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Office of Nuclear Regulatory Research
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SUBJECT: FINAL REPORT—FINAL STATUS SURVEY USING MARSSIM SURVEY METHODOLOGIES AT THE CUSHING REFINERY SITE

Dear Dr. Powers:

Enclosed are ten copies of the subject final report. NRC comments on the draft report have been incorporated.

If you have any questions, please direct them to me at (423) 576-3740 or W. L. (Jack) Beck at (423) 576-5031.

Sincerely,

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FINAL STATUS SURVEY USING MARSSIM SURVEY METHODOLOGIES AT THE CUSHING REFINERY SITE

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Prepared for the
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Division of Regulatory Applications

ORISE
OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION
Environmental Survey and Site Assessment Program
Environmental and Health Sciences Division

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FINAL REPORT

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FINAL STATUS SURVEY
USING MARSSIM SURVEY METHODOLOGIES
AT THE
CUSHING REFINERY SITE

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ABBREVIATIONS AND ACRONYMS

A&A	Auxier and Associates
AEC	Atomic Energy Commission
ASME	American Society of Mechanical Engineers
cm	centimeter
DCGL	derived concentration guideline level
DOE	Department of Energy
DQA	data quality assessment
DQOs	data quality objectives
EMC	Elevated Measurement Comparison
EML	Environmental Measurements Laboratory
EPA	Environmental Protection Agency
ESSAP	Environmental Survey and Site Assessment Program
H_a	alternative hypothesis
H_o	null hypothesis
kg	kilogram
KMC	Kerr-McGee Corporation
LBGR	lower bound of the gray region
m	meter
m	adjusted reference measurement
m^2	square meter
m^3	cubic meter
n	survey unit measurement
MARSSIM	Multiagency Radiation Survey and Site Investigation Manual
MDC	minimum detectable concentration
NaI	sodium iodide
NIST	National Institute of Standards and Technology
NMSS	Office of Nuclear Material Safety and Safeguards
NRC	Nuclear Regulatory Commission
ORISE	Oak Ridge Institute for Science and Education
pCi/g	picocuries per gram
RMA	radioactive material area
UF_6	uranium hexafluoride
UF_4	uranium tetrafluoride
W_r	sum of the ranks of the adjusted measurements from the reference area
WRS	Wilcoxon Rank Sum (statistical test)

FINAL STATUS SURVEY
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CUSHING REFINERY SITE

INTRODUCTION

The Cushing refinery site is located two miles north of the City of Cushing in Payne County, Oklahoma and was operated from 1915 to 1972. Kerr-McGee Corporation (KMC) purchased the Cushing site from General American Oil Company of Texas in 1956 and operated an oil refinery there from 1956 to 1972. From 1962 to 1966, KMC used part of the Cushing refinery site to process natural thorium and natural, depleted, and enriched uranium under two Atomic Energy Commission (AEC) licenses, SMB-664 and SNM-695.

AEC license SMB-664 was issued to KMC on November 7, 1962 and authorized unlimited quantities in a variety of chemical forms of uranium and thorium. The bulk of uranium material received was UF_6 (uranium hexafluoride). Typical products were oxides, carbides, fluorides, nitrates, metal, etc. Thorium material was received in the form of concentrates. Typical products were oxides or carbides or combinations of uranium and thorium compounds at various ratios of thorium to uranium (KMC 1995).

AEC license SNM-695 was issued to KMC on April 23, 1963 and authorized possession of any enrichment of uranium in any form, except metal, including scrap recovery, not to exceed 1000 kilograms (kg) of uranium-235. The uranium was received in the form of UF_6 and other chemical compounds and was converted to other compounds of uranium suitable for nuclear fuels. AEC license SNM-695 was amended to permit reduction of high enriched UF_4 (green salt) to uranium metal buttons.

Enriched uranium was processed at Cushing from early 1963 until September 1965 and thorium processing was performed from December 1964 until February 1966. In April 1966 KMC reported to the AEC that as of April 26, 1966, all special nuclear material had been transferred from the Cushing site to KMC's new Cimarron facility in Crescent, Oklahoma and that all Cushing buildings

in which licensed activities had been performed were cleaned and decontaminated. The AEC conducted a close-out survey of the Cushing facility on July 6, 1966. On the basis of this survey, and in response to KMC's request for authorization to release the facility for unrestricted use, licenses SMB-664 and SNM-695 were terminated on July 25, 1966 (KMC 1995).

KMC has performed characterization surveys and subsequent remediation for a large portion of their site. During cleanup activities, some radioactively contaminated materials were placed in burial trenches, old petroleum storage tanks dike areas, and part of a hydrocarbon waste impoundment (Pit 4) on the site. A final status survey is being planned by KMC to demonstrate compliance with the Nuclear Regulatory Commission (NRC) guidelines. A portion of the site was surveyed by the Environmental Survey and Site Assessment Program (ESSAP) of the Oak Ridge Institute for Science and Education (ORISE) using the Multiagency Radiation Survey and Site Investigation Manual (MARSSIM) methodology, as a demonstration of its applicability. Specifically, land areas slightly contaminated with thorium were selected for this evaluation.

SITE DESCRIPTION

The KMC Cushing site is located in Payne County, Oklahoma, two miles north of the City of Cushing. Cushing lies about midway between Tulsa and Oklahoma City. The terrain of the region is rolling, oil-producing pasture land. Several oil fields were developed in the immediate area. The elevation of the refinery site ranges from 250 to 280 meters above sea level. The entire Cushing site encompasses approximately 178 hectares.

The Class 1 area selected for this evaluation is Radioactive Material Area (RMA)-4. RMA-4 has a land area of approximately 2,300 square meters (m^2). Class 1 survey areas are those areas with the highest potential for contamination—including the potential for small areas of elevated activity. The Class 2 area was selected from Cushing grid block 46—located on the eastern portion of the site. The Class 2 area consisted of approximately 2,300 m^2 located in the northern portion of grid block 46. Class 2 survey areas exhibit a potential for contamination, but they have little or no potential for small areas of elevated activity. An appropriate background reference area was identified during

a previous NRC visit to the Cushing site. A preliminary assessment performed by NRC's contractor, the Environmental Measurements Laboratory (EML), indicated that Cushing grid block 61 was an appropriate reference area for the selected Class 1 and 2 areas (Figure 1).

OBJECTIVES

The objective of the final status survey was to demonstrate the feasibility of implementing the MARSSIM methodology in a final status survey of land areas at a site contaminated with thorium.

DOCUMENT REVIEW

ESSAP and Auxier and Associates (A&A) reviewed the historical site assessment data for the Cushing Refinery Site. KMC provided characterization data for RMA-4 and grid block 46 that included analytical results for Th-232 concentrations in soil. The standard deviation calculated using all 115 data points in RMA-4 was 0.31 picocuries per gram (pCi/g) Th-232. The RMA-4 characterization data was evaluated, and based on the distribution of Th-232 concentrations, it was apparent that contamination was present in two of the samples. Because it was anticipated that remediation would be performed prior to the final status survey, the decision was made to remove these two outliers at the upper end of the distribution and to compute a revised standard deviation (0.27 pCi/g Th-232). In a similar manner, the revised standard deviation in grid block 46 was also 0.27 pCi/g for Th-232. It was expected that the standard deviation in the background reference area (grid block 61) would not be greater than the standard deviations determined in the Class 1 and 2 areas. Therefore, a standard deviation of 0.27 pCi/g for Th-232 was used to determine the necessary sample size for the nonparametric statistical tests.

PROCEDURES

The final status survey design followed the methodology presented in the MARSSIM Public Review Draft (MARSSIM 1996a). ESSAP performed visual inspections and final status survey measurements and sampling from October 28 through 30, 1996. Survey activities were conducted

in accordance with a site-specific survey plan dated October 21, 1996 and the ORISE/ESSAP Survey Procedures and Quality Assurance Manuals (ORISE 1996, 1995a and b). This report summarizes the procedures and results of the final status survey activities. Additional information regarding major instrumentation, sampling equipment and procedures, and analytical procedures is provided in Appendices A and B.

FINAL STATUS SURVEY DESIGN

The process of designing a final status survey began with development of data quality objectives (DQOs); on the basis of these objectives and the known or anticipated radiological conditions of the site, the numbers and locations of measurement and sampling points, required to demonstrate compliance with derived concentration guideline levels (DCGLs) and conditions, were then determined. DCGLs are radionuclide-specific levels corresponding to the release criterion, as determined by exposure pathway modeling. Survey techniques, appropriate to develop adequate data, were selected and implemented. Survey instrumentation was selected based on detection sensitivity to the radiations of concern.

A meeting of NRC and contractor personnel was held on June 26 and 27, 1996 for the purpose of designing a limited prototype final status survey at the Kerr-McGee facility in Cushing, Oklahoma. The seven-step DQO process was followed in this planning meeting. Steps I through V were accomplished without major difficulty; Step VI—Specifying Limits on Decision Errors—introduced problems because of the need to identify actual values of various parameters. Type I and Type II decision errors were specified after some discussion on the anticipated survey difficulty, but DCGLs and area factors were not available at that time. The final DQO step—Optimizing the Survey Design—was accomplished using example values for necessary parameters to determine the number of necessary data points. A conference call between NRC and contractor personnel was held on October 9, 1996 for the purpose of confirming details of the prototype final status survey, including the DCGL and area factors for thorium, decision errors, and locations of Class 1 and 2 areas.

Application of Decommissioning Criteria

As part of the DQO process the objective of the survey and the null and alternate hypotheses should be clearly stated. The objective of final status surveys is to demonstrate that residual radioactivity levels meet the release criterion. In demonstrating that this objective is met, the null hypothesis, H_o, tested is that residual contamination exceeds the release criterion; the alternative hypothesis, H_a, is that residual contamination meets the release criterion.

Null Hypothesis (H_o): Residual contamination exceeds the release criterion

For contaminants that are present in background—e.g., uranium and thorium—the Wilcoxon Rank Sum (WRS) test is used. To determine data needs for this test, the acceptable probability of making Type I and Type II decision errors are established. The Type I decision error occurs when the H_o is rejected when it is true—results in concluding that survey units incorrectly satisfy release criterion (regulator's risk). The Type II decision error occurs when the H_o is accepted when it is false—results in unnecessary remediation (licensee's risk). The acceptable decision error rates were determined during the DQO process to reflect the anticipated difficulty of measuring residual uranium and thorium radioactivity at near-background levels. The Type I error (α) was specified as 0.05 and Type II decision error (β) was set at 0.10.

Derived Concentration Guideline Levels (DCGLs)

Results from previous surveys indicated the presence of thorium and uranium (including various enrichments of uranium). The thorium chain appeared to be in equilibrium with Th-232. For planning purposes for this prototype survey, the only contaminant of concern considered was thorium, uranium contamination identified was not evaluated in the survey design or subsequent demonstration of compliance. The applicable DCGL for residual thorium concentrations in soil is:

Th-232 (in equilibrium with progeny): 0.16 pCi/g (above background)

Contaminant Present in Background—Determining Numbers of Data Points for Statistical Tests

The following steps detail the procedure for determining the number of data points for the WRS test.

A. Calculate the Relative Shift

The contaminant DCGL value, lower bound of the gray region, and the standard deviation in the background level of the contaminant were used to calculate the relative shift, Δ/σ. When the estimated standard deviation in the reference area and survey units are different, the larger of these values should be used to calculate the relative shift.

The following information is used in the determination of relative shift:

1) The DCGL for Th-232 — 0.16 pCi/g in soil

2) Standard deviation of Th-232 in reference area and survey units—0.27 pCi/g in the Class 1 area and 0.27 pCi/g in the Class 2 area. It was assumed that the standard deviation in the reference area was not larger than the standard deviation in the Class 1 and 2 areas. The MARSSIM recommends using the larger value of standard deviation (0.27 pCi/g) when the standard deviation in the survey units and reference area are different.

3) Selection of the Lower Bound of the Gray Region (LBGR). Because Th-232 has a small DCGL, the LBGR was selected as zero.

The gray region is bounded above by the DCGL and below by the LBGR. The width of the gray region is delta, Δ. Thus, Δ = DCGL - LBGR (0.16 minus 0). The relative shift was then calculated directly—0.16/0.27 equals 0.593, rounded to 0.6.

B. Determine P_r

Table 1 contains a listing of relative shift values and values for P_r (Table 5.1 in MARSSIM 1996b). P_r is the probability that a measurement at a random location in the survey unit is greater than a measurement performed at a random location in the background reference area. Using the relative shift value calculated previously, the value of P_r was obtained from Table 1. Therefore, for a relative shift value of 0.6, the value of P_r was 0.664.

C. Determine Decision Error Percentiles

The next step in this process was to determine the percentiles, $Z_{1-\alpha}$ and $Z_{1-\beta}$, represented by the selected decision error levels, α and β, respectively (Table 2). As stated earlier, α was selected at 0.05 and β was selected at 0.10. From Table 2, the percentile $Z_{1-\alpha}$ equals 1.645, and $Z_{1-\beta}$, equals 1.282 (Table 2 from MARSSIM 1996b).

D. Calculate Number of Data Points for WRS Test

The number of data points, N, to be obtained from each reference area/survey unit pair for the WRS test was calculated using:

$$N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{3\ (P_r - 0.5)^2}.$$

Substituting in the values determined above, N was calculated:

$$N = \frac{(1.645 + 1.282)^2}{3\ (0.664 - 0.5)^2} = 106.2$$

Of this total number, 53 samples were designated to be collected from the reference area and 53 from each survey unit.

To assure sufficient data points to attain the desired power level with the statistical tests and allow for possible lost or unusable data, it is recommended that the number of calculated data be increased by 20%, and rounded up, for further assurance of sufficient data points. This yielded 64 samples to be collected in both the survey unit and reference area.

Table 1: Values of P_r for a Given Shift Δ/σ

Δ/σ	P_r	Δ/σ	P_r
---	----	2	0.921
0.0625	0.518	2.0625	0.928
0.125	0.535	2.125	0.933
0.1875	0.553	2.1875	0.939
0.25	0.570	2.25	0.944
0.3125	0.587	2.3125	0.949
0.375	0.605	2.375	0.953
0.4375	0.621	2.4375	0.958
0.5	0.638	2.5	0.961
0.5625	0.655	2.5625	0.965
0.6	0.664	2.625	0.968
0.6875	0.687	2.6875	0.971
0.75	0.702	2.75	0.974
0.8125	0.717	2.8125	0.977
0.875	0.732	2.875	0.979
0.9375	0.746	2.9375	0.981
1	0.760	3	0.983
1.0625	0.774	3.0625	0.985
1.125	0.787	3.125	0.986
1.1875	0.799	3.1875	0.988
1.25	0.812	3.25	0.989
1.3125	0.823	3.3125	0.990
1.375	0.835	3.375	0.991
1.4375	0.845	3.4375	0.992
1.5	0.856	3.5	0.993
1.5625	0.865	3.5625	0.994
1.625	0.875	3.625	0.995
1.6875	0.884	3.6875	0.995
1.75	0.892	3.75	0.996
1.8125	0.900	3.8125	0.996
1.875	0.908	3.875	0.997
1.9375	0.915	3.9375	0.997

Table 2: Percentiles Represented by Selected Values of α and β.

α (or β)	$Z_{1-\alpha}$ (or $Z_{1-\beta}$)
0.005	2.576
0.01	2.326
0.025	1.960
0.05	1.645
0.10	1.282
0.20	0.842
0.25	0.674

Determining Data Points for Areas of Elevated Activity

For Class 1 areas, the number of data points required by the WRS test for uniform levels of contamination may need to be supplemented to ensure a reasonable level of assurance that any small areas of elevated residual radioactivity are not missed during the final status survey. Soil sampling on a specified grid size, in conjunction with surface scanning, are used to obtain an adequate assurance level that small areas of residual radioactive contamination will still satisfy DCGLs—applicable to small areas.

The number of survey data points needed for the WRS test (64 for both reference area and survey units) were positioned, on a scale map of each survey unit, using a random-start triangular pattern (Figures 2 through 4 show scale maps of each survey unit and the reference area). The number of calculated survey locations, 64, was used to determine the grid spacing, L, of the triangular pattern (Figure 2). Specifically, the spacing, L, of the triangular pattern was given by:

$$L = \sqrt{\frac{A}{0.866\ n}},$$

where A is the area of the Class 1 survey unit (2,300 m^2) and n is the number of data points in the survey unit. The spacing equals 6.44 m. The grid area bounded by these survey locations was calculated by $A = 0.866 \cdot L^2$ (equals 36 m^2). This area represented the largest elevated area that could exist and not be sampled by the random-start triangular grid pattern established for the WRS test.

Next, the magnitude (area factor) by which the concentration in this potential elevated area (36 m^2) can exceed the DCGL value while maintaining compliance with the release criterion was determined. Table 3 provides outdoor area factors for Th-232.

Table 3: Outdoor Area Dose Factors

	Area Factor								
	1 m^2	3 m^2	10 m^2	30 m^2	100 m^2	300 m^2	1000 m^2	3000 m^2	10000 m^2
Th-232	3610	1200	361	120	36.1	5.54	2.32	1.47	1.00

The minimum detectable concentration (MDC) of the scan procedure that is required to detect an elevated area at the limit determined by the area factor was determined. That is, the required scan MDC for Th-232 was calculated by (area factor logarithmically interpolated for 36 m^2 area equals 100):

$$Scan\ MDC\ (required) = (DCGL) * (Area\ Factor) = 0.16 * 100 = 16\ pCi/g$$

The actual MDCs of scanning techniques were determined for performing gamma scanning with NaI scintillation detectors. The following scan MDCs were determined using current human factors research and modeling of an elevated area and assessing the NaI scintillation detector's response to that radionuclide and radionuclide distribution. These values were purposefully determined conservatively for sample size design considerations.

Table 4: Scan MDCs

Radionuclide(s)	Scan MDC (pCi/g)
Th-232	3.8

The actual MDC of the selected scanning technique was compared to the required scan MDC. Because the actual scan MDC (3.8 pCi/g for Th-232) is less than the required scan MDC (16 pCi/g), no additional sampling points (above the 64 calculated previously) were necessary for assessment of potential elevated areas. That is, the NaI scintillation gamma scan survey exhibited adequate sensitivity to detect any elevated areas of concern.

Determining Survey Locations

A scale drawing of each of the survey units at the Cushing site was prepared (Figures 2 through 4), along with the overlying planer reference coordinate system. Any location within the survey area was identifiable by a unique set of coordinates. The maximum length, X, and width, Y, dimensions of the survey unit were then determined.

For the Class 1 area (RMA-4), a triangular pattern, having dimensions determined by the requirements for the WRS test described in the previous section, was installed on the survey unit. The starting point for this pattern was selected at random. Beginning at the random starting coordinate, a row of points was identified, parallel to the X axis, at intervals of L (6.44 m). A second row of points was then developed, parallel to the first row, at a distance of 0.866•L (5.58 m) from the first row. Survey points along that second row were located midway (on the X-axis) between the points on the first row. This process was repeated to identify a pattern of survey locations throughout the affected survey unit—following this process 68 sampling locations were positioned on the map. If identified points fell outside of the survey unit or at locations which could not be surveyed, additional points were determined using the random process described above, until the desired total number of points was identified. Once in the field, it was realized that the RMA-4 map contained inaccuracies and modifications to sampling locations were necessary; a total of 69 soil

sample locations were identified in the field (Figure 2). This points out the importance of having accurate, to-scale maps for planning and design purposes.

The Class 2 area was also sampled on a random-start triangular pattern. The number of calculated sample locations was identified in the same manner as for the Class 1 area. Sixty-three sample locations were determined using the triangular pattern described above; an additional sample location was then selected at random (Figure 3). The same sampling locations determined in the office were sampled in the field.

Background reference area samples were collected from a triangular pattern, using the same spacing as in the Class 1 area. Sixty-six sample locations were determined using the triangular pattern (Figure 4); the same sampling locations determined in the office were sampled in the background reference area.

INTEGRATED FINAL STATUS SURVEY STRATEGY

General

RMA-4 is the Class 1 area that was surveyed in this prototype final status survey. It is located in the northwest section of the Cushing site and covers an area of approximately 2,300 m^2. The Class 2 survey unit comprised an area of approximately 2,300 m^2 selected from the northern portion of grid block 46. The background reference area was an area of approximately 2,300 m^2 within KMC grid block 61. The extent of survey coverage was based on the guidance contained in MARSSIM—as developed in the previous sections of this plan. Contamination potential has been based on a review of site history and the results of previous surveys.

Survey Plan

A. Reference Coordinate System

A 10-meter reference coordinate system was established by ESSAP in the Class 1, Class 2 and background reference areas to reference sampling locations—as determined from the triangular sampling pattern.

B. Surface Scans

Exterior soil surfaces were scanned for gamma radiation using NaI scintillation detectors. Surface scans were performed by passing the NaI detectors slowly (about 0.5 m/s) over the surface; the distance between the detector and the surface was maintained at a minimum - nominally about 10 cm. A 100 percent scan of the soil within the Class 1 survey units was performed. The scan coverage in the Class 2 area was dependent upon site conditions and results as the survey progressed, but at a minimum, 50% of the Class 2 survey unit was scanned. All detectors were coupled to ratemeters with audible indicators. Locations of elevated direct radiation, based on increases in the audible signal from the instrument, were marked for further investigation.

C. Soil Sampling

Background soil samples were collected from the selected reference area in grid block 61. The number of background soil samples collected, 66, was determined previously. Systematic (Class 1 and Class 2) surface soil samples—at a depth of 0 to 15 cm—were collected from the locations determined in the previous section, using the prepared figures as a guide in locating sampling points. As discussed previously, 69 samples were collected from the Class 1 area and 64 samples were collected from the Class 2 area. Soil samples were collected from locations of elevated direct radiation identified by surface scans.

Investigation Levels

Investigation levels for Class 1 areas established action levels for individual measurements that approach or exceed the DCGL level. According to MARSSIM, the results of the investigation and any additional remediation that was performed should be included in the final status survey report. Data are evaluated; additional data collected, as necessary; and the final complete data set tested for compliance with elevated area criteria and statistical parameters. Surface scans in the Class 1 area identified locations of elevated direct radiation that required the collection of additional (biased) samples.

Investigation levels for Class 2 areas established action levels for individual measurements close to but below the DCGL. The results of the investigation of the positive measurements and basis for reclassifying all or part of the survey unit as Class 1 should be included in the final status survey report. Surface scans in the Class 2 area did not identify any locations of elevated direct radiation—therefore, there were no indications that investigations should be conducted in this survey unit.

Sample Analysis and Data Interpretation

Samples and data were returned to ORISE's ESSAP laboratory in Oak Ridge, Tennessee for analysis and interpretation. Laboratory analyses were conducted in accordance with the ORISE/ESSAP Laboratory Procedures Manual (ORISE 1995c). Soil samples were analyzed by gamma spectroscopy. The radionuclide of interest was Th-232; however, spectra were also reviewed for other identifiable photopeaks. The MDC for gamma spectroscopy was approximately 0.5 pCi/g for Th-232; count times were selected to maintain relative standard errors of the analysis to less than 10%.

Soil sample results from gamma spectroscopy were reported in pCi/g—the DCGL unit. After data were converted to DCGL units, the process of comparing the results to the DCGLs, conditions, and objectives began. Individual measurements and soil sample concentrations were compared to DCGL

levels for evidence of elevated areas. This Elevated Measurement Comparison (EMC) was performed to ensure that any areas that may have the potential for significant dose contributions were identified. The need for additional data or additional remediation and resurvey were evaluated. Data were then evaluated using the WRS test to determine if release criteria had been satisfied. If release criteria were not met or if results indicated the need for additional data points, appropriate further actions were determined by the NRC. Finally, the results of the survey were compared with the data quality objectives established during the planning phase of the project. The data generated were compared with the NRC release criterion (via evaluating the null hypothesis).

INTERPRETATION OF SURVEY RESULTS

SURVEY RESULTS

The interpretation of survey results was performed in accordance with the MARSSIM Draft for Public Comment (MARSSIM 1996b).

Surface Scans

Surface scans performed within the Class 1 survey unit identified several locations of elevated direct radiation. Additional investigations were performed, including surface scans, to generally bound the areas of elevated direct radiation (refer to Figure 5). Biased soil samples were collected in some of the areas identified by surface scans—these samples provided data on the Th-232 levels within the areas of elevated direct radiation. Additional characterization (sampling) would be necessary to better delineate the extent of contamination and need for additional remediation.

Surface scans performed within the Class 2 survey unit did not identify any locations of elevated direct radiation.

Th-232 Concentrations in Soil

Concentrations of Th-232 in soil samples collected in the Class 1 survey unit, Class 2 survey unit, and background reference area are shown in Tables 6 through 8, respectively. Thorium-232 concentrations determined by gamma spectroscopy ranged from 0.95 to 3.26 pCi/g in the Class 1 survey unit (systematic samples only); from 0.62 to 1.53 pCi/g in the Class 2 survey unit; and from 0.89 to 1.54 pCi/g in the background reference area. The range of Th-232 concentrations from seven biased samples in the Class 1 survey unit ranged from 3.23 to 66.69 pCi/g.

The Elevated Measurement Comparison (EMC) was performed for both measurements obtained from systematic sampling and those flagged by surface scans. As illustrated on Figure 5, surface scans identified a relatively large (~ 300 m^2) area of elevated radiation that ran through the middle of RMA-4. Surface scans, confirmed by biased sampling, identified a particularly significant location of elevated direct radiation (~ 20 m^2) near coordinates 25E, 40N. The derived concentration guideline level for the EMC—$DCGL_{EMC}$—is obtained by multiplying the DCGL (0.16 pCi/g) by the area factor that corresponds to the actual area of the elevated concentration. An elevated area is deemed acceptable provided that the appropriate $DCGL_{EMC}$ is not exceeded. For example, the area factor for the 300 m^2 elevated area is 5.54, resulting in a $DCGL_{EMC}$ of 0.87 pCi/g (not including background). Further investigation and sampling would be necessary to determine the average Th-232 concentration over this 300 m^2 elevated area in order to make a comparison to the $DCGL_{EMC}$.

An EMC determination was made for the smaller area (20 m^2)—the area factor is 208 (based on interpolation of values in Table 3), which resulted in a $DCGL_{EMC}$ of 33.3 pCi/g. The average of the two biased samples in that 20 m^2 area is 40.6 pCi/g, which exceeds the $DCGL_{EMC}$. It should be recognized that any combination of area and radionuclide concentration that exceeds the appropriate $DCGL_{EMC}$ should be sufficient for concluding that the survey unit does not satisfy release criteria.

DATA QUALITY ASSESSMENT

The MARSSIM manual recommends that a data quality assessment (DQA) be performed to determine if the data are of the right type, quality, and quantity to support their use (MARSSIM 1996b). The DQA process is the scientific and statistical evaluation of data and includes 1) review of DQOs, 2) preliminary data review, 3) selection of statistical tests and verification of assumptions of the tests, and 4) drawing conclusions from the data.

Review of the DQOs

The DQOs were reviewed to ensure that they were still applicable. The survey unit results were reviewed to determine if each survey unit was properly classified. Data results indicated that each survey unit was properly classified, however, the background reference area selected may not have been appropriate for the Class 2 survey unit (this is explored further in a subsequent data evaluation section).

The sampling design and data collection documentation were reviewed for consistency with the DQOs. Because all collected samples were analyzed and no data losses occurred, the necessary sample size for the statistical tests was achieved.

The accuracy of the prospective power curve depends on the number of samples collected and estimates of the standard deviation for each survey unit and the background reference area. Note that this assessment of the retrospective power curve is only necessary when the null hypothesis is accepted (i.e. survey unit does not pass release criteria). The estimated standard deviation in the Class 1 and Class 2 survey units was 0.27 pCi/g, which represented a revised standard deviation (refer to Document Review). The standard deviations obtained during the final status survey were 0.16, 0.40, and 0.22, respectively, for the reference area, Class 1, and Class 2 survey units. The Class 1 survey unit standard deviation, assumed during the survey design, may be too small relative to the standard deviation obtained during the final status survey. This may indicate an insufficient number of samples were collected to achieve the desired test power ($1-\beta$), and result in unnecessary

remediations. However, the Class 1 revised standard deviation—by removing the highest three Th-232 concentration values (outliers)—is 0.25 pCi/g, consistent with that assumed during survey design.

Preliminary Data Review

To evaluate the structure of the data—identifying patterns and relationships—graphs of the data were prepared and basic statistical quantities calculated. Figures 6 through 8 provide posting plots that illustrate the Th-232 concentration versus location for the Class 1 and Class 2 survey units, and background reference area, respectively. Inspection of the Class 1 data posting plot (Figure 6) clearly indicates several samples with Th-232 concentrations in excess of the background in this survey unit—particularly running north to south between east coordinates 25 to 35. Posting plots for the Class 2 survey unit and background reference area do not reveal any systematic spatial trends.

Figures 9 through 11 provide frequency plots, or histograms, of the Th-232 concentration in the background reference area, Class 1, and Class 2 survey units, respectively. Again, using the histograms to compare the reference area data with the Class 2 survey unit data (overlaying the two histograms) shows that the Class 2 data are shifted to lower Th-232 concentrations, relative to the background reference area. The histogram for the Class 1 survey unit clearly illustrates two distributions of Th-232—therefore, it may be possible to consider the background distribution as shown in this histogram (Figure 10) as a survey unit-specific background reference area for the Class 1 survey unit. As cautioned in MARSSIM, the interpretation of the data for this purpose should only be pursued after consultation with the responsible regulatory agency.

Basic statistical quantities were calculated for the background reference area, Class 1, and Class 2 survey units.

Table 5: Basic Statistical Quantities

Location	Th-232 (pCi/g)		
	Mean	Median	Standard Deviation
Background Reference Area	1.29	1.32	0.16
Class 1 Area	1.34	1.22	0.40
Class 2 Area	1.11	1.14	0.22

As evidenced in the Class 1 survey unit, large differences between the mean and the median provide an indication of skewness in the data (as discussed previously, the histogram actually shows that two distributions exist in the Class 1 survey unit). Also, the basic statistical parameters (both the mean and the median) show that the Class 2 survey unit data are 0.18 pCi/g less than the background reference area. Therefore, if the two areas were interchanged, it is likely that the background reference area would fail to reject the null hypothesis (not pass the release criterion of 0.16 pCi/g) as compared to the Th-232 concentration in the Class 2 survey unit.

Selection of Statistical Test and Verification of Test Assumptions

The Wilcoxon Rank Sum (WRS) test is used to evaluate the Th-232 concentrations in the Class 1 and Class 2 survey units because the contaminant of concern (Th-232) is present in background. The null hypothesis tested by the WRS test is that "the median concentration in the survey unit exceeds that in the reference area by more than the DCGL." Therefore, rejection of this null hypothesis results in a decision that the survey unit passes (satisfies the release criterion). Specifically, the result of the WRS hypothesis test determines whether or not the survey unit as a whole is deemed to meet the release criterion.

The assumptions underlying the WRS test are that 1) the samples from the background reference area and the survey unit are independent random samples, and 2) each measurement is independent of every other measurement—regardless of the set of samples from which it came. Each of the samples from the background reference area, Class 1, and Class 2 survey units were collected on a

random-start triangular grid pattern (biased samples are not included in statistical tests), thus, the assumption of independent random samples is valid. Further, the posting plots (Figures 6 through 8) do not suggest that spatial dependencies exist in any of the sampled areas.

Draw Conclusions from the Data

The specific details for conducting the WRS test are as follows:

1) Obtain adjusted reference area measurements by adding the DCGL to each background reference area measurement.
2) Rank the pooled adjusted reference area measurements (m) and survey unit measurements (n) from 1 to N (N=m+n).
3) If several measurements are tied (have the same value), they are assigned the average rank for that group of tied measurements.
4) Sum the ranks of the adjusted measurements from the reference area, W_r.
5) Compare W_r with tabulated critical value (MARSSIM Appendix I; based on n, m, and α):

Reject H_0 if W_r > critical value

MARSSIM Appendix I (page I-30) provides spreadsheet formulas for ranking the data. The analysis for the WRS test is well suited for calculation on a spreadsheet. Appendix C (of this report) provides the results (in spreadsheets) of the WRS test for both the Class 1 and Class 2 survey units. To summarize these results, the W_r in the Class 1 survey unit was 5,580 and the critical value was 4,862. Because W_r is greater than the critical value, the null hypothesis is rejected and the survey unit passes the WRS test. However, as mentioned previously, the Class 1 survey unit contains subsurface contamination that must be fully characterized before the survey unit can be determined to have satisfied release criteria. Additionally, because of the difficulty of assessing the surface area associated with each of the hot spots, a determination of whether these locations of elevated activity satisfy the elevated measurement comparison cannot be made.

The W_r in the Class 2 survey unit was 5,976 and the critical value was 4,676. Because W_r is greater than the critical value, the null hypothesis is rejected and the survey unit easily passes the WRS test. However, the concern in this case is that the background reference area is not representative of the Class 2 survey unit—as discussed previously, Th-232 concentrations in the Class 2 survey unit are significantly less than the concentrations in the background reference area. Nonetheless, upon review of all the data, the Class 2 survey unit satisfies the release criterion.

To assess whether or not the background reference area is representative of the Class 2 survey unit, the WRS test was conducted assuming that the Class 2 area (Grid Block 46) was the background reference area and the original background reference area (Grid Block 61) was the tested survey unit. The W_r in this case was 4,120 and the critical value was 4,545. Therefore, the null hypothesis was not rejected and the survey unit fails (refer to Appendix C). The significance of this result is that both Grid Block 46 and 61 likely contain only naturally occurring levels of Th-232—yet at different enough levels (relative to the DCGL) to fail the WRS test. This occurs because it is assumed that any difference between the reference area and survey unit concentration distributions is due to the presence of residual radioactivity in addition to background. This result clearly shows the importance of having background reference areas that are truly representative of the survey units being evaluated.

SUMMARY

During the period October 28 through 30, 1996, the Environmental Survey and Site Assessment Program of ORISE performed final status survey activities at the Cushing Refinery Site in Cushing, Oklahoma. The objective of the final status survey activities was to demonstrate the feasibility of implementing the MARSSIM methodology in Class 1 and Class 2 land area survey units at a site contaminated with thorium. Survey activities conducted included document reviews, surface scans, and surface soil sampling and analysis.

The results of the final status survey were interpreted using the guidance contained in MARSSIM. Both survey units passed the WRS statistical test, but the Class 1 survey unit did not pass the Elevated Measurement Comparison. Additionally, while the Class 2 survey unit did pass the release criterion, it was evident that the background reference area did not sufficiently represent the Class 2 area.

FIGURES

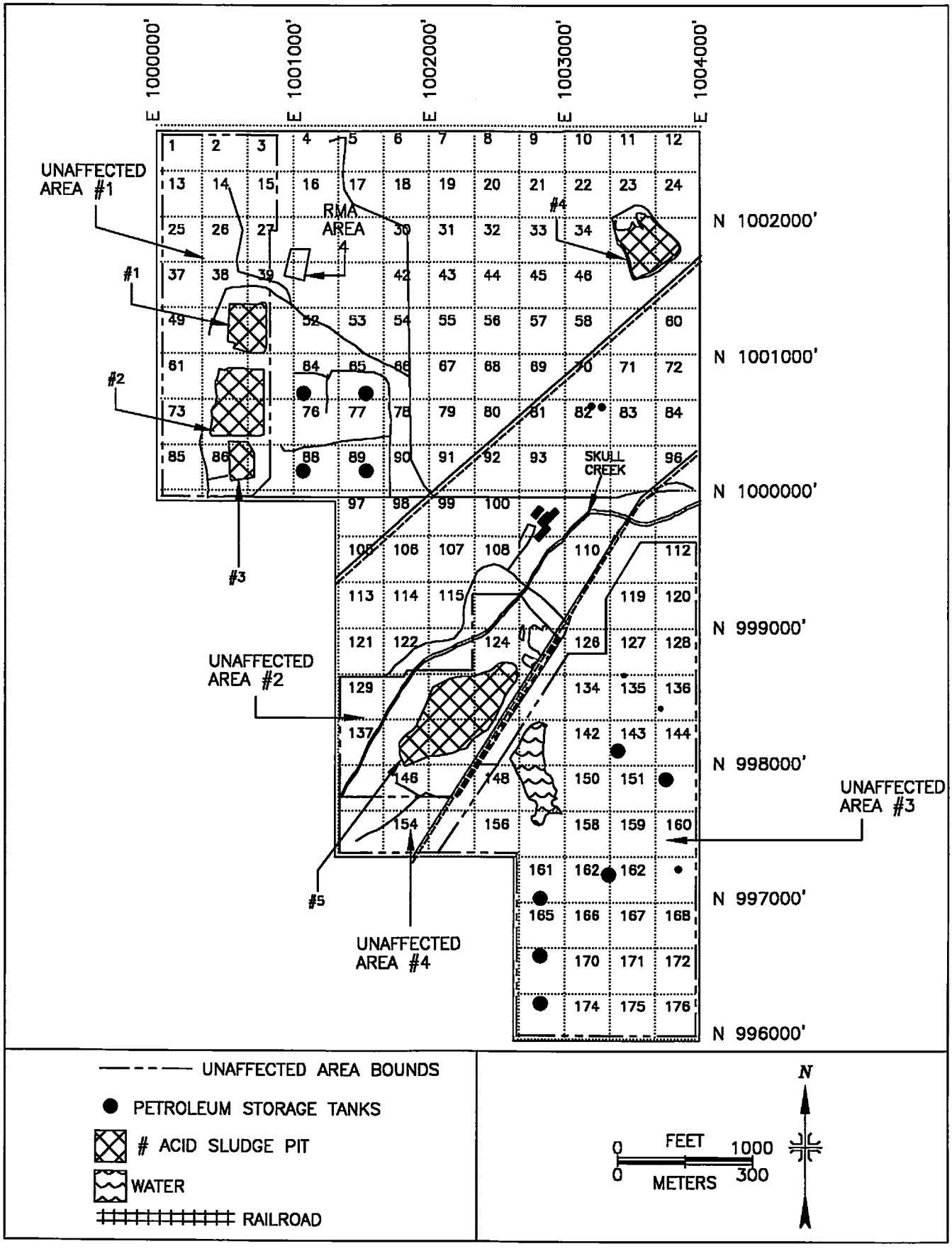


FIGURE 1: Kerr-McGee Corporation, Cushing, Oklahoma - Cushing Site Grid Block Areas

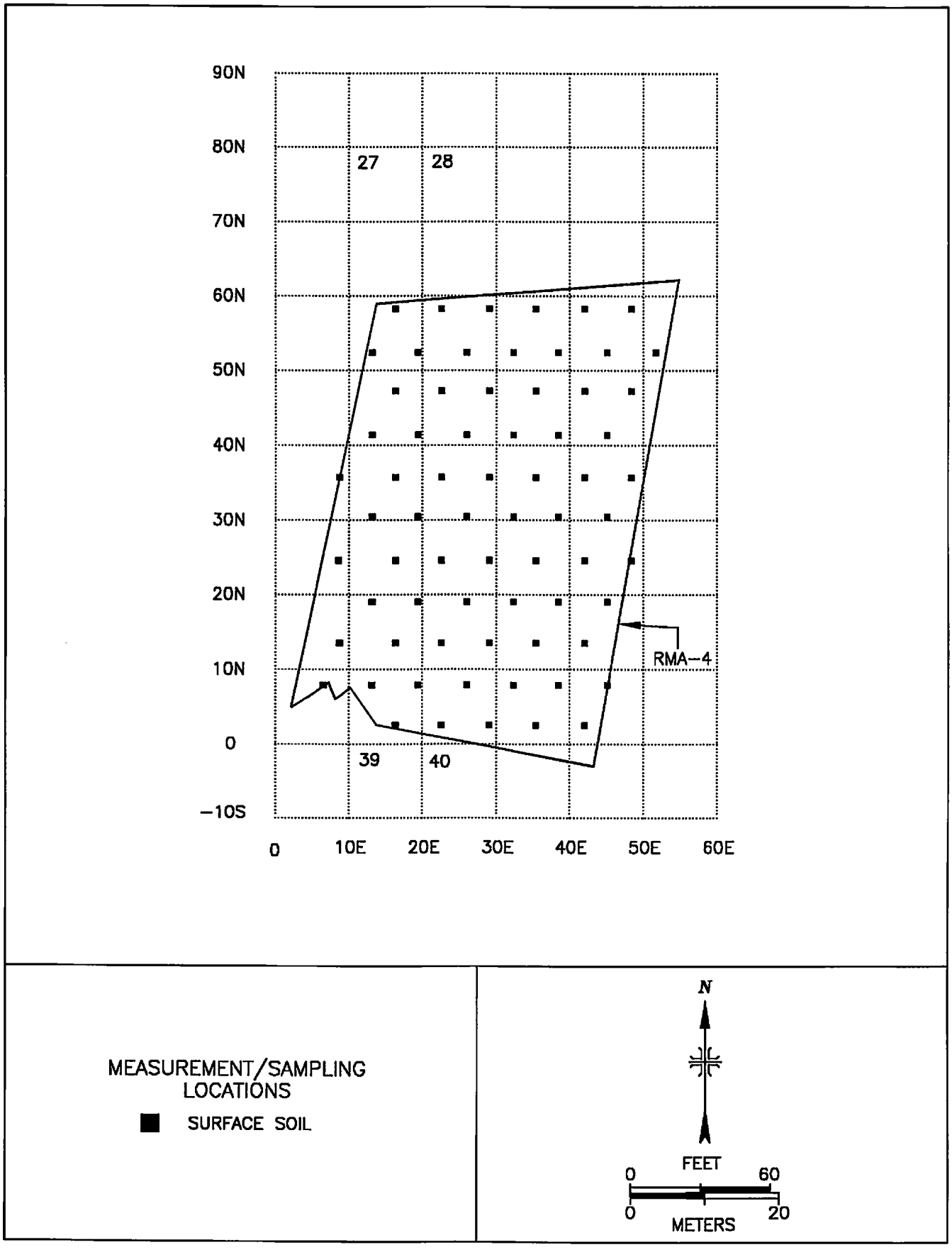


FIGURE 2: Kerr-McGee Corporation Site, Cushing, Oklahoma, RMA-4 - Measurement and Sampling Locations

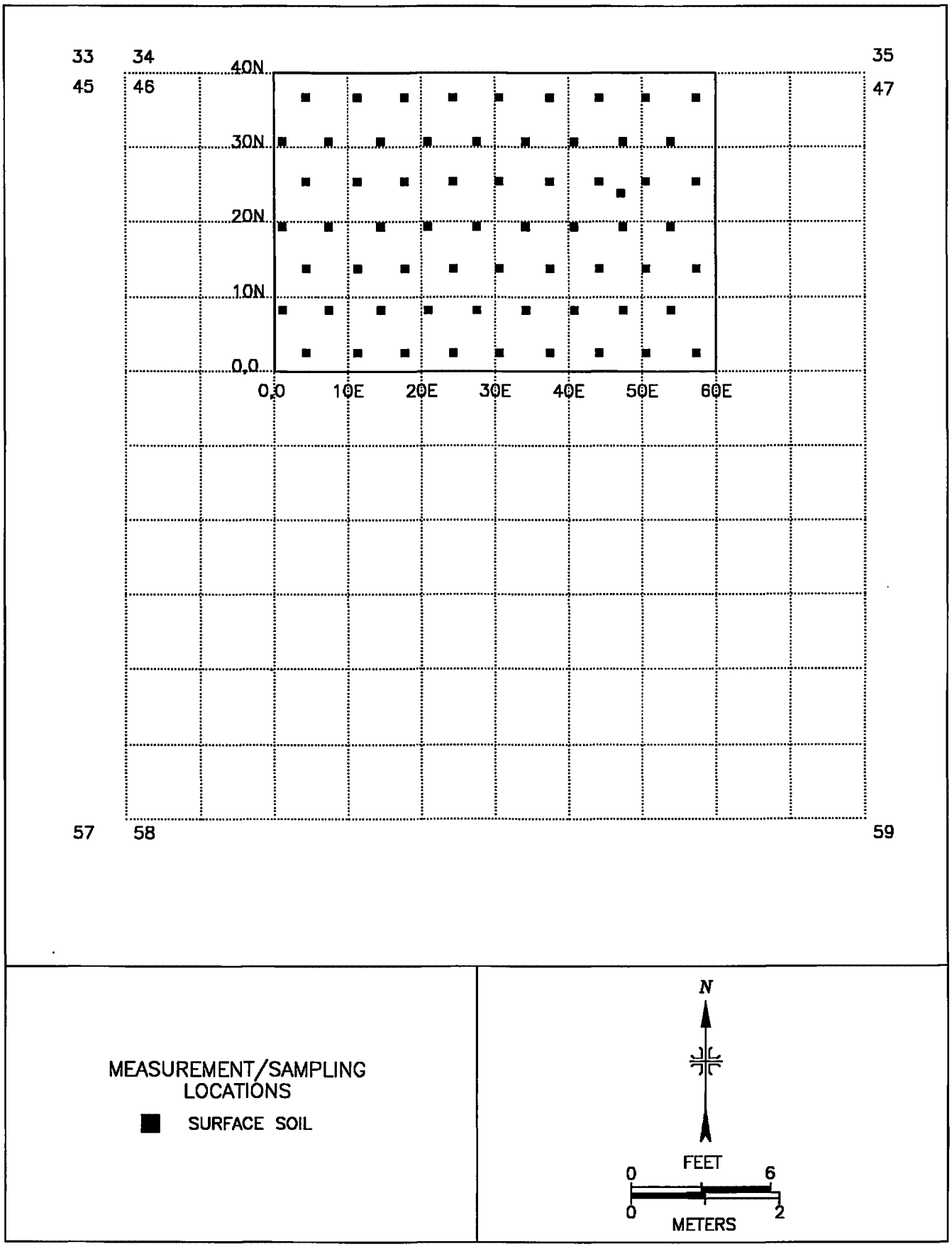


FIGURE 3: Kerr-McGee Corporation Site, Cushing, Oklahoma – Survey Block 46 (Class 2) – Measurement and Sampling Locations

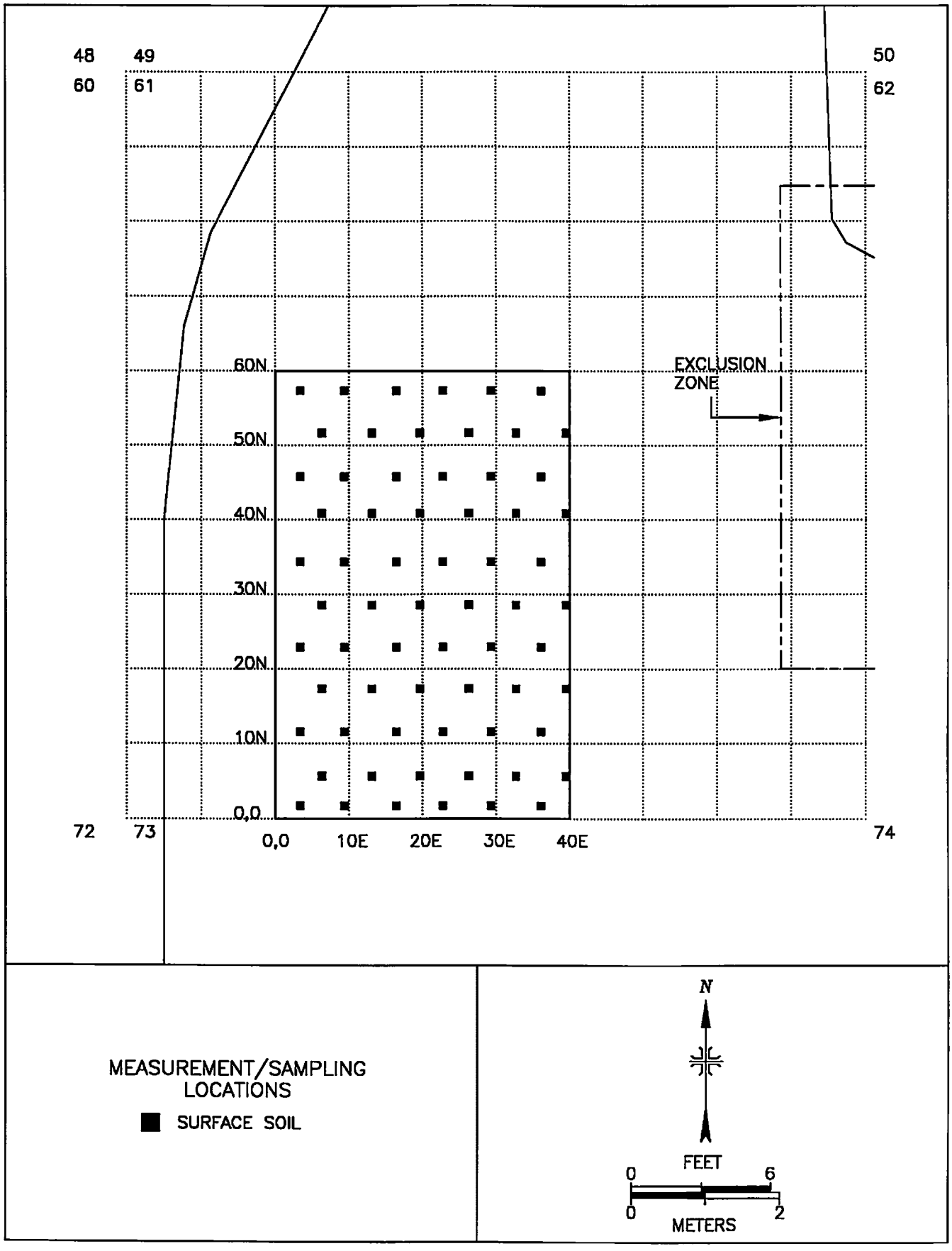


FIGURE 4: Kerr–McGee Corporation Site, Cushing, Oklahoma, Survey Block 61 (Background Reference Area) – Measurement and Sampling Locations

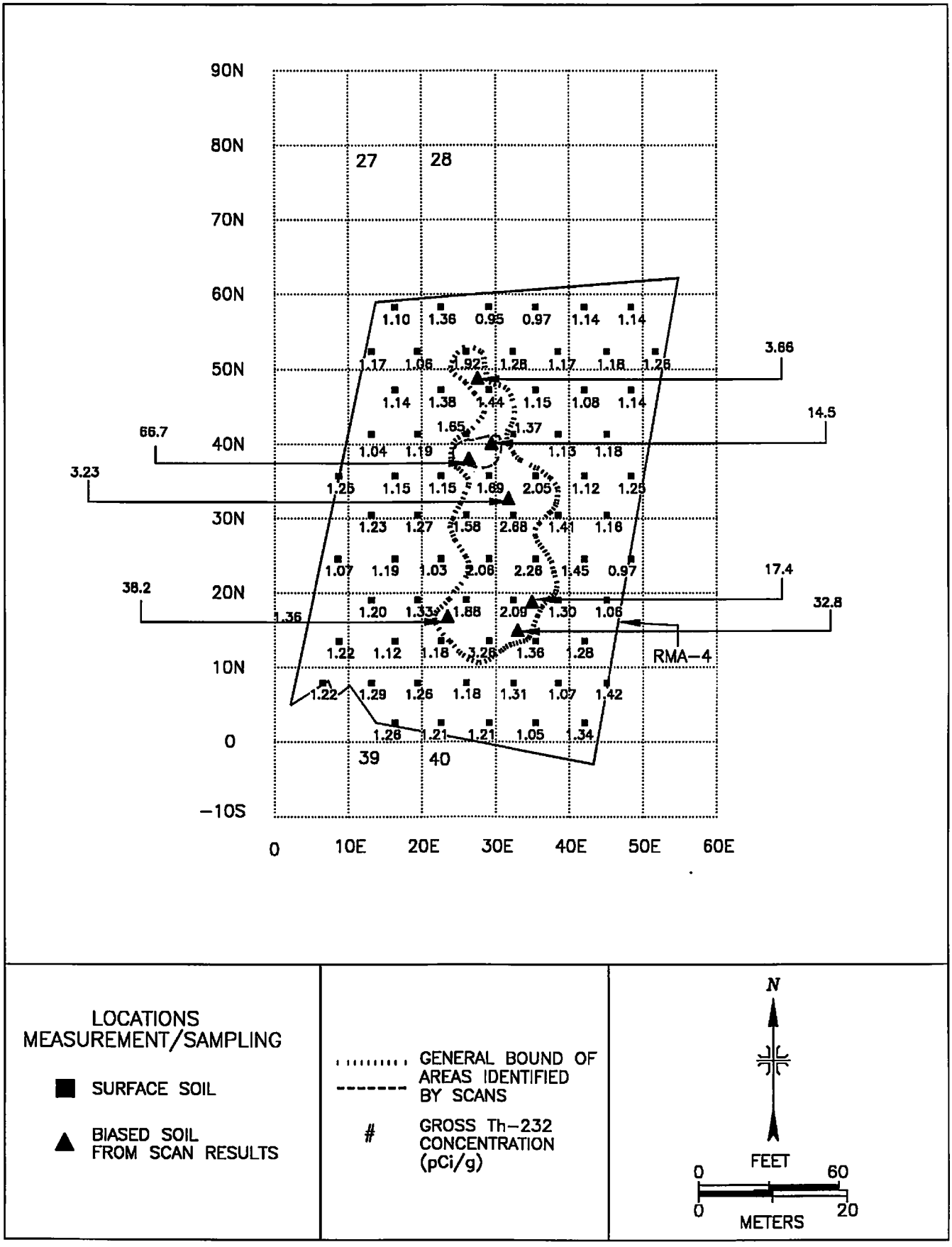
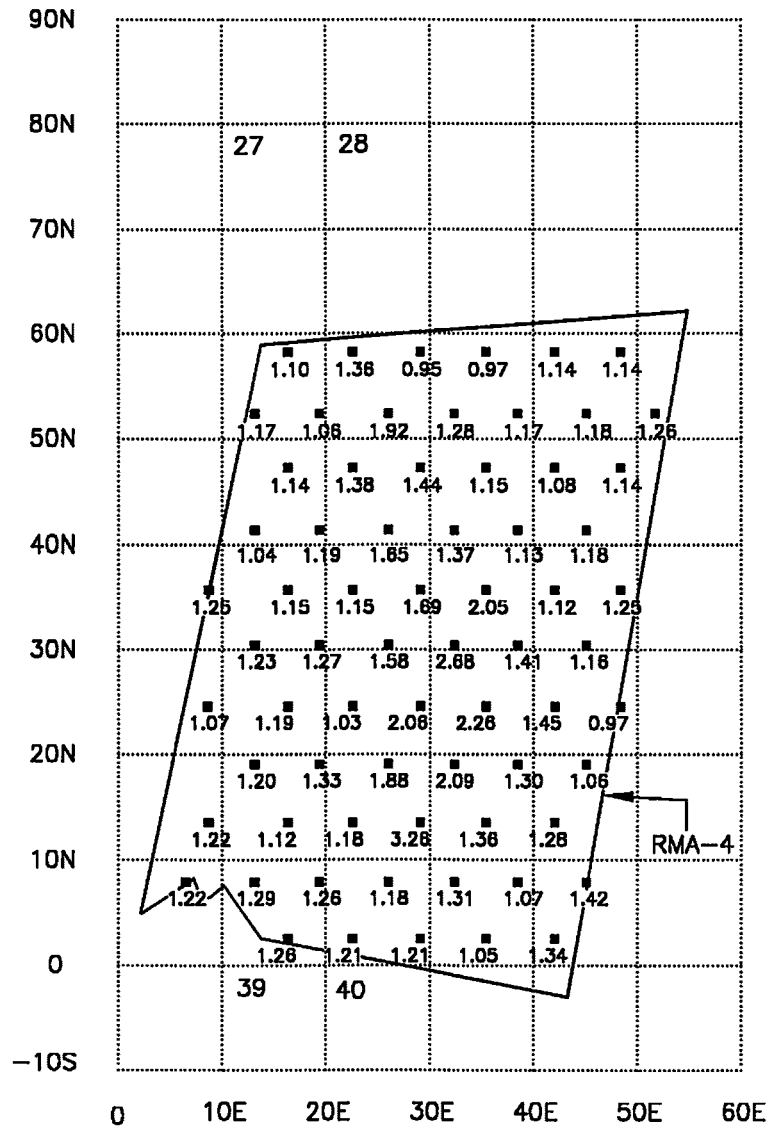


FIGURE 5: Kerr-McGee Corporation Site, Cushing, Oklahoma, RMA-4 (Class 1) - Elevated Areas Identified by Scans and Soil Sample Locations



MEASUREMENT/SAMPLING LOCATIONS

■ SURFACE SOIL

\# GROSS Th-232 CONCENTRATION (pCi/g)

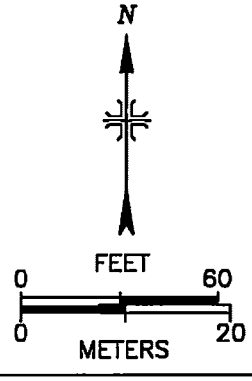


FIGURE 6: Kerr-McGee Corporation Site, Cushing, Oklahoma, RMA-4 (Class 1) - Posting Plot

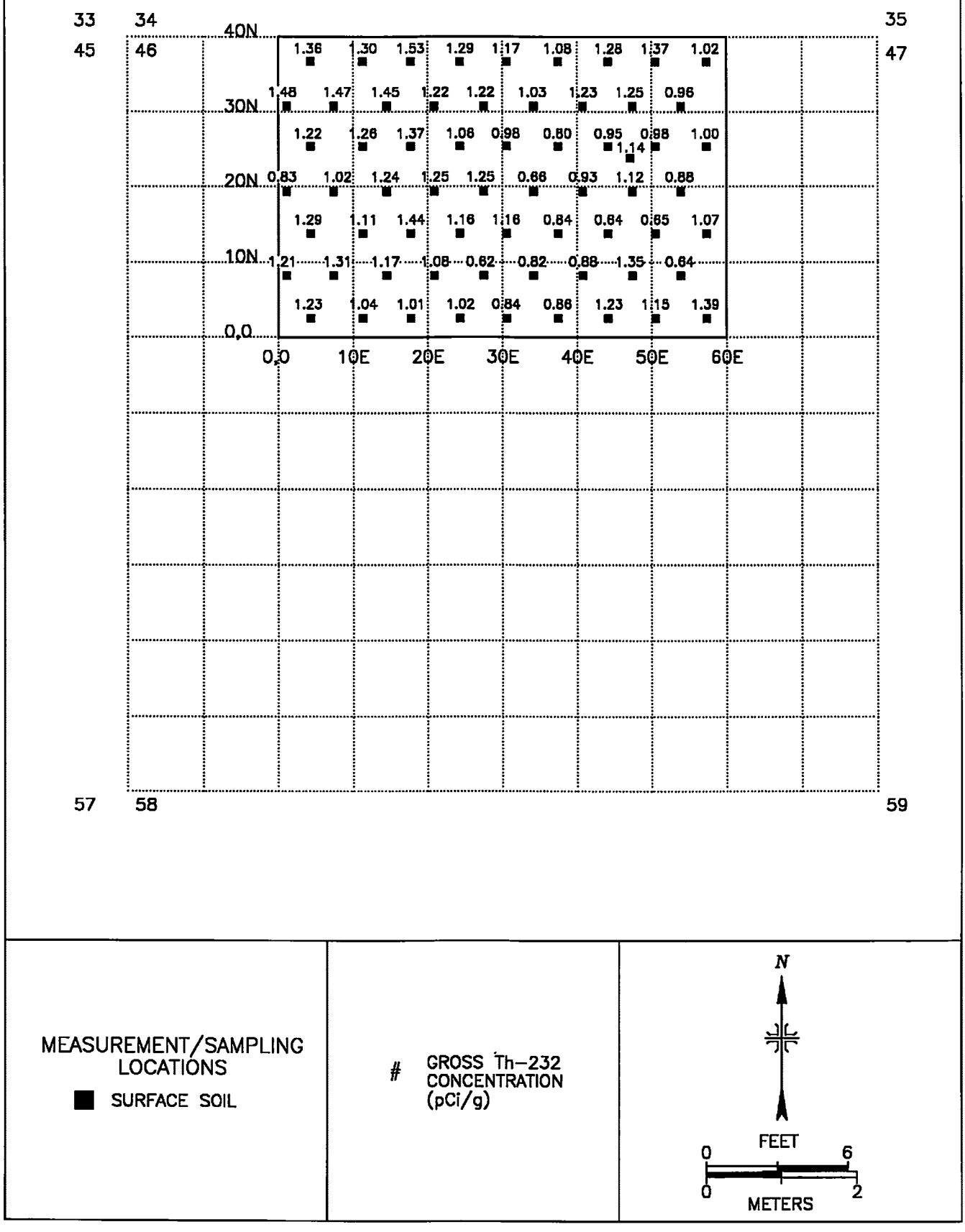


FIGURE 7: Kerr–McGee Corporation Site, Cushing, Oklahoma – Survey Block 46 (Class 2) – Posting Plot

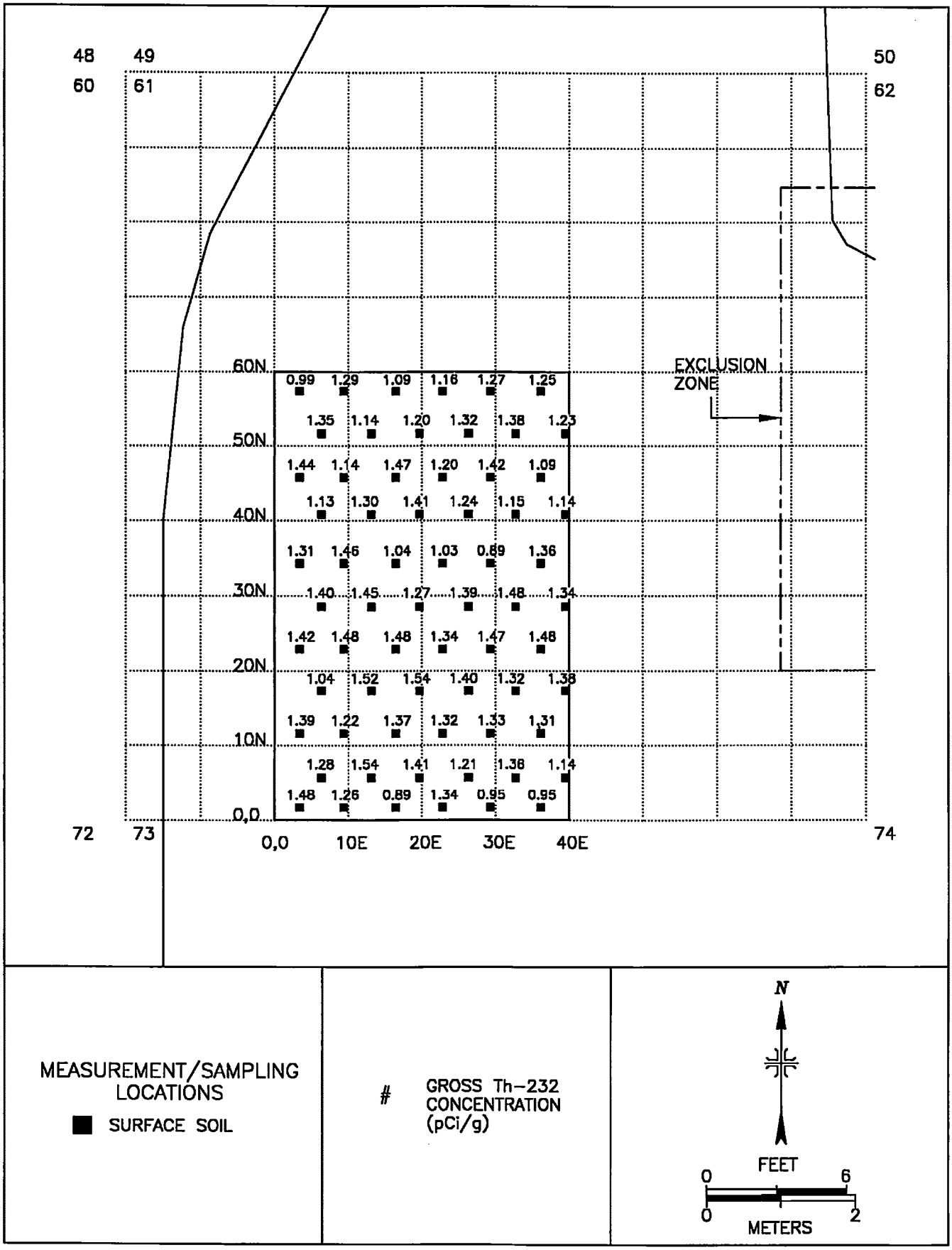


FIGURE 8: Kerr-McGee Corporation Site, Cushing, Oklahoma – Survey Block 61 (Background Reference Area) – Posting Plot

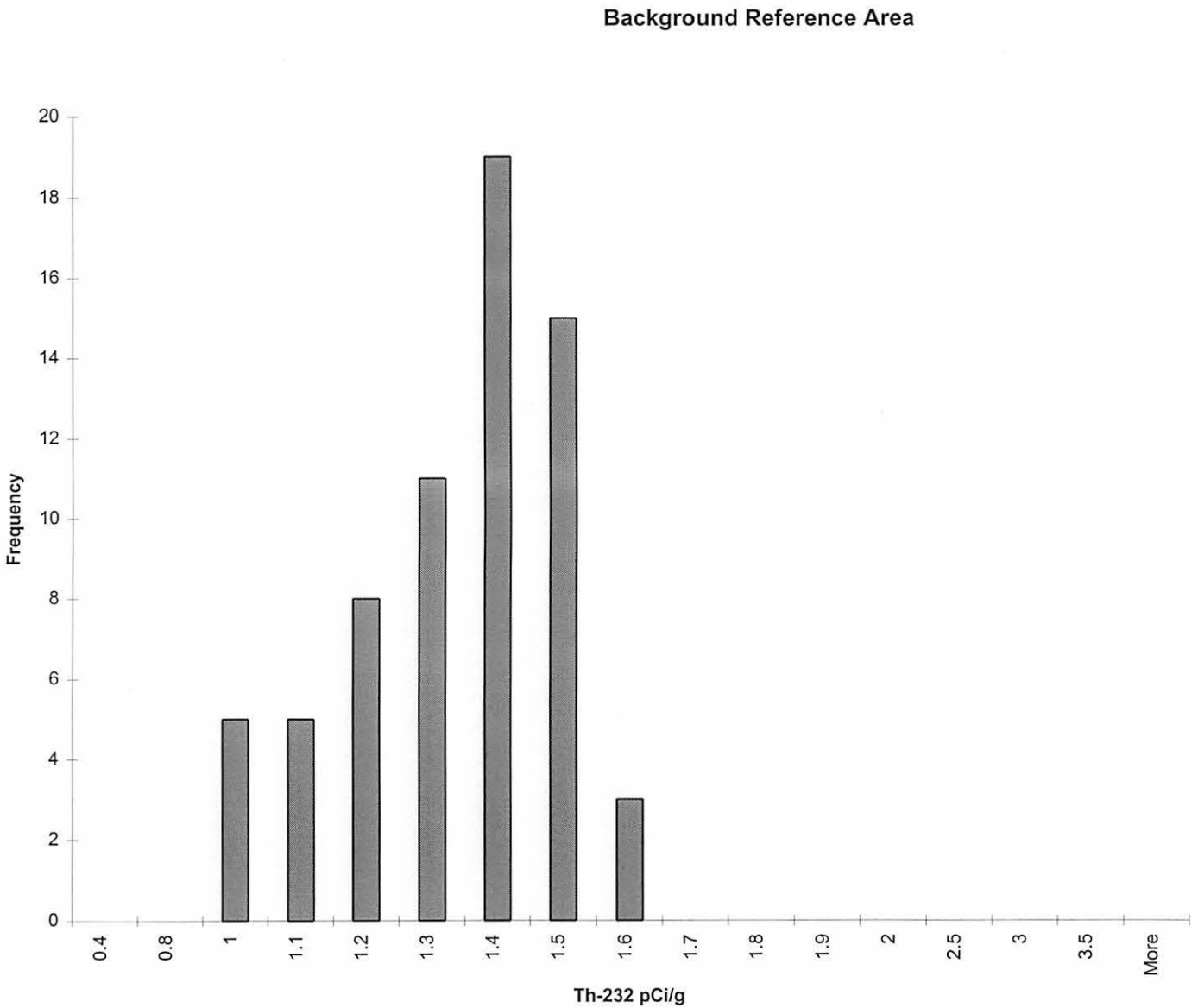


Figure 9: Histogram - Background Reference Area

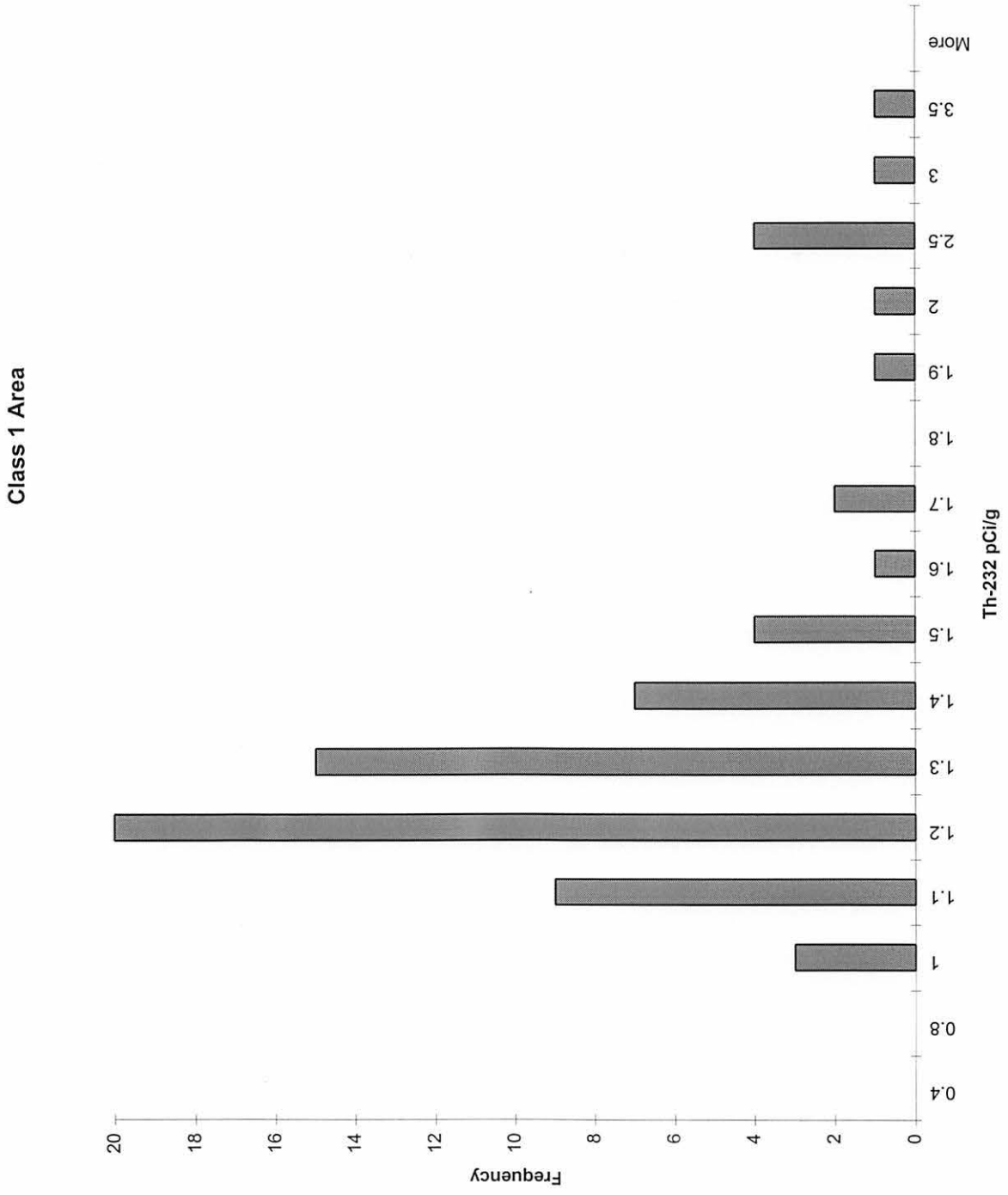


Figure 10: Histogram - Class 1 Area

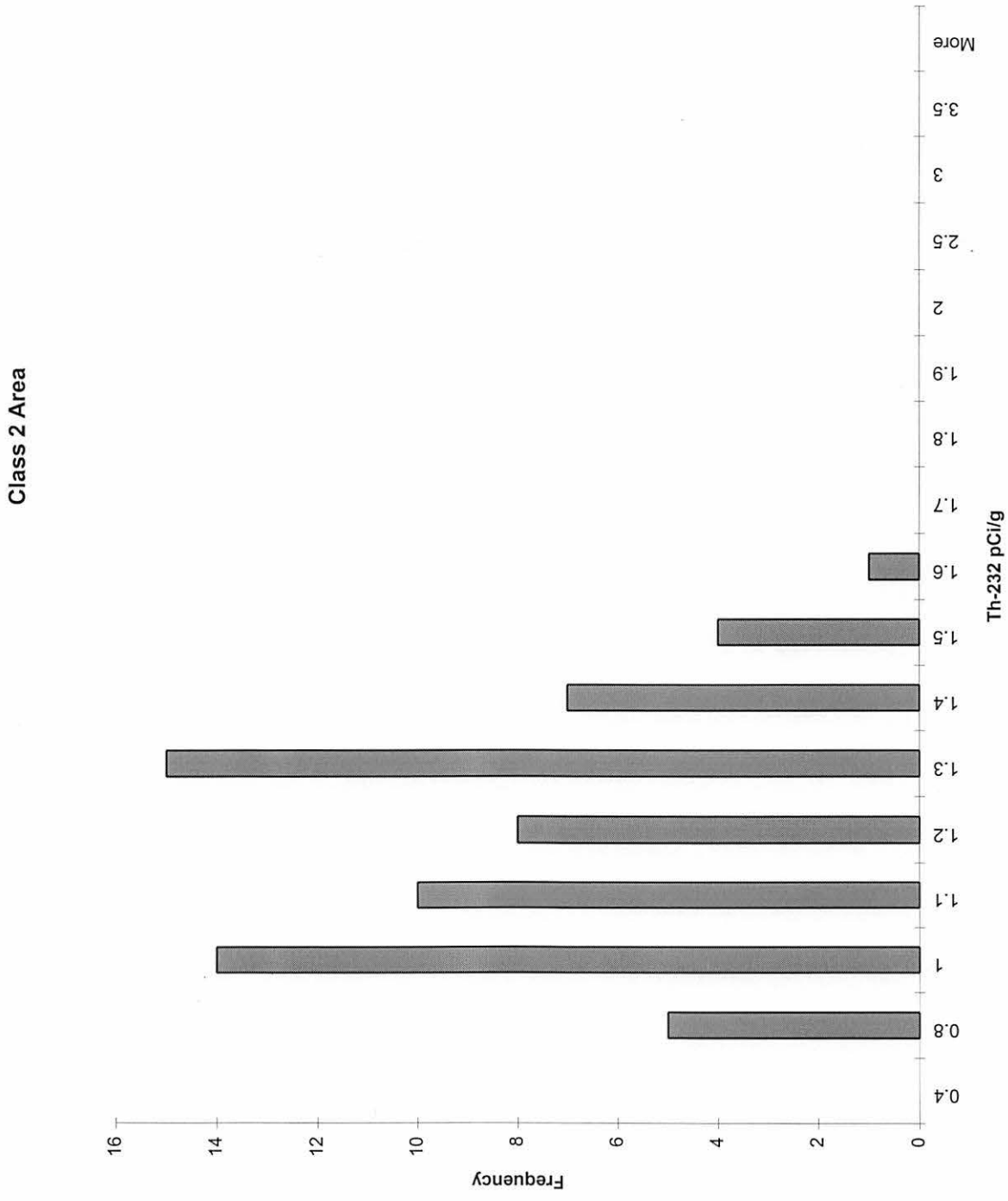


Figure 11: Histogram - Class 2 Area

TABLES

TABLE 6

RADIONUCLIDE CONCENTRATIONS IN SOIL
CLASS 1 AREA—RMA-4
KERR-McGEE CORPORATION
CUSHING, OKLAHOMA

Location[a] (E, N coordinates)	ORISE Sample ID	Radionuclide Concentration (pCi/g)	
		Th-232[b]	Th-228[c]
SYSTEMATIC SOIL SAMPLES			
16.30, 2.42	508S041	1.26 ± 0.12[d]	1.28 ± 0.04
22.74, 2.42	508S042	1.21 ± 0.11	1.07 ± 0.03
29.18, 2.42	508S043	1.21 ± 0.11	1.11 ± 0.03
35.62, 2.42	508S044	1.05 ± 0.08	1.12 ± 0.03
42.06, 2.42	508S045	1.34 ± 0.11	1.39 ± 0.04
6.64, 8.00	508S046	1.22 ± 0.09	1.22 ± 0.03
13.08, 8.00	508S047	1.29 ± 0.08	1.22 ± 0.03
19.52, 8.00	508S048	1.26 ± 0.09	1.31 ± 0.03
25.96, 8.00	508S049	1.18 ± 0.09	1.17 ± 0.03
32.40, 8.00	508S050	1.31 ± 0.11	1.38 ± 0.04
38.84, 8.00	508S051	1.07 ± 0.08	1.14 ± 0.03
45.28, 8.00	508S052	1.42 ± 0.09	1.28 ± 0.04
9.86, 13.58	508S053	1.22 ± 0.09	1.21 ± 0.03
16.30, 13.58	508S054	1.12 ± 0.08	1.22 ± 0.03
22.74, 13.58	508S055	1.18 ± 0.10	1.24 ± 0.03
29.18, 13.58	508S056	3.26 ± 0.14	3.31 ± 0.05`
35.62, 13.58	508S057	1.36 ± 0.09	1.40 ± 0.03
42.06, 13.58	508S058	1.28 ± 0.09	1.13 ± 0.03
13.08, 19.16	508S059	1.20 ± 0.09	1.22 ± 0.03
19.52, 19.16	508S060	1.33 ± 0.08	1.32 ± 0.03
25.96, 19.16	508S061	1.88 ± 0.10	1.90 ± 0.04

TABLE 6 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SOIL
CLASS 1 AREA—RMA-4
KERR-McGEE CORPORATION
CUSHING, OKLAHOMA

Location[a] (E, N coordinates)	ORISE Sample ID	Radionuclide Concentration (pCi/g)	
		Th-232[b]	Th-228[c]
SYSTEMATIC SOIL SAMPLES (Continued)			
32.40, 19.16	508S062	2.09 ± 0.10	2.15 ± 0.04
38.84, 19.16	508S063	1.30 ± 0.10	1.25 ± 0.03
45.28, 19.16	508S064	1.06 ± 0.09	1.09 ± 0.03
9.86, 24.74	508S065	1.07 ± 0.08	0.96 ± 0.03
16.30, 24.74	508S066	1.19 ± 0.09	1.19 ± 0.03
22.74, 24.74	508S067	1.03 ± 0.08	1.08 ± 0.03
29.18, 24.74	508S068	2.06 ± 0.10	1.78 ± 0.05
35.62, 24.74	508S069	2.26 ± 0.12	2.03 ± 0.04
42.06, 24.74	508S070	1.45 ± 0.08	1.33 ± 0.03
48.50, 24.74	508S071	0.97 ± 0.08	0.96 ± 0.03
13.08, 30.32	508S072	1.23 ± 0.09	1.18 ± 0.04
19.52, 30.32	508S073	1.27 ± 0.09	1.08 ± 0.03
25.96, 30.32	508S074	1.58 ± 0.09	1.42 ± 0.03
32.40, 30.32	508S075	2.68 ± 0.13	2.72 ± 0.04
38.84, 30.32	508S076	1.41 ± 0.11	1.35 ± 0.04
45.28, 30.32	508S077	1.16 ± 0.09	1.08 ± 0.03
9.86, 35.90	508S078	1.25 ± 0.10	1.03 ± 0.04
16.30, 35.90	508S079	1.15 ± 0.10	1.05 ± 0.03
22.74, 35.90	508S080	1.15 ± 0.10	1.11 ± 0.03
29.18, 35.90	508S081	1.69 ± 0.11	1.54 ± 0.04
35.62, 35.90	508S082	2.05 ± 0.10	1.99 ± 0.04

TABLE 6 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SOIL
CLASS 1 AREA—RMA-4
KERR-McGEE CORPORATION
CUSHING, OKLAHOMA

Location[a] (E, N coordinates)	ORISE Sample ID	Radionuclide Concentration (pCi/g)	
		Th-232[b]	Th-228[c]
SYSTEMATIC SOIL SAMPLES (Continued)			
42.06, 35.90	508S083	1.12 ± 0.10	1.01 ± 0.03
48.50, 35.90	508S084	1.25 ± 0.08	1.08 ± 0.03
13.08, 41.48	508S085	1.04 ± 0.08	1.06 ± 0.03
19.52, 41.48	508S086	1.19 ± 0.11	1.15 ± 0.04
25.96, 41.48	508S087	1.65 ± 0.10	1.58 ± 0.04
32.40, 41.48	508S088	1.37 ± 0.08	1.36 ± 0.03
38.84, 41.48	508S089	1.13 ± 0.08	1.08 ± 0.03
45.28, 41.48	508S090	1.18 ± 0.08	1.12 ± 0.04
16.30, 47.06	508S091	1.14 ± 0.08	1.05 ± 0.03
22.74, 47.06	508S092	1.38 ± 0.11	1.29 ± 0.04
29.18, 47.06	508S093	1.44 ± 0.09	1.42 ± 0.03
35.62, 47.06	508S094	1.15 ± 0.10	1.15 ± 0.03
42.06, 47.06	508S095	1.08 ± 0.07	1.07 ± 0.03
48.50, 47.06	508S096	1.14 ± 0.09	1.10 ± 0.03
13.08, 52.64	508S097	1.17 ± 0.10	1.15 ± 0.03
19.52, 52.64	508S098	1.06 ± 0.08	1.09 ± 0.03
25.96, 52.64	508S099	1.92 ± 0.12	1.81 ± 0.05
32.40, 52.64	508S100	1.28 ± 0.09	1.31 ± 0.03
38.84, 52.64	508S101	1.17 ± 0.07	1.12 ± 0.03
45.28, 52.64	508S102	1.18 ± 0.09	1.10 ± 0.03
51.72, 52.64	508S103	1.26 ± 0.09	1.23 ± 0.04

TABLE 6 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SOIL
CLASS 1 AREA—RMA-4
KERR-McGEE CORPORATION
CUSHING, OKLAHOMA

Location[a] (E, N coordinates)	ORISE Sample ID	Radionuclide Concentration (pCi/g)	
		Th-232[b]	Th-228[c]
SYSTEMATIC SOIL SAMPLES (Continued)			
16.30, 58.22	508S104	1.10 ± 0.08	1.14 ± 0.03
22.74, 58.22	508S105	1.36 ± 0.09	1.31 ± 0.04
29.18, 58.22	508S106	0.95 ± 0.08	1.11 ± 0.03
35.62, 58.22	508S107	0.97 ± 0.08	1.04 ± 0.03
42.06, 58.22	508S108	1.14 ± 0.10	1.05 ± 0.03
48.50, 58.22	508S109	1.14 ± 0.09	1.02 ± 0.04
BIASED SOIL SAMPLES FROM SCAN RESULTS			
near 35.62, 13.58	508S110	32.83 ± 0.36	32.88 ± 0.15
near 38.84, 19.16	508S111	17.42 ± 0.26	17.45 ± 0.11
near 25.96, 19.16	508S112	38.19 ± 0.39	38.15 ± 0.16
near 35.62, 35.90	508S113	3.23 ± 0.11	3.50 ± 0.05
near 25.96, 41.48	508S114	66.69 ± 0.49	66.89 ± 0.21
near 25.96, 41.48	508S115	14.45 ± 0.22	14.67 ± 0.10
near 25.96, 52.64	508S116	3.66 ± 0.14	3.64 ± 0.05

[a]Refer to Figure 2.
[b]Th-232 concentration based on gamma emission from Ac-228 (911 keV).
[c]The Th-228 concentration was based on the gamma emission from Pb-212 (239 keV).
[d]Uncertainties represent the 95% confidence level, based only on counting statistics.

TABLE 7

RADIONUCLIDE CONCENTRATIONS IN SOIL
CLASS 2 AREA—GRID BLOCK 46
KERR-McGEE CORPORATION
CUSHING, OKLAHOMA

Location[a] (E, N coordinates)	ORISE Sample ID	Radionuclide Concentration (pCi/g)	
		Th-232[b]	Th-228[c]
4.54, 2.4	508S183	1.23 ± 0.09[d]	1.25 ± 0.03
11.12, 2.4	508S184	1.04 ± 0.08	1.01 ± 0.03
17.70, 2.4	508S185	1.01 ± 0.08	1.01 ± 0.03
24.28, 2.4	508S186	1.02 ± 0.07	1.01 ± 0.03
30.86, 2.4	508S187	0.84 ± 0.08	0.79 ± 0.03
37.44, 2.4	508S188	0.86 ± 0.08	0.77 ± 0.04
44.02, 2.4	508S189	1.23 ± 0.09	1.18 ± 0.03
50.60, 2.4	508S190	1.15 ± 0.08	1.08 ± 0.03
57.18, 2.4	508S191	1.39 ± 0.09	1.29 ± 0.03
1.25, 8.10	508S192	1.21 ± 0.08	1.33 ± 0.03
7.83, 8.10	508S193	1.31 ± 0.08	1.21 ± 0.03
14.41, 8.10	508S194	1.17 ± 0.08	1.19 ± 0.03
20.99, 8.10	508S195	1.08 ± 0.08	1.01 ± 0.03
27.57, 8.10	508S196	0.62 ± 0.06	0.57 ± 0.02
34.15, 8.10	508S197	0.82 ± 0.06	0.75 ± 0.03
40.73, 8.10	508S198	0.88 ± 0.08	0.86 ± 0.03
47.31, 8.10	508S199	1.35 ± 0.10	1.30 ± 0.04
53.89, 8.10	508S200	0.64 ± 0.06	0.60 ± 0.02
4.54, 13.8	508S201	1.29 ± 0.10	1.06 ± 0.03
11.12, 13.8	508S202	1.11 ± 0.08	1.21 ± 0.03
17.70, 13.8	508S203	1.44 ± 0.10	1.35 ± 0.03
24.28, 13.8	508S204	1.16 ± 0.07	1.12 ± 0.03

TABLE 7 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SOIL
CLASS 2 AREA—GRID BLOCK 46
KERR-McGEE CORPORATION
CUSHING, OKLAHOMA

Location[a] (E, N coordinates)	ORISE Sample ID	Radionuclide Concentration (pCi/g)	
		Th-232[b]	Th-228[c]
30.86, 13.8	508S205	1.16 ± 0.08	1.08 ± 0.03
37.44, 13.8	508S206	0.84 ± 0.07	0.85 ± 0.03
44.02, 13.8	508S207	0.64 ± 0.06	0.73 ± 0.02
50.60, 13.8	508S208	0.65 ± 0.06	0.66 ± 0.03
57.18, 13.8	508S209	1.07 ± 0.08	1.19 ± 0.03
1.25, 19.5	508S210	0.83 ± 0.06	0.87 ± 0.03
7.83, 19.5	508S211	1.02 ± .0.08	0.96 ± 0.03
14.41, 19.5	508S212	1.24 ± 0.09	1.32 ± 0.03
20.99, 19.5	508S213	1.25 ± 0.10	1.13 ± 0.03
27.57, 19.5	508S214	1.25 ± 0.08	1.17 ± 0.03
34.15, 19.5	508S215	0.66 ± 0.06	0.76 ± 0.02
40.73, 19.5	508S216	0.93 ± 0.07	0.79 ± 0.03
47.31, 19.5	508S217	1.12 ± 0.08	1.03 ± 0.03
53.89, 19.5	508S218	0.88 ± 0.07	0.93 ± 0.03
4.54, 25.20	508S219	1.22 ± 0.09	1.28 ± 0.03
11.12, 25.20	508S220	1.26 ± 0.08	1.23 ± 0.03
17.70, 25.20	508S221	1.37 ± 0.08	1.31 ± 0.03
24.28, 25.20	508S222	1.06 ± 0.08	1.06 ± 0.03
30.86, 25.20	508S223	0.98 ± 0.09	1.01 ± 0.03
37.44, 25.20	508S224	0.80 ± 0.06	0.75 ± 0.02
44.02, 25.20	508S225	0.95 ± 0.08	0.86 ± 0.03

TABLE 7 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SOIL
CLASS 2 AREA—GRID BLOCK 46
KERR-McGEE CORPORATION
CUSHING, OKLAHOMA

Location[a] (E, N coordinates)	ORISE Sample ID	Radionuclide Concentration (pCi/g)	
		Th-232[b]	Th-228[c]
50.60, 25.20	508S226	0.98 ± 0.08	0.93 ± 0.03
57.18, 25.20	508S227	1.00 ± 0.07	0.97 ± 0.03
1.25, 30.90	508S228	1.48 ± 0.09	1.37 ± 0.03
7.83, 30.90	508S229	1.47 ± 0.10	1.48 ± 0.04
14.41, 30.90	508S230	1.45 ± 0.09	1.36 ± 0.03
20.99, 30.90	508S231	1.22 ± 0.08	1.26 ± 0.03
27.57, 30.90	508S232	1.22 ± 0.08	1.16 ± 0.03
34.15, 30.90	508S233	1.03 ± 0.07	0.98 ± 0.03
40.73, 30.90	508S234	1.23 ± 0.10	1.13 ± 0.03
47.31, 30.90	508S235	1.25 ± 0.09	1.11 ± 0.04
53.89, 30.90	508S236	0.96 ± 0.09	0.96 ± 0.03
4.54, 36.6	508S237	1.36 ± 0.09	1.40 ± 0.04
11.12, 36.6	508S238	1.30 ± 0.10	1.29 ± 0.03
17.70, 36.6	508S239	1.53 ± 0.10	1.50 ± 0.04
24.28, 36.6	508S240	1.29 ± 0.10	1.27 ± 0.03
30.86, 36.6	508S241	1.17 ± 0.09	1.24 ± 0.03
37.44, 36.6	508S242	1.08 ± 0.07	1.06 ± 0.03
44.02, 36.6	508S243	1.28 ± 0.08	1.20 ± 0.03
50.60, 36.6	508S244	1.37 ± 0.09	1.33 ± 0.03
57.18, 36.6	508S245	1.02 ± 0.08	0.95 ± 0.03
47.29, 23.87	508S246	1.14 ± 0.07	1.17 ± 0.03

[a]Refer to Figure 3.
[b]Th-232 concentration based on gamma emission from Ac-228 (911 keV).
[c]The Th-228 concentration was based on the gamma emission from Pb-212 (239 keV).
[d]Uncertainties represent the 95% confidence level, based only on counting statistics.

TABLE 8

RADIONUCLIDE CONCENTRATIONS IN SOIL
BACKGROUND REFERENCE AREA—GRID BLOCK 61
KERR-McGEE CORPORATION
CUSHING, OKLAHOMA

Location[a] (E, N coordinates)	ORISE Sample ID	Radionuclide Concentration (pCi/g)	
		Th-232[b]	Th-228[c]
3.25, 0.19	508S117	1.48 ± 0.12[d]	1.49 ± 0.04
9.83, 0.19	508S118	1.26 ± 0.08	1.34 ± 0.03
16.41, 0.19	508S119	0.89 ± 0.09	0.92 ± 0.03
22.99, 0.19	508S120	1.34 ± 0.10	1.27 ± 0.03
29.57, 0.19	508S121	0.95 ± 0.10	1.07 ± 0.03
36.15, 0.19	508S122	0.95 ± 0.11	0.92 ± 0.03
6.54, 5.89	508S123	1.28 ± 0.10	1.27 ± 0.04
13.12, 5.89	508S124	1.54 ± 0.09	1.38 ± 0.03
19.70, 5.89	508S125	1.41 ± 0.10	1.23 ± 0.04
26.28, 5.89	508S126	1.21 ± 0.10	1.39 ± 0.04
32.86, 5.89	508S127	1.36 ± 0.10	1.50 ± 0.04
39.44, 5.89	508S128	1.14 ± 0.09	1.12 ± 0.04
3.25, 11.59	508S129	1.39 ± 0.09	1.30 ± 0.03
9.83, 11.59	508S130	1.22 ± 0.09	1.34 ± 0.03
16.41, 11.59	508S131	1.37 ± 0.09	1.40 ± 0.03
22.99, 11.59	508S132	1.32 ± 0.11	1.30 ± 0.04
29.57, 11.59	508S133	1.33 ± 0.09	1.35 ± 0.04
36.15, 11.59	508S134	1.31 ± 0.11	1.39 ± 0.04
6.54, 17.29	508S135	1.04 ± 0.10	1.22 ± 0.04
13.12, 17.29	508S136	1.52 ± 0.10	1.31 ± 0.04
19.70, 17.29	508S137	1.54 ± 0.09	1.31 ± 0.03
26.28, 17.29	508S138	1.40 ± 0.10	1.39 ± 0.04
32.86, 17.29	508S139	1.32 ± 0.09	1.48 ± 0.04

TABLE 8 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SOIL
BACKGROUND REFERENCE AREA—GRID BLOCK 61
KERR-McGEE CORPORATION
CUSHING, OKLAHOMA

Location[a] (E, N coordinates)	ORISE Sample ID	Radionuclide Concentration (pCi/g)	
		Th-232[b]	Th-228[c]
39.44, 17.29	508S140	1.38 ± 0.10[d]	1.41 ± 0.04
3.25, 22.99	508S141	1.42 ± 0.11	1.38 ± 0.04
9.83, 22.99	508S142	1.48 ± 0.09	1.17 ± 0.04
16.41, 22.99	508S143	1.48 ± 0.09	1.33 ± 0.04
22.99, 22.99	508S144	1.34± 0.12	1.34 ± 0.04
29.57, 22.99	508S145	1.47 ± 0.10	1.41 ± 0.04
36.15, 22.99	508S146	1.48 ± 0.09	1.58 ± 0.04
6.54, 28.69	508S147	1.40 ± 0.10	1.33 ± 0.04
13.12, 28.69	508S148	1.45 ± 0.10	1.39 ± 0.04
19.70, 28.69	508S149	1.27 ± 0.08	1.30 ± 0.03
26.28, 28.69	508S150	1.39 ± 0.10	1.44 ± 0.04
32.86, 28.69	508S151	1.48 ± 0.09	1.39 ± 0.04
39.44, 28.69	508S152	1.34 ± 0.09	1.35 ± 0.04
3.25, 34.39	508S153	1.31 ± 0.10	1.28 ± 0.04
9.83, 34.39	508S154	1.46 ± 0.09	1.27 ± 0.03
16.41, 34.39	508S155	1.04 ± 0.07	0.91 ± 0.02
22.99, 34.39	508S156	1.03 ± 0.08	0.98 ± 0.03
29.57, 34.39	508S157	0.89 ± 0.08	0.88 ± 0.03
36.15, 34.39	508S158	1.36 ± 0.09	1.34 ± 0.03
6.54, 40.09	508S159	1.13 ± 0.08	1.11 ± 0.03
13.12, 40.09	508S160	1.30 ± 0.08	1.23 ± 0.03
19.70, 40.09	508S161	1.41 ± 0.10	1.41 ± 0.04
26.28, 40.09	508S162	1.24 ± 0.09	1.13 ± 0.04

TABLE 8 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SOIL
BACKGROUND REFERENCE AREA—GRID BLOCK 61
KERR-McGEE CORPORATION
CUSHING, OKLAHOMA

Location[a] (E, N coordinates)	ORISE Sample ID	Radionuclide Concentration (pCi/g)	
		Th-232[b]	Th-228[c]
32.86, 40.09	508S163	1.15 ± 0.09	1.16 ± 0.03
39.44, 40.09	508S164	1.14 ± 0.11	1.10 ± 0.03
3.25, 45.79	508S165	1.44 ± 0.11	1.33 ± 0.04
9.83, 45.79	508S166	1.14 ± 0.10	1.16 ± 0.03
16.41, 45.79	508S167	1.47 ± 0.12	1.57 ± 0.04
22.99, 45.79	508S168	1.20 ± 0.10	1.22 ± 0.03
29.57, 45.79	508S169	1.42 ± 0.09	1.39 ± 0.04
36.15, 45.79	508S170	1.09 ± 0.09	1.19 ± 0.03
6.54, 51.49	508S171	1.35 ± 0.09	1.23 ± 0.03
13.12, 51.49	508S172	1.14 ± 0.11	1.24 ± 0.03
19.70, 51.49	508S173	1.20 ± 0.10	1.18 ± 0.03
26.28, 51.49	508S174	1.32 ± 0.07	1.17 ± 0.03
32.86, 51.49	508S175	1.38 ± 0.10	1.40 ± 0.03
39.44, 51.49	508S176	1.23 ± 0.09	1.24 ± 0.03
3.25, 57.19	508S177	0.99 ± 0.09	1.17 ± 0.03
9.83, 57.19	508S178	1.29 ± 0.09	1.19 ± 0.03
16.41, 57.19	508S179	1.09 ± 0.11	1.32 ± 0.04
22.99, 57.19	508S180	1.16 ± 0.10	1.27 ± 0.03
29.57, 57.19	508S181	1.27 ± 0.09	1.20 ± 0.03
36.15, 57.19	508S182	1.25 ± 0.09	1.31 ± 0.03

[a]Refer to Figure 4.
[b]Th-232 concentration based on gamma emission from Ac-228 (911 keV).
[c]The Th-228 concentration was based on the gamma emission from Pb-212 (239 keV).
[d]Uncertainties represent the 95% confidence level, based only on counting statistics.

REFERENCES

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Multiagency Radiation Survey and Site Investigation Manual (MARSSIM). Public Review Draft. October 1996a.

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Oak Ridge Institute for Science and Education (ORISE). Survey Procedures Manual for the Energy/Environment Systems Division, Environmental Survey and Site Assessment Program, Revision 9. Oak Ridge, TN; April 30, 1995a.

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Oak Ridge Institute for Science and Education. Revised Draft—Final Status Survey Plan Using MARSSIM Survey Methodologies for the Cushing Refinery site, Kerr-McGee Corporation, Cushing, Oklahoma. Oak Ridge, TN; October 21, 1996.

APPENDIX A

MAJOR INSTRUMENTATION

APPENDIX A

MAJOR INSTRUMENTATION

The display of a specific product is not to be construed as an endorsement of the product or its manufacturer by the author or his employer.

DIRECT RADIATION MEASUREMENT

Instruments

Eberline Pulse Ratemeter
Model PRM-6
(Eberline, Santa Fe, NM)

Ludlum Ratemeter
Model 12
(Ludlum Measurements, Inc.,
Sweetwater, TX)

Detectors

Victoreen NaI Scintillation Detector
Model 489-55
3.2 cm x 3.8 cm Crystal
(Victoreen, Cleveland, OH)

LABORATORY ANALYTICAL INSTRUMENTATION

High Purity Extended Range Intrinsic Detectors
Model No. ERVDS30-25195
(Tennelec, Oak Ridge, TN)
Used in conjunction with:
Lead Shield Model G-11
(Nuclear Lead, Oak Ridge, TN) and
Multichannel Analyzer
3100 Vax Workstation
(Canberra, Meriden, CT)

High-Purity Germanium Detector
Model GMX-23195-S, 23% Eff.
(EG&G ORTEC, Oak Ridge, TN)
Used in conjunction with:
Lead Shield Model G-16
(Gamma Products, Palos Hills, IL) and
Multichannel Analyzer
3100 Vax Workstation
(Canberra, Meriden, CT)

APPENDIX B

SURVEY AND ANALYTICAL PROCEDURES

APPENDIX B

SURVEY AND ANALYTICAL PROCEDURES

SURVEY PROCEDURES

Surface Scans

Surface scans were performed by passing the detectors slowly over the surface; the distance between the detector and the surface was maintained at a minimum - nominally about 10 cm. Identification of elevated levels was based on increases in the audible signal from the recording and/or indicating instrument. Combinations of detectors and instruments used for the scans were:

Gamma - NaI scintillation detector with ratemeter

Soil Sampling

Approximately 1 kg of soil was collected at each sample location. Surface soil samples were collected at 0-15 cm depth. Collected samples were placed in a plastic bag, sealed, and labeled in accordance with ESSAP survey procedures.

ANALYTICAL PROCEDURES

Gamma Spectroscopy

Soil samples were dried, mixed, crushed, and/or homogenized as necessary, and a portion sealed in 0.5-liter Marinelli beaker or other appropriate container. The quantity placed in the beaker was chosen to reproduce the calibrated counting geometry. Net material weights were determined and the samples counted using intrinsic germanium detectors coupled to a pulse height analyzer system. Background and Compton stripping, peak search, peak identification, and concentration calculations

were performed using the computer capabilities inherent in the analyzer system. All photopeaks associated with the radionuclides of concern were reviewed for consistency of activity. Energy peaks used for determining the activities of radionuclides of concerns are:

Th-228	0.239 MeV from Pb-212*
Th-232	0.911 MeV from Ac-228*

*Secular equilibrium assumed.

UNCERTAINTIES AND DETECTION LIMITS

The uncertainties associated with the analytical data presented in the tables of this report represent the 95% confidence level for that data. These uncertainties were calculated based on both the gross sample count levels and the associated background count levels. Additional uncertainties, associated with sampling and measurement procedures, have not been propagated into the data presented in this report.

Detection limits, referred to as minimum detectable concentration (MDC), were based on 3 plus 4.65 times the standard deviation of the background count [$3 + 4.65\sqrt{BKG}$]. When the activity was determined to be less than the MDC of the measurement procedure, the result was reported as less than MDC. Because of variations in background levels, measurement efficiencies, and contributions from other radionuclides in samples, the detection limits differ from sample to sample and instrument to instrument.

CALIBRATION AND QUALITY ASSURANCE

Calibration of all field and laboratory instrumentation was based on standards/sources, traceable to NIST, when such standard/sources were available. In cases where they were not available, standards of an industry recognized organization were used.

Analytical and field survey activities were conducted in accordance with procedures from the following documents of the Environmental Survey and Site Assessment Program:

- Survey Procedures Manual, Revision 9 (April 1995)
- Laboratory Procedures Manual, Revision 9 (January 1995)
- Quality Assurance Manual, Revision 7 (January 1995)

The procedures contained in these manuals were developed to meet the requirements of DOE Order 5700.6C and ASME NQA-1 for Quality Assurance and contain measures to assess processes during their performance.

Quality control procedures include:

- Daily instrument background and check-source measurements to confirm that equipment operation is within acceptable statistical fluctuations.
- Participation in EPA and EML laboratory Quality Assurance Programs.
- Training and certification of all individuals performing procedures.
- Periodic internal and external audits.

APPENDIX C

SPREADSHEET RESULTS FOR WILCOXON RANK SUM TESTS

Spreadsheet for WRS Test					
Class 1 Area (RMA-4)					
Th-232	**Area**	**Adjusted Data**	**Ranks**	**Ref Area Ranks**	
(pCi/g)					
1.48	R	1.636	120	120	
1.26	R	1.415	80	80	
0.89	R	1.0528	7	7	
1.34	R	1.498	96	96	
0.95	R	1.1093	15	15	
0.95	R	1.1149	16	16	
1.28	R	1.442	84.5	84.5	
1.54	R	1.703	126.5	126.5	
1.41	R	1.567	109	109	
1.21	R	1.37	72	72	
1.36	R	1.521	100	100	
1.14	R	1.297	59	59	
1.39	R	1.551	104	104	
1.22	R	1.383	75	75	
1.42	R	1.581	112	112	
1.48	R	1.639	121	121	
1.48	R	1.64	122	122	
1.34	R	1.504	97	97	
1.47	R	1.625	116	116	
1.48	R	1.635	118.5	118.5	
1.40	R	1.562	107	107	
1.45	R	1.609	114	114	
1.27	R	1.428	82	82	
1.39	R	1.554	105	105	
1.37	R	1.532	101	101	
1.32	R	1.479	92	92	
1.33	R	1.493	94	94	
1.31	R	1.472	89	89	
1.04	R	1.203	40	40	
1.52	R	1.679	124	124	
1.54	R	1.703	126.5	126.5	
1.40	R	1.559	106	106	
1.32	R	1.484	93	93	
1.38	R	1.543	103	103	
1.48	R	1.635	118.5	118.5	
1.34	R	1.496	95	95	
1.31	R	1.473	90	90	
1.46	R	1.621	115	115	
1.04	R	1.198	38.5	38.5	
1.03	R	1.185	35	35	
0.89	R	1.0455	6	6	
1.36	R	1.515	99	99	
1.13	R	1.285	56	56	
1.30	R	1.462	88	88	
1.41	R	1.565	108	108	

1.24	R	1.395	77	77	
1.15	R	1.314	64	64	
1.14	R	1.297	59	59	
1.44	R	1.599	113	113	
1.14	R	1.297	59	59	
1.47	R	1.626	117	117	
1.20	R	1.362	71	71	
1.42	R	1.577	110	110	
1.09	R	1.249	48	48	
1.35	R	1.514	98	98	
1.14	R	1.304	62	62	
1.20	R	1.359	70	70	
1.32	R	1.476	91	91	
1.38	R	1.539	102	102	
1.23	R	1.387	76	76	
0.99	R	1.1499	26	26	
1.29	R	1.449	86	86	
1.09	R	1.253	49	49	
1.16	R	1.319	65	65	
1.27	R	1.434	83	83	
1.25	R	1.408	78	78	
1.26	S	1.26	52	0	
1.21	S	1.212	42	0	
1.21	S	1.211	41	0	
1.05	S	1.054	8	0	
1.34	S	1.336	67	0	
1.22	S	1.219	44	0	
1.29	S	1.293	57	0	
1.26	S	1.259	51	0	
1.18	S	1.182	33	0	
1.31	S	1.31	63	0	
1.07	S	1.068	11	0	
1.42	S	1.423	81	0	
1.22	S	1.218	43	0	
1.12	S	1.12	17	0	
1.18	S	1.177	31	0	
3.26	S	3.259	135	0	
1.36	S	1.357	69	0	
1.28	S	1.278	55	0	
1.20	S	1.198	38.5	0	
1.33	S	1.326	66	0	
1.88	S	1.884	128	0	
2.09	S	2.085	132	0	
1.30	S	1.299	61	0	
1.06	S	1.059	9	0	
1.07	S	1.069	12	0	
1.19	S	1.186	36	0	
1.03	S	1.027	4	0	
2.06	S	2.055	131	0	

2.26	S	2.256	133	0	
1.45	S	1.452	87	0	
0.97	S	0.9687	3	0	
1.23	S	1.23	45	0	
1.27	S	1.268	53	0	
1.58	S	1.578	111	0	
2.68	S	2.677	134	0	
1.41	S	1.409	79	0	
1.16	S	1.159	28	0	
1.25	S	1.247	47	0	
1.15	S	1.147	25	0	
1.15	S	1.146	24	0	
1.69	S	1.693	125	0	
2.05	S	2.052	130	0	
1.12	S	1.124	18	0	
1.25	S	1.245	46	0	
1.04	S	1.035	5	0	
1.19	S	1.191	37	0	
1.65	S	1.653	123	0	
1.37	S	1.372	73	0	
1.13	S	1.128	19	0	
1.18	S	1.184	34	0	
1.14	S	1.142	21	0	
1.38	S	1.376	74	0	
1.44	S	1.442	84.5	0	
1.15	S	1.154	27	0	
1.08	S	1.081	13	0	
1.14	S	1.136	20	0	
1.17	S	1.171	29	0	
1.06	S	1.063	10	0	
1.92	S	1.922	129	0	
1.28	S	1.275	54	0	
1.17	S	1.172	30	0	
1.18	S	1.179	32	0	
1.26	S	1.258	50	0	
1.10	S	1.098	14	0	
1.36	S	1.356	68	0	
0.95	S	0.9461	1	0	
0.97	S	0.966	2	0	
1.14	S	1.143	22	0	
1.14	S	1.144	23	0	
Mean of reference area		1.29			
STD DEV Ref. Area		0.16	Wr =	5580	
Mean of Class 1 area		1.34	**The critical value is 4862; since Wr is greater than**		
STD DEV Class 1		0.40	**critical value, hypothesis rejected & survey unit passes**		

Spreadsheet for WRS Test					
Class 2 Area (Grid block 46)					
Th-232	**Area**	**Adjusted Data**	**Ranks**	**Ref Area Ranks**	
(pCi/g)					
1.48	R	1.636	125	125	
1.26	R	1.415	84	84	
0.89	R	1.0528	27	27	
1.34	R	1.498	101	101	
0.95	R	1.1093	32	32	
0.95	R	1.1149	34	34	
1.28	R	1.442	88	88	
1.54	R	1.703	129.5	129.5	
1.41	R	1.567	115	115	
1.21	R	1.37	78	78	
1.36	R	1.521	105	105	
1.14	R	1.297	65	65	
1.39	R	1.551	110	110	
1.22	R	1.383	79	79	
1.42	R	1.581	117	117	
1.48	R	1.639	126	126	
1.48	R	1.64	127	127	
1.34	R	1.504	102	102	
1.47	R	1.625	121	121	
1.48	R	1.635	123.5	123.5	
1.40	R	1.562	113	113	
1.45	R	1.609	119	119	
1.27	R	1.428	85	85	
1.39	R	1.554	111	111	
1.37	R	1.532	107	107	
1.32	R	1.479	96	96	
1.33	R	1.493	99	99	
1.31	R	1.472	93	93	
1.04	R	1.203	45	45	
1.52	R	1.679	128	128	
1.54	R	1.703	129.5	129.5	
1.40	R	1.559	112	112	
1.32	R	1.484	98	98	
1.38	R	1.543	109	109	
1.48	R	1.635	123.5	123.5	
1.34	R	1.496	100	100	
1.31	R	1.473	94	94	
1.46	R	1.621	120	120	
1.04	R	1.198	44	44	
1.03	R	1.185	43	43	
0.89	R	1.0455	26	26	
1.36	R	1.515	104	104	
1.13	R	1.285	61.5	61.5	
1.30	R	1.462	91	91	
1.41	R	1.565	114	114	

1.24	R	1.395	82	82	
1.15	R	1.314	70	70	
1.14	R	1.297	65	65	
1.44	R	1.599	118	118	
1.14	R	1.297	65	65	
1.47	R	1.626	122	122	
1.20	R	1.362	75	75	
1.42	R	1.577	116	116	
1.09	R	1.249	55	55	
1.35	R	1.514	103	103	
1.14	R	1.304	68	68	
1.20	R	1.359	74	74	
1.32	R	1.476	95	95	
1.38	R	1.539	108	108	
1.23	R	1.387	80	80	
0.99	R	1.1499	37	37	
1.29	R	1.449	90	90	
1.09	R	1.253	58	58	
1.16	R	1.319	71	71	
1.27	R	1.434	86	86	
1.25	R	1.408	83	83	
1.23	S	1.227	50	0	
1.04	S	1.038	25	0	
1.01	S	1.01	20	0	
1.02	S	1.016	21	0	
0.84	S	0.8406	9	0	
0.86	S	0.8612	11	0	
1.23	S	1.229	51	0	
1.15	S	1.151	38	0	
1.39	S	1.391	81	0	
1.21	S	1.21	46	0	
1.31	S	1.313	69	0	
1.17	S	1.171	42	0	
1.08	S	1.081	30	0	
0.62	S	0.6223	1	0	
0.82	S	0.8207	7	0	
0.88	S	0.8816	13	0	
1.35	S	1.353	72	0	
0.64	S	0.6439	3	0	
1.29	S	1.287	63	0	
1.11	S	1.111	33	0	
1.44	S	1.436	87	0	
1.16	S	1.161	40	0	
1.16	S	1.158	39	0	
0.84	S	0.8448	10	0	
0.64	S	0.6357	2	0	
0.65	S	0.6549	4	0	
1.07	S	1.068	29	0	
0.83	S	0.8333	8	0	

1.02	S	1.019	23	0	
1.24	S	1.237	53	0	
1.25	S	1.25	57	0	
1.25	S	1.249	56	0	
0.66	S	0.6617	5	0	
0.93	S	0.9301	14	0	
1.12	S	1.115	35	0	
0.88	S	0.879	12	0	
1.22	S	1.22	49	0	
1.26	S	1.264	59	0	
1.37	S	1.369	77	0	
1.06	S	1.063	28	0	
0.98	S	0.9832	17	0	
0.80	S	0.8016	6	0	
0.95	S	0.9452	15	0	
0.98	S	0.9842	18	0	
1.00	S	0.9992	19	0	
1.48	S	1.479	97	0	
1.47	S	1.47	92	0	
1.45	S	1.446	89	0	
1.22	S	1.216	47	0	
1.22	S	1.219	48	0	
1.03	S	1.03	24	0	
1.23	S	1.231	52	0	
1.25	S	1.245	54	0	
0.96	S	0.9621	16	0	
1.36	S	1.355	73	0	
1.30	S	1.303	67	0	
1.53	S	1.527	106	0	
1.29	S	1.285	61.5	0	
1.17	S	1.169	41	0	
1.08	S	1.082	31	0	
1.28	S	1.277	60	0	
1.37	S	1.367	76	0	
1.02	S	1.018	22	0	
1.14	S	1.138	36	0	
Mean of reference area		1.29			
STD DEV Ref. Area		0.16	**Wr =**	**5975.5**	
Mean of Class 2 area		1.11	**The critical value is 4676; Wr is greater than**		
STD DEV of Class 2		0.22	**critical value, hypothesis rejected & survey unit passes**		

Spreadsheet for WRS Test (for reversed Class 2 and Background Reference Area)					
Class 2 Area - (AS THE BACKGROUND REFERENCE AREA)					
Th-232	**Area**	**Adjusted Data**	**Ranks**	**Ref Area Ranks**	
(pCi/g)					
1.48	S	1.476	115	0	
1.26	S	1.255	54	0	
0.89	S	0.8928	7	0	
1.34	S	1.338	75	0	
0.95	S	0.9493	8	0	
0.95	S	0.9549	9	0	
1.28	S	1.282	59	0	
1.54	S	1.543	123.5	0	
1.41	S	1.407	97	0	
1.21	S	1.21	45	0	
1.36	S	1.361	79	0	
1.14	S	1.137	29	0	
1.39	S	1.391	89.5	0	
1.22	S	1.223	47	0	
1.42	S	1.421	101	0	
1.48	S	1.479	116	0	
1.48	S	1.48	117	0	
1.34	S	1.344	76	0	
1.47	S	1.465	110	0	
1.48	S	1.475	113.5	0	
1.40	S	1.402	94	0	
1.45	S	1.449	107	0	
1.27	S	1.268	55	0	
1.39	S	1.394	91	0	
1.37	S	1.372	81	0	
1.32	S	1.319	68	0	
1.33	S	1.333	73	0	
1.31	S	1.312	64	0	
1.04	S	1.043	21	0	
1.52	S	1.519	120	0	
1.54	S	1.543	123.5	0	
1.40	S	1.399	93	0	
1.32	S	1.324	70	0	
1.38	S	1.383	86	0	
1.48	S	1.475	113.5	0	
1.34	S	1.336	74	0	
1.31	S	1.313	65	0	
1.46	S	1.461	108	0	
1.04	S	1.038	18	0	
1.03	S	1.025	17	0	
0.89	S	0.8855	6	0	
1.36	S	1.355	78	0	
1.13	S	1.125	27	0	
1.30	S	1.302	62	0	
1.41	S	1.405	95.5	0	

1.24	S	1.235	50	0	
1.15	S	1.154	34	0	
1.14	S	1.137	29	0	
1.44	S	1.439	104	0	
1.14	S	1.137	29	0	
1.47	S	1.466	111	0	
1.20	S	1.202	44	0	
1.42	S	1.417	100	0	
1.09	S	1.089	22	0	
1.35	S	1.354	77	0	
1.14	S	1.144	32	0	
1.20	S	1.199	43	0	
1.32	S	1.316	66	0	
1.38	S	1.379	83.5	0	
1.23	S	1.227	48	0	
0.99	S	0.9899	12	0	
1.29	S	1.289	60	0	
1.09	S	1.093	24	0	
1.16	S	1.159	35	0	
1.27	S	1.274	57	0	
1.25	S	1.248	53	0	
1.23	R	1.387	87	87	
1.04	R	1.198	42	42	
1.01	R	1.17	37	37	
1.02	R	1.176	38	38	
0.84	R	1.0006	14	14	
0.86	R	1.0212	16	16	
1.23	R	1.389	88	88	
1.15	R	1.311	63	63	
1.39	R	1.551	125	125	
1.21	R	1.37	80	80	
1.31	R	1.473	112	112	
1.17	R	1.331	72	72	
1.08	R	1.241	51	51	
0.62	R	0.7823	1	1	
0.82	R	0.9807	11	11	
0.88	R	1.0416	20	20	
1.35	R	1.513	118	118	
0.64	R	0.8039	3	3	
1.29	R	1.447	106	106	
1.11	R	1.271	56	56	
1.44	R	1.596	126	126	
1.16	R	1.321	69	69	
1.16	R	1.318	67	67	
0.84	R	1.0048	15	15	
0.64	R	0.7957	2	2	
0.65	R	0.8149	4	4	
1.07	R	1.228	49	49	

0.83	R	0.9933	13	13	
1.02	R	1.179	40	40	
1.24	R	1.397	92	92	
1.25	R	1.41	99	99	
1.25	R	1.409	98	98	
0.66	R	0.8217	5	5	
0.93	R	1.0901	23	23	
1.12	R	1.275	58	58	
0.88	R	1.039	19	19	
1.22	R	1.38	85	85	
1.26	R	1.424	102	102	
1.37	R	1.529	122	122	
1.06	R	1.223	46	46	
0.98	R	1.1432	31	31	
0.80	R	0.9616	10	10	
0.95	R	1.1052	25	25	
0.98	R	1.1442	33	33	
1.00	R	1.1592	36	36	
1.48	R	1.639	129	129	
1.47	R	1.63	128	128	
1.45	R	1.606	127	127	
1.22	R	1.376	82	82	
1.22	R	1.379	83.5	83.5	
1.03	R	1.19	41	41	
1.23	R	1.391	89.5	89.5	
1.25	R	1.405	95.5	95.5	
0.96	R	1.1221	26	26	
1.36	R	1.515	119	119	
1.30	R	1.463	109	109	
1.53	R	1.687	130	130	
1.29	R	1.445	105	105	
1.17	R	1.329	71	71	
1.08	R	1.242	52	52	
1.28	R	1.437	103	103	
1.37	R	1.527	121	121	
1.02	R	1.178	39	39	
1.14	R	1.298	61	61	
Mean of reference area		1.11			
STD DEV Ref. Area		0.22	**Wr =**	**4120.5**	
Mean of Class 2 area		1.29	**The critical value is 4545; Wr is less than**		
STD DEV of Class 2		0.16	**critical value, hypothesis NOT rejected & survey unit fails WRS**		