 (\text{IM}); R^2 = 0.833$$

Table 2-1

Means, Standard Deviations, and Correlation Matrix for Parameters Studied in Test Quadrangles

MEANS AND STD DEVIATIONS

	ELEV	LONG	LAT	PE	P	AE	D	S
MEAN	1072	102.4	36.53571	819.786	527.643	445.071	374.714	82.57143
STD DEV	759.042	14.47336	4.25867	209.607	371.922	249.347	296.079	163.359

	R	SA	IM	PBIO	LBIO	THTA	UHUA
MEAN	453.214	15.57143	-32.50714	11.52857	8.21429	1.82372	1.50408
STD DEV	70.97143	19.96039	49.39966	11.96985	4.83335	1.14163	0.61434

NUMBER OF OBSERVATIONS= 14

CORRELATION MATRIX

	ELEV	LONG	LAT	PE	P	AE	D	S
ELEV	1.00000	0.60568	-0.15081	-0.15958	-0.56590	-0.43446	0.25291	-0.62524
LONG	0.60568	1.00000	-0.02742	-0.01387	-0.92236	-0.79599	0.66053	-0.88497
LAT	-0.15081	-0.02742	1.00000	-0.82358	-0.15241	-0.36160	-0.27852	0.20494
PE	-0.15958	-0.01387	-0.82358	1.00000	0.05079	0.17647	0.55933	-0.15372
P	-0.56590	-0.92236	-0.15241	0.05079	1.00000	0.93713	-0.75326	0.84631
AE	-0.43446	-0.79599	-0.36160	0.17647	0.93713	1.00000	-0.71723	0.60719
D	0.25291	0.66053	-0.27852	0.55933	-0.75326	-0.71723	1.00000	-0.62018
S	-0.62524	-0.88497	0.20494	-0.15372	0.84631	0.60719	-0.62018	1.00000
R	0.45383	0.73827	-0.55180	0.45861	-0.57156	-0.43960	0.69489	-0.63028
SA	-0.17273	0.27468	0.24778	-0.15919	-0.15175	-0.26467	0.11020	0.05849
IM	-0.49104	-0.90228	0.16058	-0.26622	0.91916	0.77320	-0.83963	0.91243
PBIO	-0.63322	-0.85602	0.12308	-0.10209	0.85578	0.72826	-0.68559	0.83677
LBIO	-0.38362	-0.83513	0.30357	-0.33453	0.74567	0.51313	-0.66897	0.91445
THTA	-0.54863	-0.78637*	-0.03724	-0.05104	0.87738*	0.73409*	-0.65435*	0.87705*
UHUA	-0.44425	-0.81123*	0.29069	-0.39309	0.84407*	0.69600*	-0.86444*	0.85934*

	R	SA	IM	PBIO	LBIO	THTA	UHUA
ELEV	0.45383	-0.17273	-0.49104	-0.63322	-0.38362	-0.54863	-0.44425
LONG	0.73827	0.27468	-0.90228	-0.85602	-0.83513	-0.78637	-0.81123
LAT	-0.55180	0.24778	0.16058	0.12308	0.30357	-0.03724	0.29069
PE	0.45861	-0.15919	-0.26622	-0.10209	-0.33453	-0.05104	-0.39309
P	-0.57156	-0.15175	0.91916	0.85578	0.74567	0.87738	0.84407
AE	-0.43960	-0.26467	0.77320	0.72826	0.51313	0.73409	0.69600
D	0.69489	0.11020	-0.83963	-0.68559	-0.66897	-0.65435	-0.86444
S	-0.63028	0.05849	0.91243	0.83677	0.91445	0.87705	0.85934
R	1.00000	0.11128	-0.67512	-0.67883	-0.66739	-0.39844	-0.72103
SA	0.11128	1.00000	-0.18196	0.06042	-0.11443	0.04457	0.01880
IM	-0.67512	-0.18196	1.00000	0.80091	0.88910	0.86208	0.93923
PBIO	-0.67883	0.06042	0.80091	1.00000	0.78904	0.86171	0.80367
LBIO	-0.66739	-0.11443	0.88910	0.78904	1.00000	0.82579	0.84047
THTA	-0.39844	0.04457	0.86803*	0.86171*	0.82579*	1.00000	0.84041
UHUA	-0.72103*	0.01880	0.93923*	0.80367*	0.84047*	0.84041	1.00000

Figure 2-1. UHUA vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 2-2. UHUA vs P (A = 1 observation; B = 2 observations, etc.)

Figure 2-3. UHUA vs S (A = 1 observation; B = 2 observations, etc.)

Figure 2-4. UHUA vs PBIO (A = 1 observation; B = 2 observations, etc.)

Figure 2-5. UHUA vs LBIO (A = 1 observation; B = 2 observations, etc.)

Figure 2-6. THTA vs IM (A = 1 observation; B = 2 observations, etc.)

Figure 2-7, THTA vs P (A = 1 observation; B = 2 observations, etc.)

Figure 2-8. THTA vs S (A = 1 observation; B = 2 observations, etc.)

Figure 2-9. THTA vs PBIO (A = 1 observation; B = 2 observations, etc.)

Figure 2-10. THTA vs LBIO (A = 1 observation; B = 2 observations, etc.)

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

The multiple linear regression analysis indicates that the pair of two-variable models relating UHUA and THTA to IM and PBIO are reasonably satisfactory in that they account for between 80 and 90 percent of the variance in these terms. These models could be applied to the aerial data in the more humid regions to approximately correct for soil moisture and vegetation gamma-ray absorption effects by multiplying apparent aerial radiometric (eU and eTh) values by the appropriate UHUA or THTA factors. However, it must be recognized that much more surface calibration information is needed to improve the models and optimize the results of such corrections.

It is recommended that bedrock radioelement measurements be obtained and evaluated over at least five selected quadrangles in each of the major physiographic provinces of the conterminous United States and Alaska to provide calibration information leading to a clear understanding of these very important influences. This can be done by selecting from the formations mapped during the aerial reconnaissance survey formations that can be readily sampled on the surface. A statistically significant representative group of "fresh" (unweathered) samples should be obtained and analyzed by laboratory gamma-spectral measurements for eU, eTh, and K. The ratios of the mean surface sample analyses to the corresponding aerial-survey mean values can then be utilized to refine the UHUA and THTA models and to create similar models for the potassium data as well.

SECTION IV

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APPENDIX
ADDITIONAL SCATTERGRAMS OF
RADIOELEMENT VERSUS ENVIRONMENTAL VARIABLES

TEST QUADRANGLES

4

PLOT OF UHUA*P

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF UHUA*AE

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

7

PLOT OF UHUA*D

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

8

PLOT OF UHUA*S

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF THTA*AE

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF THTA*D

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

18

PLOT OF THTA*S

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LU*P LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LU*AE LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF $LU \times D$ LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LU*S

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LT*P LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF $LT \times AE$ LEGEND: A = 1 OBS, D = 2 OBS, ETC.

TEST QUADRANGLES

38

PLOT OF LT×S LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LT*D LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF UHUA*P LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF UHUA*AE

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

16

PLOT OF UHUA/D

LEGEND: A = 1 DEG, B = 2 DEG, ETC.

TEST QUADRANGLES

97

PLOT OF UHUA*S

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF THTA*P

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF THTA*AE

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

106

PLOT OF THTA*D

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

107

PLOT OF THTA*S

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LT*P LEGEND: A = 1 OBS, E = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF $LT \times AE$ LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

126

PLOT OF LT%D LEGEND: A = 1 OBS, B = 2 CBS, ETC.

TEST QUADRANGLES

127

PLOT OF LT*S

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LU*P LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

115

PLOT OF LU*AE

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LUxD LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

117

PLOT OF LU*S

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

154

PLOT OF UHUA*P

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

156

PLOT OF UHUA*AE LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF UHUA*D LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF UHUA*S LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF THTA*P

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF THTA*AE

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF THTA * D

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

168

PLOT OF THTA*S LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LUXP LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LU*AE

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

177

PLOT OF LU*D LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

178

PLOT OF LU*S

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

184

PLOT OF LT*P

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

186

PLOT OF $LT \times AE$

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF $LT \times D$ LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

188

PLOT OF LT×S LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

213

PLOT OF UHUA*P

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

215

PLOT OF UHUA*AE

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

216

PLOT OF UHUAxD

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

223

PLOT OF THTA*P

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

225

PLOT OF THTA*AE

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

226

PLOT OF THTA*D

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF THTA*S

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

233

PLOT OF LU*P LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF $LU \times AE$

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

236

PLOT OF LU×D

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

237

PLOT OF LU*S

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

243

PLOT OF LT*P LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

245

PLOT OF LT*AE

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

PLOT OF $LT \times D$ LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LT*S LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF UHUA*P

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

273

PLOT OF UHUA*AE

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF UHUA*D

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

275

PLOT OF UHUA*S LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

281

PLOT OF THTA*P LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF $THTA \times AE$

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF $THTA \times S$

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF $LU \times P$ LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF $LUX \times AE$ LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LUxD

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

295

PLOT OF LU*S

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LT*P

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

303

PLOT OF $LT \times AE$ LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF $LT \times D$

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

TEST QUADRANGLES

PLOT OF LT*S

LEGEND: A = 1 OBS, B = 2 OBS, ETC.