FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

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COMPARABILITY OF *IN-SITU* GAMMA SPECTROMETRY AND LABORATORY DATA

JANUARY 1999

U.S. DEPARTMENT OF ENERGY
FERNALD AREA OFFICE

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REVISION 1

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EXECUTIVE SUMMARY

In July 1997, a report entitled "Comparability of In-Situ Gamma Spectrometry and Laboratory Data" (hereafter referred to as the July 1997 Comparability Study) was issued that assessed the comparability of high-purity germanium (HPGe) detector measurements with laboratory data generated from the analysis of physical samples. The July 1997 report provided the basis for five subsequent reports.

1. An addendum to the July 1997 report entitled "Comparability of Total Uranium Data as Measured by In-Situ Gamma Spectrometry and Four Laboratory Methods" (September 1997) extended the comparability of HPGe to laboratory data to total uranium concentrations in excess of WAC levels (1030 ppm).

2. A second addendum to the July 1997 report entitled "Comparability of In-situ Gamma Spectrometry and Laboratory Measurements of Radium-226" (October 1997) resulted in the development of a method of compensating for radon-222 disequilibrium in radium-226 measurements.

3. A third addendum to the July 1997 report entitled "Effect of Environmental Variables Upon In-Situ Gamma Spectrometry and Laboratory Data" (December 1998) demonstrated that control charts based upon repeated measurements at a single location for long periods of time constituted an effective means of assessing the effects of weather and climatic variables upon HPGe measurements.

4. A document entitled "User Guidelines, Measurement Strategies, and Operational Factors for Deployment of In-Situ Gamma Spectrometry at the Fernald Site" (July 1998) provided practical guidelines for measurement strategies and approaches, data integration, and display. This document is referred to as the "User's Manual" throughout this report.

5. A document entitled "In-Situ Gamma Spectrometry Addendum to the Sitewide CERCLA Quality Assurance Project Plan" (August 1998) outlined the QA/QC requirements that govern the collection of HPGe measurements.

This document (Revision 1.0 of the July 1997 Comparability Study) builds and expands upon the above five documents: it consolidates the three addenda to the July 1997 Comparability Study with the July 1997 Comparability Study itself to form a single document; it incorporates data resulting from additional laboratory measurements of physical samples into the study; it incorporates six months of additional measurements pertaining to the effect of weather and climatic factors into the study; and it substitutes HPGe data processed by a commercially available software package (GammaVision) as a replacement for the same data originally processed using EGAS (a consultant software package).

As a major part of this study, twelve months worth of morning and afternoon HPGe measurements were made at a single location in order to assess weather and climatic effects upon HPGe measurements. This twelve-month study demonstrated that HPGe measurements for total uranium and thorium-232 are quite robust with respect to climatic and weather influences and that comparisons of laboratory and HPGe measurements for these two analytes can be made with confidence. Conversely, this twelve-month study also indicated that laboratory and HPGe measurements for radium-226 may not be directly comparable unless radon disequilibrium effects are taken into account. In this regard, measurements for radium-226 should be made in the afternoon whenever possible.

With respect to the method validation study itself, HPGe measurements and physical samples were collected from 18 areas representing low, medium, and high degrees of contamination. The number of physical samples collected ranged from six for low contamination areas to 15 for highly contaminated areas. The distribution of physical samples was arranged in a "bulls eye" pattern to mimic the averging done by the HPGe detector, and each sample was weighted based upon the photon fluence expected for that sample.

Comparability of HPGe and laboratory data was evaluated by assessing the degree of closeness and the degree of correlation of the data sets. Results for total uranium demonstrated that HPGe can be used to accurately measure total uranium concentrations over a wide range of values from near background to greater than WAC levels (1030 ppm). HPGe shows very good comparability between HPGe data for total uranium with data measured by a variety of laboratory analytical methods. Thus, comparability is independent of the analytical method used. Finally, HPGe yields more representative average total uranium concentrations in areas in which uranium is very heterogeneously distributed than individual physical samples. For thorium-232, HPGe data are higher than laboratory alpha spectrometry data and lower than laboratory gamma data. However, HPGe data are very comparable to the average of laboratory alpha and gamma spectrometry data. This average is believed to be the most representative laboratory data for comparability purposes.

In general, HPGe measurements were not comparable with laboratory data for radium-226. HPGe derived radium-226 concentrations are consistently lower than laboratory measured concentrations, and the difference between the two sets of measured values increases as the concentration of radium-226 in the soil increases. This effect results from radon-222 disequilibrium in the soil as noted above.

However, a process for obtaining correction factors for HPGe measured radium-226 concentrations was derived to compensate for "loss" of radium-226 due to radon-222 emanation from soils. HPGe measurements for radium-226 are very comparable to laboratory data when these correction factors are used.

Three studies were carried out to independently verify HPGe comparability and accuracy. In the first of these, FEMP results are very comparable to those obtained by DOE-EML based upon measurements carried out at the same time and same locations. The second study involved an intercomparison performed at Brookhaven National Laboratory by six groups using in-situ gamma spectrometry. Two of those groups using the same type of calibration method and similar software as used by the FEMP obtained results for radium-226 and thorium-232 that were very comparable to laboratory-measured concentrations in soil. The third, and last, study involved comparing HPGe measurements with laboratory data at the location at which twelve months worth of HPGe measurements were collected to assess climatic and weather factors. Excellent comparability between HPGe and laboratory data was obtained. Taken together, these three independent studies provide an excellent affirmation of the comparability data, discussions, and conclusions in Sections 5, 6, and 7 of this report.

Finally, this study concludes that HPGe measurements for the three analytes investigated in this study (total uranium, thorium-232, and radium-226) meet all of the QC acceptance criteria for both ASL D and ASL B for all QC elements. However, for HPGe measurements for radium-226, the measurements must be corrected for radon disequilibrium in order to meet the ASL D criterion for accuracy. Otherwise, radium-226 measurements may only be used for ASL B purposes.

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LIST OF ACRONYMS AND ABBREVIATIONS

ARAR	applicable or relevant and appropriate requirement
ASL	analytical support level
ASTM	American Society of Testing and Materials
BromoPADAP	2-(5-bromo-2-pyridylazo)-5-diethylaminophenol
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CLP	Contract Laboratory Program
cm	centimeter
CU	certification unit
DOE	US Department of Energy
DQO	data quality objective
EGAS	environmental gamma analysis software
EML	Environmental Measurements Laboratory
EPA	US Environmental Protection Agency
eV	electron volt
FCS	field quality control station
FDF	Fluor Daniel Fernald
FEMP	Fernald Environmental Management Project
FRL	final remediation level
ft	feet
FWHM	full width half maximum
GPS	global positioning system
GV	GammaVision
HPGe	high-purity germanium
ICP/MS	inductively coupled plasma/mass spectrometry
K	potassium
keV	kiloelectron volt
LCL	lower control limit or lower confidence limit
LWL	lower warning limit
m	meter
MDA	minimum detectable activity
MDC	minimum detectable concentration
NaI	sodium iodide
OSDF	on-site disposal facility
pCi/g	picocuries per gram
ppm	parts per million
QA/QC	quality assurance/quality control
Ra	radium
RPD	relative percent difference or deviation
RTRAK	Radiation Tracking System
SCQ	Sitewide CERCLA Quality Assurance Project Plan
SD	standard deviation
SED	Sitewide Environmental Database
SOW	statement of work
STP	Sewage Treatment Plant
Th	thorium
TPU	total propagated uncertainty

U	uranium
UCL	upper confidence limit or upper control limit
WAC	waste acceptance criteria

1.0 INTRODUCTION, OBJECTIVES, AND REPORT ORGANIZATION

1.1 INTRODUCTION

In July 1997, a report entitled "Comparability of In-Situ Gamma Spectrometry and Laboratory Data" (hereafter referred to as the July 1997 Comparability Study) was issued that assessed the comparability of high-purity germanium (HPGe) detector measurements with laboratory data generated from the analysis of physical samples. Additionally, that report identified and defined key parameters that affect the known quality of data for the HPGe system and established values, limits, and acceptance criteria for those parameters based upon HPGe measurements collected in the July 1997 Comparability Study.

The July 1997 report also provided the basis for five subsequent reports.

1. An addendum to the July 1997 report entitled "Comparability of Total Uranium Data as Measured by In-Situ Gamma Spectrometry and Four Laboratory Methods" (September 1997) extended the comparability of HPGe to laboratory data to total uranium concentrations in excess of WAC levels (1030 ppm).

2. A second addendum to the July 1997 report entitled "Comparability of In-Situ Gamma Spectrometry and Laboratory Measurements of Radium-226" (October 1997) resulted in the development of a method of compensating for radon-222 disequilibrium in radium-226 measurements.

3. A third addendum to the July 1997 report entitled "Effect of Environmental Variables Upon In-Situ Gamma Spectrometry and Laboratory Data" (December 1997) demonstrated that control charts based upon repeated measurements at a single location for long periods of time constituted an effective means of assessing the effects of weather and climatic variables upon HPGe measurements.

4. A document entitled "User Guidelines, Measurement Strategies, and Operational Factors for Deployment of In-Situ Gamma Spectrometry at the Fernald Site" (July 1998) provided practical guidelines for measurement strategies and approaches, data interpretation, and display. This document is referred to as the "User's Manual" throughout this report.

5. A document entitled "In-Situ Gamma Spectrometry Addendum to the Sitewide CERCLA Quality Assurance Project Plan" (August 1998) outlined the QA/QC requirements that govern the collection of HPGe measurements.

The five documents above collectively resulted in regulatory approval for HPGe to be used in support of pre-design, excavation control, and pre-certification activities.

1.2 SCOPE

This report differs in content from the July 1997 Comparability Study in three major respects. First, and most importantly, this report does not contain any data pertaining to "Part A" of the July 1997 Comparability Study. "Part A" data and ancillary discussions will now be included in a companion, albeit stand-alone, report to this one. Second, in a further effort to consolidate this report, certain parts of Section 4.0 of the July 1997 Comparability Study are not included. Section 4.0 presented the results of a DOE-EML comparability study. The interested reader can refer to the July 1997 report for information. Third, only data for the three major contaminants of concern are addressed in this report - total uranium, thorium-232 and radium-226. Potassium-40 and cesium-137 data, although included in the July 1997 report, are not of sufficient remediation interest to warrant inclusion in this revision. Again, the interested reader can refer to the July 1997 Comparability Study for information.

1.3 OBJECTIVES

This document (Revision 1.0 of the July 1997 Comparability Study) builds and expands upon the above five documents. In this regard, the following are the major objectives of the report:

1. Consolidate the three addenda to the July 1997 Comparability Study with the July 1997 Comparability Study itself to form a single document;

2. Incorporate data resulting from additional laboratory measurements of physical samples into the study;

3. Incorporate six months of additional measurements pertaining to the effect of weather and climatic factors into the study;

4. Substitute HPGe data processed by a commercially available software package (GammaVision) as a replacement for the same data originally processed using EGAS (a consultant software package); and

5. Address various comments made by regulatory agencies to the July 1997 Comparability Study and its three addenda.

1.4 REPORT FORMAT

Section 1 introduces, delineates objectives, and provides an overview of Revision 1.0 of this comparability study report. Section 2 discusses the effects of weather and climatic variables upon in-situ gamma spectrometry data. Section 3 outlines the design and methodologies used for the method validation studies. Section 4 presents the basis for assessing comparability of laboratory and HPGe data. Sections 5, 6 and 7 evaluate comparability data for total uranium, thorium-232 and radium-226,

respectively. Section 8 delineates their significance relative to data quality levels. Section 9 summarizes the most important conclusions drawn in the preceding sections. All supporting data, technical details, calculations and technology descriptions appear in Appendices A through J.

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2.0 EFFECT OF WEATHER AND CLIMATIC VARIABLES UPON IN-SITU GAMMA SPECTROMETRY DATA

This section presents results of twelve months (April 8, 1997 through March 31, 1998) of morning and afternoon HPGe measurements at the Field Quality Control Station (FCS). These data allow the assessment of weather and climatic effects upon HPGe measurements; they enable warning and control limits to be set for quality control charts; they provide additional information on the comparability of laboratory and HPGe data; and they allow insight as to radon-222 disequilibrium relative to radium-226 measurements.

2.1 METHODOLOGY

To delineate the effect of weather and climatic conditions upon HPGe measurements, the field analogue of a laboratory control standard was adopted. The basic concept is that measurements over an extended period of time at a single field location can be related to weather and climatic variables. Trends, peaks, and valleys in data may be related to both long term and short term weather and climatic conditions. In this report, such conditions refer to weather related phenomena such as soil moisture, rainfall, atmospheric temperature, and humidity. FCS measurements thus offer the possibility of normalizing all in-situ gamma spectrometry measurements to a standard set of conditions, thereby enabling in-situ gamma spectrometry project personnel to tell when HPGe measurements are "in control."

2.1.1 Field Measurements

A field location with a total uranium content of approximately 70-80 ppm (wet weight basis) and 90 to 100 ppm (dry weight basis) was chosen as the FCS. This location was selected over other possible locations because of the closeness of its total uranium concentration to a FRL of 82 ppm. The location of the FCS is north of the Sewage Treatment Plant at northing 480391.4131 and easting 1351675.862 (Figure 2-0).

HPGe measurements were taken twice daily, wherever possible; in the early morning and mid/late afternoon at the coolest and warmest times of the day, respectively. Measurements were taken on Mondays through Thursdays unless weather conditions or other work priorities interfered. HPGe measurements were performed at a 1.0 meter detector height using a 15-minute data acquisition time. Five different HPGe detectors were used, on a rotating basis, to make measurements. In practical

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terms, detector down-time due to maintenance and/or repair usually meant that one or more detectors were not available to make measurements at any given time.

Temperatures at the time of HPGe measurements were obtained from the FEMP Meteorological Station. Humidities were recorded using a field humidity measuring device. Soil moisture measurements were taken with a Troxler instrument at a point directly beneath the HPGe detector location, as described in FEMP Procedure EQT-32. Additional weather information, such as rainfall, was obtained from the FEMP Meteorological Station.

2.1.2 Physical Sample Analysis

Ten samples were collected for laboratory analyses of total uranium, thorium-232 and radium-226. The ten samples were collected in a "bulls-eye" pattern as described in Section 3.2.3. However, the numbering of the samples relative to their location in the "bulls-eye" is different than described in Section 3.2.3, and that numbering is shown in Figure 2-0. A duplicate sample was taken at Position #5. The sample cores were 3 inches in diameter and 4 inches long (0 to 4 inches depth).

Total uranium was analyzed by four different methods: alpha spectrometry, gamma spectrometry, ICP/MS and bromoPADAP. The use of four different methods is explained in Section 5.0 and in Appendix H. Thorium-232 and radium-226 were analyzed by both alpha and gamma spectrometry as described in Section 6.0 and Section 7.0, respectively. Radium-226 analyses utilized the total dissolution sample preparation technique described in Section 7.0 for alpha spectrometry and were also analyzed by gamma spectrometry.

2.2 HPGe, WEATHER, AND SOIL MOISTURE DATA

HPGe, weather and soil moisture data are contained in Appendices A, B and C. Appendix A contains weather and soil moisture data; Appendices B and C contain radionuclide concentrations as measured by HPGe on a wet weight and dry weight basis, respectively.

Appendix A contains the dates HPGe measurements were made (days in which no measurements were made are shaded), the time of day measurements were made, the air temperature at the the time measurements were made, the atmospheric humidity at the time measurements were made, and the soil moisture at the time and location of the measurements.

Some of the soil moisture data were adjusted because they were not consistent with soil moistures taken on the same day, immediately preceding days, immediately following days, with patterns of rainfall, or because soil moisture measurements were not taken. These adjusted data appear under the column heading entitled "Corrected Soil Moisture (%)." In total, 30 moisture measurements out of 250 HPGe measurements (12%) were adjusted. Six of these adjustments occurred because no soil moisture measurements were taken. For example, on May 8, 1997, and on February 19, 1998, no soil moisture measurements were taken. The average of morning and afternoon soil moistures on May 7 and May 12 (these dates were the closest to May 8 for which soil moisture values were available) were used for May 8. Soil moisture values of 28% were assigned to February 19 using a reasonableness criterion taking into account precipitation and soil moistures measured on February 24 and February 12. A second example of soil moisture adjustment is provided by the afternoon soil moisture measurement on August 5. Because no valid reason exists why the afternoon soil moisture measurement is 4% (absolute) lower than the morning soil moisture measurement, the morning soil moisture measurement was also used for the afternoon soil moisture. A third example of soil moisture adjustments is represented by soil moisture data on August 18 and 19. On both days, the afternoon soil moistures were over 6% (absolute) lower than the morning soil moistures. Because of the difficulty in ascertaining which data (morning or afternoon) were more correct, the average of the morning and afternoon soil moisture data for each day was used as the moisture content of the soil. A fourth example occurs on August 11, 1997. The afternoon soil moisture is almost 10% (absolute) higher than the morning soil moisture; consequently, the value of the morning soil moisture was assigned to the afternoon measurement.

No apparent reason exists for the apparent anomalous soil moistures. The anomalous values probably were not real given the patterns of soil moisture and rainfall surrounding them. Instrument malfunctions were not recorded on field logs. The most probable explanation is faulty seating of the Troxler instrument on the soil and/or seating on vegetation.

Data for rainfall, daily high and low temperatures, and weather descriptions (in the "comment" column) were obtained from the FEMP meteorologist. Daily high and low temperatures and weather comments were provided beginning May 1, 1998. No weather descriptions appear in Appendix A from January 9, 1998 through February 19, 1998, resulting from the FEMP meteorologist's unavailability.

Occasionally in the winter of 1997 and 1998, humidity measurements were not taken. This usually was the result of the temperature being too low to obtain reliable data.

Appendices B and C contain some of the same data which appears in Appendix A. However, Appendices B and C also contain concentrations of total uranium (ppm,), thorium-232 (pCi/g), radium-226 (pCi/g) and potassium-40 (pCi/g) on a wet weight and dry weight basis, respectively. Wet weight concentrations are converted to dry weight concentrations using the soil moisture content.

Additionally, Appendices B and C contain the identification number of the HPGe detector used to make the measurement. Finally, Appendices B and C contain alphanumeric symbols appearing in the "Index" column. A given indice is merely an abbreviation of the date and time the measurement was taken. For example, an indice of 41 signifies April 1. Indices of 513a and 513p, for example, indicate that the measurements were made on May 13 in the morning and in the afternoon. The data in Appendices B and C are contained in spreadsheets. These spreadsheets formed the basis for all calculations and graphs in succeeding sections of this report.

2.3 EFFECT OF SOIL MOISTURE ON HPGe MEASUREMENTS

Figures 2-1A through 2-1D show plots of total uranium and thorium-232 as a function of soil moisture. Figures 2-1A and 2-1C clearly show that, on a wet weight basis, there is a distinct trend of decreasing concentration with increasing soil moisture. This is not surprising as water acts as a diluent. However, when wet weight concentrations are converted to dry weight concentrations (Figures 2-1B and 2-1D), there is still a slight trend of decreasing dry weight concentrations with increasing soil moisture content. Although the dry weight concentration dependency upon soil moisture is evidenced by very low correlation coefficients (shown as R^2 values) of 0.22 and 0.21, respectively, in Figures 2-1B and 2-1D, the upper and lower 95% confidence limits for the slope (Table 2-1) do not bound zero. Hence, the slopes in Figures 2-1B and 2-1D are significantly different than zero. The slight trend of increasing dry weight concentration with decreasing soil moisture content may reflect the fact that a soil moisture depth gradient usually exists. In drying periods, the surface soil is usually drier than soil a few inches deeper. After periods of rain, surface soil is usually wetter than soil a few inches deeper. Because a Troxler soil measurement represents an average, the surface soil is usually a little drier or wetter than the average. Therefore, because a majority of the gamma photons are emitted from surface soils, it is not surprising that concentrations derived from abundances of these photons still show a

residual dependency upon moisture even following correction from wet weight to dry weight. Although not shown in this report to avoid undue redundancy, radium-226 displays the same relationships to soil moisture as do total uranium and thorium-232.

Figure 2-1E shows how soil moisture at the FCS has varied during the twelve month period from April 18, 1997 to March 31, 1998. A number of distinct drying periods have occurred during which the soil moisture decreased. For example, the first of these periods occurred from May 4 through May 23, when soil moistures decrease from approximately 22 to 16%. The second such drying period occurred from June 23 through August 12, when soil moisture decreased from approximately 25.5 to approximately 12%. Each of the drying trends ended due to periods of substantial rainfall. Thus, from May 24 through June 22, eleven inches of rain fell. From August 12 through August 17, over 4 inches of rain fell.

In summary, a recurring pattern has occurred at the FCS of rainfall and higher soil moistures followed by extended periods of no rainfall, concomitant soil drying, and lower soil moistures. The periods of higher soil moistures have lower concentrations of radionuclides on a wet weight basis due to dilution by water. The dryer periods have higher concentrations of radionuclides on a wet weight basis due to a lesser amount of soil moisture acting as a diluent. The dependency of concentration on soil moisture substantially diminishes when concentrations are converted to a dry weight basis. From a practical perspective, whenever HPGe measurements are compared to a regulatory limit, the comparison must be made on a dry weight basis; first, because the regulatory limit is on a dry weight basis, and second to largely remove the effect of moisture on concentration.

2.4 EFFECT OF ATMOSPHERIC TEMPERATURE ON HPGe MEASUREMENTS

Figure 2-2A shows morning and afternoon temperatures at the times HPGe measurements were taken at the FCS. A 10-point moving average (referred to as a 10 period moving average in the legend of Figure 2-2A) has been employed to make temperature trends more distinct from day-to-day variations and to better distinguish morning temperatures from afternoon temperatures.

Morning lows increased from 20° - 40° in April 1997 to 60° - 75° in June, July and August 1997, and then decreased to 20° - 30° in December 1997 and January 1998. Similarly daily highs increased from 40° - 60° in April 1997 to 80° - 90° in June, July, August and September 1997, and then decreased to

20° - 40° in December 1997 and January 1998. The data in Figure 2-2A and in Appendix A indicates that temperature differences between morning lows and afternoon highs generally did not exceed 30° F.

Figures 2-2B and 2-2E are plots of total uranium and thorium-232 concentrations as a function of temperature. Regression lines indicate a slight trend of increasing measured HPGe concentrations with increasing temperature. Although the trend in Figures 2-2B through 2-2E is slight, it is real. As indicated in Table 2-1, the slopes of the lines of dry weight concentrations vs. temperature are significantly different than zero. From the regression equations given in Figures 2-2B through 2-2E, the increase in measured concentrations over a 30° F temperature increase (maximum difference between daily highs and lows) can be calculated. Over a 30° temperature increase, total uranium increases by 3.8 ppm and thorium-232 by 0.04 pCi/g, both on a dry weight basis. Further, as shown in Figures 2-2B through 2-2E, the degree of data scatter about the regression lines is quite high as noted by the very low correlation coefficients (R^2 values). At any given temperature, the variation in measured concentrations generally is far larger than any temperature effect on HPGe measurements.

The origin of the trend (albeit slight) of increasing measured concentration with increasing temperature is not clear. Discussions with gamma spectroscopists suggest that it is not instrumental in origin. Speculation is that the trend results from soil moisture gradients. At higher temperatures, more of a gradient between surface soils (drier) and soils at depth (wetter) may exist. At lower temperatures, less of a gradient may exist. Because most of the gamma photons are emitted from surface soils, they reflect radionuclide concentrations less diluted with water than in bulk soils. Hence, higher apparent concentrations are measured at higher temperatures.

To summarize, an average higher temperature will result in higher HPGe measurements. However, the effect is small, and the variation in measured concentrations due to other factors greatly exceeds any temperature effect on measured HPGe concentrations. Thus, for all practical purposes, temperature can be ignored as having a significant effect upon HPGe data.

2.5 EFFECT OF HUMIDITY ON HPGe MEASUREMENTS

Figure 2-3A shows humidity measurements at the times HPGe measurements were taken at the FCS. A 10-point moving average (referred to as a 10 period moving average in the legend of Figure 2-3A) was employed to differentiate humidity trends from daily variations and to better distinguish between

morning and afternoon humidities. Not surprisingly, morning humidities are generally much higher than afternoon humidities with maximum differences in the range of 40 to 50% humidity.

Figures 2-3B through 2-3E depict total uranium and thorium-232 concentrations as a function of humidity. Although not shown, potassium-40 and radium-226 displays the same trend in concentrations as a function of humidity, as do total uranium and thorium-232. Regression lines fitted to the data points have slopes very near zero and extremely low correlation coefficients (expressed as R^2 values). As shown in Table 2-1, the slopes of concentration vs humidity are generally not significantly different than zero. These facts demonstrate that humidity has little effect upon HPGe measurements.

2.6 CONTROL CHARTS FOR TOTAL URANIUM AND THORIUM-232

Previous sections of the report have demonstrated that soil moisture has a large effect (on a wet weight basis but not on a dry weight basis) on measured HPGe concentrations, that temperature has a small effect, and that humidity has little effect. The effects of these three variables on HPGe measurements is easy to ascertain, because the parameters are easy to measure.

There are other parameters, particularly weather and climate related, that could also possibly affect HPGe measurements. However, rather than collect a voluminous amount of data for multiple parameters, the use of control charts is employed instead to evaluate the cumulative effect of environmental and weather conditions upon HPGe measurements. Initial "means" control charts were constructed using typical conventions (warning limits are ± 2 standard deviations from the mean; control limits are ± 3 standard deviations from the mean). All of the data collected between April 8, 1997 and March 31, 1998 were utilized in calculating standard deviations in order that the standard deviations represent data collected over a wide range of environmental, climatic, and weather conditions. (Although data collected during the mornings of November 5, 1997 and February 11, 1998 fall below the lower control limits, there is no reason to believe that the low concentrations result from instrument malfunction. The same detector yielded "in control" results on the afternoon of November 5, 1997 and on February 12, 1998.) Table 2-2 shows values of means, standard deviations, standard deviations as percentages of means, warning limits, and control limits on both a wet weight and dry weight basis.

One significant aspect of the data in Table 2-2 is that the standard deviation as a percent of the mean for the two radionuclide averages approximately 6% on a dry weight basis. The standard deviations shown in Table 2-2 are interpreted to represent the long-term total system uncertainty, and this long-term total system uncertainty is equal to or less than 20%. Thus, not only is the precision between duplicates less than 20% for HPGe measurements as demonstrated in Section 9.0, but the long term-total system uncertainty also meets the same less than 20% guideline discussed in Section 9.0.

Control charts displaying data resulting from all of the HPGe measurements performed between April 8, 1997 and March 31, 1998 are presented in Figures 2-4A through 2-4D for total uranium and thorium-232. Both wet weight and dry weight control charts are shown. Using the wet weight control chart for total uranium (Figure 2-4A) as an example, the data plotted clearly show previously discussed trends in soil drying. In this regard, examination of Figure 2-4A shows trends of increasing uranium concentration followed by abrupt decreases in uranium concentration. The trends of increasing total uranium concentrations in June and in July, and in August and September, for example, represent the periods of soil drying discussed earlier. Figure 2-4A also clearly shows that total uranium for the winter months of November, December, January and February is lower than for the summer months. This results from soil moistures being consistently higher for the winter months than for the summer months. The wet weight control chart for thorium-232 (Figure 2-4C) shows the same trends as does the wet weight control chart for total uranium (Figure 2-4A).

As discussed earlier, when wet weight concentrations are converted to dry weight concentrations, the dependence of HPGe measurements upon soil moisture percentages largely disappears. Thus, the data trends in the wet weight control charts discussed above also largely disappear when dry weight control charts are employed (Figures 2-4B and 2-4D). However, the control charts still point out that on an average basis, measured concentrations are somewhat lower in the winter months than in the summer months. As discussed in Section 2.3, this is believed to be a soil moisture gradient effect.

Approximately 95% of the points in a data set will fall within ± 2 standard deviations of the mean of the data set, and approximately 99% will fall within ± 3 standard deviations of the mean. Because 250 data points were used to construct the control charts, based purely on random statistics, no more than about two data points should fall outside control limits and no more than about 12 should fall outside warning limits. Examination of dry weight basis control charts (Figures 2-4B and 2-4D) shows

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that only two data points in each of the two control charts fall outside control limits and no more than five fall outside warning limits. Instrument problems could not be ascribed to the points outside warning and control limits. For example, the total uranium concentration measured on April 23 was originally thought to be low because of possible battery failure. However, thorium-232, radium-226 and potassium-40 did not similarly display concentrations falling below warning limits. Therefore, possible low battery conditions did not cause the low concentration.

2.7 CONTROL CHARTS FOR RADIUM-226

Whereas data points for total uranium, thorium-232, and potassium-40 are predominately within warning and control limits, the situation for radium-226 appears quite different. As shown in Figures 2-5A and 2-5B, numerous radium-226 measurements fall outside warning and control limits. The basis for establishing warning and control limits and the reason why so many radium-226 measurements exceed those limits are discussed below.

Table 2-3 compares the mean and standard deviation of radium-226 measurements taken in the morning and afternoon. Clearly, the means and standard deviations of morning measurements are substantially greater than means and standard deviations of afternoon measurements. More specifically, morning means are 25% higher than afternoon means, and morning standard deviations are approximately three times greater than afternoon standard deviations. "F" tests indicate that morning standard deviations are statistically significantly different than afternoon standard deviations at the 95% confidence level, while "t" tests indicate that differences between morning and afternoon means are statistically significant at the 95% confidence limits. Examination of expanded dry weight basis control charts (Figure 2-5C) demonstrates very well that for radium-226 measurements taken on the same day, very often the morning measurements are higher than the afternoon measurements. Because radium-226 is determined from gamma rays emitted by radon-222 daughters, the differences between morning and afternoon measurements are related to radon buildup and its subsequent dissipation from soils. Typically, at the FEMP weather conditions in the morning are favorable for "bad radon days." That is, morning weather conditions are not favorable for the dissipation and dispersion of radon accumulations from very near to the surface of soils to the atmosphere. Conversely, by late morning or early afternoon weather conditions are such that near surface radon has dissipated and dispersed. Appendix A and Figure 2-5C indicate when the FEMP meteorologist observed fog at the site. Usually, mornings

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with fog also had high measured concentrations of radium-226; thus, one indicator as to whether HPGe measurements for radium-226 should be carried out is the presence of fog.

The effect of environmental influences on measurements for radium-226 is an important issue and has major practical ramifications. This section indicates that morning measurements for radium-226 can be anomalously high due to radon accumulations near the ground surface. These observations lead to the implementation of a radon monitor (as discussed in Section 5.3.2.1 of the User's Manual) to compensate for such accumulations. Conversely, this section also demonstrates that afternoon radium-226 measurements generally have a much lower degree of variation among them than morning measurements (Table 2-3). This observation was an important consideration in developing the radium correction factors in Section 7.6 to compensate for radon disequilibrium.

One important aspect of the data in Table 2-3 is that the standard deviation as a percentage of the mean for radium-226 averages 9.5% on a dry weight basis for afternoon measurements (no interference from morning radon accumulations). This standard deviation can be construed to represent the long-term total system uncertainty, and this long-term total system uncertainty is less than 20%. Thus, not only is the precision between duplicates less than 20% for HPGe radium-226 measurements as demonstrated in Section 9.0, but the long-term total system uncertainty also meets the same less than 20% guideline discussed in Section 9.0.

The warning and control limits set in Figure 2-5C are based upon the mean and standard deviation of afternoon measurements. If morning wet weight measurements exceed 1.08 pCi/g for radium-226 (Figure 2-5A), the probability is quite high that the measurement is biased high due to lack of radon-222 dispersion from surface soils. This would dictate that both HPGe and RTRAK measurements for Ra-226 should not be carried out (unless a radon monitor is employed - see the User's Manual, Section 5.3.2) until the near surface radon-222 buildup has dissipated. Conversely, if morning HPGe measurements are significantly lower than 1.07 pCi/g, the chances are good that weather conditions are favorable for radon dissipation and dispersion.

2.8 EFFECT OF DIFFERENT HPGe DETECTORS UPON HPGe MEASUREMENTS

As discussed in Section 2.1.1, five different detectors were used to take measurements at the field quality control station. Table 2-4 gives the means and standard deviations of total uranium,

thorium-232, radium-226, and potassium-40 concentrations (dry weight basis) as measured by each of the detectors. Table 2-4 also contains the means and standard deviations of all of the combined measurements. Although the means and standard deviations of concentrations measured by the five different detectors differ by very little, some of these differences are statistically significant. Most of the statistically significant differences between measured concentrations occur for total uranium. Table 2-5 summarizes the results of the statistical tests for total uranium. For thorium-232, only the differences in means between detector pairs 30716 and 30687 and 30716 and 30904 are statistically significantly different. For radium-226, none of the differences between means of any of the detector pairs are significantly different. Even though inspection of Table 2-4 indicates that the means (total uranium, for example) of the different detectors are apparently quite similar, the statistically significant differences between some of these means are principally driven by small standard deviations combined with large numbers of measurements. One reason mean concentrations of certain pairs or detections differ is that certain detectors were used more in some months than in other months (due to repair downtime). For example, detector 30687 was hardly used at all in the winter months, when lower than average concentrations were measured (Figures 2-4B and 2-4D). Thus, the dry weight averages for total uranium and thorium-232 tend to be a little higher than the overall dry weight mean. Conversely, detector 30716 was used frequently during the winter months, so its dry weight total uranium and thorium-232 averages are a little lower than the combined mean. Overall, the data in Table 5-12 demonstrate that the five different HPGe detectors have produced very similar measurements over the time frame of April 8, 1997 to March 31, 1998.

2.9 USE OF CONTROL CHARTS

This report addresses, from an analytical perspective, how control charts for total uranium, thorium-232 and radium-226 are established to evaluate weather and climate effects upon HPGe data. The report does not address how control charts will be used, how they will be maintained, nor how such charts will be integrated into the overall Real-time QA/QC Program. These latter three items are addressed in two procedures:

1. Real-Time Instrumentation Measurement Program Quality Assurance Plan (2300-PL-002), and

2. In-Situ Gamma Spectrometry Quality Control Measurements, Revision 1 (ADM-16).

2.10 SUMMARY

The following conclusions are the most important ones to be derived from the data and data interpretations in this section.

1. Soil moisture has a significant effect upon the magnitude of HPGe measurements when concentrations of radionuclides are calculated on a wet weight basis. Soil moisture has a minor effect upon HPGe measurements when concentrations are calculated on a dry weight basis. This effect is likely related to gradients of moisture from the soil surface to depth (10 inches).

2. Temperature has a minor effect upon HPGe measurements over the range of 14° F to 93° F. This effect may be related to gradients of moisture from the surface of soils to soils at depth (10 inches).

3. Humidity has no observable effect upon HPGe measurements.

4. Weather conditions have significant effects upon HPGe measurements to determine radium-226 concentrations. Because HPGe actually measures gamma photons emitted by radon-222 daughters to calculate radium-226, weather conditions leading to the buildup and dissipation of radon in surface soils greatly affect the concentration of radium-226 calculated from HPGe measurements.

5. Typically, morning radium-226 concentrations are higher than afternoon radium-226 concentrations as calculated from HPGe measurements. From April 8, 1997 through March 31, 1998, morning radium-226 concentrations averaged over 25% higher than afternoon concentrations with a high degree of variability associated with that average.

6. Whenever possible, measurements for radium-226 should be made in the afternoon to avoid potential problems with morning radon accumulation near the ground surface.

7. Control charts were established for total uranium and thorium-232 and based upon the standard deviation of all measurements made at the FCS from April 8 to October 14. Excellent long-term precision was observed for these two analytes as the standard deviations of the measurement populations averaged 6% of the population means.

8. Control charts were established for radium-226 based upon the standard deviation associated with all afternoon measurements. Long-term precision is good as the standard deviation of the measurement population averaged 9.5% of the population mean.

TABLE 2-1
STATISTICAL SIGNIFICANCE OF WEATHER AND CLIMATIC RELATIONSHIPS

Figure	Description	Slope of Line	95% UCL* of Slope	95% LCL* of Slope	Is Slope Significantly Different than 0.0?
2-1B	Total Uranium (Dry Wt) as a Function of Soil Moisture Content	-0.5268	-0.4026	-0.6511	Yes
2-1D	Thorium-232 (Dry Wt) as a Function of Soil Moisture Content	-0.00628	-0.00479	-0.00776	Yes
Not shown	Potassium-40 (Dry Wt) as a Function of Soil Moisture Content	-0.04229	-0.02715	-0.05742	Yes
2-2C	Total Uranium (Dry Wt) as a Function of Atmospheric Temperature	0.1297	0.1635	0.0960	Yes
2-2E	Thorium-232 (Dry Wt) as a Function of Atmospheric Temperature	0.00128	0.00170	0.000863	Yes
Not shown	Potassium-40 (Dry Wt) as a Function of Atmospheric Temperature	0.0118	0.0158	0.00780	Yes
2-3C	Total Uranium (Dry Wt) as a Function of Humidity	-0.05319	-0.01629	-0.09008	Yes
2-3E	Thorium-232 (Dry Wt) as a Function of Humidity	2.23E-05	0.00048	-0.00043	No
Not shown	Potassium-40 (Dry Wt) as a Function of Humidity	-0.001052	0.003316	-0.005421	No

*UCL = upper confidence limit
LCL = lower confidence limit

TABLE 2-2
STATISTICAL CALCULATIONS FOR CONTROL CHARTS

Parameter	Total Uranium (ppm)		Thorium-232 (pCi/g)	
	Wet wt.	Dry wt.	Wet wt.	Dry wt.
N=	250	250	250	250
Mean=	74.4	93.4	0.91	1.14
Std. Dev.=	7.70	5.56	0.09	0.07
Std. Dev. as % of Mean	10.4	5.96	10.3	5.83
UCL*=	97.4	110.0	1.19	1.34
UWL*=	89.8	104.5	1.09	1.28
LCL*=	51.2	76.7	0.63	0.94
LWL*=	58.9	82.2	0.72	1.01

* UCL = upper control limit
UWL = upper warning limit
LCL = lower control limit
LWL = lower warning limit

TABLE 2-3
MEANS AND STANDARD DEVIATIONS OF MORNING AND AFTERNOON RADIUM-226 CONCENTRATIONS

Time	Mean, Wet Wt. (pCi/g)	Std. Dev., Wet Wt. (pCi/g)	Mean, Dry Wt. (pCi/g)	Std. Dev., Dry Wt. (pCi/g)
Morning	1.04	0.28	1.30	0.31
Afternoon	0.84	0.08	1.05	0.10

TABLE 2-4
FIVE DIFFERENT DETECTORS YIELD SIMILAR MEASUREMENTS

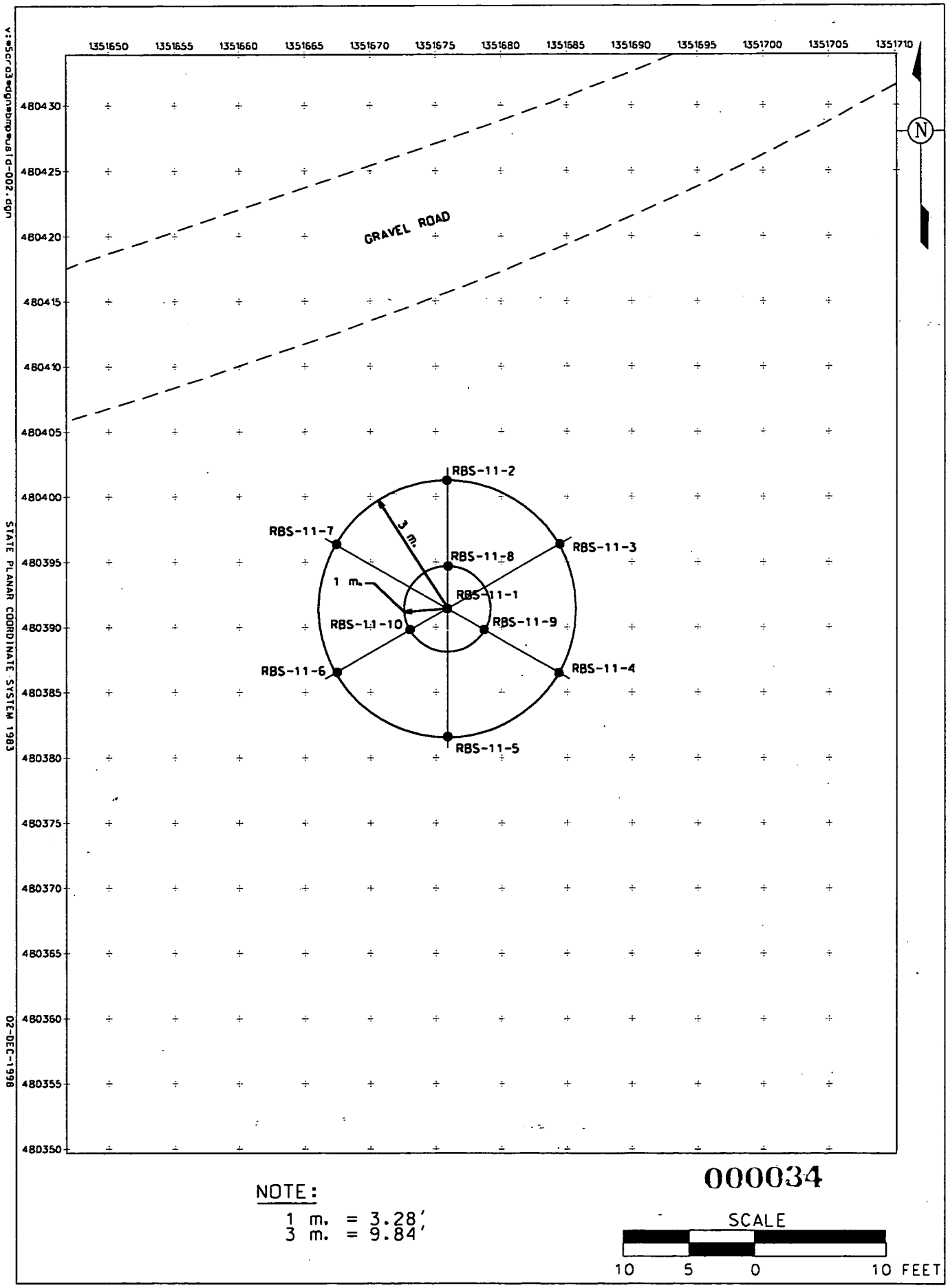
Detector	QC Element	Total Uranium Dry Wt. (ppm)	Th-232 Dry Wt. (PCi/g)	Ra-226 Dry Wt. (pCi/g)
30716	Number	53	53	53
	Mean	90.3	1.12	1.24
	Std. Dev.	6.0	0.07	0.31
	SD % of Mean	6.6	6.2	25.0
30687	Number	52	52	52
	Mean	95.2	1.15	1.16
	Std. Dev.	4.7	0.06	0.28
	SD % of Mean	4.9	5.2	24.1
30904	Number	49	49	49
	Mean	94.4	1.15	1.17
	Std. Dev.	4.7	0.06	0.22
	SD % of Mean	5.0	5.2	18.8
31108	Number	62	62	62
	Mean	94.3	1.15	1.20
	Std. Dev.	6.1	0.07	0.29
	SD % of Mean	6.6	6.1	24.2
40743	Number	34	34	34
	Mean	92.2	1.13	1.15
	Std. Dev.	4.3	0.06	0.16
	SD % of Mean	4.7	5.3	13.9
Combined (includes am plus pm radium-226 data)	Number	250	250	250
	Mean	93.4	1.14	1.19
	Std. Dev.	5.6	0.07	0.27
	SD % of Mean	6.0	6.1	22.7

TABLE 2-5
SUMMARY OF STATISTICAL TESTS COMPARING THE MEANS OF TOTAL URANIUM CONCENTRATIONS MEASURED BY DIFFERENT DETECTORS

Detectors	30716	30687	30904	31108	40743
30716		Yes*	Yes	Yes	No
30687			No	No	Yes
30904				No	Yes
31108					Yes
40743					

*Yes indicates that averages measured by detector pairs are statistically different at the 95% confidence level.

No indicates that averages measured by detector pairs are not significantly different at the 95% confidence level.



NOTE:

1 m. = 3.28'
3 m. = 9.84'

FIGURE 2-0.
SAMPLE LOCATIONS AT FIELD QUALITY CONTROL STATION (NORTH OF THE STP)

Figure 2-1A

Total Uranium (Wet Wt.) as a Function of Soil Moisture Content

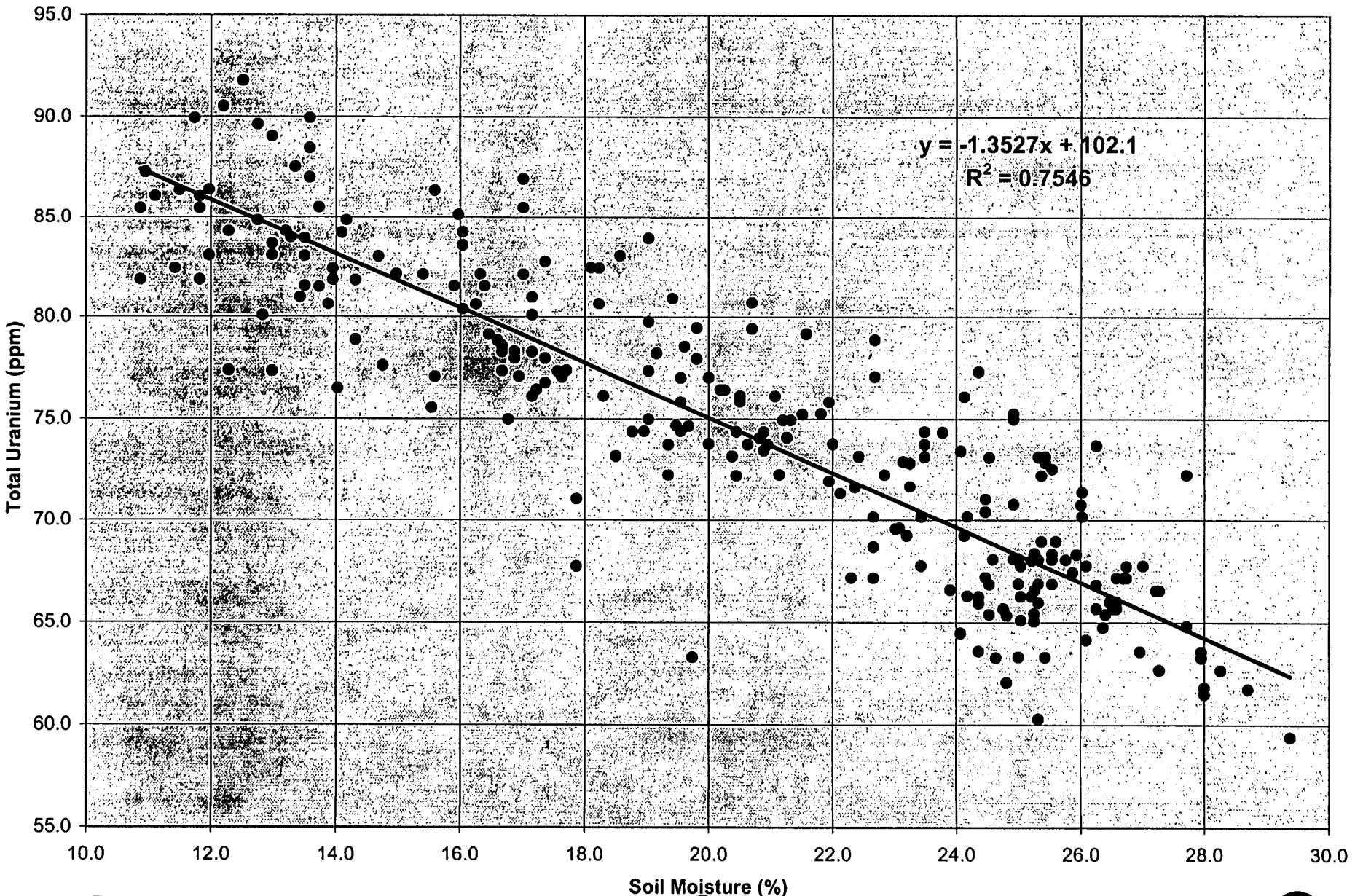


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Figure 2-1B

Total Uranium (Dry Wt.) as a Function of Soil Moisture Content

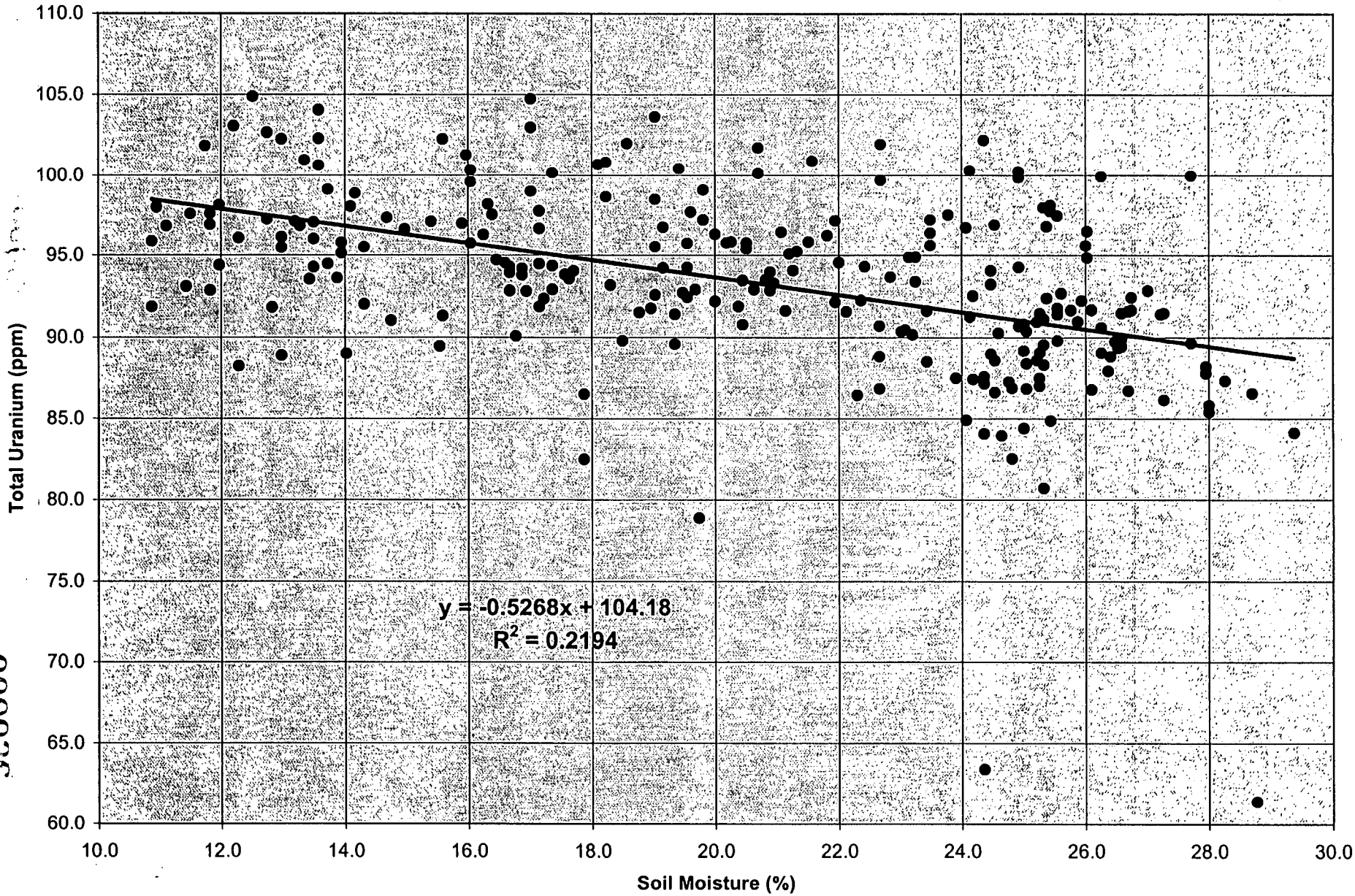

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Figure 2-1C
Thorium-232 (Wet Wt.) as a Function of Soil Moisture Content

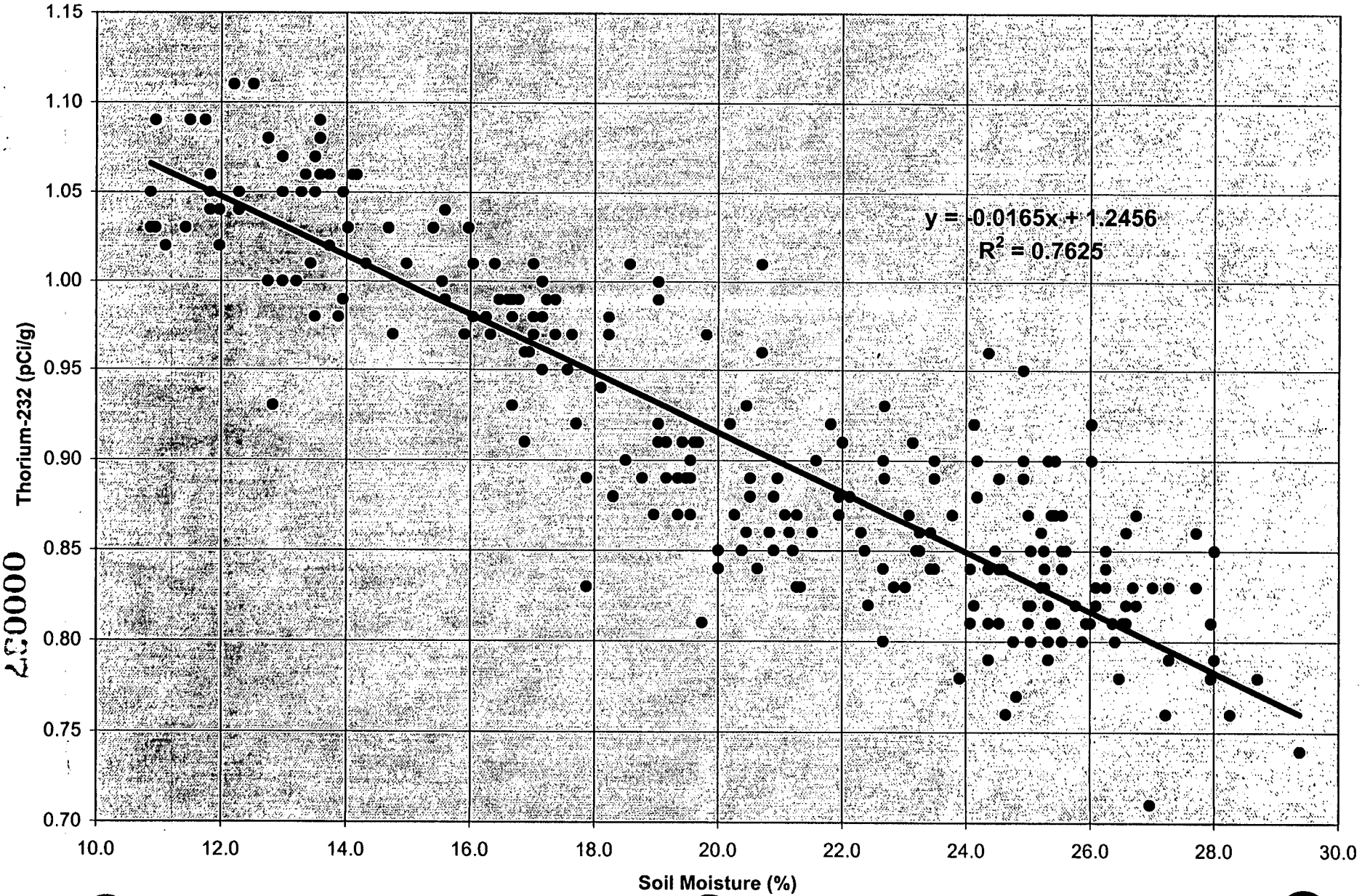

Figure 2-1D

Thorium-232 (Dry Wt.) as a Function of Soil Moisture Content

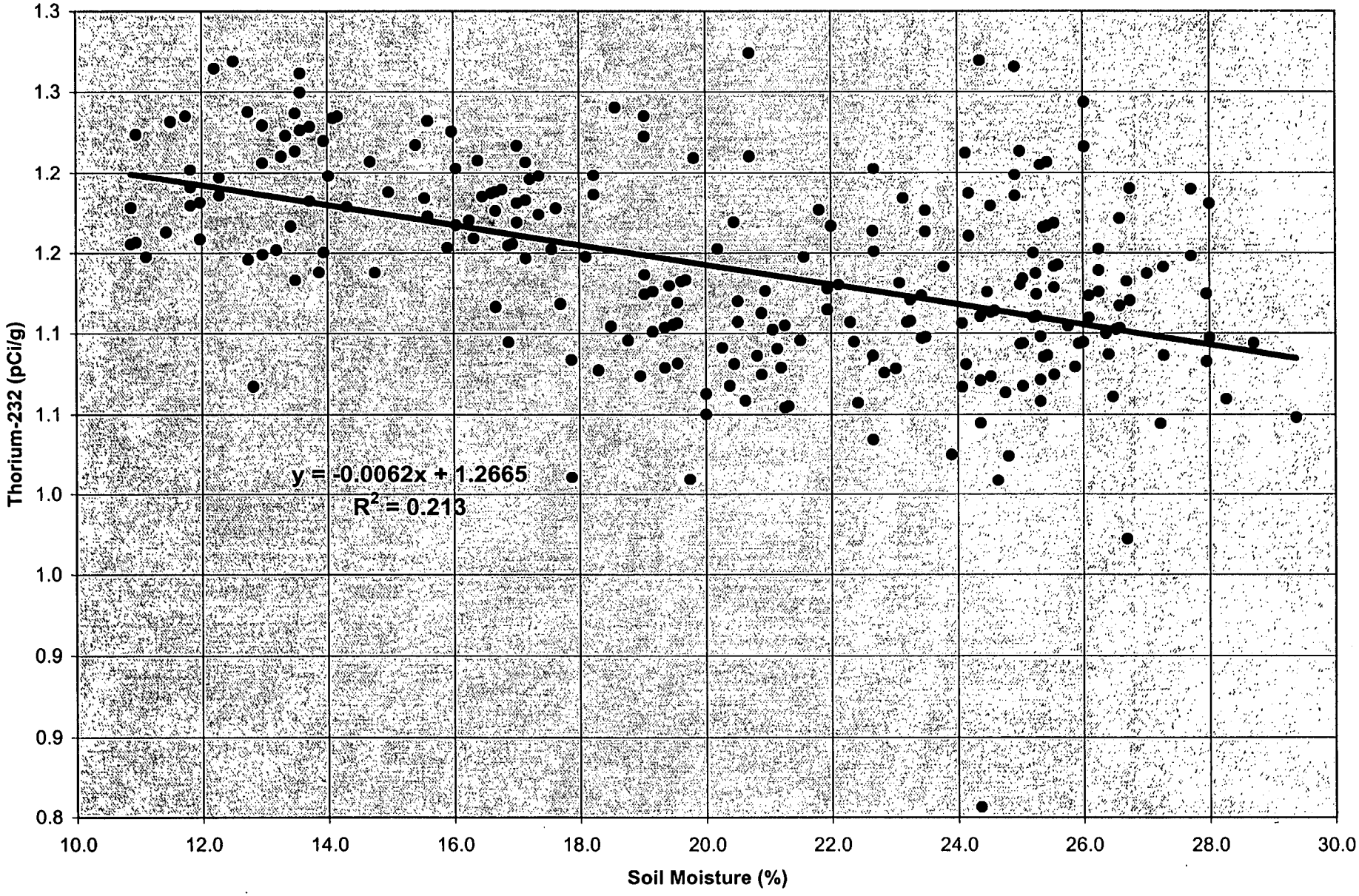

Figure 2-1E

Relationship Between Soil Moisture and Rainfall

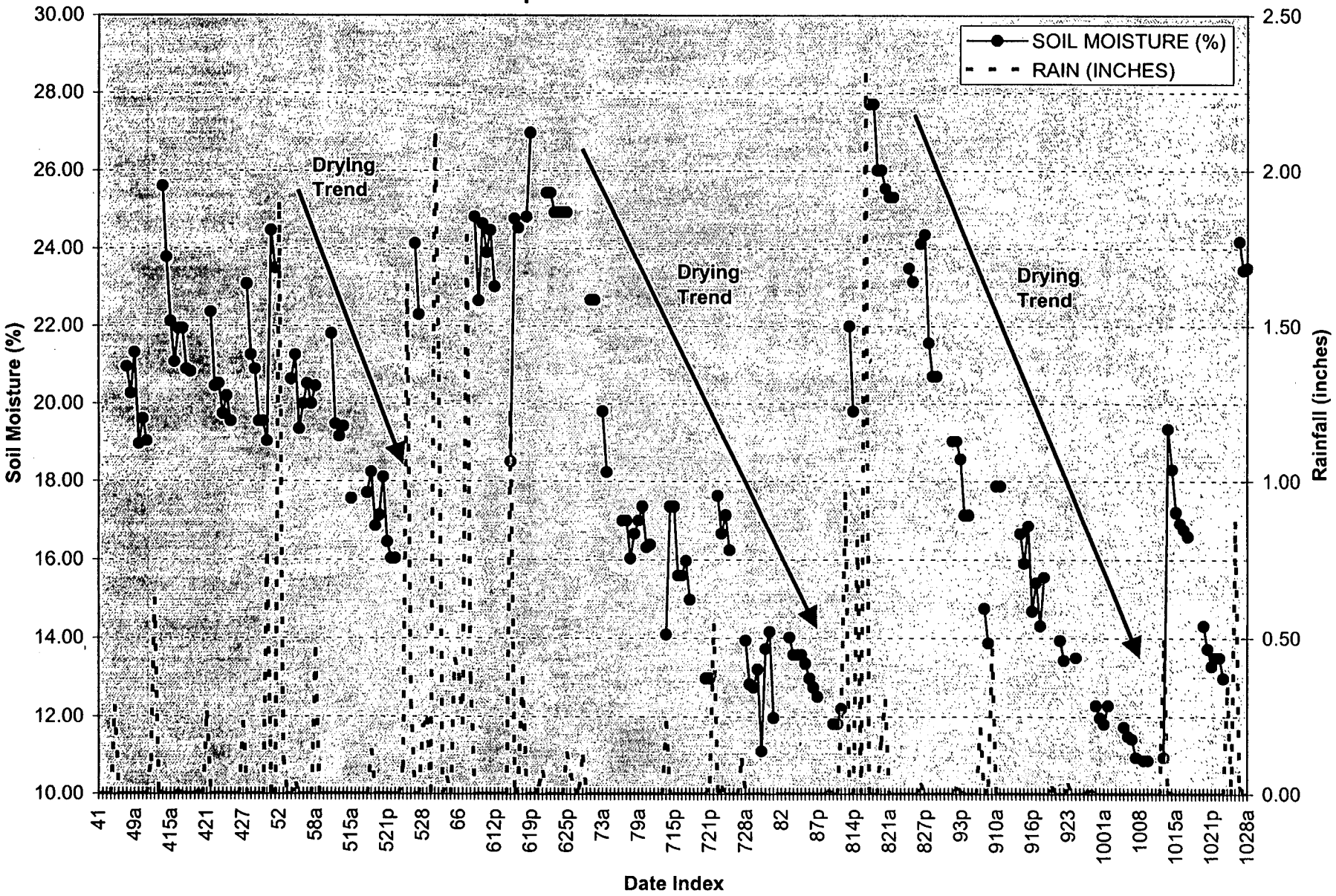

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Figure 2-1E, continued
Relationship Between Soil Moisture and Rainfall

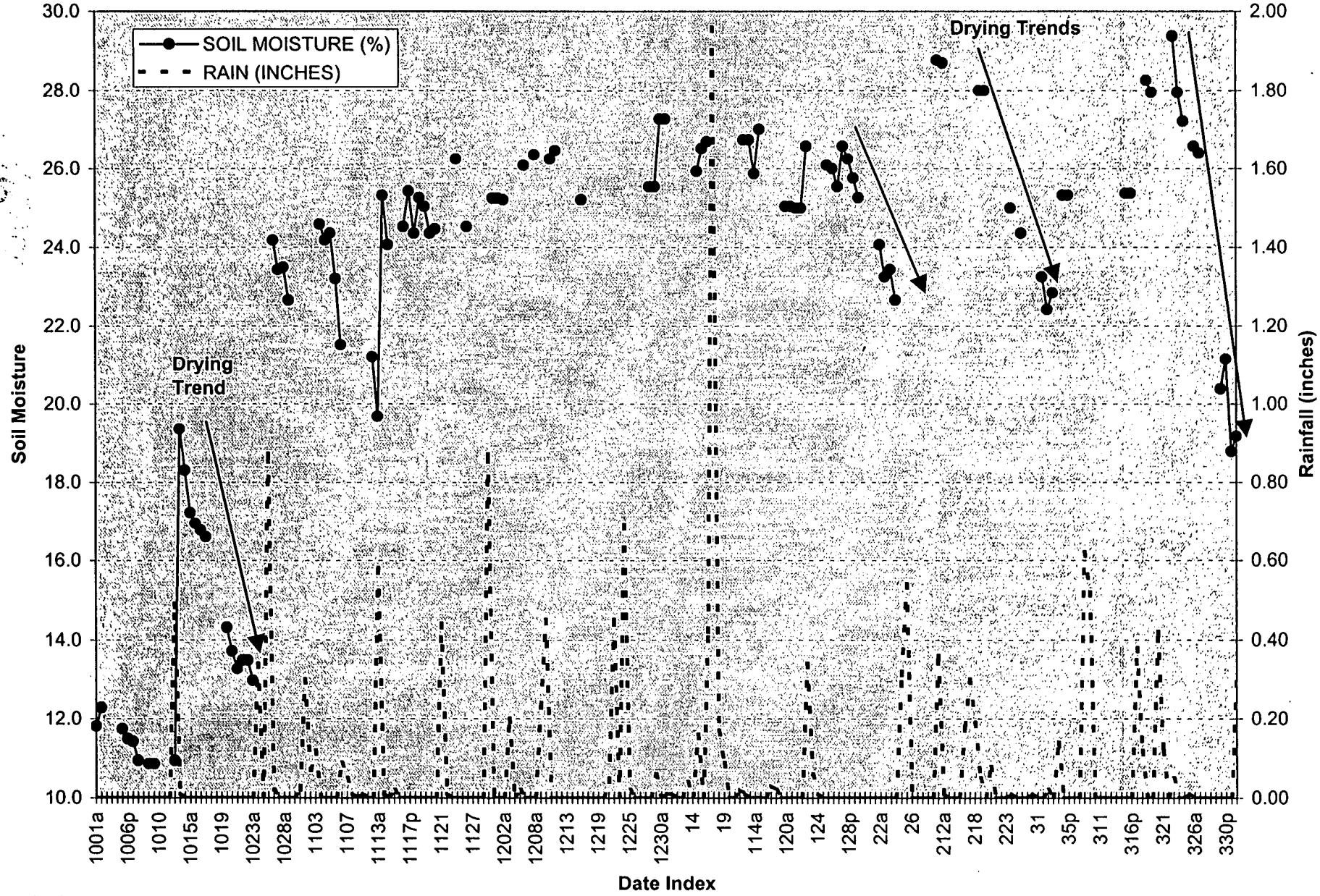

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Figure 2-2A

Atmospheric Temperature at Field Qulity Control Station

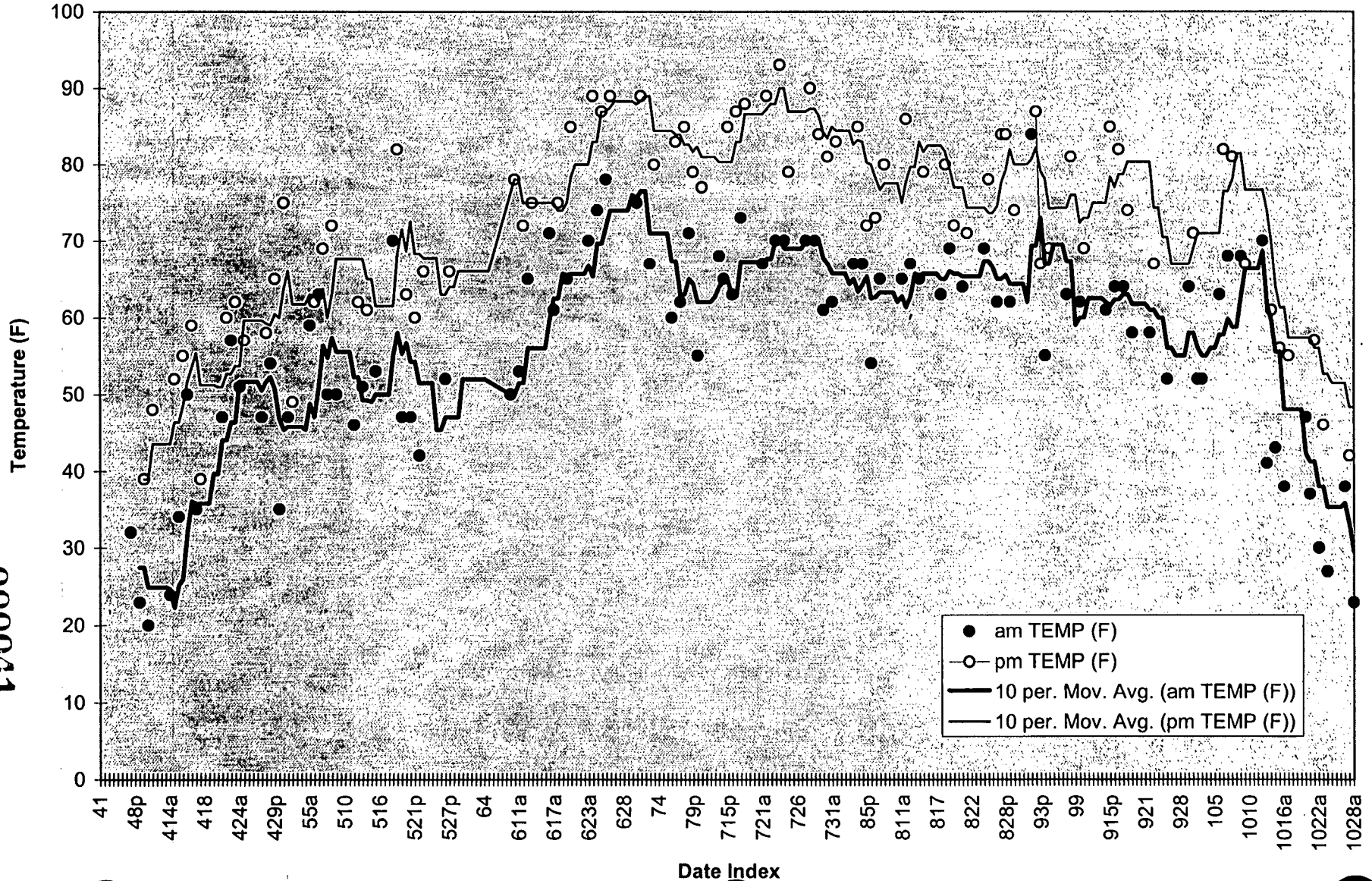

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Figure 2-2A, continued
Atmospheric Temperature at Field Quality Control Station

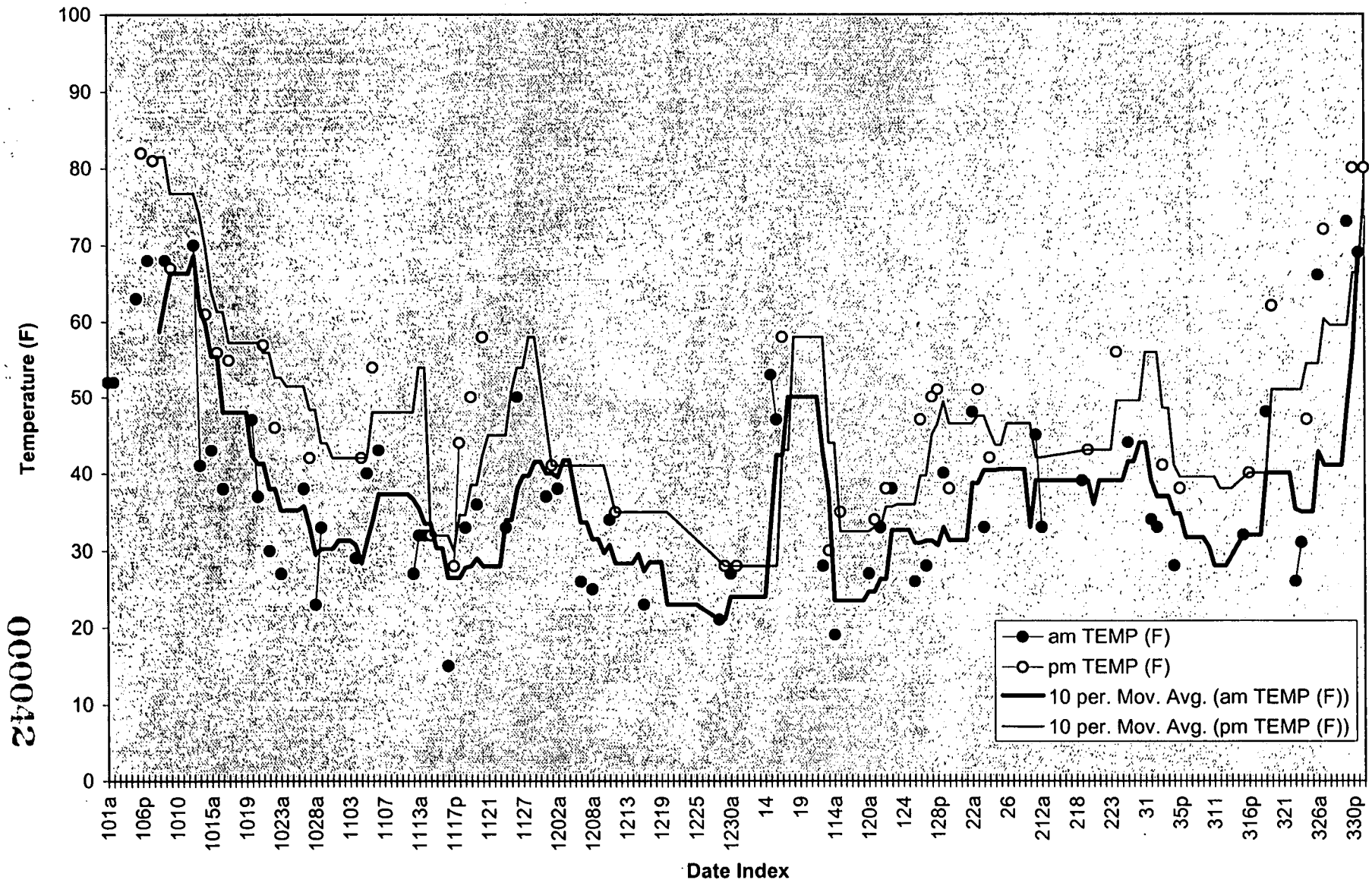

Figure 2-2B
Total Uranium (Wet Wt.) as a Function of Temperature

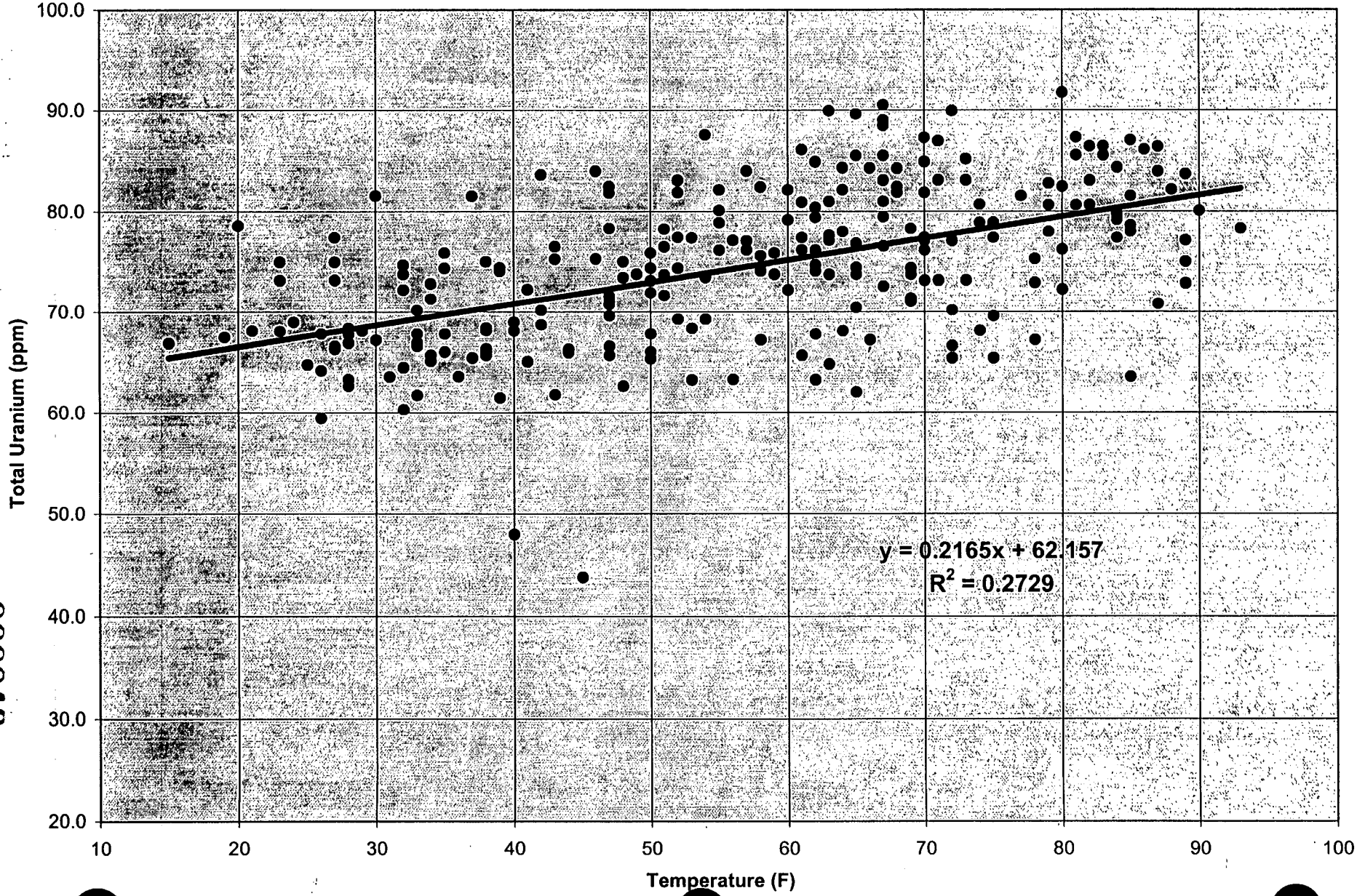

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Figure 2-2C
Total Uranium (Dry Wt.) as a Function of Atmospheric Temperature

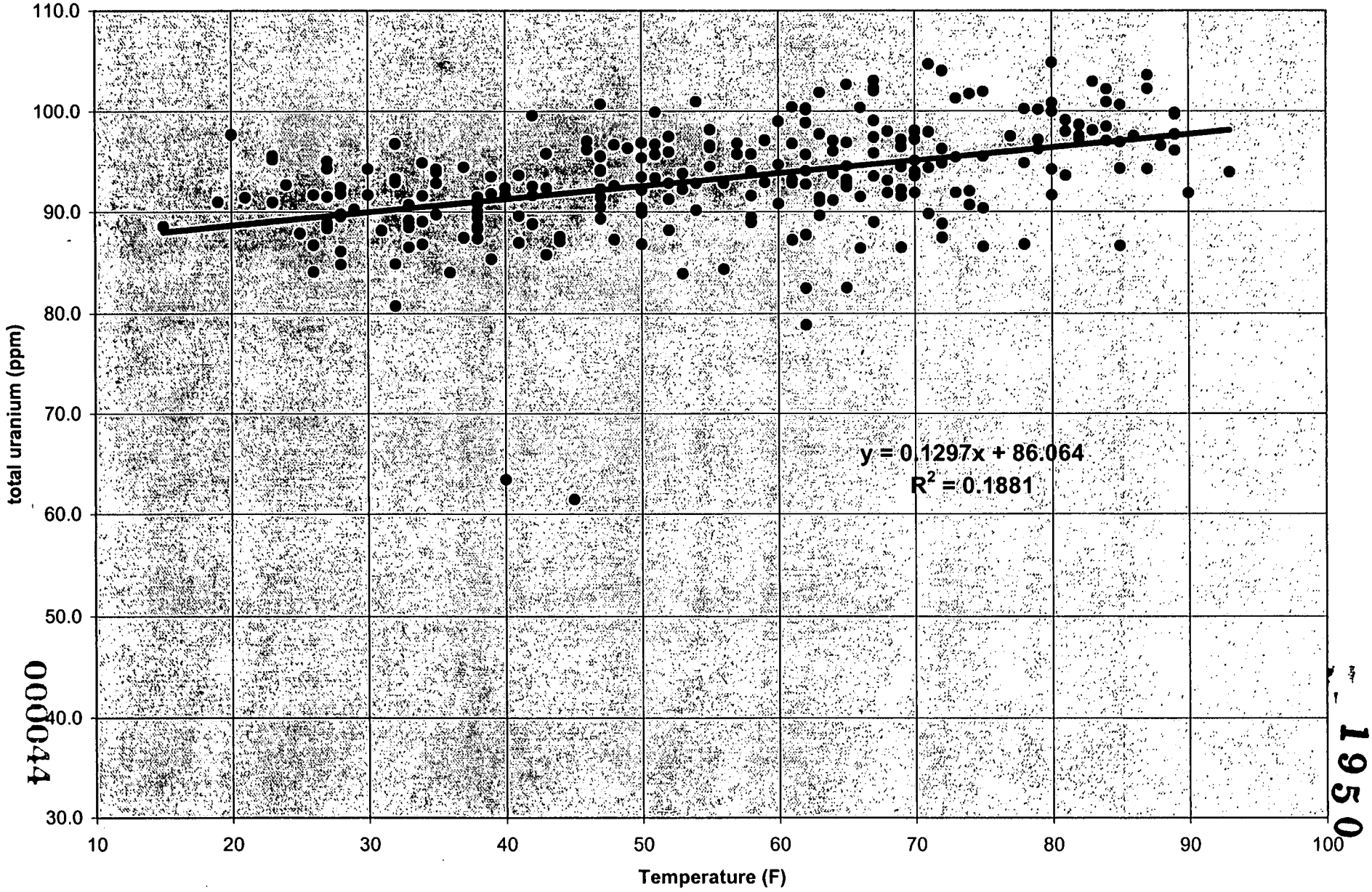

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Figure 2-2D
Thorium-232 (Wet Wt.) as a Function of Temperature

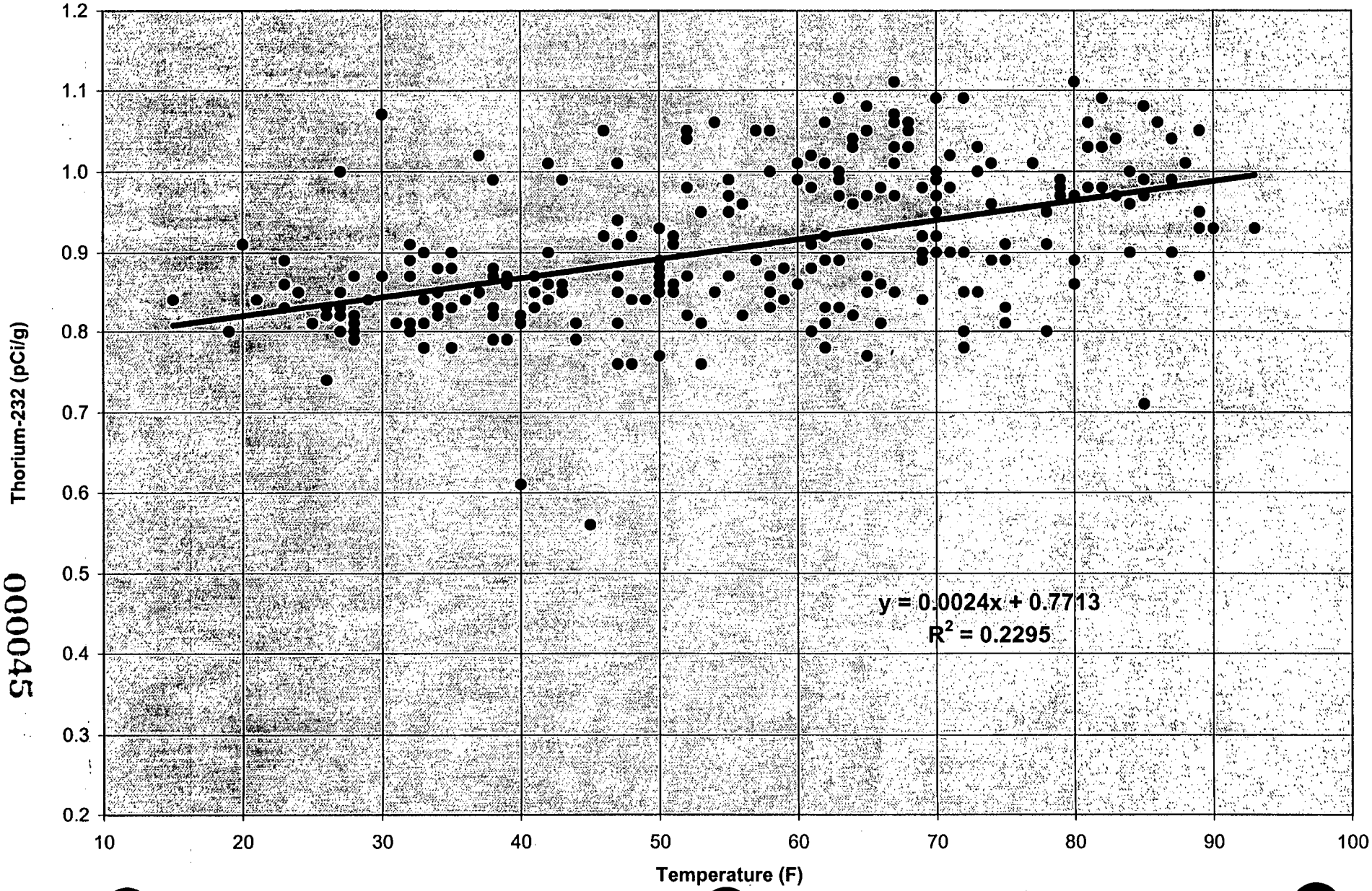

Figure 2-2E
Thorium-232 (Dry Wt.) as a Function of Atmospheric Temperature

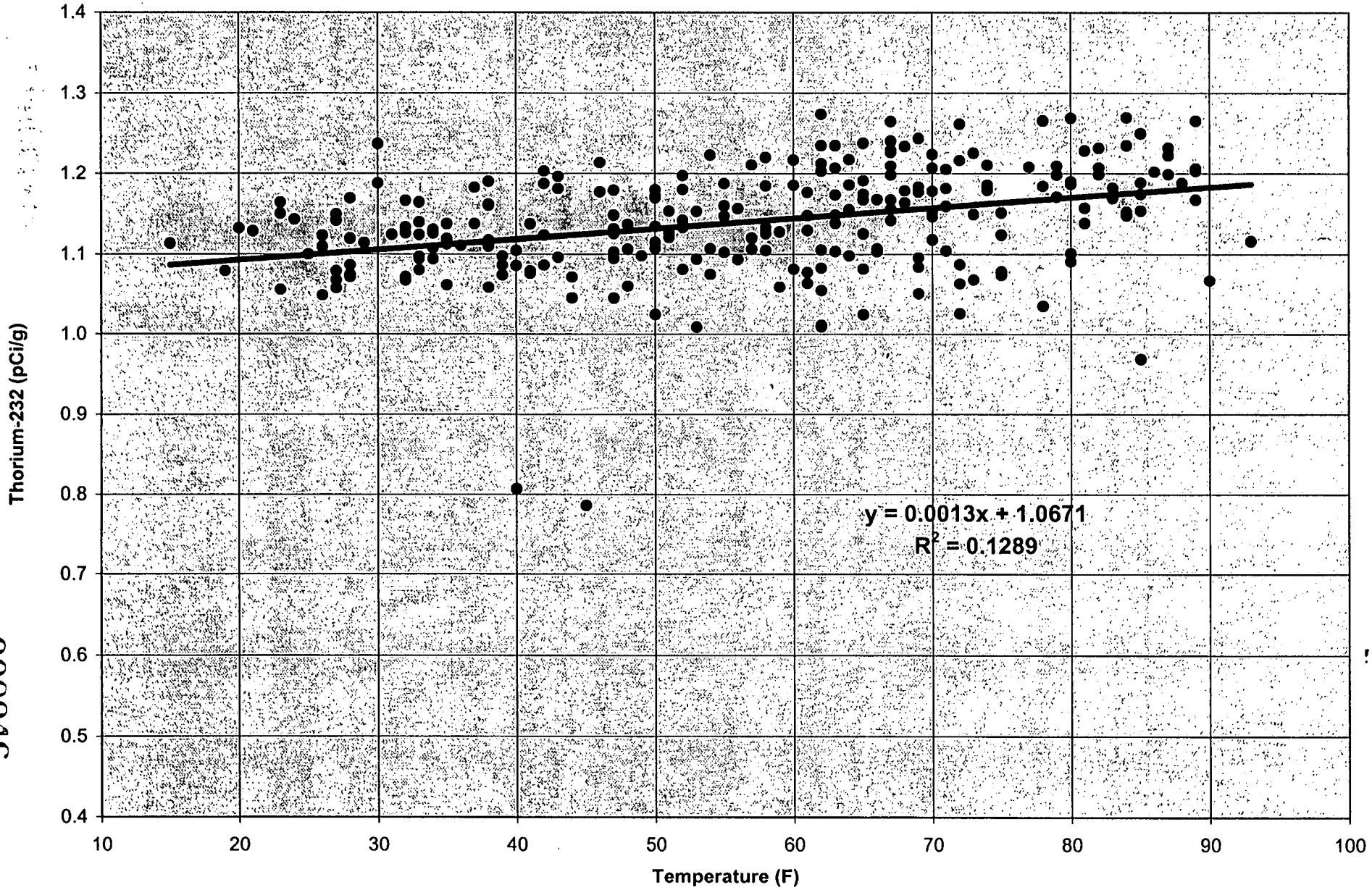

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Figure 2-3A
Humidity at Field Quality Control Station

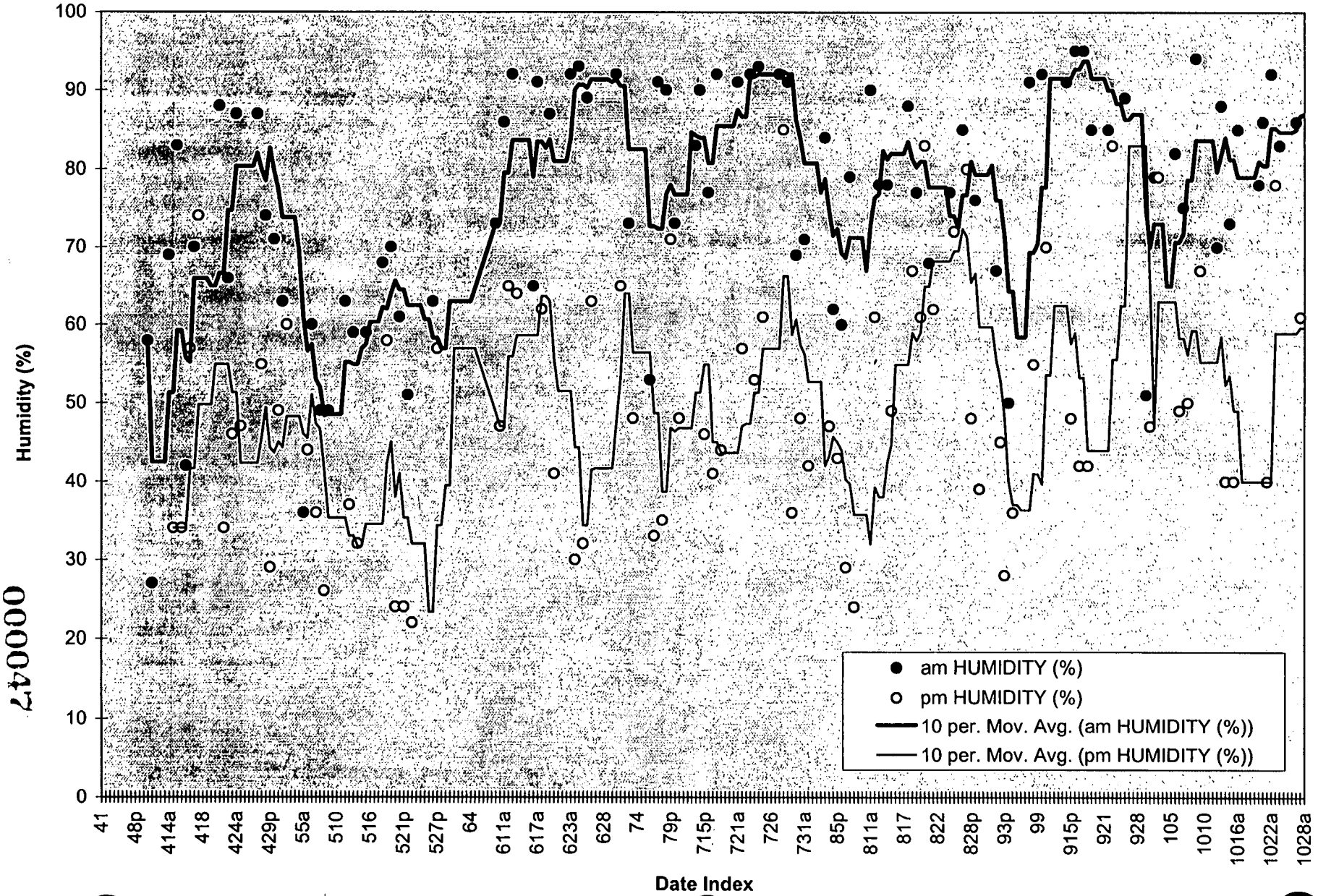

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Figure 2-3A, continued
Humidity at Field Quality Control Station

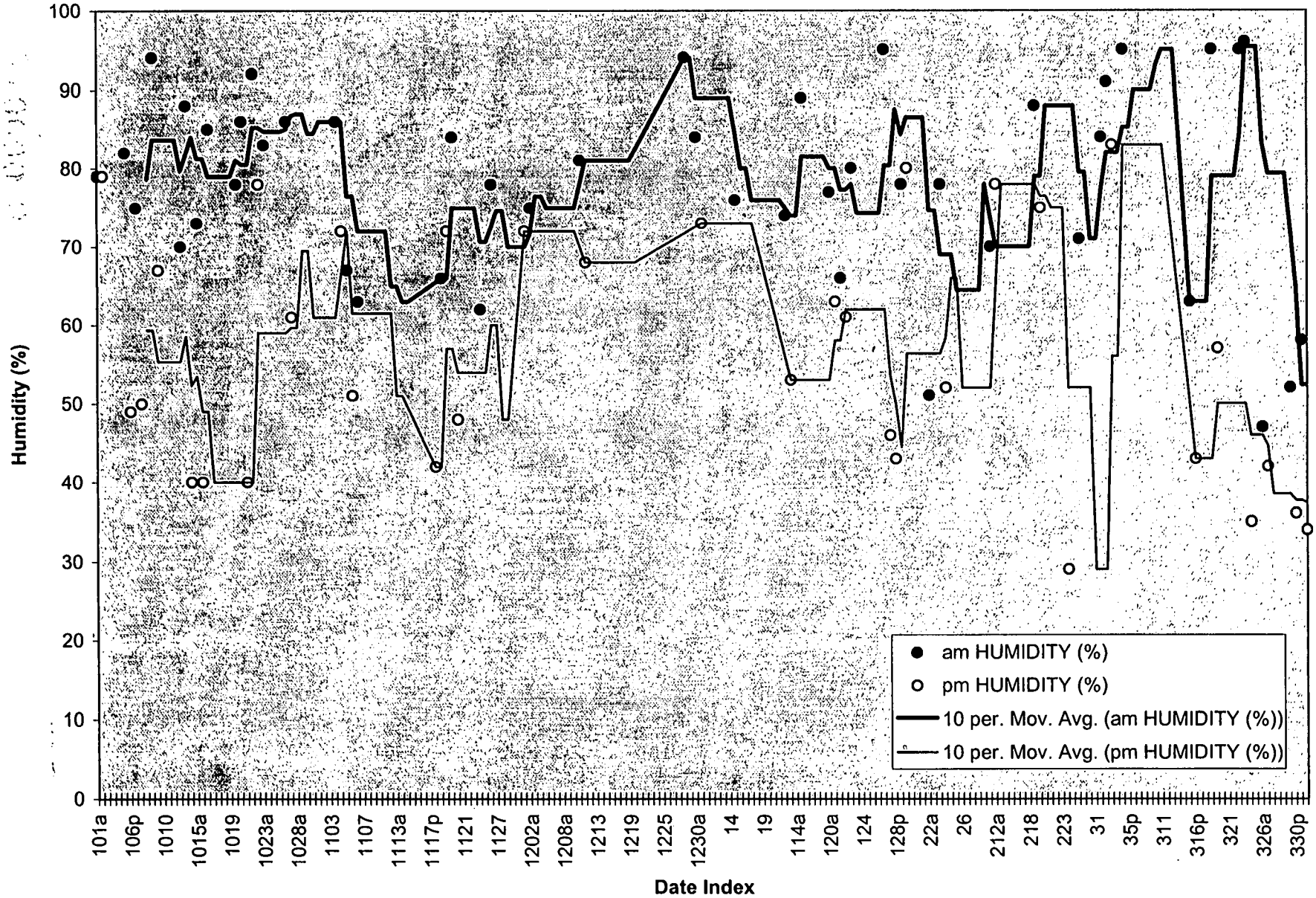

Figure 2-3B
Total Uranium (Wet Wt.) as a Function of Humidity

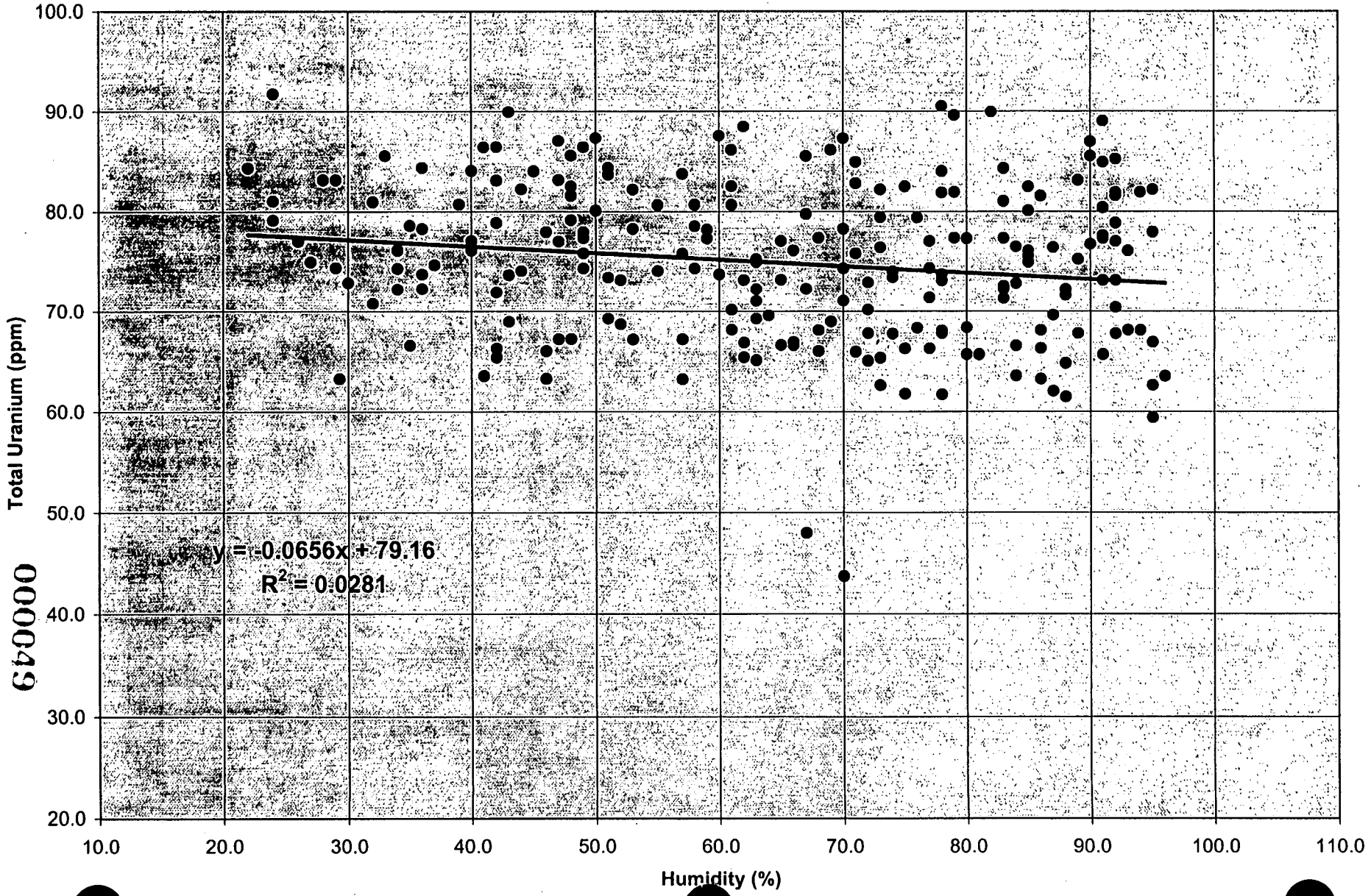

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Figure 2-3C
Total Uranium (Dry Wt.) as a Function of Humidity

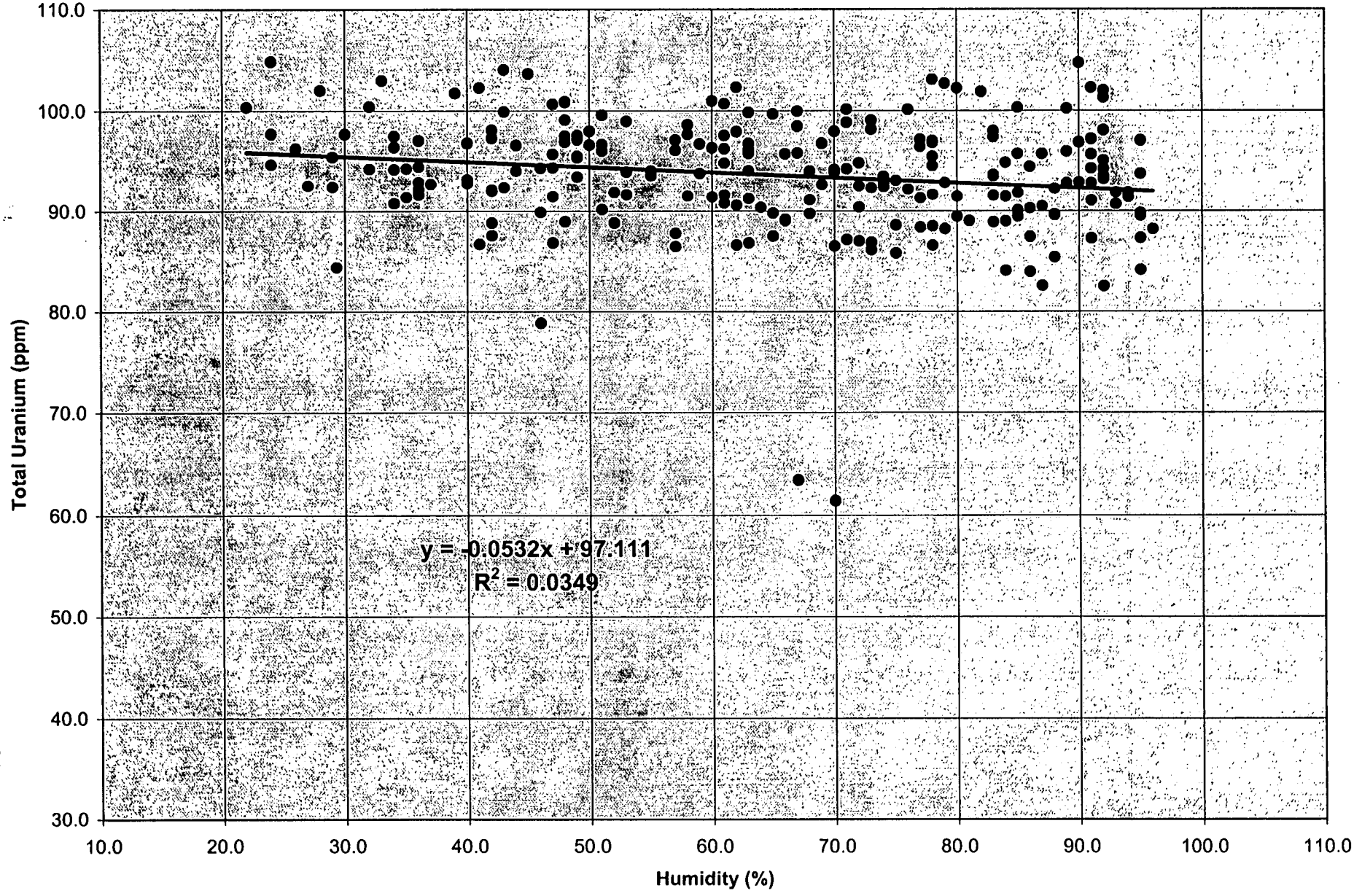

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Figure 2-3D
Thorium-232 (Wet Wt.) as a Function of Humidity

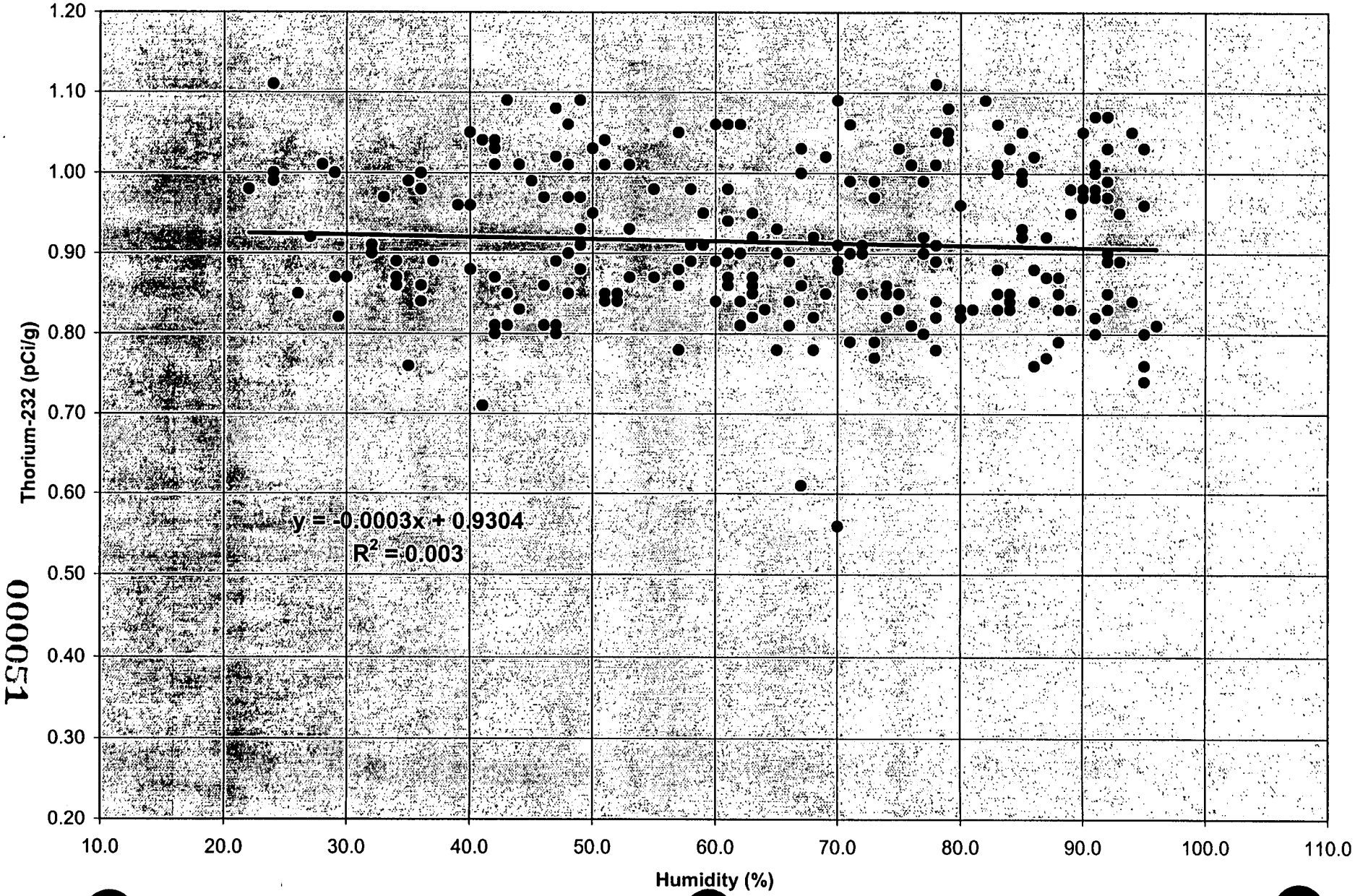

Figure 2-3E

Thorium-232 (Dry Wt.) as a Function of Humidity

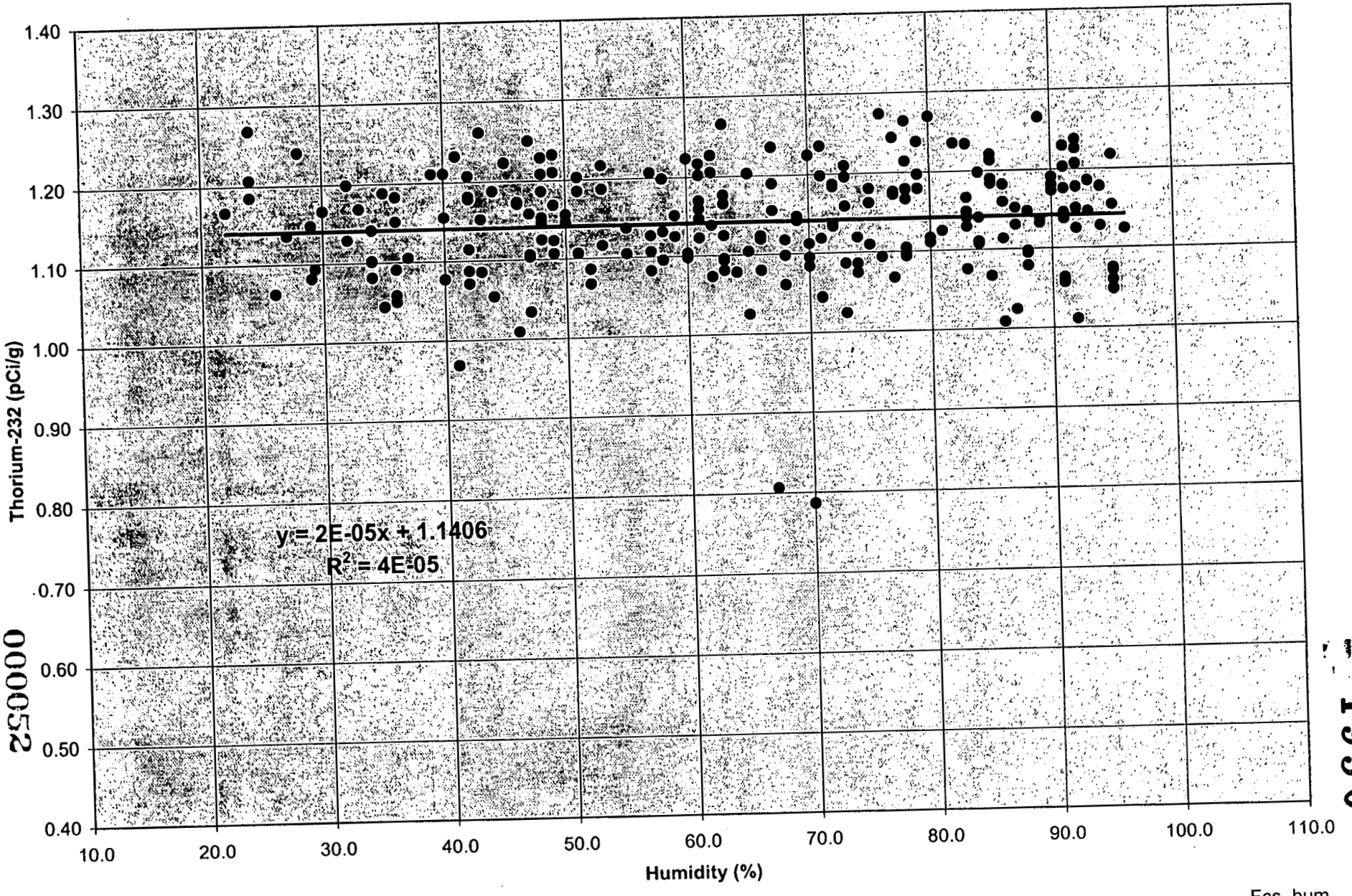

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Figure 2-4A
Control Chart for Total Uranium (Wet Wt. Basis)

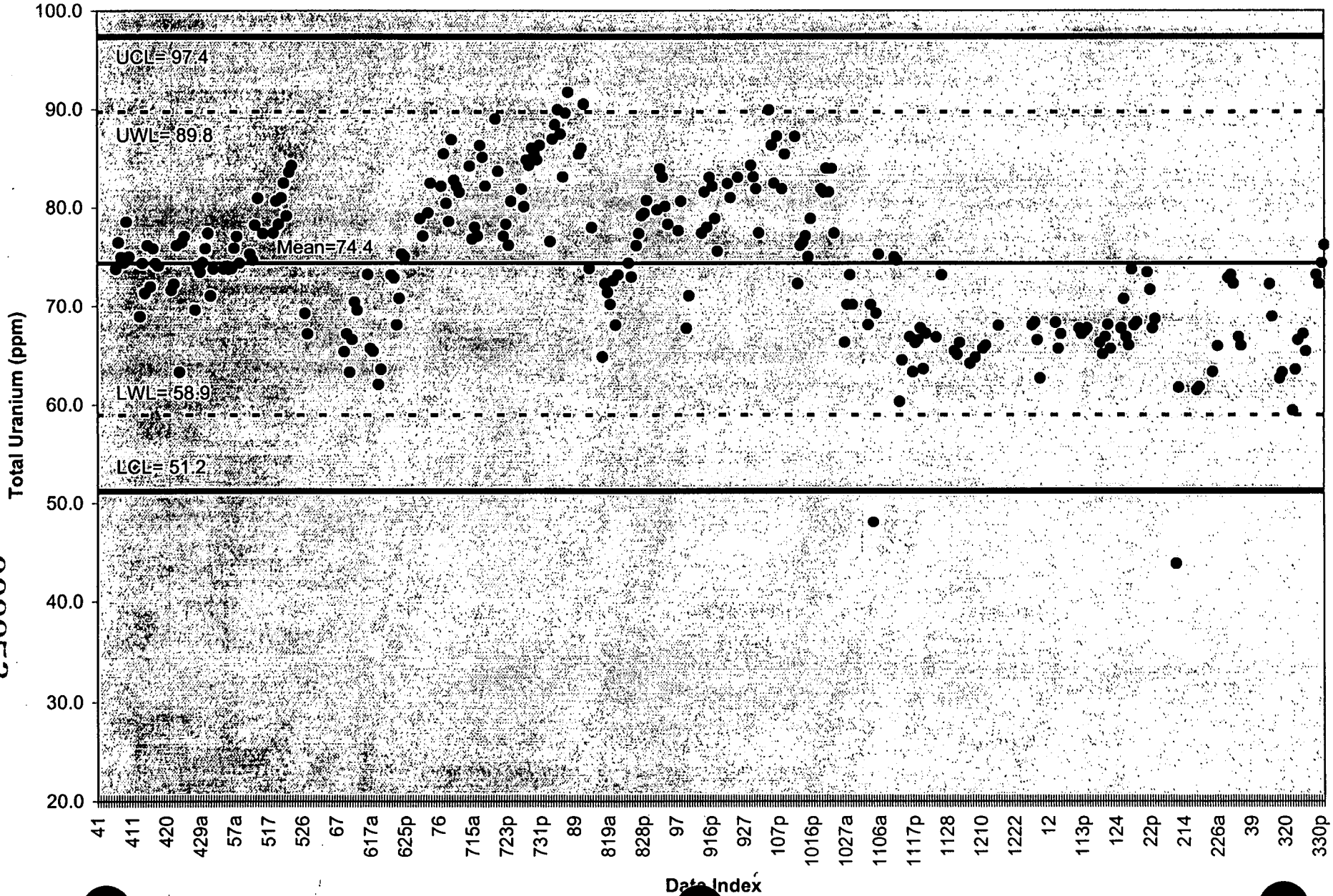

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Figure 2-4B
Control Chart for Total Uranium (Dry Wt. Basis)

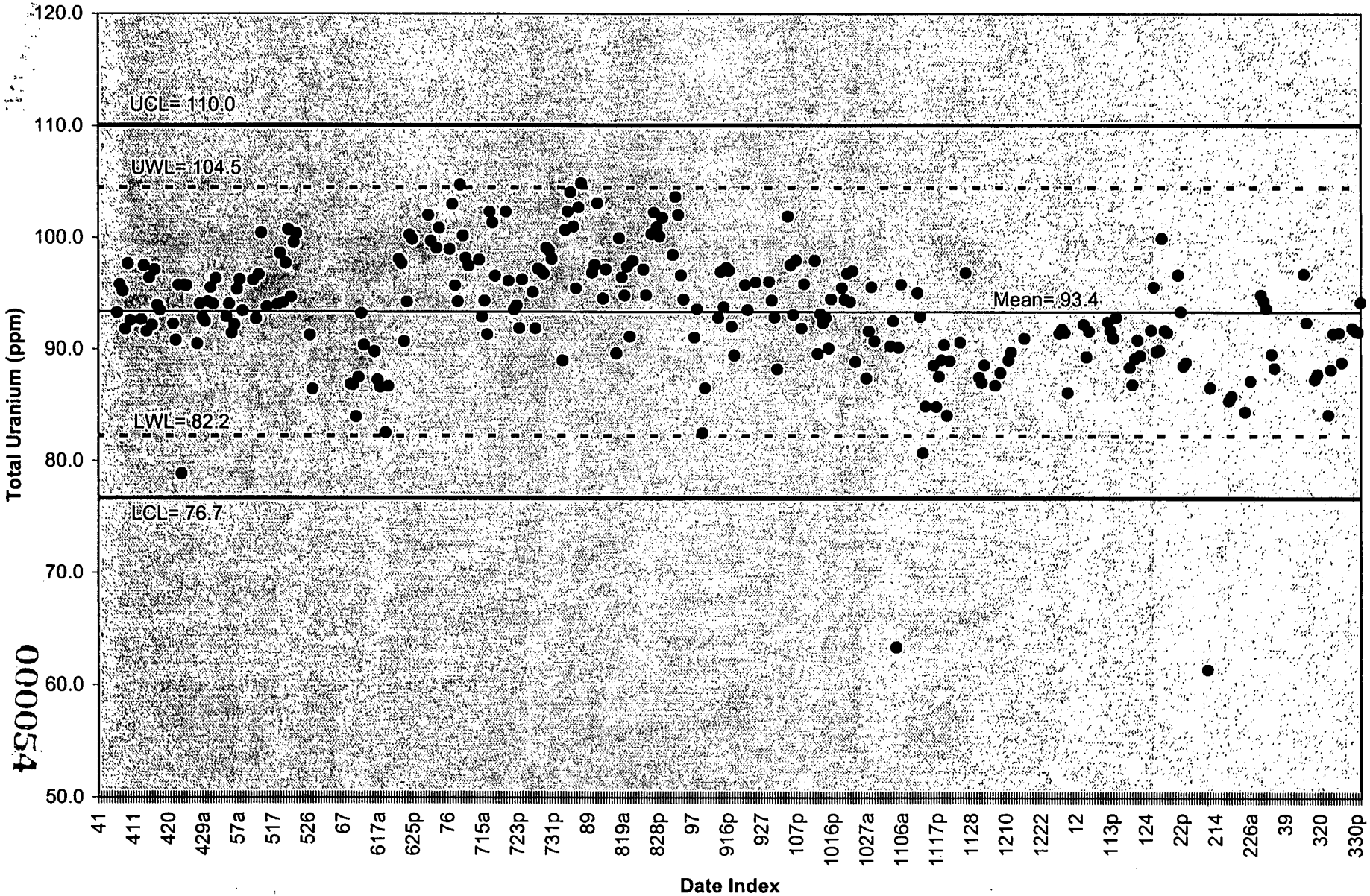

Figure 2-4C
Control Chart for Thorium-232 (Wet Wt. Basis)

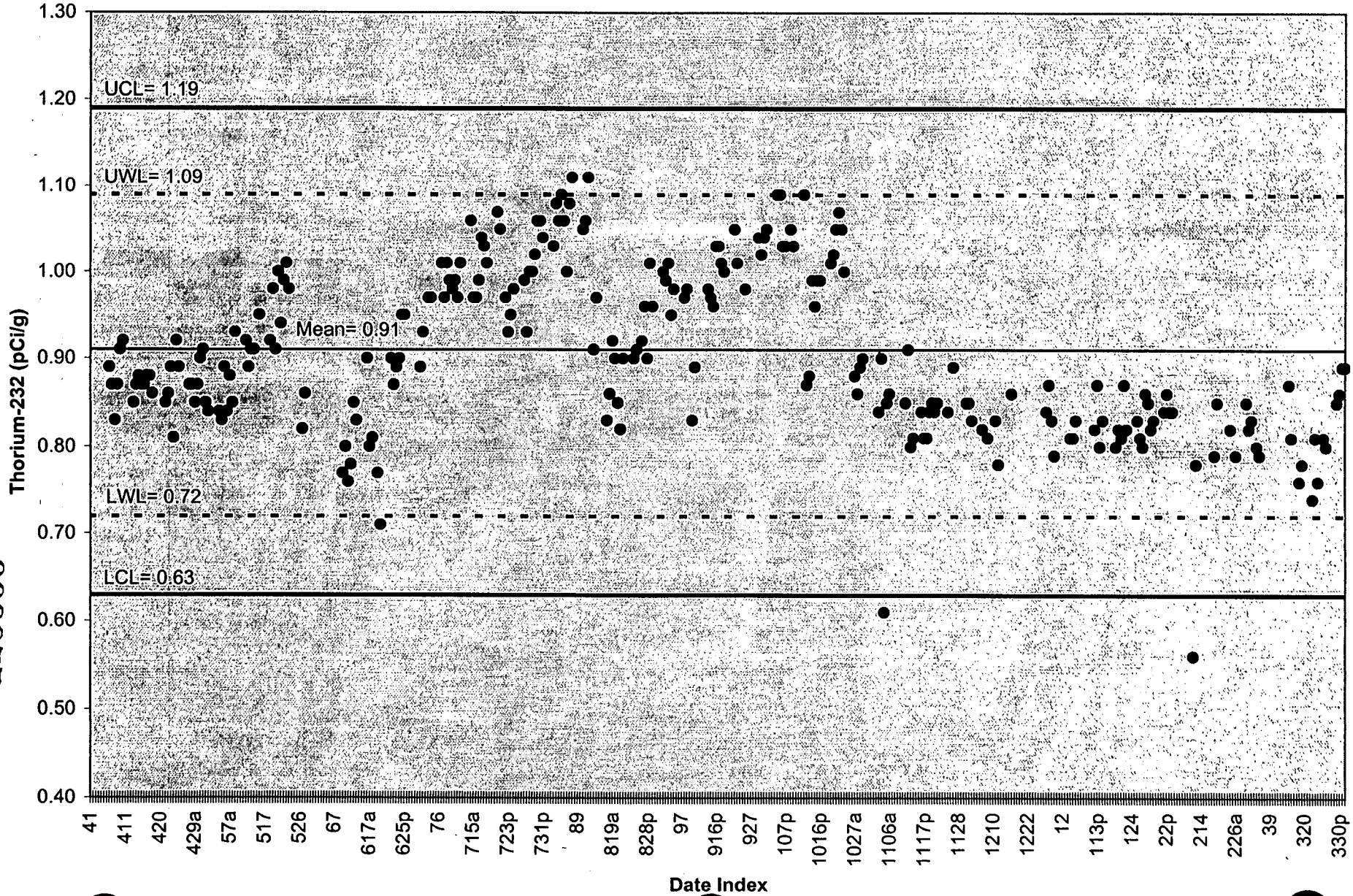

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Figure 2-4D
Control Chart for Thorium-232 (Dry Wt. Basis)

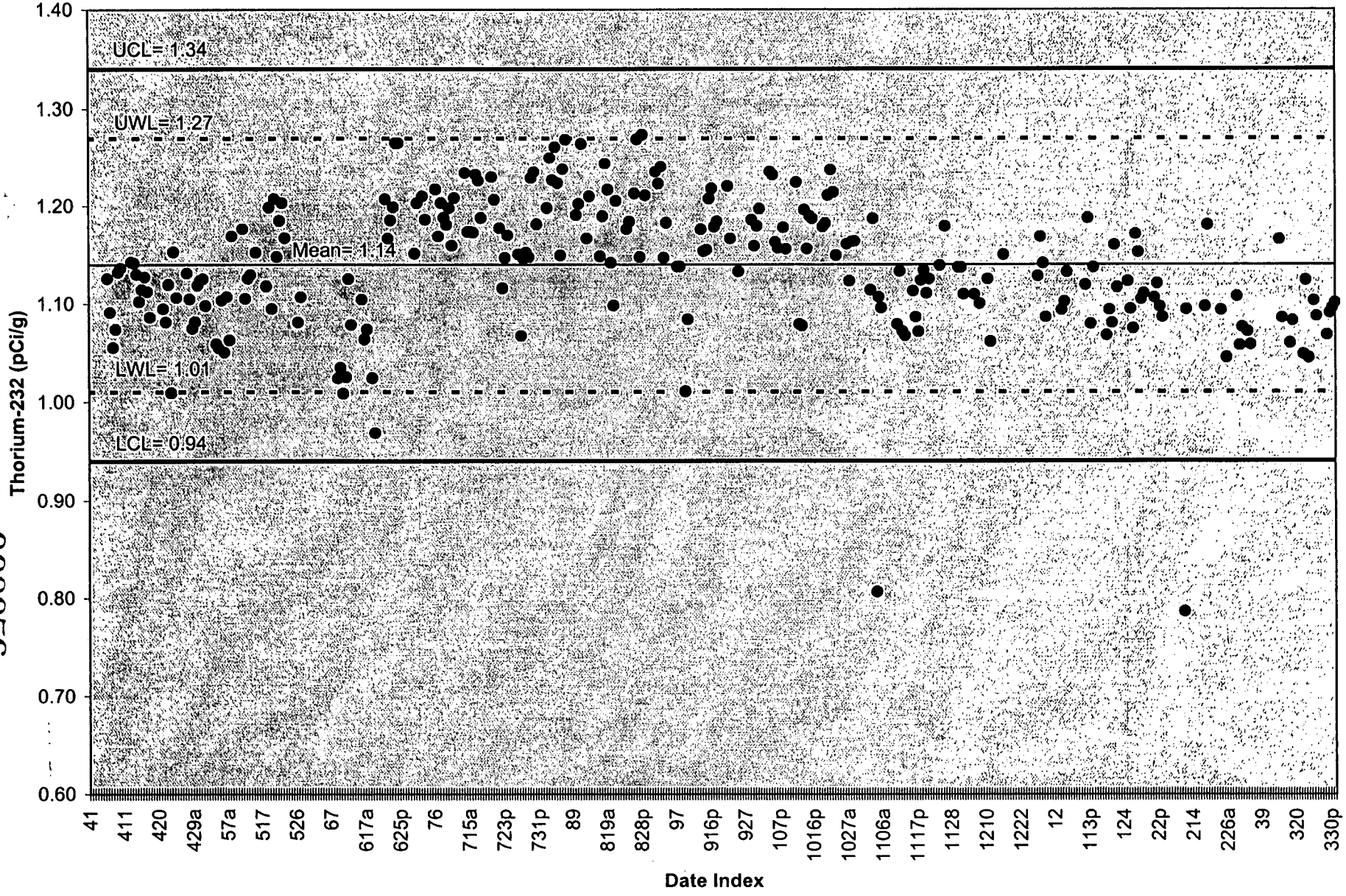

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Figure 2-5A
Control Chart for Radium-226 (Wet Wt. Basis)

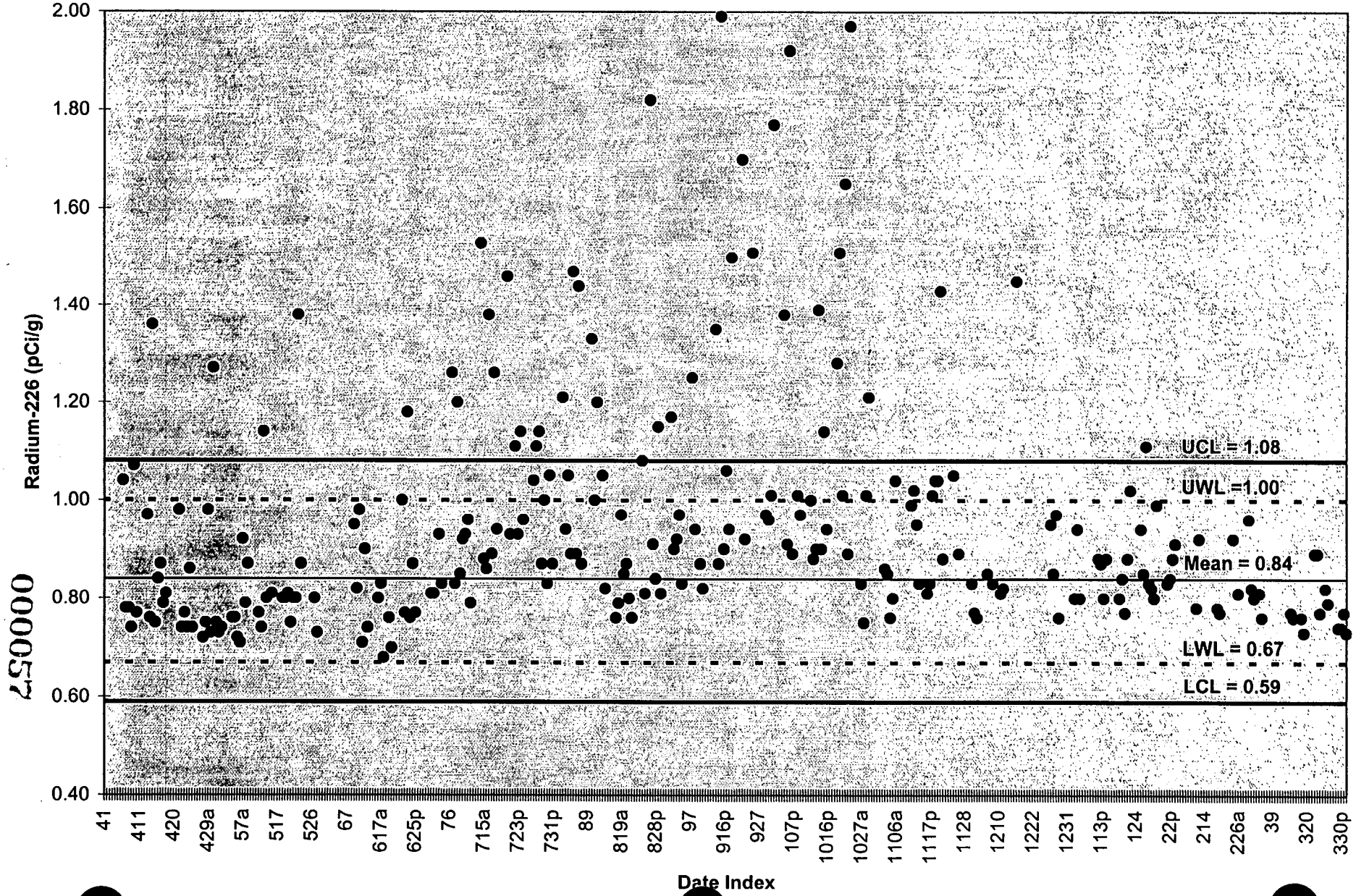

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Figure 2-5B
Control Chart for Radium-226 (Dry Wt. Basis)

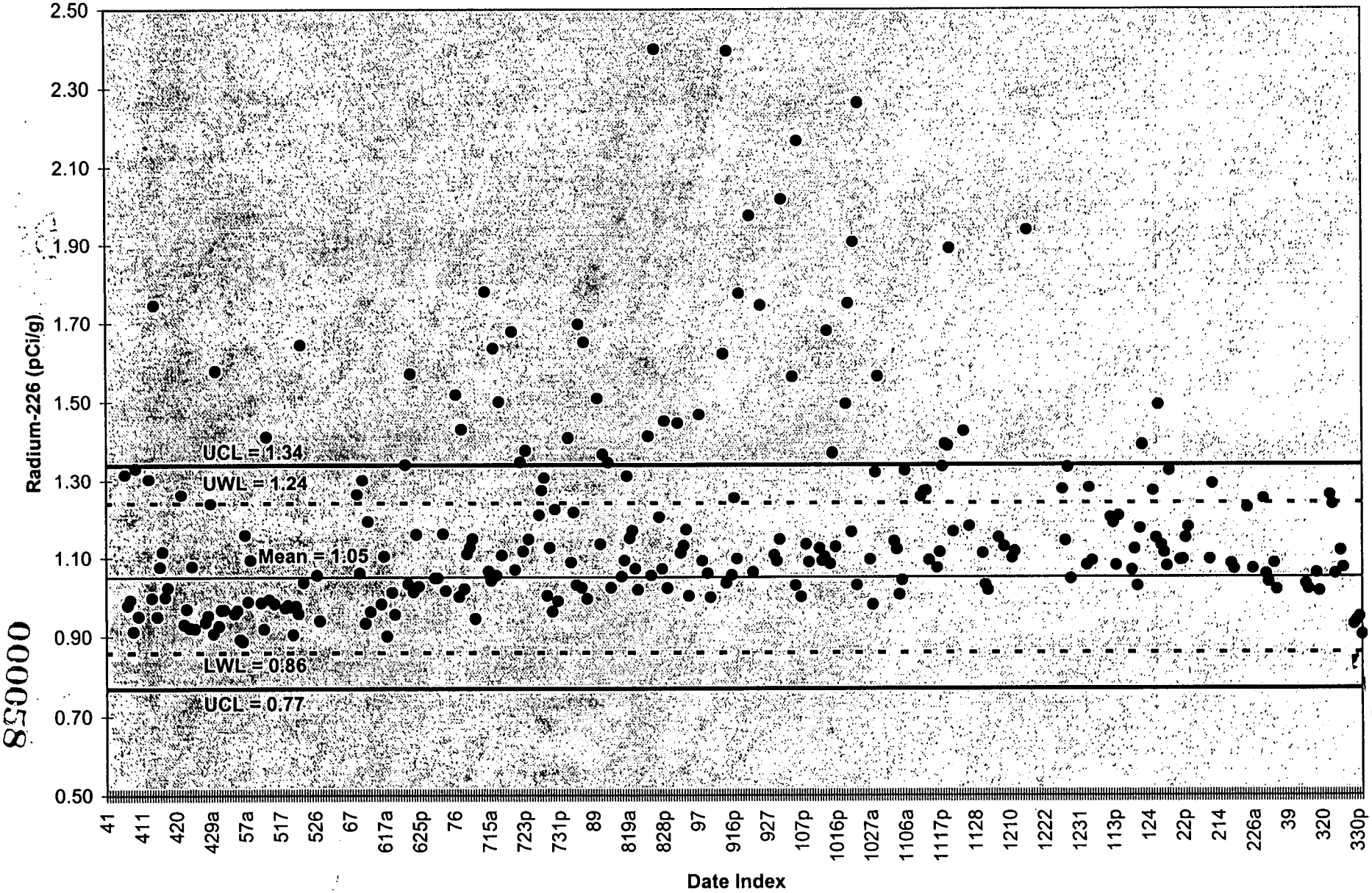

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Figure 2-5C
Expanded Control Chart for Radium-226 (Dry Wt. Basis)

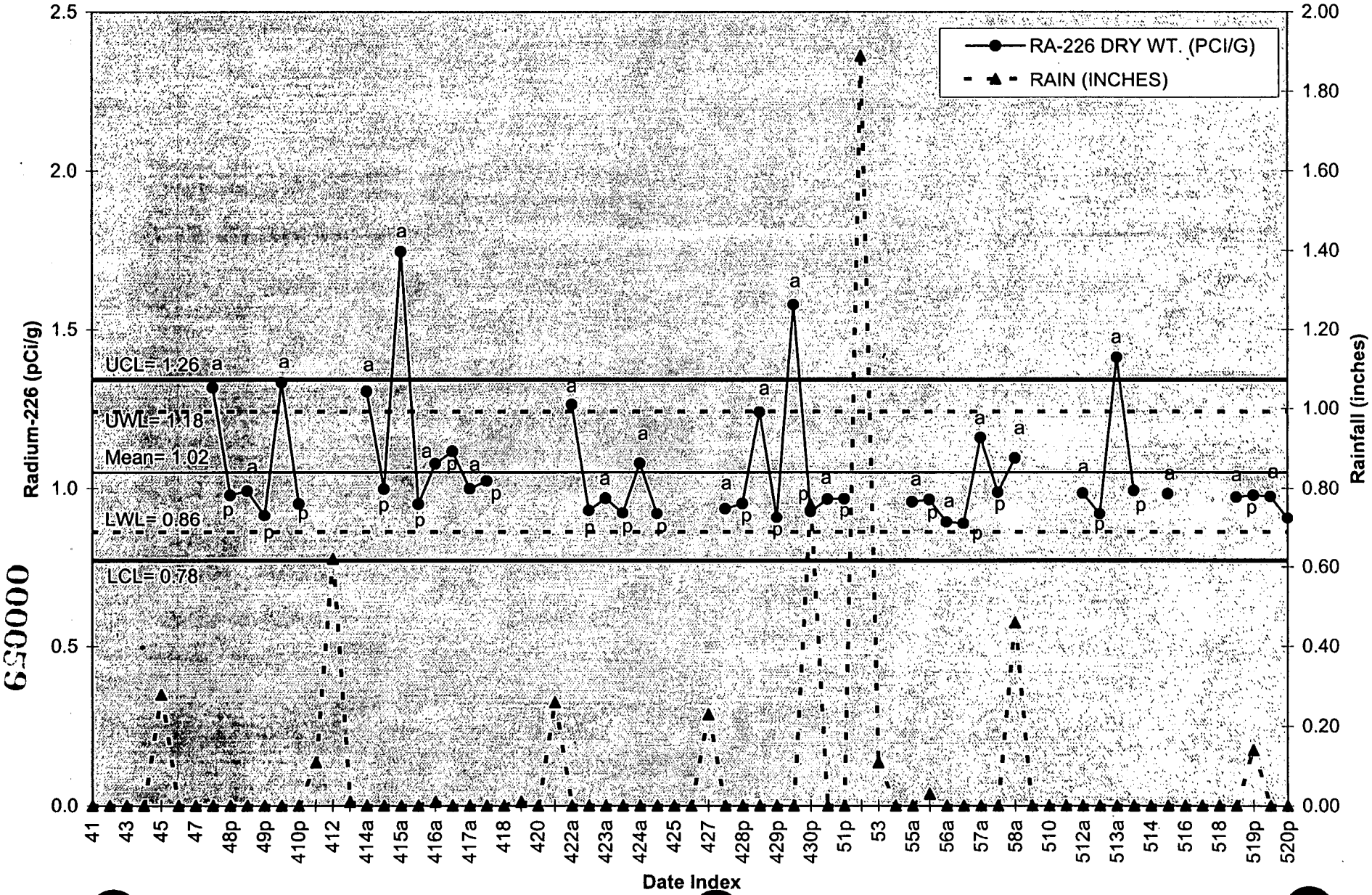

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Figure 2-5 C, continued
Expanded Control Chart for Radium-226 (Dry Wt. Basis)

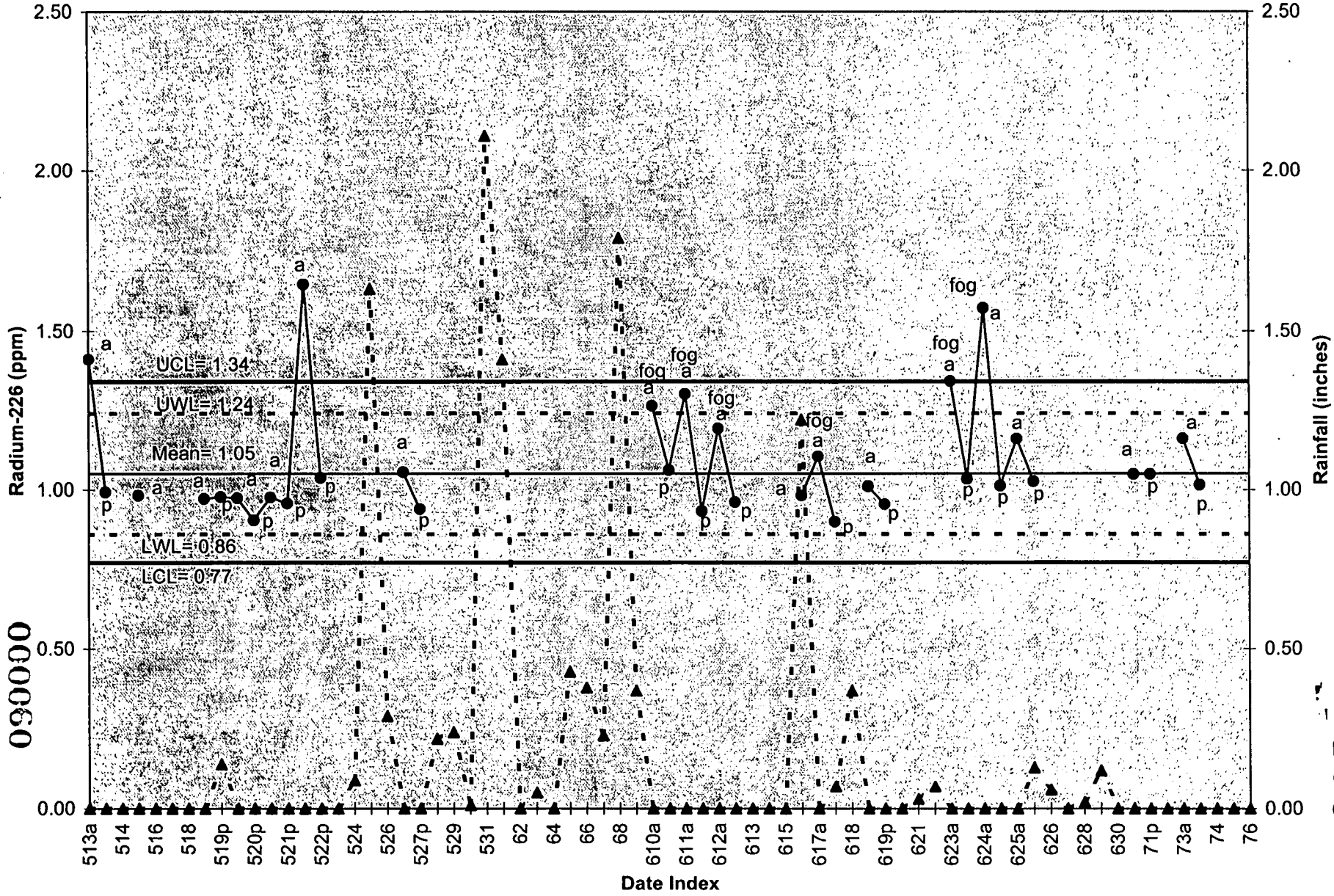

Figure 2-5C, continued
Expanded Control Chart for Radium-226 (Dry Wt. Basis)

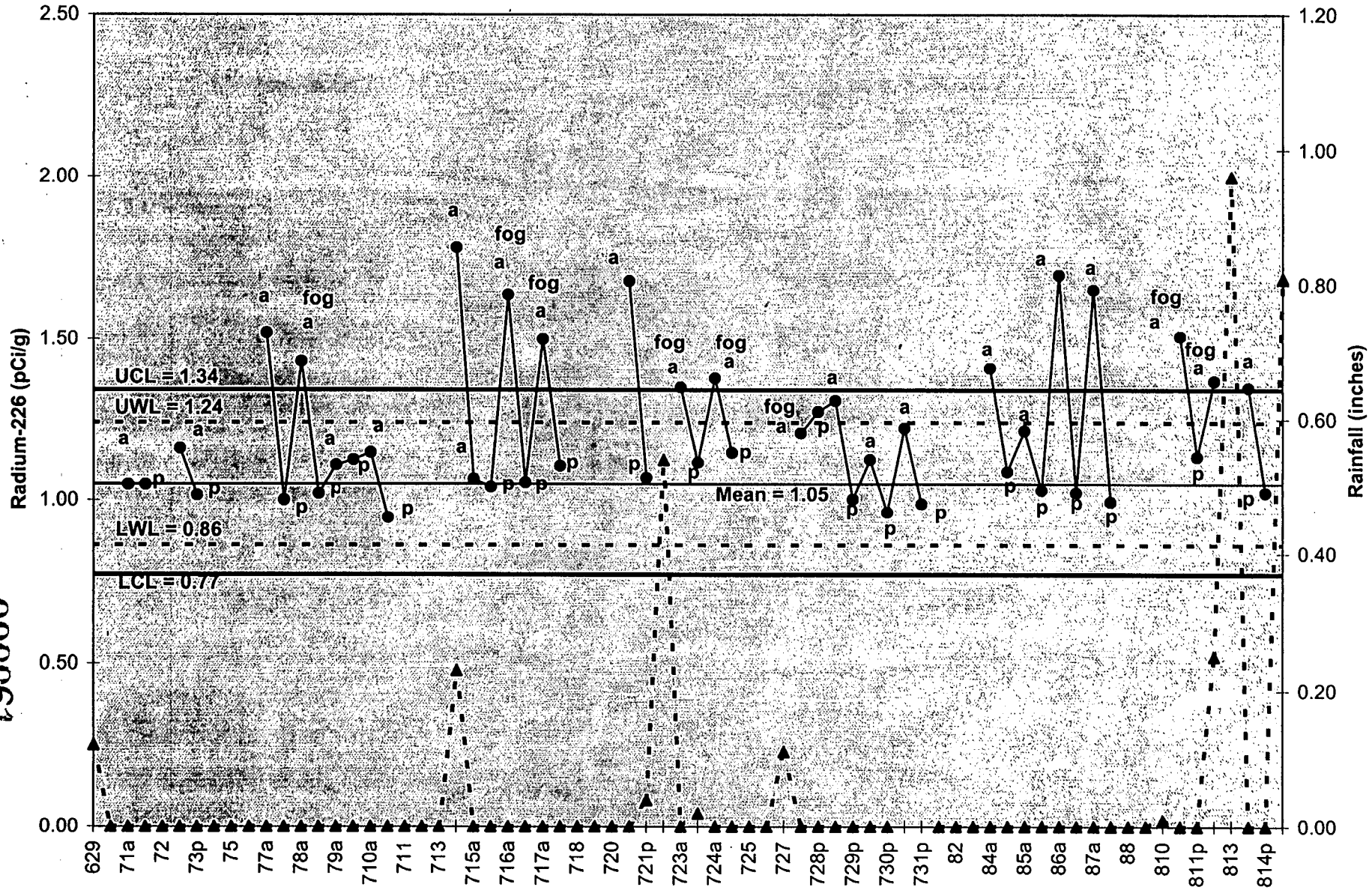

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Figure 2-5C, continued
Expanded Control Chart for Radium-226 (Dry Wt. Basis)

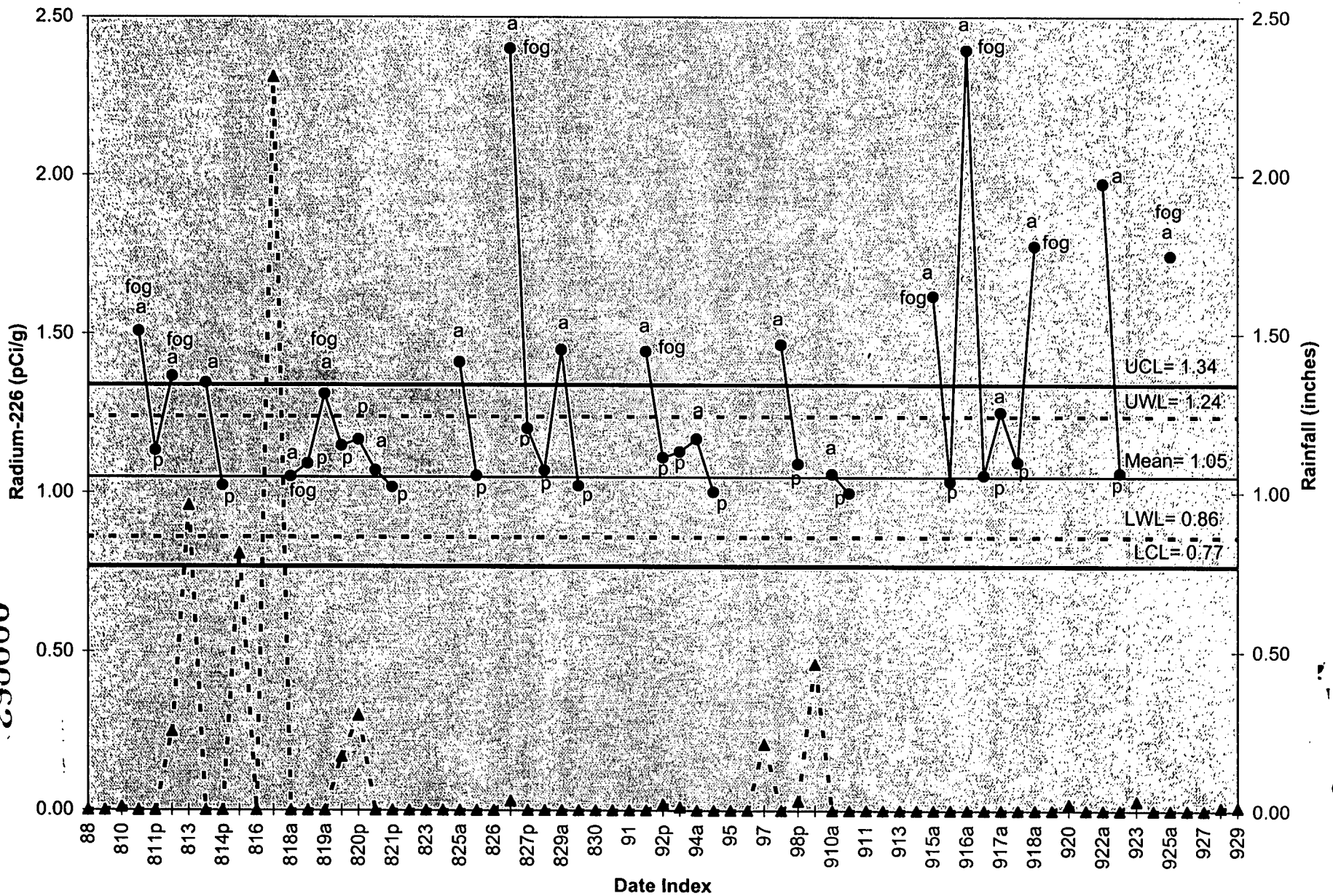

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Figure 2-5C, continued
Expanded Control Chart for Radium-226 (Dry Wt. Basis)

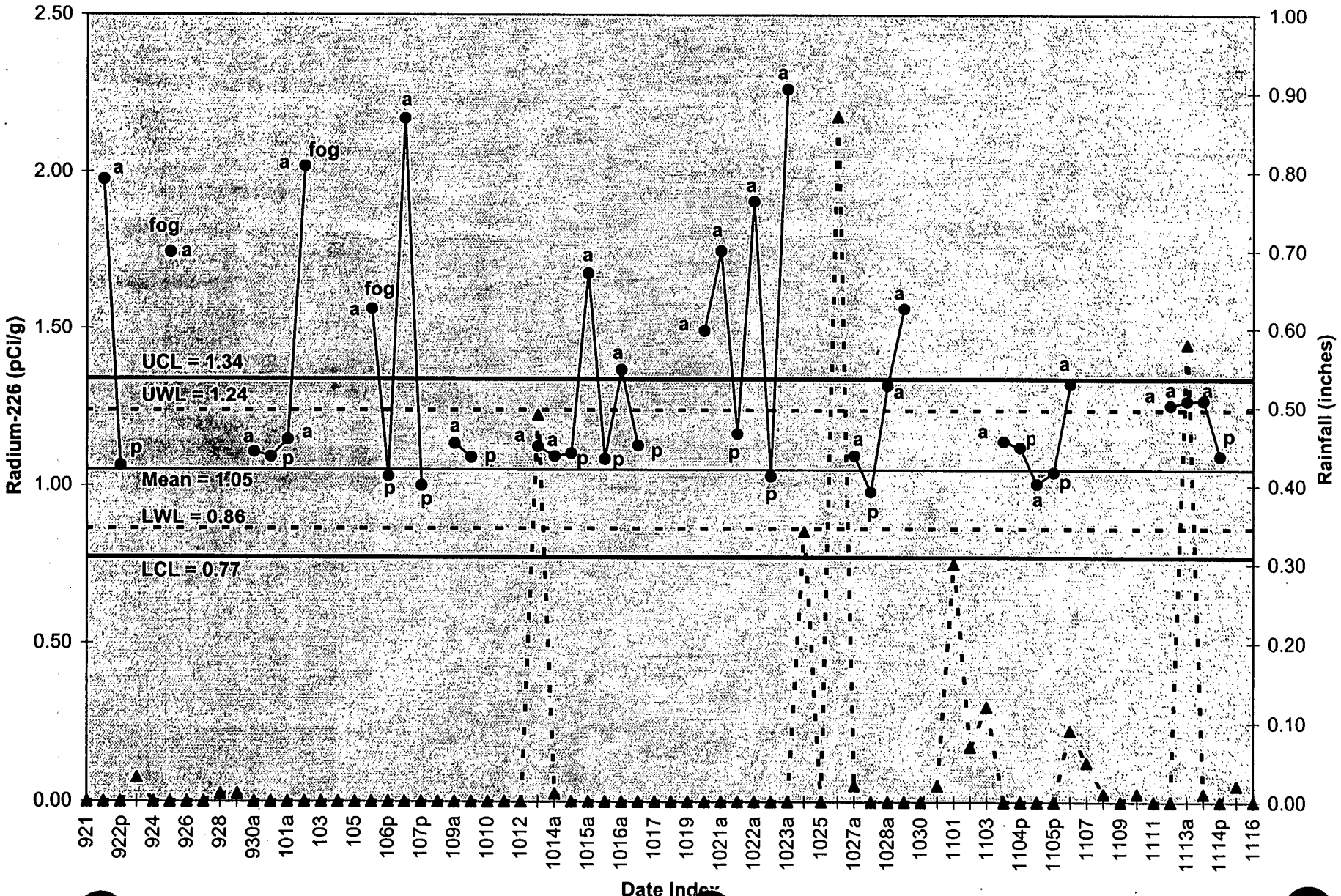

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Figure 2-5C, continued
Expanded Control Chart for Radium-226 (Dry Wt. Basis)

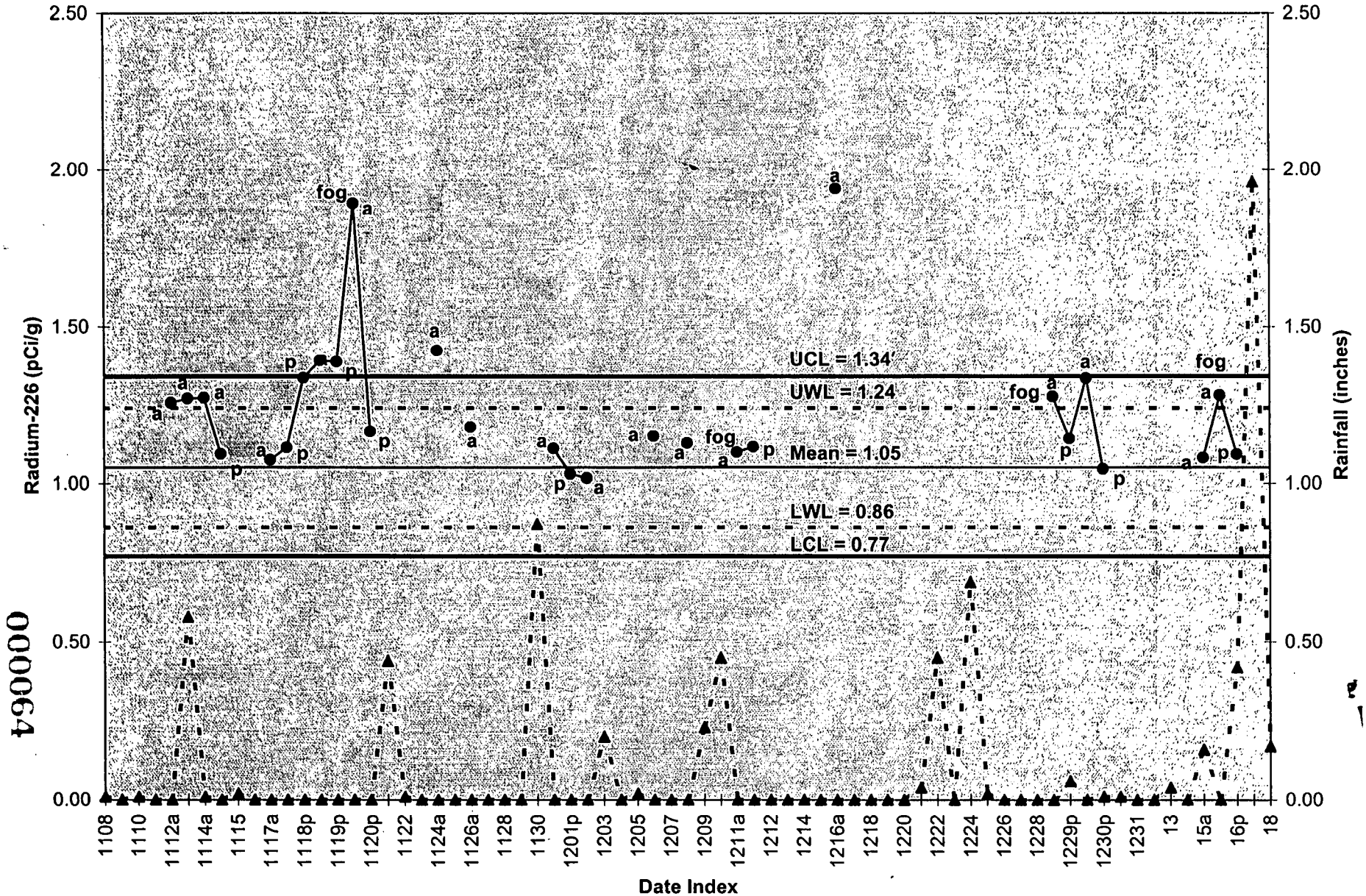

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Figure 2-5C, continued
Expanded Control Chart for Radium-226 (Dry Wt. Basis)

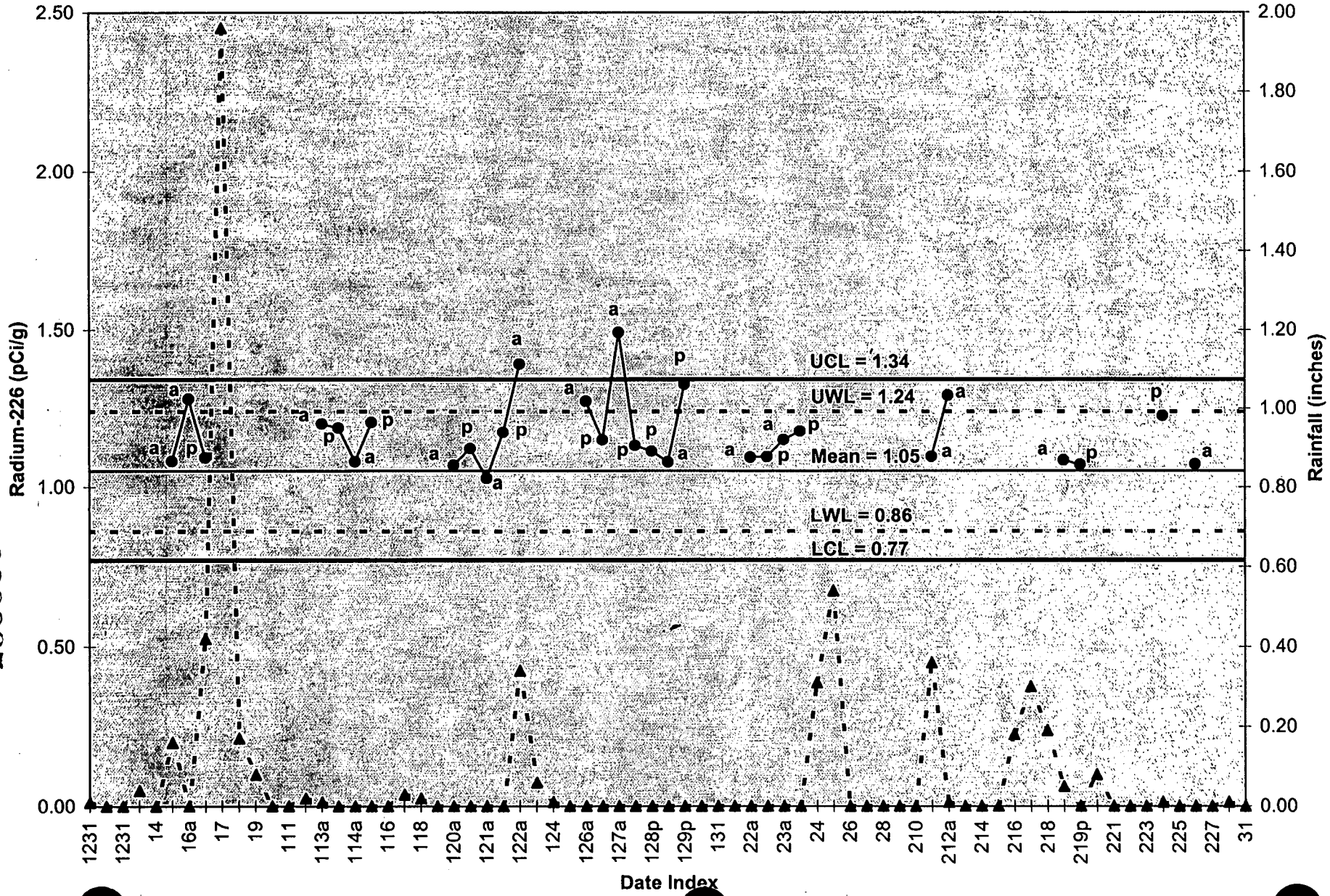

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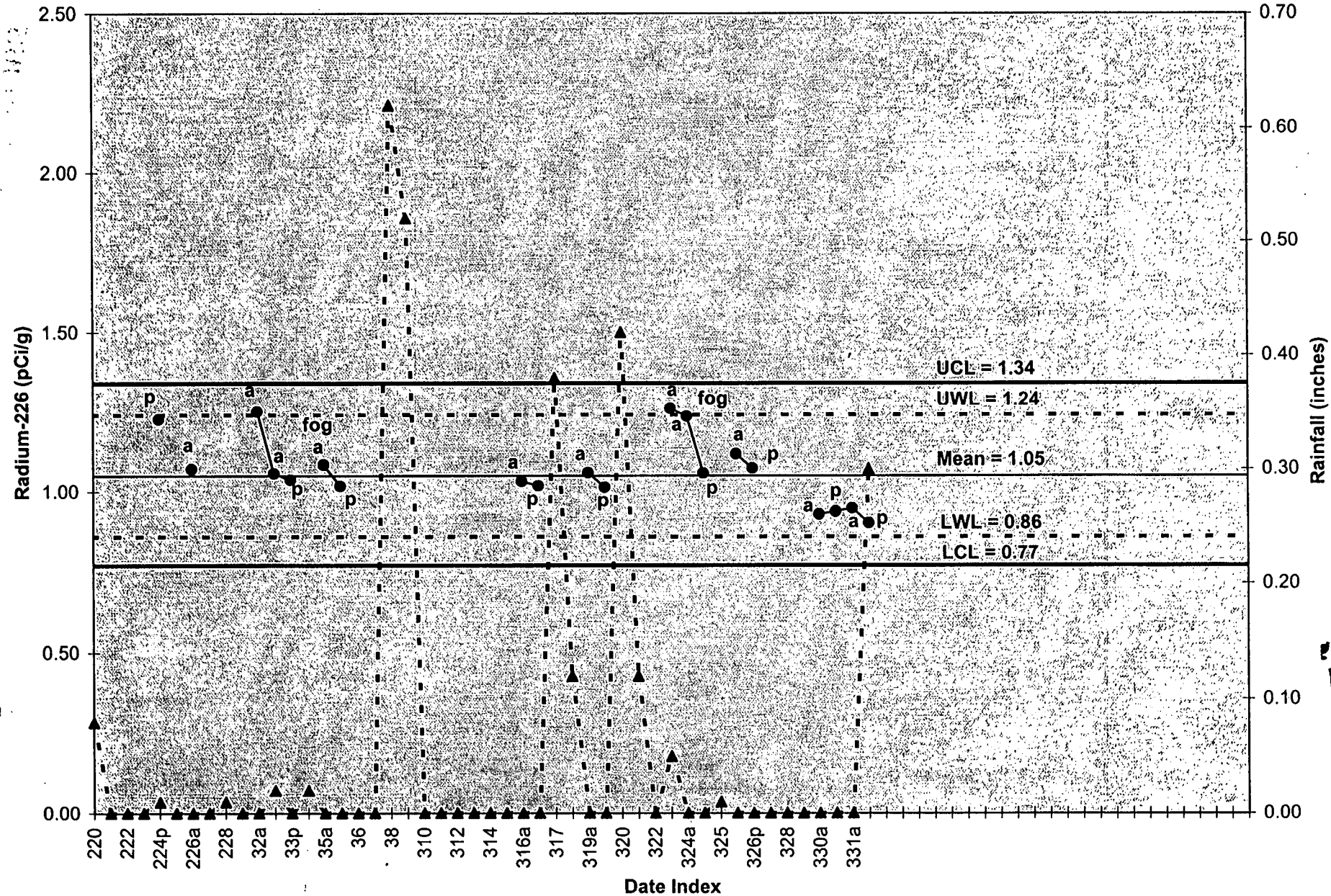
Figure 2-5, continued
Expanded Control Chart for Radium-226 (Dry Wt. Basis)



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3.0 METHOD VALIDATION STUDY DESIGN AND METHODS

3.1 OBJECTIVE

This method validation study was conducted to assess the comparability of in situ HPGe data with laboratory data generated through the analysis of discrete samples, and to demonstrate that HPGe measurements meet acceptance criteria for key parameters affecting the quality of data collected in field analytical operations.

3.2 METHODOLOGY AND STUDY DESIGN

The method validation study entails determining the similarity between data generated by HPGe measurements and data generated by laboratory analysis of physical samples. It also demonstrates that HPGe measurements meet acceptance criteria for key quality control elements and data quality elements. Three radiological contaminants of concern were measured by HPGe and by laboratory methods: total uranium, thorium-232, and radium-226.

Of the thorium isotopes of concern to soil remediation at the FEMP, only thorium-232 HPGe data are presented in this report because determination of thorium-228 entails detecting and measuring the same gamma rays as for the determination of thorium-232. Neither thorium-228 nor thorium-232 emit gamma rays that can be used to quantify them directly; both are quantified by detecting and measuring gamma rays of the same daughter products. Assuming secular equilibrium, thorium-228 and thorium-232 will have the same activity.

Similarly, of the radium isotopes of concern to soils remediation at the FEMP, only radium-226 is analyzed by HPGe and laboratory methods in this report. Radium-228, like thorium-228 and thorium-232, is quantified by detecting and measuring the same gamma photons emitted by the same daughter products. Assuming secular equilibrium, radium-228 and thorium-232 will have the same activities.

3.2.1 Layout and HPGe Measurements

Data collection areas (Table 3-1) were selected based on the concentration and estimated heterogeneity of total uranium. Data collection was initially conducted in ten selected areas designated 1 through 10 in Table 2-1 and PBC-1 through PBC-10 elsewhere in this report. Eight areas were also selected subsequent to the initial ten areas. These areas are designated 12 through 19 in Table 2-1 and PBC-12

through PBC-19 elsewhere in this report. Each area was mowed and raked (if appropriate) prior to the start of field activities. Area locations for areas 1-10 are illustrated in Figure 3-1. Area locations for areas 12 through 17 are shown in Figure 3-2, and area locations for areas 18 and 19 are shown in Figure 3-3. Five distinct activities occurred at each of the 18 selected areas:

- HPGe measurements
- Soil and air temperature measurements
- Physical soil sampling
- Surface moisture-density gauge measurements and physical samples for surface soil moistures
- Surveying

Field personnel used Geodimeter surveying instruments to survey the coordinates and elevations of each sample location.

Operation of the HPGe detector followed the requirements contained within FDF Procedure EQT-23, *Operation of ADCAM Series Analyzers with Gamma Sensitive Detectors*. HPGe measurements were obtained from both 31 cm (1 foot) and 1 meter (3.28 ft) heights above a fixed point on the ground surface for areas 1 through 10 as well as for areas 18 and 19. Areas 12 through 17 only had HPGe measurements performed at a 1.0 meter detector height. At a height of 31 cm, the HPGe effectively measures a circle that is 5 meters in diameter, which corresponds to a field of view of 19.6 m^2. At a height of 1 meter, the HPGe will effectively measure a circle that is 12 meters in diameter, which corresponds to a field of view of 113 m^2. More information on the field of view of HPGe detectors is provided in Section 4.1 of the User's Manual (August 1998). Data acquisition time was 15 minutes for each measurement. Two 15-minute measurements were taken at each sample location for each detector height to obtain information on precision of duplicates. In areas 12 through 17, both a.m. and p.m. measurements were taken to provide additional information on radon disequilibrium per Section 2.7. Surface moisture was measured adjacent to each HPGe location as necessary to provide environmental information to help interpret HPGe data. Appendix F provides additional information on HPGe instrumentation and measurement theory.

3.2.2 Temperature Measurements

A single air and a single soil temperature measurement were recorded on the Field Activity Log for each surface moisture-density gauge measurement taken. Measurements were recorded to the nearest

0.1°C. Two thermometers were used to obtain temperature measurements. The first thermometer was used to measure air temperature and was suspended in the air by means of a string attached to a stake or similar apparatus at a height of 1.0 meter above the ground. The stake or similar apparatus was located inside the 33 x 33 ft (10 x 10 m) test area. The air thermometer was set up before physical soil samples were collected.

The second thermometer was used to measure in-situ soil temperatures. The thermometer base was inserted four inches below the surface and was capable of obtaining an accurate soil temperature. The soil thermometer was inserted adjacent to the physical sampling location. The soil temperature was measured before physical soil samples were collected.

3.2.3 Physical Soil Sampling

Immediately after in-situ HPGe measurements were taken, 6 to 15 physical soil samples were collected for a given area for laboratory analysis. One duplicate sample was also collected for each area. The location and number of physical samples collected relative to the HPGe location for each of the eighteen areas depended upon the degree/heterogeneity of uranium contamination (based upon historical data) and upon the theory of in-situ gamma spectrometry. Based upon statistical considerations, collection of six physical samples was expected to be representative of low contaminated, homogeneous areas (Areas 1, 8, and 9). The collection of ten physical samples was expected to be representative of moderately contaminated, homogeneous areas (Areas 2, 4, 5, 6, 12, 13, 14 and 15). Collection of fifteen samples was expected to be representative of either highly contaminated or highly contaminated and potentially heterogeneous areas (Areas 3, 7, 10, 16, 17, 18 and 19).

Samples were collected in a "bullseye" pattern to mimic the averaging done by the field HPGe detector. That is, the area from which physical samples were taken can be envisioned as a circle, with the HPGe detector located in the center. The HPGe detector records gamma ray photons from every point within the circle; however, it records more gamma rays from soil closer to the detector than from soil further from the detector. If the circle is divided into concentric bands, the relative weighting factor for each band can be calculated based upon the percentage fluence of gamma photons at the detector which originates from a given band of soil (see, for example, Figure 6.1 in NRC Report NUREG-1506, 1995, and Section 4.1 of the User's Manual, August 1998). The relative weighting factor is the relative

importance of each band with respect to the probability of uncollided gamma rays emitted from within that band impinging upon the HPGe detector. In this regard, Figure 6.1 of NUREG-1506 shows that, for an HPGe detector 1 m off the ground, 10% of the total gamma photon fluence comes from soil within 0.5 m of the detector, while 36% of the total fluence comes from soil 0.5 to 1.5 meters from the detector. A 1 m distance is a good approximation of a midpoint to represent this 36% fluence in that 50% of the 36% fluence comes from between 0.5 and 1.0 m and 50% comes from between 1.0 and 1.5 m. Finally, approximately 54% of the total gamma photon fluence originates from 1.5 to 10 m from the detector. A 3.0 m distance is a good approximation of a midpoint in that 50% of the 54% fluence within this band occurs between 1.5 and 3.0 m and 50% occurs between 3.0 and 10.0 m. Tables 3-2 through 3-4 show the results of weighting calculations based on fluences. For example, in Table 3-2, a band of soil 1 meter from the detector would have a weighting factor at 0.33 for a detector height of 31 cm, and a weighting factor of 0.36 for a detector height 1 meter above the ground. Similarly, a band of soil 3 meters from the detector would have weighting factors of 0.18 for a 31 cm detector height and 0.54 for a 1 meter detector height. (See also Appendix F for additional information on HPGe measurement theory.)

The number of samples per band is divided into the weighting factor per band to give a weighting factor per sample. For example, Table 3-3 shows six samples on a band three meters from the detector. For a one meter detector height, that band has a weighting factor of 0.54. Therefore, the weighting factor per sample is 0.09 (0.54/6). These weighting factors have been used to calculate weighted statistical data in Sections 5, 6 and 7.

Figures 3-4 through 3-6 show the locations of physical samples relative to a central point (HPGe locations) for areas of low, medium, and high uranium contamination. The sample location distribution is based upon geometrical considerations and the total number of samples. For areas with six physical samples, one sample is taken directly beneath the detector, two on a circle one meter from the detector, and three on a circle three meters from the detector. Samples collected at the one- and three-meter radii are assumed to represent areas extending inward, as well as outward, from one- and three-meter sample points as discussed above in the paragraph on fluence weighting. Thus, the sample distribution is assumed to represent an area substantially larger than a circle with a radius of three meters. Based on this assumption, the sample location design is consistent with the HPGe field of view, in which approximately 85% of the gamma photons originate within six meters of the detector.

Each of the eighteen areas was identified as a low, medium, high, or heterogeneous uranium contamination area, based on historical information, and was assigned an arbitrary identification number from one to eighteen. Table 2-1 summarizes the area designations. The designations were used to determine both the number of physical samples to be collected from each area and the sample layout that was followed in the field to identify each physical sample location.

Physical samples were collected and submitted for on-site laboratory analysis. For all areas, the first sample was taken directly below the HPGe setup location. Sampling then proceeded radially outward in one of three patterns. For designated low contamination areas, the sampling pattern shown in Figure 3-4 was followed. For designated medium contamination areas, the sampling pattern shown in Figure 3-5 was followed. For designated high or heterogeneous contamination areas, the sampling pattern shown in Figure 3-6 was followed.

3.2.4 Physical Sample Collection

Technicians noted the condition of the sampling area, including disturbances due to excavation, vehicle traffic, etc., in the Field Activity Log. Using a clean stainless steel trowel and other tools as directed by the Field Sampling Lead, a technician removed all vegetative, loose, and disturbed material, and removed additional material as necessary to reach the top of the soil surface to be tested/sampled. Technicians took care not to remove any soil if the surface vegetation was removed.

Core samples, 0 to 4-inch deep by 3 inches in diameter, were taken in a clean polybutyrate liner with or without a split barrel sampler, as conditions required. The liner served as the sample container and was capped at both ends, using pre-fitted plastic caps after filling.

A geologist described the soil adjacent to each sample location on the Field Activity Log. The description included the sample color and percent organic material, clay, sand, and gravel per *Draft DRL-04, Classification of Soils and Completion of Lithologic Log* (American Society of Testing and Materials [ASTM] D 2488-84, Standard Practice for Description Identification of Soils). Each physical soil sampling location was staked for survey purposes. The sample identification number was inscribed on each stake.

All samples collected by field technicians were assigned a unique sample number supplied by the Field Sampling Lead. This unique sample number appeared on the Chain of Custody form and was used to identify the sample during analysis, data entry, and data management. A prefix was added to each sample number to identify why and where the sample was collected. The prefix began with the project and area identification number followed by the sample location number as shown on the Physical Sampling Patterns. Sample numbers began with a "PBC" followed by the area number (1 through 19), followed by a sample location number. For example: PBC-3-12 is the sample number for Area 3, Sample Number 12.

3.2.5 Surface Moisture and Surface Density Measurements

The Troxler Model 3440 Nuclear Gauge was used to make soil moisture and density measurements at each HPGe measurement location in areas PBC-1 through PBC-18. Surface moisture measurements were conducted in accordance with ASTM procedure D 3017-88 and in accordance with FDF procedure EQT-32, Troxler 3440 Series Surface Moisture/Density Gauge Calibration, Operation and Maintenance. Physical soil moisture samples were collected in place of moisture-density gauge readings when environmental conditions were unfavorable for gauge measurements. Unfavorable environmental conditions include periods of extended cold, causing surface soil to freeze into an irregular topography unsuitable for proper gauge-soil coupling, and periods of extreme rain, rendering the surface soil, especially clays, too muddy to safely operate the tool.

Table 3-5 shows a comparison of moisture values for areas 1 through 10 calculated from Troxler measurements vs. those calculated from laboratory measurements based upon weight loss after drying. Moisture data are presented on an "as is" basis, i.e., as weight moisture per wet weight sample, rather than on a geotechnical basis, i.e., weight moisture per dry weight sample. The Troxler, on average, yields moisture readings about 3% higher (absolute basis) than laboratory measurements. This difference is not significant with respect to adjusting data to either a wet weight basis or dry weight basis.

More information on moisture measurements of surface soils can be found in the User's Manual, Sections 3.8 and 5.2.

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3.3 SUMMARY

The following points are the most salient ones in this section:

1. HPGe measurements and physical samples were collected from 18 areas representing low, medium and high degrees of contamination.

2. The number of physical samples collected ranged from six for low contamination areas to 15 for highly contaminated areas.

3. The distribution of physical samples was arranged in a "bulls eye" pattern to mimic the averaging done by the HPGe detector.

4. Each sample was weighted based upon the photon fluence expected for that sample.

The weighting factors for physical samples form the basis for calculating a physical sample weighted average for each area in order to compare with HPGe measurements. The basis for such comparisons are described in the next section (4.0).

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TABLE 3-1
DATA COLLECTION AREA DESIGNATIONS

Area Designation	Contamination Level	Areas by Identification Number
Low	0 - 80 ppm Total Uranium and low concentrations of Thorium-232 and Radium-226	1, 8, 9
Medium	80 - 200 ppm Total Uranium and/or Thorium-232 and Radium-226 potentially exceeding 1.0 pCi/g	2, 4, 5, 6, 12, 13, 14, 15
High and potentially Heterogeneous	> 200 ppm Total Uranium and/or Thorium-232 and Radium-226 potentially exceeding 3.0 pCi/g	3, 7, 10, 16, 17, 18, 19

TABLE 3-2
WEIGHTED AVERAGE 6-SAMPLE SCHEME, LOW RANGE (0-80 ppm U)

No. of Samples	Horizontal Distance from Point Under Detector (m)	Detector Height = 31 cm		Detector Height = 1 m	
		Weight (per sample)	Weight (per circle)	Weight (per sample)	Weight (per circle)
1	0	0.49	0.49	0.1	0.1
2	1	0.165	0.33	0.18	0.36
3	3	0.06	0.18	0.18	0.54
Total = 6			Total = 1.00		Total = 1.00

TABLE 3-3
WEIGHTED AVERAGE 10-SAMPLE SCHEME, MEDIUM RANGE (80-200 ppm U)

No. of Samples	Horizontal Distance from Point Under Detector (m)	Detector Height = 31 cm		Detector Height = 1 m	
		Weight (per sample)	Weight (per circle)	Weight (per sample)	Weight (per circle)
1	0	0.49	0.49	0.1	0.1
3	1	0.11	0.33	0.12	0.36
6	3	0.03	0.18	0.09	0.54
Total = 10			Total = 1.00		Total = 1.00

TABLE 3-4
WEIGHTED AVERAGE 15-SAMPLE SCHEME, HIGH RANGE (> 200 ppm U)

No. of Samples	Horizontal Distance from Point Under Detector (m)	Detector Height = 31 cm		Detector Height = 1 m	
		Weight (per sample)	Weight (per circle)	Weight (per sample)	Weight (per circle)
1	0	0.49	0.49	0.1	0.1
4	1	0.083	0.33	0.09	0.36
10	3	0.018	0.18	0.054	0.54
Total = 15			Total = 1.00		Total = 1.00

TABLE 3-5
COMPARISON OF SOIL MOISTURES[a]
BASED UPON TROXLER AND LABORATORY MEASUREMENTS

Sample	Troxler (% Moisture)	Laboratory (% Moisture)
PBC-6-1	31.6	26.7
PBC-6-5	27.0	24.7
PBC-4-1	29.0	27.3
PBC-4-5	29.2	23.1
PBC-5-1	24.5	21.8
PBC-5-5	27.2	18.8
PBC-10-1	22.1	20.8
PBC-7-1	32.5	28.4
PBC-7-9	29.6	28.7
PBC-2-5	30.8	24.3
PBC-2-1	25.3	21.9
PBC-3-1	28.0	21.2
PBC-3-8	26.4	24.1
PBC-8-1	30.8	29.9
PBC-8-4	35.5	30.9
PBC-9-3	28.5	29.3
PBC-9-1	27.5	26.3
PBC-1-1	24.6	24.1
PBC-1-4	23.7	20.4
	mean = 27.8	mean = 24.6

[a] Moistures calculated on a wet weight basis (i.e., weight moisture per wet weight sample)

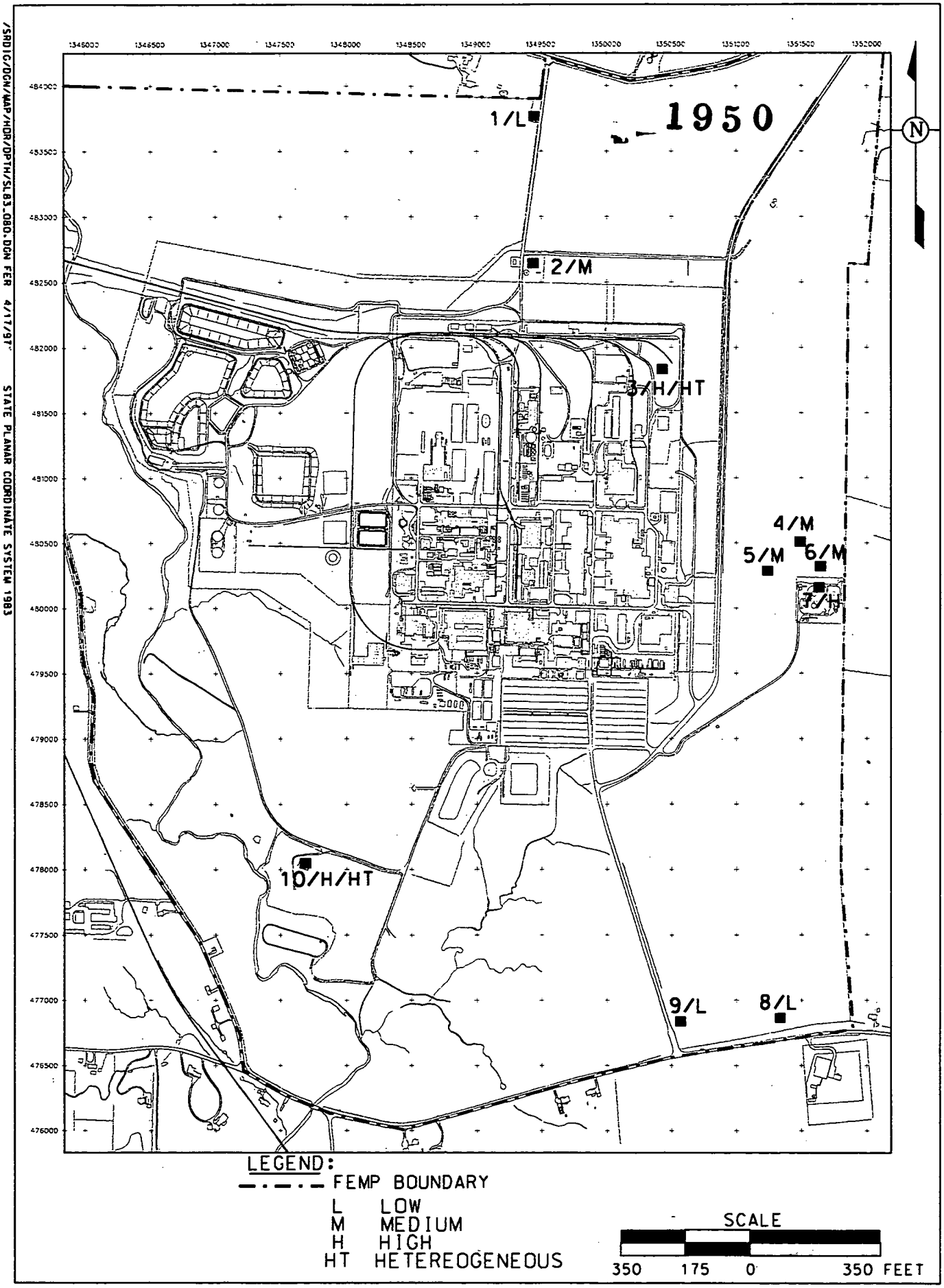


FIGURE 3-1. METHOD VALIDATION STUDY TEST LOCATIONS FOR AREAS 1 THROUGH 10

/SRDIC/DGN/MAP/HDR/DPTH/SL83_080.DGN FER 4/17/91 STATE PLANAR COORDINATE SYSTEM 1983

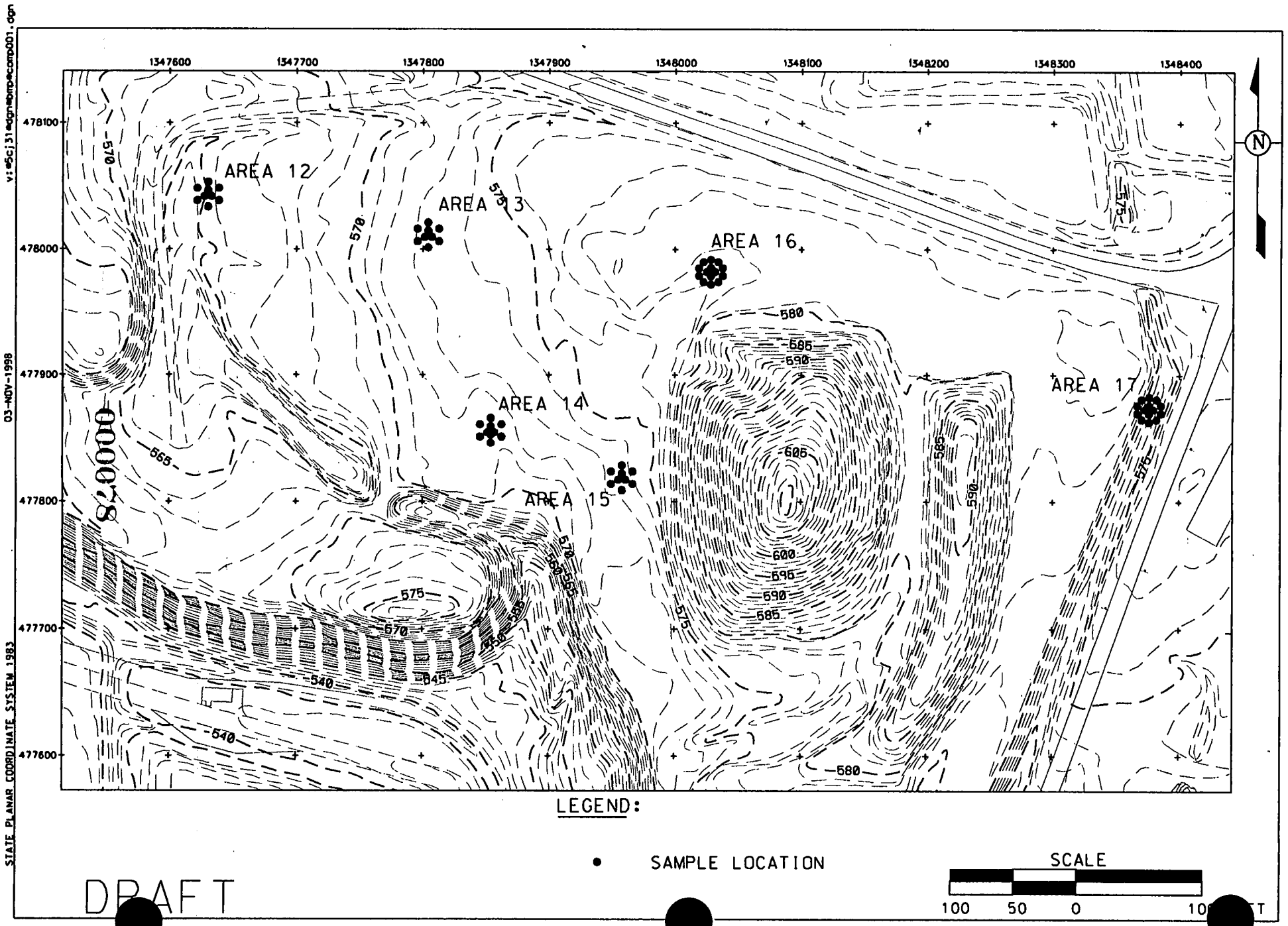
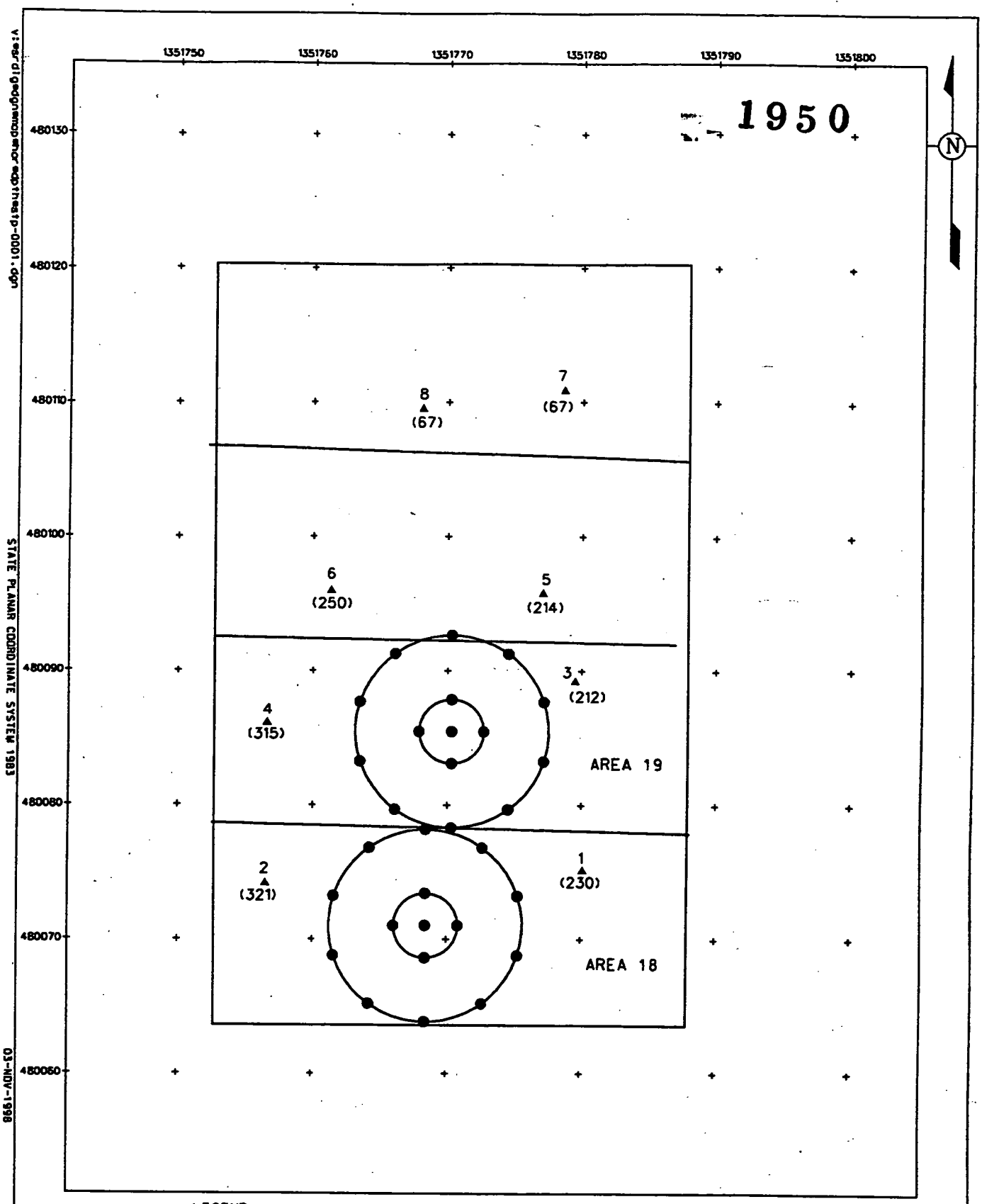


FIGURE 3-2. METHOD VALIDATION STUDY LOCATION IN SOUTH FIELD AND PHYSICAL SAMPLE PATTERN



LEGEND:

▲ EXPLORATORY SAMPLE POINT LOCATIONS

● PHYSCIAL SAMPLE LOCATIONS

(67) URANIUM 238 CONC IN pCi/gm FOR EXPLORATORY HPGE MEASUREMENTS

SCALE

15 7.5 0 15 FEET

DRAFT

FIGURE 3-3. METHOD VALIDATION STUDY LOCATIONS IN SEWAGE TREATMENT PLANT FOR AREAS 18 & 19

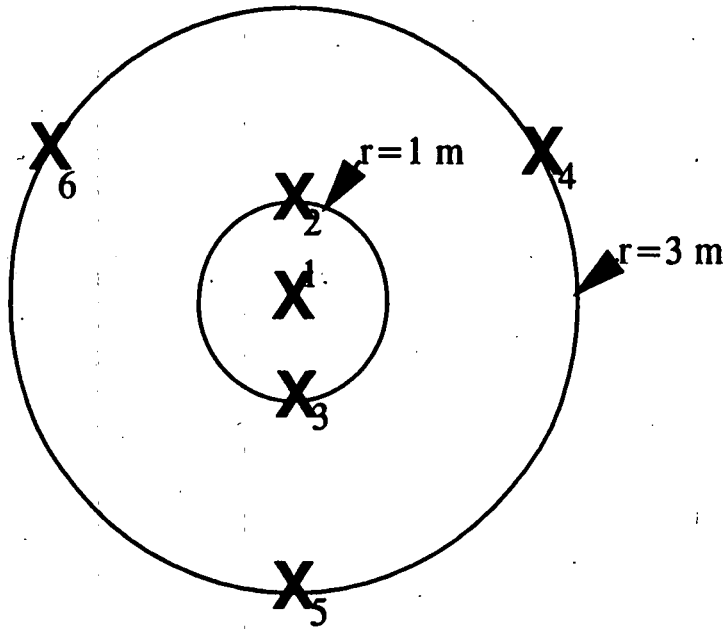


FIGURE 3-4
Low Designation (6-Point) Sampling Pattern
For Areas 1, 8, and 9

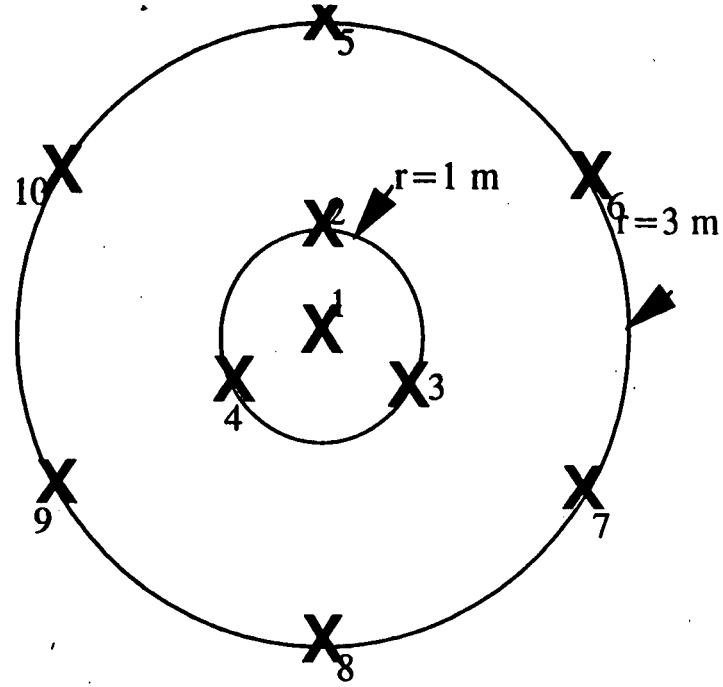
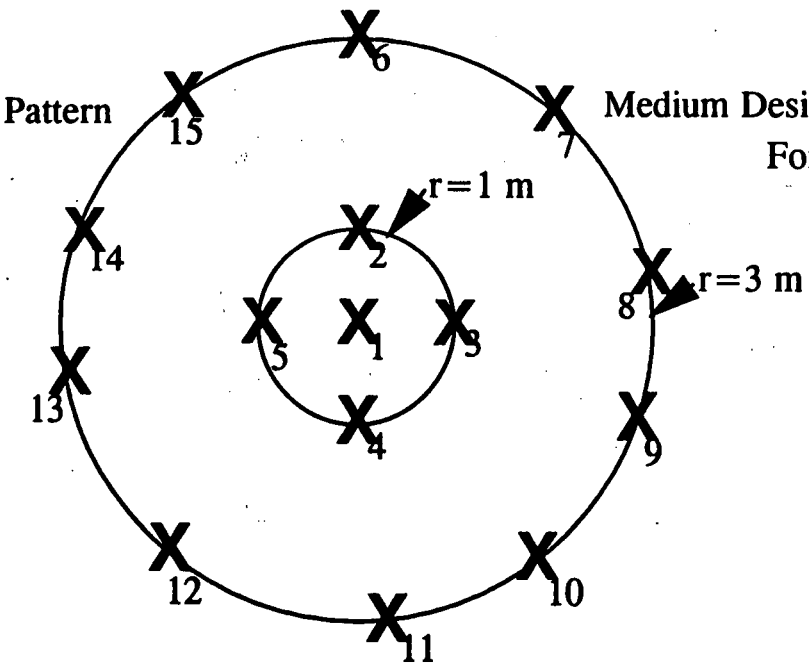


FIGURE 3-5
Medium Designation (10-Point) Sampling Pattern
For Areas 2, 4, 5, 6, 12, 13, 14 and 15



X Sampling Point

1 meter = 3.28 feet
1 foot = 0.305 meters

FIGURE 3-6
High and Heterogeneous Designations (15-Point) Sampling Pattern
For Areas 3, 7, 10, 16, 17, 18 and 19

000080

4.0 BASIS FOR ASSESSING COMPARABILITY OF HPGe AND LABORATORY DATA

This section provides the basis for assessing the comparability of HPGe and laboratory data. If defines comparability, compares and contrasts comparability as it pertains to two laboratory methods with comparability as it pertains to laboratory vs field methods, and gives the methodology used to assess comparability.

4.1 COMPARABILITY

Comparability refers to one of five elements identified by the US Environmental Protection Agency (EPA) to describe data quality. It is an expression of the confidence with which one data set can be compared to another. Analytical data for the same analyte generated by the same analytical procedure (whether by the same laboratory at different times or by different laboratories) are comparable provided that specified acceptance criteria for quality control parameters such as detection limits, accuracy, precision, matrix spikes, etc. are met or exceeded. Data for the same analytes generated by different analytical procedures are also comparable provided that specified acceptance criteria for quality control elements such as those listed above are met or exceeded (Sutton et al., 1994).

This definition implies that similarly accurate and precise data are comparable; inaccurate and imprecise data are not comparable. Comparability also implies that comparable data are correlative. Therefore, a high degree of correlation must be attained between HPGe and laboratory data for those two data sets to be comparable.

4.2 LABORATORY COMPARABILITY VS. LABORATORY/FIELD COMPARABILITY

An overview of how data comparability is determined between new and established laboratory analytical methods is helpful to better understand the assessment of comparability between HPGe and laboratory data. Typically in the laboratory, a certified standard or reference material, is analyzed as is, is spiked onto a homogeneous soil, or is spiked into distilled water. In each case, the samples to be analyzed are extremely homogenous and the concentration of the analyte in the spiked soil or certified reference material is known with certainty. The new analytical method and the established method are then used to analyze a number of replicates of the sample at selected analyte concentrations. Comparability involves comparing the difference between the analyzed and true values for both the new and established laboratory methods.

The situation is different when comparing in-situ field data resulting from HPGe measurements to laboratory data generated from discrete sample analysis. In this case, certified standards cannot be used and the comparison of data must be based on soil areas whose true concentration cannot be known with certainty, but must be estimated. Because the HPGe detects gamma rays over a wide areal extent, the HPGe measures an "average" concentration for that area. Conversely, laboratory data methods measure concentrations averaged over very small areas and volumes. If an analyte is distributed very evenly across that areal extent, the degree of heterogeneity is small, and a small number of physical samples should be adequate to characterize that area (Section 3.0). For homogeneous areas, HPGe and laboratory data should agree closely if HPGe and laboratory methods are comparable. However, if the analyte is very unevenly distributed across the areal extent, the degree of heterogeneity is large. In this case, HPGe and laboratory data may or may not agree closely, even if HPGe and laboratory methods are comparable, depending on the representativeness of the discrete samples. A potential further heterogeneity also exists but on the range of sample or subsample scales. Laboratory alpha spectrometry measurements, for example, typically use sample sizes on the order of grams. Laboratory gamma spectrometry measurements, for example, typically use sample sizes on the order of several hundred grams. Thus, unless care is taken to completely homogenize the samples, laboratory-scale heterogeneity in data could also affect comparability with HPGe data. Thus, comparability of HPGe field data with data from physical samples taken for a given areal extent depends upon the degree of analyte heterogeneity within the area as well as upon instrumental and detector factors.

The sampling strategy outlined in Section 2, combined with the weighting factors for samples, attempts to minimize the effect of analyte heterogeneity. Where successful, data differences should only reflect instrumental and/or detector differences. Where unsuccessful, data differences will also reflect a component of analyte heterogeneity.

4.3 COMPARISON OF HPGe AND LABORATORY ANALYTICAL DATA

4.3.1 Laboratory Analytical Methods

As noted above, when heterogeneity effects are removed, the comparability of HPGe and laboratory data depend upon instrumental and detector factors. In this regard, both HPGe and laboratory analytical methods may have varying degrees of random and systematic error associated with them. Thus, determining which laboratory method to use becomes critical relative to the assessment of comparability. Table 4-1 shows the laboratory analytical methods available at the on-site laboratory

for measurement of total uranium, thorium-232 and radium-226; and presents strengths and weaknesses of each method. As can be seen from Table 4-1, each method has strengths and weaknesses, and there is no reason to believe that any one method is inherently better than any other method.

To attain the most accurate laboratory data against which to compare HPGe data, physical samples have been analyzed using multiple analytical techniques as shown in Table 4-1. The average of the concentrations measured by each method for a given sample for a given radionuclide will be taken as the most accurate value. Thus, for each sample analyzed for total uranium, the most accurate value will be the average of the concentrations measured by alpha spectrometry, gamma spectrometry, ICP/MS, and BromoPADAP. Similarly, the average of alpha and gamma spectrometry data will be taken as the most accurate concentration for thorium-232 and radium-226.

4.3.2 Weighted Average

Using the weighting factors described in Section 2 (the sum of the weighting factors equals 1.0, $\Sigma w_{ij} = 1$), the weighted mean and weighted standard deviation for laboratory samples are calculated using the following equations:

$$\bar{X}_i = \sum_{j=1}^{n_i} w_{ij} X_{ij}$$

$$s_i^2 = \frac{1}{n_i - 1} \sum_{j=1}^{n_i} w_{ij} (x_{ij} - \bar{x}_i)^2$$

$$s_i = \sqrt{s_i^2}$$

where:

x_{ij} is the value of the jth sample in the ith sample area

$\bar{x}_i$ is the weighted mean of the ith sample area (PBC)

w_{ij} is the weight of the jth sample in the ith sample area

n_i is the number of samples in the ith sample area

s_i^2 is the weighted variance of the sampling distribution of the ith sample area

s_i is the weighted standard deviation of the ith sampling area

For the sample location in each area from which duplicate samples were collected, the average of the data for the duplicates was used in the following calculations.

Using the above equations, a weighted "average" value for each PBC area can be calculated against which to compare HPGe data. Assessment of similarity involves assessing the degree of closeness between alpha and gamma spectrometry weighted means results and HPGe data for each study area as well as assessing the degree of correlation between the two data sets.

Text and tables refer to the weighted standard deviation; however, the reader should bear in mind that this weighted standard deviation is the weighted standard deviation of the mean and not the weighted standard deviation of the sampling distribution.

4.3.3 Closeness of HPGe and Laboratory Data

The closeness of weighted means is expressed as the % relative deviation:

$$\% \text{ Relative Deviation} = [(|\bar{x}_1 - \bar{x}_2|)/\bar{\bar{x}}] \times 100$$

where:

$\bar{x}_1$ is the weighted mean of the laboratory data corresponding to simulate HPGe measurements at a given detector height

$\bar{x}_2$ is the mean of duplicates for HPGe measurement at a given detector height

$\bar{\bar{x}}$ is the average of the two means

| | is the absolute value symbol

Contract Laboratory Program (CLP) statements of work (SOW) and SW-846 guidelines for relative precision requirements for metals state that data are considered acceptable when the percent relative

difference between duplicates is less than 20% for data that are greater than five times the MDC. For data less than five times the MDC, the precision requirements are ± the MDC. When relative precision is greater than 20%, the analyses are either flagged with qualifiers or reanalyzed. However, US EPA CLP National Functional Guidelines for Inorganic Data Review specifies that the relative precision criterion for metals soils be 35% before data are flagged. Adopting these criteria to interpret data in Tables 3-6 through 3-12, when the relative deviation between HPGe and laboratory data is less than 20%, the data are defined as being very similar; when the relative deviation is greater than 20% but less than 35%, the data are defined as having acceptable similarity. When the relative deviation is greater than 35%, the data are defined as dissimilar.

Comparability implicitly assumes that measurements for a new analytical technique are being compared to a known standard. In reality, as explained in Section 4.2, the average of the weighted laboratory data from discrete points is only an approximation of a "true" value. Therefore, the mean of laboratory and HPGe data is used in the denominator of the relative precision calculation.

4.3.4 Correlation of HPGe and Laboratory Data

To demonstrate good comparability of data from linear correlation analysis, three criteria must be met: a high correlation coefficient (expressed as R^2), an intercept of the regression line near zero (actually, a low intercept as a percentage of the FRL), and a slope of the regression line near 1.0. A low value of the intercept as a percentage of the FRL is important. The intercept could be interpreted as a measure of inherent bias of one technique relative to another. Therefore, by measuring the ratio of the intercept to the FRL, an estimate of how important this potential bias can be made. Table 4-2 provides suggested values for these criteria for very good similarity and acceptable similarity. The values are arbitrary and were chosen on the basis of reasonableness.

4.4 MOISTURE CORRECTION

Although routine use of HPGe requires the reporting of data on a dry weight basis (User's Manual, Sections 3.8 and 5.2), the convention for Sections 5, 6, and 7 is to demonstrate comparability on a wet weight basis. The rationale for this decision was to avoid possible heterogeneity effects on calculated concentrations of soil moisture within the field of view. In this regard, some areas such as PBC-01 and PBC-07 (for example) appear fairly homogeneous with regard to moisture. Other areas such as PBC-18 and PBC-19 appear heterogeneous with respect to moisture. Correcting wet weight HPGe

data to dry weight data involves the utilization of a single moisture value to adequately represent soil moisture within the field of view of the detector. Rather than introducing a possible additional source of error into the comparability assessment, the HPGe data were left on a wet weight basis.

4.5 SUMMARY

To summarize, comparability of HPGe and laboratory data will be evaluated by assessing the closeness and the degree of correlation of the data sets. The average concentration of multiple laboratory analytical methods will be the data used to represent the most accurate laboratory data. Sections 5, 6 and 7 present the assessment of comparability between HPGe and laboratory data for total uranium, thorium-232 and radium-226, respectively.

TABLE 4-1
STRENGTHS AND WEAKNESSES OF VARIOUS LABORATORY METHODS

Analyte	Laboratory Measurement Technique	Strengths and Weaknesses
Total Uranium	Alpha spectrometry	• Small sample size (1 to 2 g) may cause data to reflect "hot particle" heterogeneities • Extensive sample cleanup may result in loss of analyte • U-234, U-235, and U-238 are measured directly • Tracer compensates for sample loss in sample preparation and acts as a detector calibration standard
	Gamma spectrometry	• Large sample size (100+ g) minimizes effect of "hot particle" heterogeneities • Minimal sample preparation ensures no loss of analyte • Uranium not measured directly; daughter products are measured • Accurate data highly depends upon calibration standard and sample having similar matrices and densities • Different gamma photons usually yield different concentrations; a weighted average is used • Analytical method is inherently more similar to HPGe than other methods
	ICP/MS	• Small sample sizes (1 to 2 g) may cause data to reflect "hot particle" heterogeneities • Sample digestion may not dissolve all uranium • Sample preparation may result in loss of analyte • Data not corrected for chemical yield • Large sample dilution due to high detector sensitivity may cause errors. Can measure sub ppm easily • Method measures mass of each isotope directly • Very good precision

TABLE 4-1
(continued)

Analyte	Laboratory Measurement Technique	Strengths and Weaknesses
	BromoPADAP	• Sample prep may not result in complete dissolution of uranium • Sample prep may result in loss of analyte • Spectrophotometric interferences may be present • Small sample size (1 to 2 g) may cause data to reflect "hot particle" heterogeneities • Data not corrected for chemical yield • Technique measures uranium directly • Ideal concentration range is 1.0 ppm to 1.0%
Thorium-232	Alpha spectrometry	• Same as above for total uranium • Sample digestion may not dissolve all thorium • Th-232, Th-230 and Th-228 are measured directly
	Gamma spectrometry	• Same as above for total uranium
Radium-226	Alpha spectrometry	• Same as above for total uranium • Tracer is measured by gamma spectrometry. (Additional sample prep may lead to errors)
	Gamma spectrometry	• Same as above for total uranium • Loss of radon may lead to low results

TABLE 4-2
DEGREES OF SIMILARITY BASED UPON LINEAR CORRELATION

Degree of Similarity	Correlation Coefficient (R^2)	Intercept as a Percent of FRL	Slope
very good	> 0.95	0 - 15	0.9 - 1.1
acceptable	0.90 - 0.95	15 - 30	0.8 - 0.9, 1.1 - 1.2
unacceptable	< 0.90	> 30	< 0.8, > 1.2

5.0 COMPARABILITY OF TOTAL URANIUM DATA

5.1 INTRODUCTION

Revision 0 of the Comparability Study (July 1997) assessed the comparability of HPGe measurements with laboratory data generated from the analysis of physical samples. Results demonstrated that total uranium data generated by the HPGe were very comparable to total uranium data generated by laboratory alpha spectrometry analysis of physical samples. Results further showed that HPGe total uranium data met all proposed quality control acceptance criteria for use at analytical support level (ASL) B and D. However, the report also noted that additional data were needed to demonstrate comparability of HPGe and alpha spectrometry data at concentrations of total uranium near or exceeding 1000 ppm in order for the HPGe to be reliably used for waste acceptance criteria (WAC) activities.

In September 1997, a report entitled "Comparability of Total Uranium Data as Measured by In-Situ Gamma Spectrometry and Four Laboratory Methods" extended the range of comparability to allow the HPGe to be used with confidence for total uranium WAC attainment measurements. Further, that report strengthened the case for the routine use of HPGe by demonstrating that HPGe data are comparable to laboratory gamma spectrometry data, laboratory BromoPADAP data, and laboratory inductively coupled plasma/mass spectrometry (ICP/MS) data, as well as with laboratory alpha spectrometry data.

Since the September 1997 report, several changes have been made to the data in that report. First, the laboratory gamma spectrometry data have been recalculated using one over the counting error squared as a weighting factor to calculate a weighted average total uranium concentration from the different energy gamma photons. Previously, one over the counting error was used as the weighting factor. Second, the HPGe data have been reprocessed using GammaVision, a commercially available software package. GammaVision is discussed in Appendix G.

5.2 ANALYTICAL METHODS

In the July 1997 HPGe comparability report, HPGe data were compared to laboratory alpha spectrometry data for total uranium. Alpha spectrometry was the method originally chosen at the Fernald Environmental Management Project (FEMP) for comparison with the HPGe because FEMP

personnel had considerable expertise using that method and because alpha spectrometry is an established laboratory method routinely used by radioanalytical laboratories to generate high quality uranium isotopic data. However, FEMP personnel also have considerable experience in analyzing uranium by gamma spectrometry, by ICP/MS, and with a colorimetric method, bromoPADAP. Thus, to strengthen the case for the routine use of HPGe, the same samples originally analyzed by alpha spectrometry were subsequently reanalyzed by these other three additional methods for the September 1997 report to demonstrate comparability of HPGe with multiple analytical methods. Appendix H contains brief descriptions of alpha spectrometry, gamma spectrometry, bromoPADAP and ICP/MS.

5.3 ANALYTICAL DATA

Appendix D1 contains laboratory alpha spectrometry, laboratory gamma spectrometry, laboratory bromoPADAP, laboratory ICP/MS, HPGe, and soil moisture data. The moisture data were used to calculate laboratory results on a wet weight basis. HPGe data are also shown on a wet weight, or "as is," basis to provide a common ground for comparing the different data sets.

Total uranium data from HPGe measurements, alpha spectrometry, and gamma spectrometry have been converted to ppm from pCi/g. The bromoPADAP method measures ppm directly, while ICP/MS data are the sum of masses of individual isotopes. Total propagated uncertainties (TPUs) are displayed for each analytical method. The laboratory TPUs are presented as 1.96 σ values while the HPGe uncertainties reflect 1.96 σ counting errors. Laboratory TPUs for alpha and gamma spectrometry are often greater than HPGe 1.96 σ counting errors for two reasons. First, alpha and gamma spectrometry probably have measured far fewer counts than the HPGe detector, and thus have a higher proportional counting error. Second, laboratory data represent total system uncertainty, while HPGe data represent only one component of system uncertainty. In this regard, however, the data (standard deviation as percent of the mean) in Table 2-2 suggest that the HPGe total system uncertainty for total uranium measurements is about six percent of the measured value.

Lastly, Appendix D1 contains a column representing the average of each sample of the concentrations determined by the four different analytical methods. For example, for PBC-1-1, the average of 7.8 ppm in the last column is the average of 7.4 ppm (alpha spectrometry), 6.5 ppm (gamma

spectrometry), 11.3 ppm (bromoPADAP), and 5.9 ppm (ICP/MS). The standard deviation of 2.4 ppm is the 1.0 σ standard deviation associated with the four measurement data values given above.

5.4 COMPARISON OF HPGe AND LABORATORY DATA

Tables 5-1A and 5-1B summarize the data in Appendix D1. Using the weighting factors shown in Tables 3-2 through 3-4 and the computational method described in Section 4.3.2, weighted means and standard deviations for each sample collection area are shown in Tables 5-1A and 5-1B. Propagated counting errors in Tables 5-1A and 5-1B for HPGe are simply derived from standard propagation of error calculations (Taylor 1990) applied to the HPGe data in Appendix D-1. By comparing the weighted average of laboratory data for each area with the HPGe data for the same area, an assessment of the degree of closeness and degree of correlation between the data sets can be made. The sections below contains such assessments for total uranium data.

5.4.1 Closeness of Laboratory and HPGe Data

Table 5-2A and 5-2B summarize the closeness between laboratory data weighted means and HPGe data. The closeness between weighted means and HPGe data is expressed as the percent relative deviations per Section 4.3.2. The percent relative deviations shown in Table 5-2A and 5-2B are shown as negative and positive values in order to provide a sense of possible bias. However, the averages of the relative deviations shown at the bottom of Table 5-2A and 5-2B are calculated based upon the absolute value of the relative deviations.

Adopting criteria from Section 4.3.3 for interpreting percent relative deviations, when the relative deviation between HPGe and laboratory data is less than 20%, the data are defined as being very similar; when the relative deviation is greater than 20% but less than 35%, the data are defined as having acceptable similarity. When the relative deviation is greater than 35%, the data are defined as dissimilar.

Excluding sample PBC-03-1, the average relative deviations for all of the HPGe/laboratory comparisons at both 31 cm and 100 cm detector heights are less than 20%. This indicates that on an average basis, HPGe and laboratory data for total uranium are very similar. In this regard, the average of the relative deviations for all four of the laboratory methods/HPGe comparisons are remarkably similar: the average percent relative deviations for alpha spectrometry/HPGe are 12.46 and 11.57 (for

31 cm and 100 cm detector heights); for gamma spectrometry/HPGe, they are 11.60 and 10.58; for bromoPADAP, they are 11.92 and 12.96; and for ICP/MS they are 12.65 and 13.37. Further, the average percent relative deviations for the "four method average" HPGe comparison is 10.17 and 10.05 respectively,for 31 cm and 100 cm HPGe detector heights.

The reason for excluding sample PBC-03-1 in the average percent relative deviation calculations is that sample PBC-03-01 was unexpectedly found to contain a very radioactive piece of cement, thereby skewing the weighted average of the entire PBC-03 area toward high concentrations of uranium relative to HPGe. This is particularly true for 31 cm weighted laboratory data relative to 100 cm weighted laboratory data. This is an example of analyte distribution heterogeneity, causing a difference in data variability rather than detector methods. When PBC-03-01 is excluded from the data sets, the weighted average of the laboratory measurements and HPGe readings are very comparable.

The discussion above dealt with the averages of the percent relative deviations. Examination of Tables 5-2A and 5-2B shows that a very large majority of the individual percent relative deviations for given sampling areas are below 20%. Some areas have percent relative deviations between 20% and 35% (acceptable similarity), but no instances occur where percent relative deviations are greater than 35%.

By using four different analytical methods to analyze the physical samples, laboratory analytical effects on the closeness of data can be differentiated from analyte heterogeneity effects. For example, bromoPADAP data for PBC-01 have percent relative deviations of 23.92 and 32.84 respectively, for 31 cm and 100 cm HPGe detector heights. Alpha spectrometry data, on the other hand, have percent relative deviations of -20.36 and -12.66 for PBC-01. Every analytical method has a percent relative deviation that is more negative than -20.0 for PBC-10 at both 31 cm and 1.0 m detector heights. This indicates that for this area, either the HPGe detector is biased high (the percent relative deviations are all negative), or that the HPGe is detecting gamma rays from high contamination areas not reflected in the weighted average of the physical samples. Use of the average of the four laboratory methods should average out, to a large extent, data variability due to analytical methods. In this regard, the percent relative deviations for the four method average in Tables 5-2A and 5-2B have smaller average values than those for any of the four analytical methods individually.

5.4.2 Correlation of Laboratory and HPGe Data

Figures 5-1 and 5-2 show x,y scatter plots for the four method average data in Table 5-1 (for the sake of brevity, only these two scatter plots are shown). These figures show the average of the two HPGe measurements taken at the same detector height except for Area PBC-06 in which six HPGe measurements were taken at each detector height. Error bars for the HPGe measurements (Table 5-1) represent the 1.96 σ propagated counting errors for the average of the HPGe measurements in each area. Error bars for laboratory data represent upper and lower 97.5% confidence limits based upon the weighted standard deviations in Tables 5-1A and 5-1B. The large laboratory data error bars for the two locations with the highest total uranium concentrations attest to the heterogeneity of the locations with respect to total uranium and not to poor analytical precision.

Figures 5-1 and 5-2 clearly demonstrate that a high degree of linear between HPGe and laboratory data can be achieved for total uranium concentrations spanning a range of 5 ppm to over 1100 ppm. These HPGe data are equally valid for assessing compliance with FRLs as with assessing compliance with WAC limits. As shown in Table 5-3, similar high degrees of linear correlation also exist between HPGe data and individual laboratory analytical method data. Thus, a high degree of linear correlation of HPGe with laboratory data is independent of the particular laboratory analytical method..

5.4.3 Linear Regression Analysis

Linear regression analyses of the data in Tables 5-1A and 5-1B were carried out using the regression tools built into a commercial spreadsheet, Excel. Table 5-3 contains the correlation coefficients (R^2), slopes and intercepts calculated from these regression analyses. Linear regressions have been performed for:

- HPGe vs alpha spectrometry data at 31 100 cm detector heights
- HPGe vs gamma spectrometry data at 31 cm and 100 cm detector heights
- HPGe vs ICP/MS data at 31 and 100 cm detector heights
- HPGe vs bromoPADAP data at 31 cm and 100 cm detector heights
- HPGe vs four method average data at 31 and 100 cm detector heights

For each regression analysis, HPGe data comprised "y" coordinates while laboratory data comprised "x" coordinates.

The 31 cm data show very good linear regression characteristics relative to criteria in Table 4-1: very high correlation coefficients (R^2 greater than 0.989), line slopes between 1.0 and 1.1, and intercepts near zero. Using criteria outlined in Table 4-2, 31 cm HPGe data display a high degree of comparability with laboratory data for total uranium for all four laboratory methods. The comparability of 100 cm HPGe data with laboratory data is also good. Based upon the criteria outlined in Table 4-2, 100 cm correlation data display good to acceptable comparability to laboratory data.

One additional aspect of the data in Table 5-3 deserves mention. Without exception, every correlation coefficient for 100 cm data is lower than the correlation coefficient for 31 cm data. Almost every regression line slope is further removed from 1.0 for 100 cm data than for 31 cm data. And every regression line intercept is further removed from 0.0 for 100 cm data than for 31 cm data. Irrespective of whether each individual pair of differences is statistically significant or not, the overall pattern indicates that these differences are consistent across all four analytical methods, and a possible reason for those differences is discussed later in Section 5.

5.5 GAMMAVISION VS EGAS DATA

As noted in the introduction (5.1) to this section, all HPGe data were reprocessed using a commercially available software package, GammaVision. Previously, all HPGe data were processed using a proprietary subcontractor software package called EGAS. Table 5-4 compares HPGe data processed by both GammaVision and EGAS. Examination of the data indicates that GammaVision data tends to be slightly higher on average than EGAS data. In this regard, the average relative percent deviation between the two data sets is approximately -4% (excluding PBC-8), irrespective of whether the detector height is 31 cm or 1.0 m. (PBC-8 is approximately equal to the MDC of the HPGe, so accuracy will be poorest for this area, hence the reason for excluding it in the above statement.)

The differences between the two data sets is not believed to be significant relative to any intended usages of the data. The differences primarily arise because of the different methods that the two software packages employ to differentiate peak areas from background and subsequent integration of each.

5.6 PHYSICAL SAMPLE COLLECTION STRATEGY IN COMPARABILITY MEASUREMENTS

Section 3.0 of this report discussed the basis for collecting physical samples at 1 and 3 meter distances from the center ("bullseye") of a circle. The sampling scheme outlined in Section 3 represented a compromise so that only one set of physical samples had to be collected to assess the comparability of both 31 cm and 100 cm data. Data in this section suggests, however, that the particular sampling grids used combined with the per sample weighting factors used are more appropriate for 31 cm HPGe detector heights than for 100 cm HPGe detector heights. Or, put differently, at a 100 cm detector height, HPGe is seeing a much larger area than is adequately represented by the physical samples that were collected in these study areas.

Evidence to support this suggestion includes both the degree of closeness of HPGe and laboratory data and the degree of correlation with laboratory data. Examination of Tables 5-2A and 5-2B indicates that the percent relative deviations are consistently greater for 100 cm detector heights than for 31 cm detector heights. Additionally, as noted earlier, the regression parameters in Table 5-3 are consistently less good for 100 cm detector heights than for 31 cm detector heights. Thus, the fact that 100 cm HPGe and laboratory data are consistently a little less comparable than 31 cm data may reflect the distribution of physical samples and may have nothing to do with analytical accuracy and bias.

5.7 CONCLUSIONS

The following conclusions are the most important ones to be drawn from the data and discussions in this section:

1. HPGe can be used to accurately measure total uranium concentrations over a wide range of values from near background to greater than WAC levels (1030 ppm).

2. HPGe shows good comparability of data with data measured by a variety of laboratory analytical methods. Thus comparability is independent of the analytical method used.

3. HPGe yields more representative average total uranium concentrations in areas in which uranium is very heterogeneously distributed than do individual physical samples.

4. Differences between HPGe data processed by EGAS and HPGe data processed by GammaVision are not significant with respect to potential usages of the data.

5. Differences between HPGe data and laboratory data suggest that the sampling scheme for the collection of physical samples better represents 31 cm detector height data than 1.0 m detector height data.

TABLE 5-1A
COMPARISON OF LABORATORY AND HPGe DATA
31 cm DETECTOR HEIGHT

HPGe Setting	Area	Alpha Spectrometry		Gamma Spectrometry		ICP/MS		BromoPADAP		Four Method Average		HPGe	
		Weighted Mean (ppm)	Weighted Std. Dev. (ppm)	Weighted Mean (ppm)	Weighted Std. Dev. (ppm)	Weighted Mean (ppm)	Weighted Std. Dev. (ppm)	Weighted Mean (ppm)	Weighted Std. Dev. (ppm)	Weighted Mean (ppm)	Weighted Std. Dev. (ppm)	Mean (ppm)	Propagated CE
31 cm (1 ft)	PBC-01	7.5	0.3	7.4	0.8	7.1	0.7	11.7	0.3	8.4	0.3	9.2	2.9
	PBC-02	30	1.4	33	2.7	35.2	1.9	31.6	1.6	32.4	1.7	33.5	5.1
	PBC-03	1079	216	1181	242	1028	208	985	188	1068	213	319	12.1
	PBC-03*	288	16	301	21	268	21	297	18	289	18	319	12.1
	PBC-04	58	1.9	56	3.3	55.5	1.7	60.4	2.0	57.4	2.0	60.8	4.3
	PBC-05	36	3.9	37	3.1	39.2	3.0	41.2	2.5	38.4	3.0	42.6	5.5
	PBC-06	84	2.6	84	5.0	95.1	3.2	83.6	2.5	86.8	3.1	81.4	2.6
	PBC-07	161	8.6	167	11	160	9.1	157	10	161	9.4	154	5.7
	PBC-08	5.1	0.5	5.3	0.5	3.2	0.2	5.3	0.2	4.7	0.2	3.8	2.3
	PBC-09	5.9	0.2	6.8	0.4	6.3	0.4	6.8	0.2	6.5	0.2	5.9	3.0
	PBC-10	65	3.1	70	4.2	67.2	3.5	66.4	3.0	67.2	3.1	85.9	6.5
	PBC-18	1140	120	1184	97	1120	90	1125	91	1142	98	1155	11.8
	PBC-19	894	71	1029	82	915	86	880	101	929	83	1084	9.6

* PBC-03-01 excluded from data set.

TABLE 5-1B
COMPARISON OF LABORATORY AND HPGe DATA
1.0 m DETECTOR HEIGHT

HPGe Setting	Area	Alpha Spectrometry		Gamma Spectrometry		ICP/MS		BromoPADAP		Four Method Average		HPGe	
		Weighted Mean (ppm)	Weighted Std. Dev. (ppm)	Weighted Mean (ppm)	Weighted Std. Dev. (ppm)	Weighted Mean (ppm)	Weighted Std. Dev. (ppm)	Weighted Mean (ppm)	Weighted Std. Dev. (ppm)	Weighted Mean (ppm)	Weighted Std. Dev. (ppm)	Mean (ppm)	Propagated CE
1.0 m (3.28 ft)	PBC-01	7.4	0.4	7.9	0.8	8.5	0.8	11.7	0.5	8.9	0.2	8.4	3.4
	PBC-02	26	1.4	26	2.3	31.5	2.6	28.2	2.1	27.9	1.9	27.4	6.0
	PBC-03	447	130	482	146	422	126	433	114	446	129	330	13.8
	PBC-03*	285	16.7	306	23	267	19.0	293	18.1	288	19	330	13.8
	PBC-04	56	3.1	60	4.2	55.0	2.8	58.0	3.2	57.2	3.2	63.4	5.0
	PBC-05	45	5.4	44	4.5	47.1	4.0	47.1	3.5	46.0	4.2	46.6	5.6
	PBC-06	88	3.8	94	4.3	99.6	3.7	87.8	3.3	92.4	3.5	85.1	3.1
	PBC-07	174	13	186	17	180	14	179	15	180	14	158	6.7
	PBC-08	4.9	0.6	4.6	0.6	3.5	0.2	5.3	0.4	4.6	0.2	4.2	2.7
	PBC-09	6.2	0.2	6.9	0.6	6.3	0.5	6.7	0.2	6.5	0.2	6.0	3.2
	PBC-10	55	3.5	66	4.8	56.7	4.0	58.9	3.6	59.2	3.4	76.2	7.3
	PBC-18	1053	140	1197	129	1100	116	1137	124	1122	125	922	11.4
	PBC-19	764	82	918	99	787	99	857	113	831	97	863	9.8

* Sample PBC-03-01 excluded from data set.

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TABLE 5-2A
CLOSENESS OF LABORATORY AND HPGe 31 cm DATA

Area	Alpha Spectrometry % Relative Deviation of Means (31 cm)*	Gamma Spectrometry % Relative Deviation of Means (31 cm)*	ICP/MS % Relative Deviation of Means (31 cm)*	BromoPADAP % Relative Deviation of Means (31 cm)*	Four Method Average % Relative Deviation of Means (31 cm)*
PBC-01	-20.36	-21.69	-25.77	23.92	-9.09
PBC-02	-11.02	-1.50	4.95	-5.84	-3.34
PBC-03	114.97	121.03	111.75	108.71	114.35
PBC-03**	-1.04	-5.81	-17.38	-7.14	-9.87
PBC-04	-4.71	-8.22	-9.11	-0.66	-5.75
PBC-05	-16.68	-13.95	-8.20	-3.22	-10.25
PBC-06	3.14	3.14	15.52	2.67	6.42
PBC-07	4.77	8.42	4.15	2.25	4.77
PBC-08	30.51	34.25	-15.83	34.25	22.49
PBC-09	0.00	14.17	6.56	14.17	9.68
PBC-10	-27.64	-20.34	-24.37	-25.55	-23.93
PBC-18	-1.26	2.52	-3.03	-2.59	-1.09
PBC-19	-19.21	-5.21	-16.91	-20.77	-15.40
	Average (using PBC-03**) = 12.46	Average (using PBC-03**) = 11.60	Average (using PBC-03**) = 12.65	Average (using PBC-03**) = 11.92	Average (using PBC-03**) = 10.17

* Negative signs indicate laboratory data are less than HPGe data; positive signs indicate laboratory data are greater than HPGe data. Signs are not taken into account in the computation of the above averages which appear at the bottom of each column.

** Sample PBC-03-01 excluded from data set.

TABLE 5-2B
CLOSENESS OF LABORATORY AND HPGe 100 cm DATA

Area	Alpha Spectrometry % Relative Deviation of Means*	Gamma Spectrometry % Relative Deviation of Means*	ICP/MS % Relative Deviation of Means*	BromoPADAP % Relative Deviation of Means*	Four Method Average % Relative Deviation of Means*
PBC-01	-12.66	-6.13	1.18	32.84	5.78
PBC-02	-5.24	-5.24	13.92	2.88	1.81
PBC-03	43.60	51.30	38.08	40.56	43.60
PBC-03**	-14.63	-7.55	-21.11	-11.88	-13.59
PBC-04	-12.32	-5.43	-14.11	-8.82	-10.20
PBC-05	-3.49	-5.74	1.07	1.07	-1.30
PBC-06	3.35	9.94	15.70	3.12	8.23
PBC-07	9.95	16.59	13.33	12.78	13.33
PBC-08	15.38	9.09	-18.18	23.16	9.09
PBC-09	4.12	14.79	5.71	11.86	8.84
PBC-10	-32.25	-14.28	-29.28	-25.55	-25.05
PBC-18	-13.32	26.01	17.66	20.94	19.62
PBC-19	-12.17	6.18	-9.21	-0.70	-3.78
	Average (using PBC-03**) = 11.57	Average (using PBC-03**) = 10.58	Average (using PBC-03**) = 13.37	Average (using PBC-03**) = 12.96	Average (using PBC-03**) = 10.05

* Negative signs indicate laboratory data are less than HPGe data; positive signs indicate laboratory data are greater than HPGe data. Signs are not taken into account in the computation of the above averages which appear at the bottom of each column.

** Sample PBC-03-01 excluded from data set.

TABLE 5-3
LINEAR REGRESSION PARAMETERS

Analyte	HPGe Detector Height	Correlation Coefficient (R^2)	Slope of Regression Line	Intercept of Regression Line (ppm)	Intercept as Percent of FRL*
Alpha Spectrometry	31 cm	0.989	1.086	1.8	2.20
	100 cm	0.977	0.955	11.6	14.1
Gamma Spectrometry	31 cm	0.998	1.007	2.7	3.29
	100 cm	0.984	0.826	15.0	18.3
BromoPADAP	31 cm	0.989	1.103	-1.4	ND*
	100 cm	0.981	0.875	13.8	16.8
ICP/MS	31 cm	0.993	1.093	0.39	0.48
	100 cm	0.972	0.918	13.6	16.6
Four Method Average	31 cm	0.993	1.072	0.65	0.79
	100 cm	0.979	0.891	13.4	16.3

* Not defined because intercept is negative

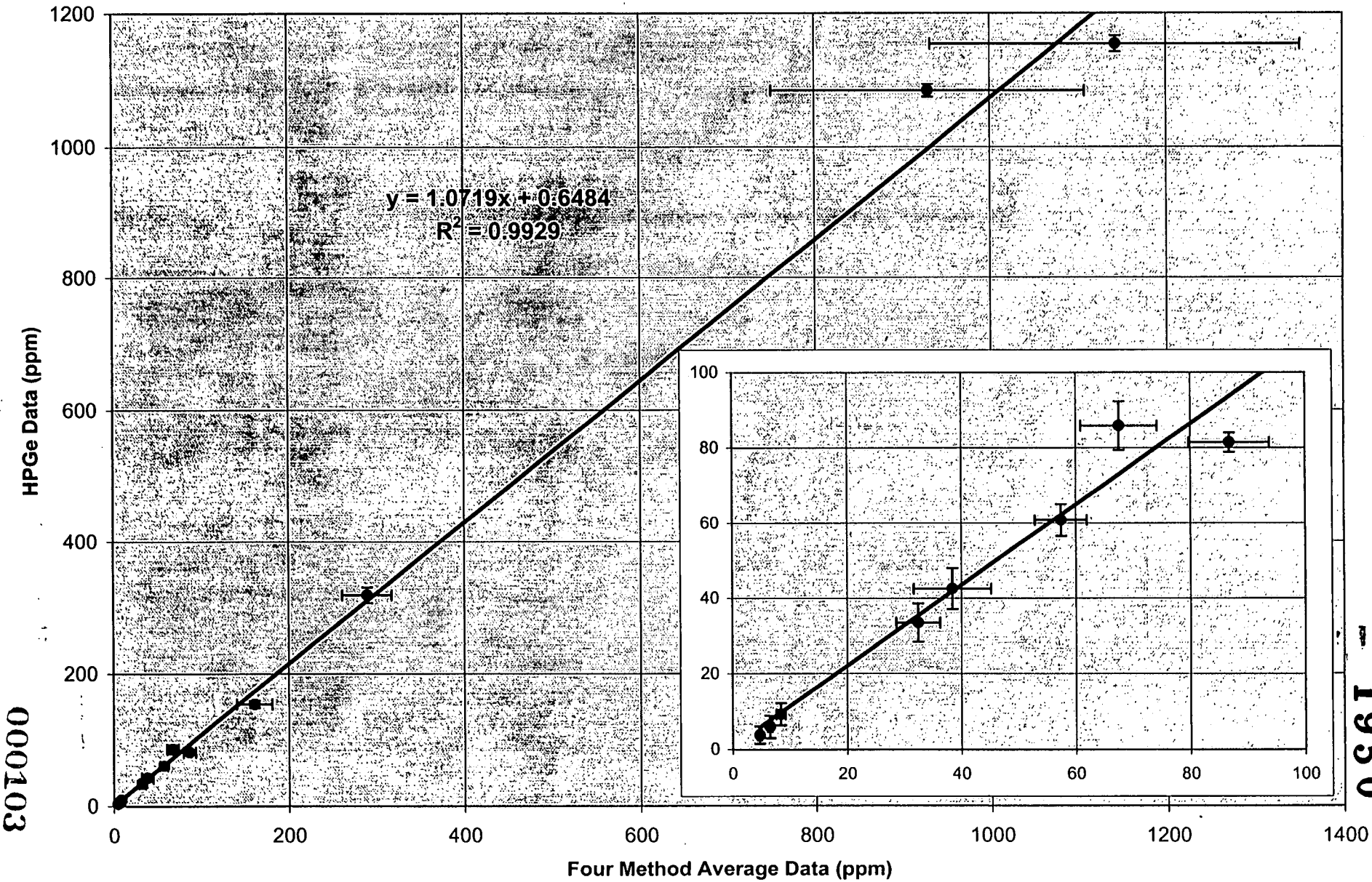
TABLE 5-4
COMPARISON OF EGAS AND GAMMAVISION HPGe DATA

Area	EGAS 31 cm Total Uranium Data (ppm)	GammaVision 31 cm Total Uranium Data (ppm)	% Relative Deviation* (RPD)	Absolute Value of % Relative Deviation*
PBC-1	9.0	9.2	-2.20	2.20
PBC-2	31.2	33.5	-7.11	7.11
PBC-3	291	319	-9.18	9.18
PBC-4	56.6	60.8	-7.16	7.16
PBC-5	42.2	42.6	-0.94	0.94
PBC-6	76.7	81.4	-5.95	5.95
PBC-7	141	154	-8.81	8.81
PBC-8	5.8	3.8	41.67	41.67
PBC-9	6.6	5.9	11.20	11.20
PBC-10	80.9	85.9	-6.00	6.00
PBC-18	1064	1155	-8.20	8.20
PBC-19	1047	1084	-3.47	3.47
		Average RPD =	-0.51	9.32
		Average RPD excluding PBC-8 =	-4.35	6.38
Area	**EGAS 100 cm Total Uranium Data (ppm)**	**GammaVision 100 cm Total Uranium Data (ppm)**	**% Relative Deviation* (RPD)**	**Absolute Value of % Relative Deviation***
PBC-1	8.0	8.4	-4.88	4.88
PBC-2	26.0	27.4	-5.24	5.24
PBC-3	287	330	-13.94	13.94
PBC-4	58.6	63.4	-7.87	7.87
PBC-5	47.9	46.6	2.75	2.75
PBC-6	75.9	85.1	-11.43	11.43
PBC-7	140	158	-12.08	12.08
PBC-8	5.3	4.2	23.16	23.16
PBC-9	6.9	6	13.95	13.95
PBC-10	74.0	76.2	-2.93	2.93
PBC-18	891	922	-3.42	3.42
PBC-19	871	863	0.92	0.92
		Average RPD =	-1.75	8.55
		Average RPD excluding PBC-8 =	-3.83	7.33

* RPD = EGAS-GammaVision divided by the average of EGAS and GammaVision.

Figure 5-1

Correlation Between 31 cm HPGe and Four Method Average Data for Total Uranium (w/o PBC-03-1)



1/15/99 Chart1 Wt_Ave_U

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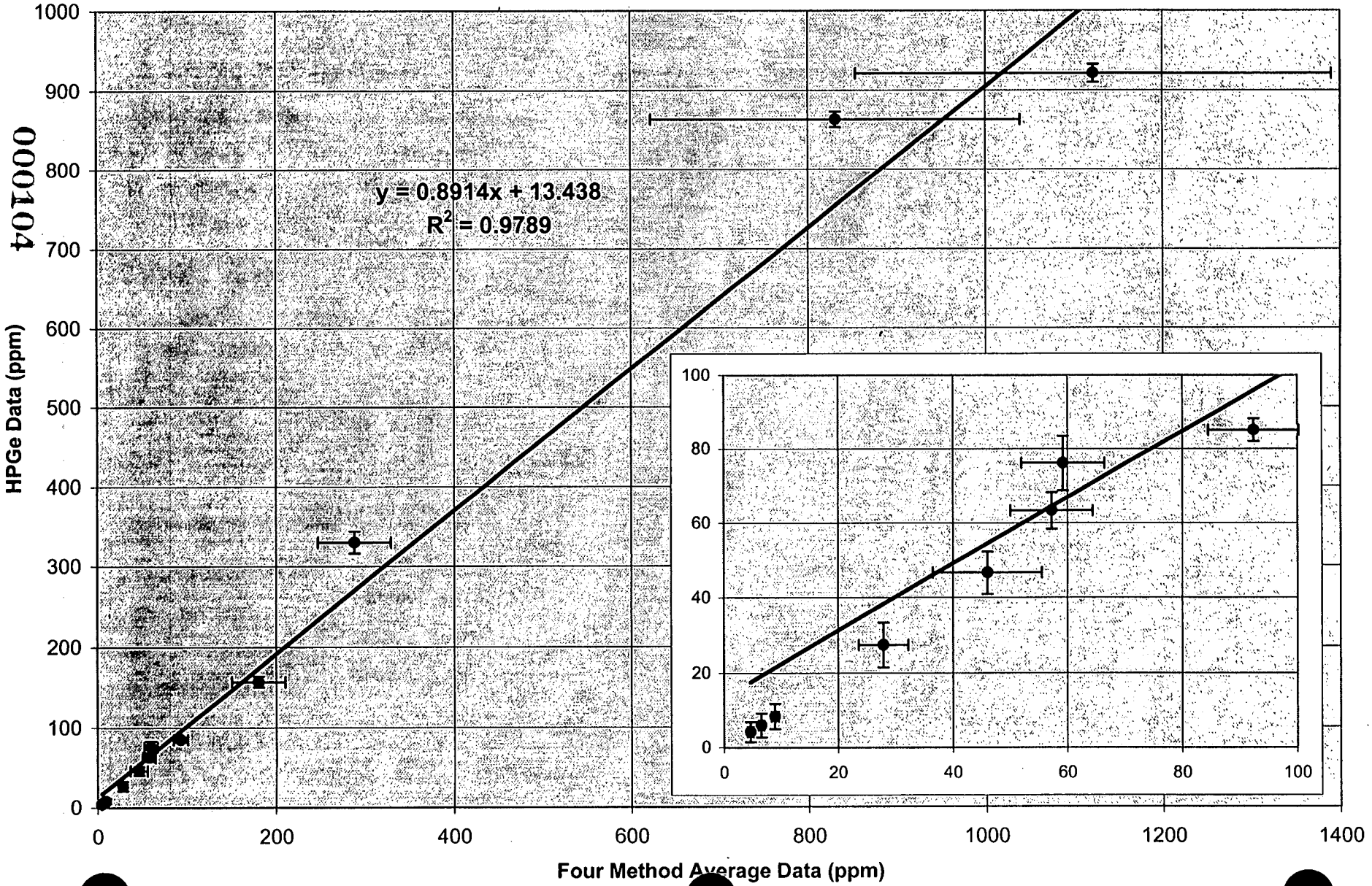
Figure 5-2
Correlation Between 100 cm HPGe and Four Method Average Data for Total Uranium (w/o PBC-03-1)



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6.0 COMPARABILITY OF THORIUM-232 DATA

6.1 INTRODUCTION

Revision 0 of the Comparability Study (July 1997) assessed the comparability of HPGe measurements for thorium-232 with laboratory thorium-232 data generated from the analysis of physical samples. Results demonstrated that thorium-232 data generated by the HPGe were very comparable to thorium-232 data generated by laboratory alpha spectrometry analysis of physical samples. Results further showed that HPGe thorium-232 data met all proposed quality control acceptance criteria for use at analytical support level (ASL) B and D.

Since the July 1997 Comparability Study, several additions to the data have been made. First, gamma spectrometry data were obtained for areas PBC-1 through PBC-10. As with total uranium, analytical data reflecting the average of several different methods should be less prone to bias than either individual method. Second, laboratory gamma spectrometry measurements were performed on physical samples from areas PBC-12 through PBC-17, in order to infill data gaps. Third, the HPGe data have been reprocessed using GammaVision, a commercially available software package (Appendix G).

6.2 ANALYTICAL METHODS

In Revision 0 of this report, HPGe data were compared to laboratory alpha spectrometry data for thorium-232. Alpha spectrometry was the method originally chosen at the FEMP for comparison with the HPGe because FEMP personnel had considerable experience using that method and because alpha spectrometry is an established laboratory method routinely used by radioanalytical laboratories to generate high quality thorium isotopic data. However, FEMP personnel also have considerable experience in analyzing thorium-232 by gamma spectrometry. Thus, to strengthen the case for the routine use of HPGe, the same samples originally analyzed by alpha spectrometry were also analyzed by gamma spectrometry to demonstrate comparability of HPGe with the average of multiple analytical methods. Appendix H contains brief descriptions of alpha and gamma spectrometry methods for thorium-232.

6.3 ANALYTICAL DATA

Appendix D2 contains laboratory alpha spectrometry, laboratory gamma spectrometry, and soil moisture data. The moisture data were used to calculate laboratory results on a wet weight basis. HPGe data are also shown in a wet weight basis to provide a common ground for comparing the different data sets. Thorium-232 data from both HPGe and laboratory measurements have units of pCi/g. Total propagated uncertainties (TPUs) are displayed for each analytical method. The laboratory TPUs are presented as 1.96 σ values while the HPGe uncertainties reflect 1.96 σ counting errors. Laboratory TPUs for alpha and gamma spectrometry are often greater than HPGe 1.96 σ counting errors (particularly at higher concentrations) for two reasons. First, alpha and gamma spectrometry have likely measured far fewer counts than the HPGe detector, and thus have a higher proportional counting error. Second, laboratory data represent total system uncertainty, while HPGe data represent only one component of system uncertainty. In this regard, however, the data in Table 2-2 suggest that the HPGe total system uncertainty for thorium-232 is about 5.83% of the measured value. Lastly, Appendix D2 contains a column representing the average for each sample of the concentrations determined by the two analytical methods. The standard deviations listed are the 1.0 σ standard deviations associated with the average of the two methods.

6.4 COMPARISON OF HPGe AND LABORATORY DATA

Tables 6-1 and 6-2 summarize the data in Appendix D2. Using the weighting factors shown in Tables 3-2 through 3-4 and the computational method described in Section 4.3.2, weighted means and standard deviations for each sample collection area are shown in Tables 6-1 and 6-2. Propagated counting errors in Tables 6-1 and 6-2 for HPGe are simply derived from standard propagation of error calculations (Taylor 1990) applied to the HPGe data in Appendix D-2. By comparing the weighted average of laboratory data for each area with the HPGe data for that same area, an assessment of the degree of closeness and the degree of correlation between the data sets can be made. The sections below contains such assessments for thorium-232.

6.4.1 Closeness of Laboratory and HPGe Data

Tables 6-3 and 6-4 summarize the closeness between laboratory data weighted means and HPGe data. The closeness between weighted means and HPGe data is expressed as the percent relative deviation per Section 4.3.2. The percent relative deviations shown in Tables 6-3 and 6-4 are shown as negative and positive values in order to provide a sense of possible bias. However, the averages of the relative

deviations shown at the bottom of Table 6-3 and 6-4 are calculated based upon the absolute value of the relative deviations.

Adopting criteria from Section 4.3.3 for interpreting percent relative deviations, when the relative deviation between HPGe and laboratory data is less than 20%, the data are defined as being very similar; when the relative deviation is greater than 20% but less than 35%, the data are defined as having acceptable similarity. When the relative deviation is greater than 35%, the data are defined as dissimilar.

The average relative percent deviations (absolute values) are rather high for alpha spectrometry and gamma spectrometry, approaching 20% for both data sets. Although the averages for alpha and gamma spectrometry are less than 20% for both 31 and 100 cm detector heights, numerous individual areas have absolute values of percent relative deviations greater than 20%, and one relative deviation is greater than 35%. Alpha spectrometry data are low relative to HPGe, while gamma spectrometry data are high relative to HPGe. Overall, HPGe data are acceptably similar to both alpha and gamma spectrometry data.

The situation changes, however, when HPGe thorium-232 data are compared to the average of alpha and gamma spectrometry data. The average percent relative deviations (absolute values) for 31 cm and 100 cm data are 7.88% and 9.08%, respectively. Such low averages indicate very similar data. Further, for each of the 31 cm and 100 cm data sets, only one relative deviation in each set exceeds 20%. Use of the average of alpha and gamma spectrometry should average out, to a large extent, data variability due to laboratory analytical methods. The percent relative deviations for the two method average should then mostly reflect either HPGe detector bias or viability, analyte heterogeneity in soil, or as explained in Section 5.6, possible limitations in the physical sample grid pattern.

6.4.2 Correlation of Laboratory and HPGe Thorium-232 Data

Figures 6-1 and 6-2 show x,y scatter plots for the two method average data in Tables 6-1 and 6-2. These figures show the average of the two HPGe measurements taken at each detector height, except for area PBC-06, where six HPGe measurements were taken at each detector height. Error bars for the HPGe measurements (Tables 6-1 and 6-2) represent the 1.96 σ propagated counting errors for the

average of the measurements in each area. Error bars for laboratory data represent upper and lower 97.5% confidence limits based upon the weighted standard deviations in Tables 6-1 and 6-2.

Figures 6-1 and 6-2 clearly demonstrate that a high degree of linear correlation between HPGe and laboratory data can be achieved spanning a range of 0.6 pCi/g to 8 pCi/g. Thus, HPGe data are equally valid for assessing compliance with thorium-232 FRLs (1.5 pCi/g) as for assessing compliance with hot spots of 3xFRL (4.5 pCi/g).

Figures 6-1 and 6-2 indicate that gaps exist in the data between 1.0 and 2.5 pCi/g and between 2.5 and 8.0 pCi/g. In an attempt to acquire additional data to infill the gaps, gamma spectrometry measurements were performed on samples in areas PBC-12 through PBC-17 (Note: the samples in PBC-12 through PBC-17 were originally collected to provide additional sample points for radium-226 data). HPGe measurements were performed only at 1.0 m detector height in these areas (see Section 7.0 for explanation).

Figures 6-3 and 6-4 show the linear correlation between HPGe and gamma spectrometry data. Both figures exhibit very similar degrees of correlation as expressed by very high correlation coefficients (R^2 values), and very similar slopes and intercepts. However, Figure 6-4 does have six additional data points relative to Figure 6-3. This suggests that the data gaps are not critical, and that the correlation between HPGe and laboratory data are valid despite the data gaps.

The large error bars for certain laboratory data in Figures 6-1 through 6-4 reflect heterogeneity of thorium-232 contamination in those areas. The error bars do not reflect poor precision of laboratory analytical data.

6.4.3 Linear Regression Analysis

Linear regression analyses of the data in Tables 6-1 and 6-2 were carried out using the regression tools built into a commercial spreadsheet, Excel. Table 6-5 contains the correlation coefficients (expressed as R^2), slopes and intercepts calculated from these regression analyses. Linear regressions have been performed for:

- HPGe vs. alpha spectrometry data at 31 cm and 100 cm detector heights
- HPGe vs. gamma spectrometry data at 31 cm and 100 cm detector heights

- HPGe vs. two method average data at 31 cm and 100 cm detector heights

For each regression analysis, HPGe data comprised "y" coordinates while laboratory data comprised "x" coordinates.

The 31 and 100 cm data both show very good linear regression characteristics: very high correlation coefficients (R^2 greater than 0.993), line slopes between 1.0 and 1.1, and intercepts near zero. Using criteria outlined in Table 4-2, 31 and 100 cm HPGe data both display a high degree of comparability with laboratory data for thorium-232 for both laboratory methods as well as for the average of those two methods.

Section 5.4.3 indicated that 31 cm data appear to be a little closer to laboratory data than 100 cm data are. The data in Table 6-5 do not support a similar conclusion. The differences between 31 cm and 100 cm data are less for thorium-232 than for total uranium, and may reflect the fact that thorium appears to be more homogeneously distributed in the various areas than is uranium.

6.5 GAMMAVISION VS. EGAS DATA

As noted in the introduction (6.1), all HPGe data were processed using a commercially available software package, GammaVision. Previously, all HPGe data were processed using a proprietary subcontractor software package called EGAS. Table 6-6 compares HPGe data processed by both GammaVision and EGAS. Examination of the data indicates that GammaVision data are consistently higher on average than EGAS data. In this regard, the average relative percent deviation between the two data sets is approximately -12 to -14 for detector heights of 100 cm and 31 cm, respectively.

One major reason contributing to the difference between EGAS and GammaVision processed data is in the gamma photons used. The EGAS data used the 238.6 keV photon emitted by lead-212 as one of three photons to quantify thorium-232. GammaVision utilizes the 338 keV gamma photon emitted by actinium-228. Experience has shown that interferences from other gamma photons tend to result in lower peak areas for the 238.6 keV photon, thereby leading to lower calculated thorium-232 values. The 338 keV photon, however, is free of spectral interferences. If the EGAS data previously acquired were preprocessed to include the 338 keV gamma photon, then EGAS data would probably be closer to GammaVision data.

A second reason for the difference between EGAS and GammaVision results from differences in the way calibration data are handled to produce an efficiency curve. GammaVision has a better curve fitting program, and therefore (for thorium-232) produces a better (and higher) efficiency curve.

6.6 CONCLUSIONS

The following conclusions are the most important ones to be drawn from the data and discussions in this section:

- HPGe data are higher than laboratory alpha spectrometry data and lower than laboratory gamma data.
- HPGe data are very comparable to the average of laboratory alpha and gamma spectrometry data. This average is believed to be the most representative laboratory data for comparability purposes.
- HPGe data processed by GammaVision is 12% to 14% higher than data previously processed by EGAS. This difference primarily reflects a change in the gamma photons used to quantify thorium-232 using GammaVision relative to EGAS in order to eliminate spectral interferences resulting in lower calculated concentrations.

TABLE 6-1
COMPARISON OF 31 cm LABORATORY AND HPGe THORIUM-232 DATA

HPGe Setting	Area	Alpha Spectrometry (pCi/g)		Gamma Spectrometry (pCi/g)		Two Method Average (pCi/g)		HPGe (pCi/g)	
		Weighted Mean	Weighted Std. Dev.	Weighted Mean	Weighted Std. Dev.	Weighted Mean	Weighted Std. Dev.	Mean	Propagated CE
31 cm (1 ft)	PBC-01	0.50	0.01	0.66	0.04	0.58	0.02	0.66	0.06
	PBC-02	0.55	0.08	0.60	0.03	0.57	0.04	0.74	0.05
	PBC-03	2.0	0.06	2.9	0.11	2.4	0.08	2.4	0.13
	PBC-04	0.77	0.01	1.2	0.05	0.96	0.02	0.85	0.06
	PBC-05	0.76	0.03	0.95	0.03	0.85	0.02	0.94	0.08
	PBC-06	0.76	0.01	1.1	0.06	0.93	0.03	0.91	0.04
	PBC-07	0.99	0.02	1.3	0.03	1.2	0.02	1.1	0.08
	PBC-08	0.53	0.02	0.79	0.08	0.66	0.05	0.64	0.06
	PBC-09	0.53	0.01	0.87	0.03	0.70	0.01	0.73	0.06
	PBC-10	6.1	0.87	7.0	0.87	6.5	0.85	6.7	0.17

TABLE 6-2
COMPARISON OF 100 cm LABORATORY AND HPGe THORIUM-232 DATA

HPGe Setting	Area	Alpha Spectrometry (pCi/g)		Gamma Spectrometry (pCi/g)		Two Method Average (pCi/g)		HPGe (pCi/g)	
		Weighted Mean	Weighted Std. Dev.	Weighted Mean	Weighted Std. Dev.	Weighted Mean	Weighted Std. Dev.	Mean	Propagated CE
100 cm (3.28 ft)	PBC-01	0.50	0.02	0.71	0.04	0.60	0.02	0.61	0.06
	PBC-02	0.55	0.09	0.63	0.04	0.59	0.05	0.74	0.07
	PBC-03	2.1	0.10	2.9	0.16	2.5	0.12	2.8	0.14
	PBC-04	0.74	0.01	1.2	0.06	0.96	0.03	0.84	0.06
	PBC-05	0.79	0.04	1.0	0.04	0.90	0.03	0.86	0.07
	PBC-06	0.79	0.01	1.2	0.06	0.98	0.03	0.89	0.04
	PBC-07	1.0	0.03	1.3	0.04	1.2	0.03	1.0	0.07
	PBC-08	0.50	0.02	0.78	0.09	0.64	0.06	0.61	0.05
	PBC-09	0.52	0.01	0.86	0.03	0.69	0.02	0.68	0.06
	PBC-10	7.3	1.4	8.5	1.4	7.9	1.4	8.1	0.18
	PBC-12			1.8	0.39			1.5	0.05
	PBC-13			3.1	0.85			2.8	0.06
	PBC-14			0.77	0.03			0.62	0.03
	PBC-15			0.86	0.04			0.76	0.04
	PBC-16			1.3	0.10			1.0	0.04
	PBC-17			1.0	0.04			0.72	0.03

TABLE 6-3
CLOSENESS OF LABORATORY AND HPGe 31 cm THORIUM-232 DATA

Area	Alpha Spectrometry % Relative Deviation of Means (31 cm)*	Gamma Spectrometry % Relative Deviation of Means (31 cm)*	Two Method Average % Relative Deviation of Means (31 cm)*
PBC-01	-28.33	-0.75	-13.65
PBC-02	-30.12	-21.56	-26.22
PBC-03	-13.33	18.87	0.00
PBC-04	-9.88	34.15	12.15
PBC-05	-20.65	1.59	-9.52
PBC-06	-17.96	18.91	2.17
PBC-07	-14.08	13.11	5.13
PBC-08	-19.57	20.21	2.30
PBC-09	-31.75	17.50	-4.20
PBC-10	-9.38	4.38	-3.03
	Average = 19.50	Average = 15.10	Average = 7.88

* Negative signs indicate laboratory data are less than HPGe data; positive signs indicate laboratory data are greater than HPGe data. Signs are not taken into account in the computation of the above averages which appear at the bottom of each column.

TABLE 6-4
CLOSENESS OF LABORATORY AND HPGe 100 cm THORIUM-232 DATA

Area	Alpha Spectrometry % Relative Deviation of Means (100 cm)*	Gamma Spectrometry % Relative Deviation of Means (100 cm)*	Two Method Average % Relative Deviation of Means (100 cm)*
PBC-01	-19.82	15.15	-1.65
PBC-02	-29.46	-16.06	-22.56
PBC-03	-26.80	5.31	-9.52
PBC-04	-12.06	35.87	13.93
PBC-05	-8.48	15.05	4.55
PBC-06	-11.90	29.67	11.64
PBC-07	0.00	26.09	18.18
PBC-08	-19.82	24.46	4.80
PBC-09	-26.67	23.38	1.46
PBC-10	-10.39	4.82	-2.50
PBC-12		18.18	
PBC-13		10.17	
PBC-14		21.58	
PBC-15		12.35	
PBC-16		26.09	
PBC-17		32.56	
	Average = 16.54	Average = 19.80	Average = 9.08

* Negative signs indicate laboratory data are less than HPGe data; positive signs indicate laboratory data are greater than HPGe data. Signs are not taken into account in the computation of the above averages which appear at the bottom of each column.

TABLE 6-5
LINEAR REGRESSION PARAMETERS FOR THORIUM-232

Analyte	HPGe Detector Height	Correlation Coefficient (R^2)	Slope of Regression Line	Intercept of Regression Line (pCi/g)	Intercept as % of FRL
Alpha Spectrometry	31 cm	0.995	1.082	0.10	6.67
	100 cm	0.996	1.109	0.07	4.67
Gamma Spectrometry	31 cm	0.993	0.952	0.08	5.33
	100 cm	0.996	0.968	0.16	10.67
Two-Method Average	31 cm	0.998	1.026	-0.002	ND*
	100 cm	0.997	1.035	-0.05	ND*

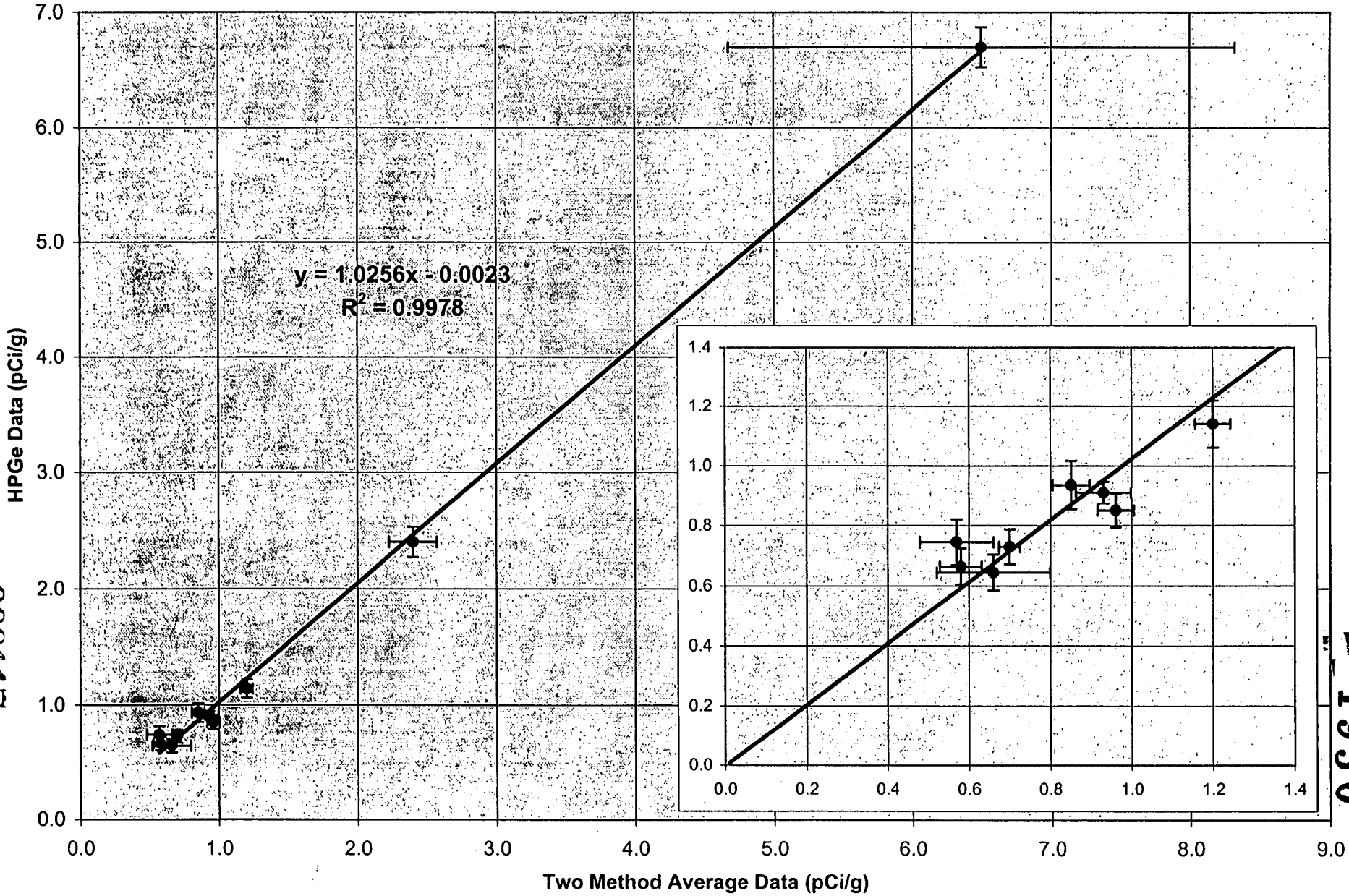
* ND = not defined for negative intercepts

TABLE 6-6
COMPARISON OF EGAS AND GAMMAVISION HPGe DATA FOR THORIUM-232

Area	EGAS 31 cm Thorium-232 Data (ppm)	GammaVision 31 cm Thorium-232 Data (ppm)	% Relative Deviation	Absolute Value of % Relative Deviation
PBC-1	0.52	0.66	-23.73	23.73
PBC-2	0.64	0.74	-14.49	14.49
PBC-3	2.2	2.4	-8.70	8.70
PBC-4	0.80	0.85	-6.06	6.06
PBC-5	0.79	0.94	-17.34	17.34
PBC-6	0.81	0.91	-11.63	11.63
PBC-7	0.99	1.1	-10.53	10.53
PBC-8	0.55	0.64	-15.13	15.13
PBC-9	0.63	0.73	-14.71	14.71
PBC-10	5.8	6.7	-14.40	14.40
		Average RPD =	-13.67	13.67
Area	**EGAS 100 cm Thorium-232 Data (ppm)**	**GammaVision 100 cm Thorium-232 Data (ppm)**	**% Relative Deviation**	**Absolute Value of % Relative Deviation**
PBC-1	0.51	0.61	-17.86	17.86
PBC-2	0.63	0.74	-16.06	16.06
PBC-3	2.5	2.8	-11.32	11.32
PBC-4	0.78	0.84	-7.41	7.41
PBC-5	0.79	0.86	-8.48	8.48
PBC-6	0.80	0.89	-10.65	10.65
PBC-7	0.97	1.0	-3.05	3.05
PBC-8	0.53	0.61	-14.04	14.04
PBC-9	0.58	0.68	-15.87	15.87
PBC-10	6.9	8.1	-16.00	16.00
PBC-12	1.0	1.5	-40.00	40.00
PBC-13	2.6	2.8	-7.41	7.41
PBC-14	0.6	0.62	-8.40	8.40
PBC-15	0.7	0.76	-11.11	11.11
PBC-16	1.0	1.0	0.00	0.00
PBC-17	0.69	0.72	-4.26	4.26
		Average RPD =	-11.99	11.99

Figure 6-1

Correlation Between 31 cm HPGe and Two Method Average Data for Th-232



1/15/99 Chart10 Wt_Ave_Thorium

Figure 6-2

Correlation Between 100 cm HPGe and Two Method Average Data for Th-232

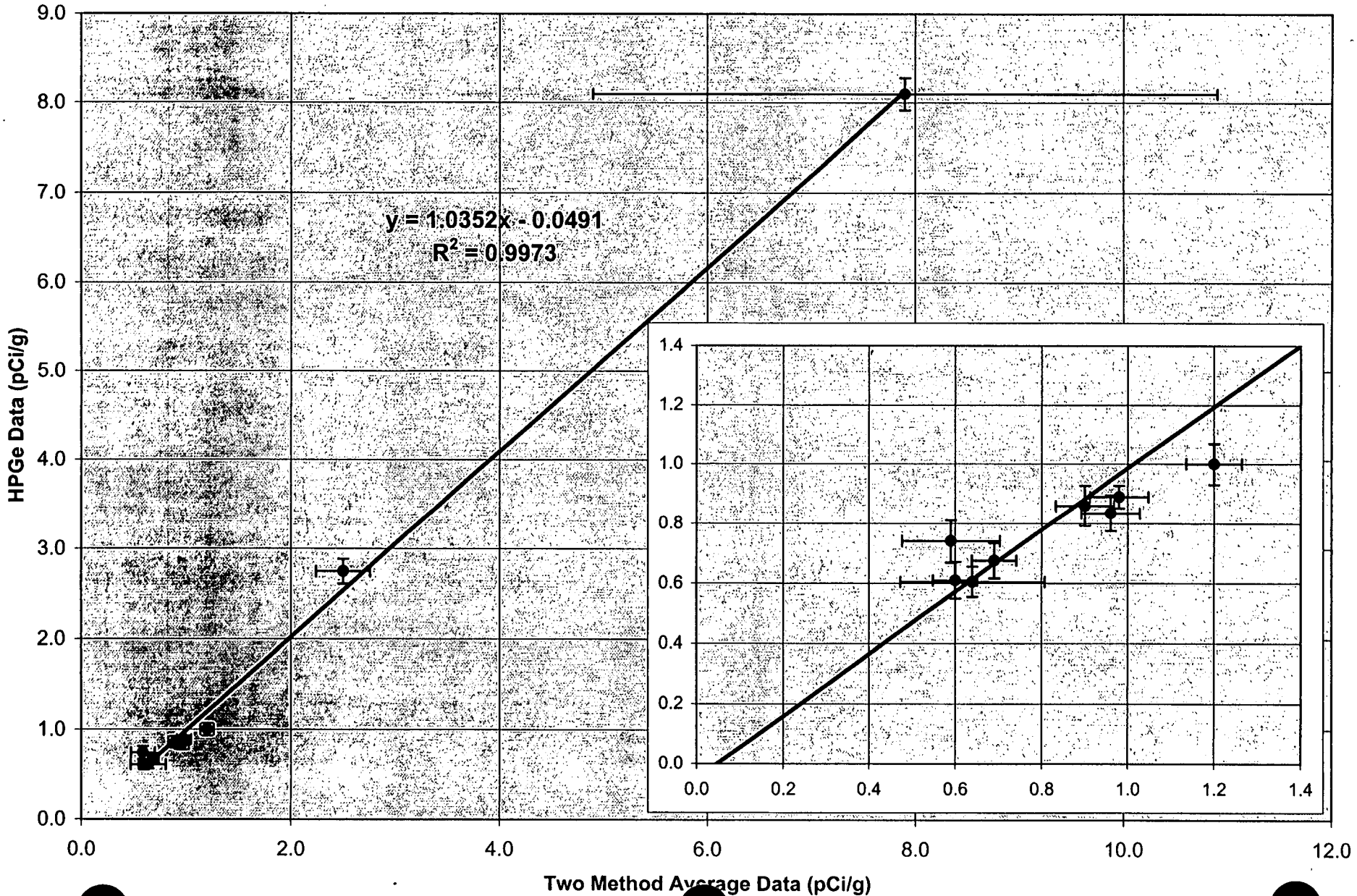


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Figure 6-3

Correlation Between 31 cm HPGe and Gamma Spectrometry Data for Th-232

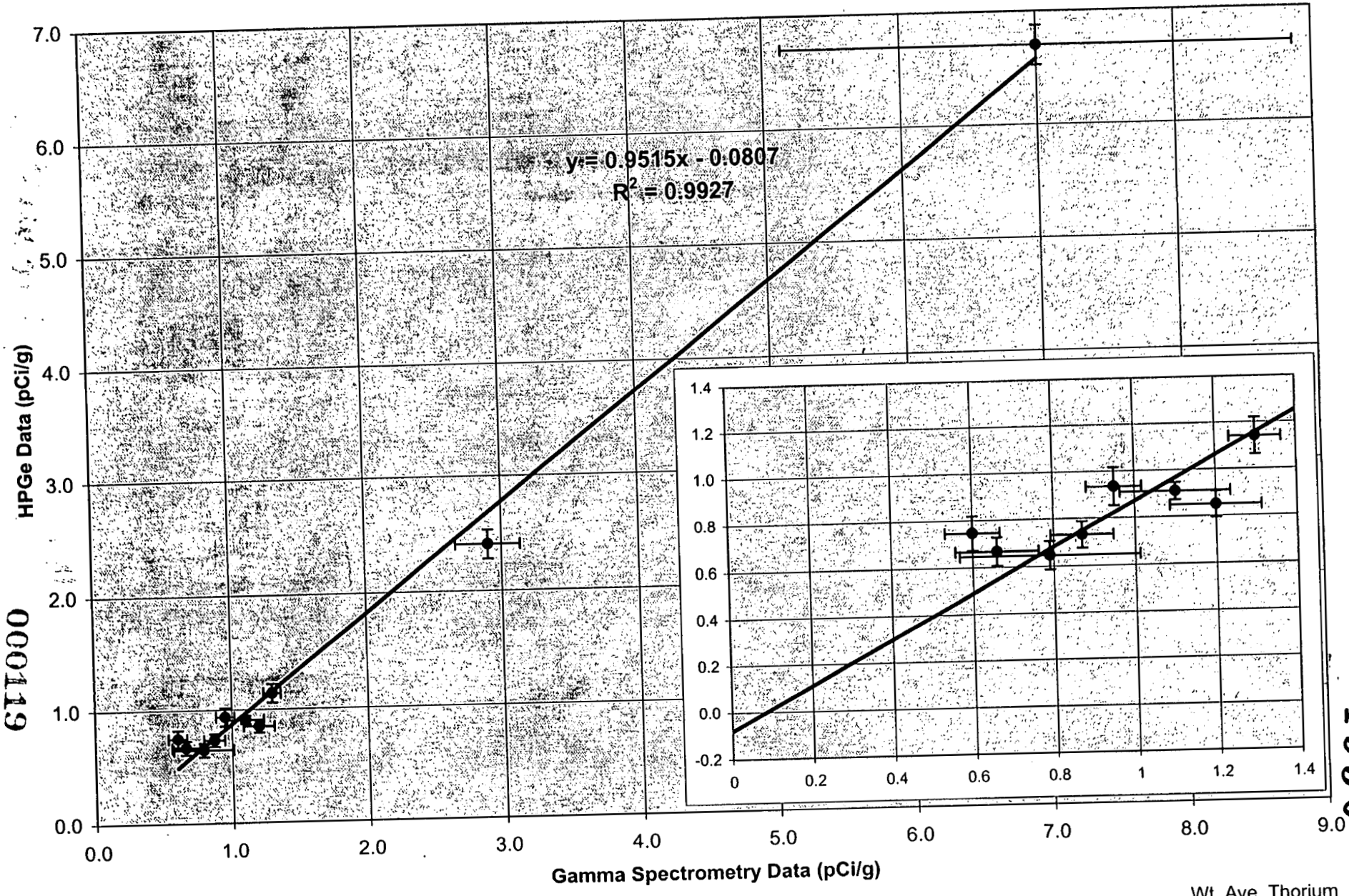

Chart3

Wt_Ave_Thorium

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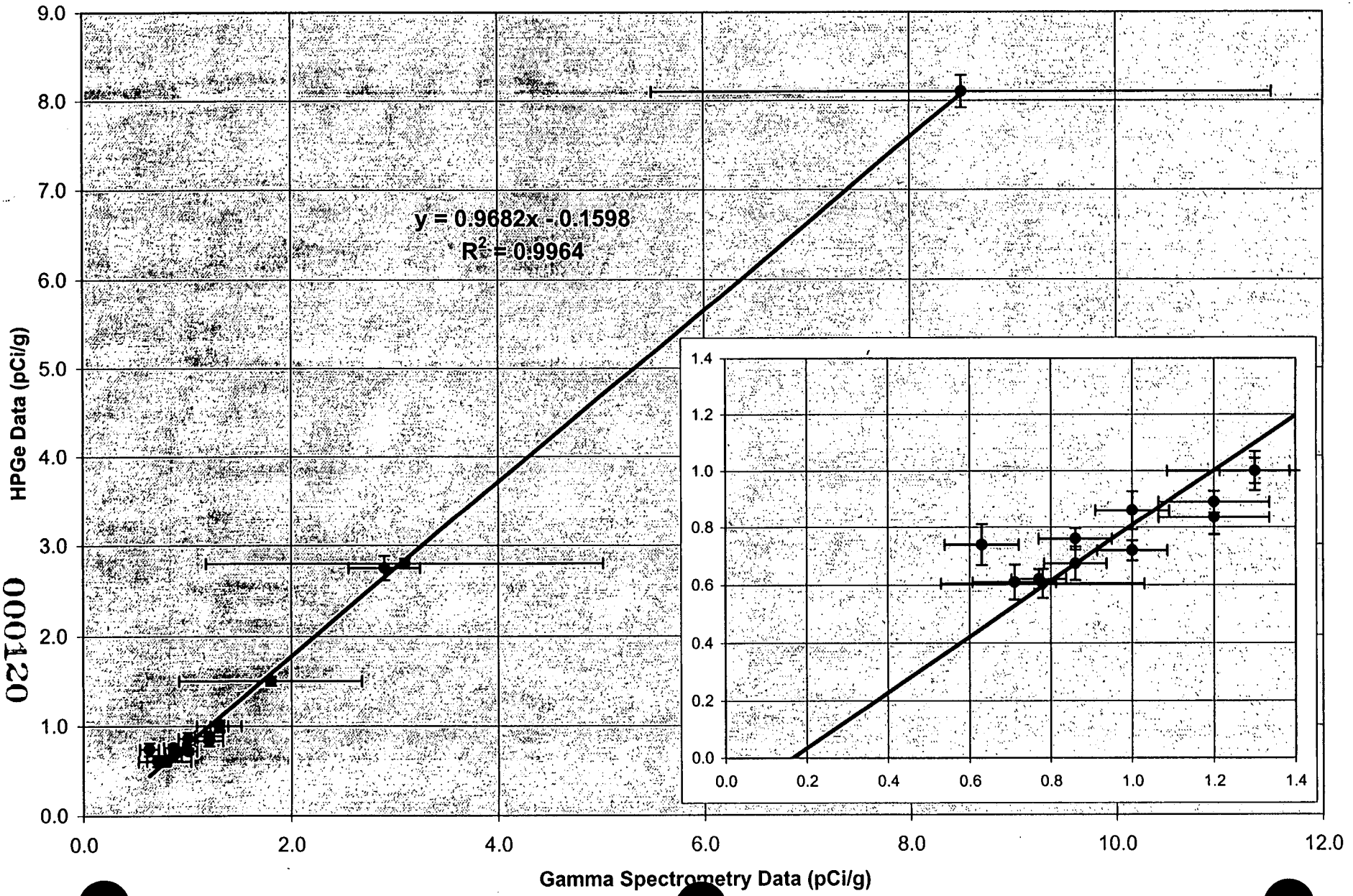
000119

1950

Figure 6-4

Correlation Between 100 cm HPGe and Gamma Spectrometry Data for Th-232



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7.0 COMPARABILITY OF RADIUM-226 DATA

7.1 INTRODUCTION

As noted in Sections 5.0 and 6.0, Revision 0 of the Comparability Study (July 1997) assessed the comparability of HPGe measurements with laboratory data generated from the analysis of physical samples. The data in that report indicated that radium-226 concentrations less than 1.0 pCi/g as measured by the HPGe were generally close to, albeit higher than, those concentrations measured by alpha spectrometry. However, for activities greater than 3.0 pCi/g, HPGe measurements were much lower than alpha spectrometry measurements. Two studies subsequently were initiated to help resolve these differences between laboratory and HPGe data. The first of these two studies addressed additional HPGe measurements of radium-226 in the field in order to better assess the comparability between HPGe and laboratory data at higher concentrations of radium-226. The second investigated the accuracy of laboratory alpha spectrometry itself for radium-226.

In October 1997, a report entitled "Comparability of In-Situ Gamma Spectrometry and Laboratory Measurements of Radium-226" assessed the accuracy of laboratory alpha spectrometry measurements of radium-226 and infilled data gaps with physical samples and HPGe measurements from six additional locations. That report also presented an empirical approach to adjusting HPGe measurements for radium-226 to compensate for radon-222 disequilibrium phenomena.

Since the October 1997 report, several additions have been made to data in that report. First, laboratory gamma spectrometry data are presented in addition to alpha spectrometry data for analyses of physical samples from areas PBC-1 through PBC-10 and PBC-12 through PBC-17. The rationale for the additional measurements is discussed in Section 4.3-1; the average of several different laboratory analytical techniques is assumed to be more representative than data generated by an individual method. Second, the HPGe data have been reprocessed using GammaVision, a commercially available software package (Appendix G). Third, data from laboratory analyses of physical samples co-located with HPGe measurements (near the Sewage Treatment Plant) have been added to assess the validity of the HPGe/laboratory data correlation curve.

7.2 ANALYTICAL METHODS

In the July 1997 HPGe comparability report, HPGe data were compared to laboratory alpha spectrometry data for radium-226. Alpha spectrometry was the method originally chosen at the FEMP for comparison with the HPGe because FEMP personnal had consderable expertise using that method and because alpha spectrometry is an established laboratory commonly used by radioanalytical laboatories to generate high quality radium isotopic data. However, FEMP personnel also have considerable experience in analyzing radium-226 by gamma spectrometry. Thus, to strengthen the case for the routine use of HPGe, the same samples originally analyzed by alpha spectrometry were subsequently reanalyzed by gamma spectrometry to demonstrate comparability of HPGe with multiple analytical methods.

Appendix H contains brief descriptions of laboratory alpha spectrometry and laboratory gamma spectrometry methods for radium-226. Additional information pertaining to the accuracy of laboratory alpha spectrometry analyses for radium-226 is given below.

7.2.1 Accuracy of Alpha Spectrometry for Radium-226

In order to assess the accuracy of the laboratory alpha spectrometry method employed by the FEMP laboratory, a small subset of samples (5) analyzed as part of the July 1997 Study was sent to DOE's Environmental Measurements Laboratory (EML) for analysis using a radon emanation technique. EML also employed a fusion flux sample preparation technique to achieve total dissolution of the sample. The same small subset of samples was also reanalyzed by the FEMP laboratory with a sample preparation method used for isotopic uranium analysis of soils. In this reanalysis, the FEMP laboratory used an alternative soil digestion technique (a digestion solution consisting of a mixture of concentrated nitric acid and concentrated hydrofluoric acid) which results in total dissolution of soil. The soil digestion technique originally employed by the FEMP for the July 1997 radium-226 dataa involved a vigorous nitric acid leach method, but may not have resulted in complete solution of radium-226, particularly at low concentrations in soils. If soils were not totally dissolved, then background levels of radium primarily contained in the interiors of mineral grains were not released into solution for subsequent measurement.

Results of the FEMP and EML analyses on the small subset of samples are shown in Table 7-1. The original results obtained using a vigorous nitric acid leach are contained in the second column. The

results obtained using the nitric/hydrofluoric acid total dissolution procedure are contained in the fourth column. Finally, the results obtained by EML using a fusion flux total dissolution technique combined with a radon emanation analytical method are shown in the sixth column.

In general, the nitric/hydrofluoric acid total dissolution resulted in a significant increase in measured radium-226 relative to the nitric acid leach for low concentration samples (PBC-05-6, PBC-09-1). The nitric/hydrofluoric acid total dissolution resulted in very comparable results to the nitric acid results for high concentration samples (PBC-03-7, PBC-03-9). Finally, the nitric/hydrofluoric acid total dissolution data agrees well with data generated by EML's fusion flux/radon emanation technique, with the exception of PBC-10-1. The data in Table 7-1 for PBC 10-1 do not exhibit good agreement, and this is believed to result from heterogeneity in the sample despite extensive grinding and homogenization. As discussed below, this heterogeneity manifests itself in other high concentration radium-226 samples, probably as a result of the presence of very small radium-226 enriched particles which are practically impossible to homogenize.

All of the samples originally analyzed in the July 1997 report were reanalyzed using the nitric/hydrofluoric acid technique. These are the results reported in Appendix D-3 of this report. Table 7-2 compares the original data contained in the July 1997 report with the reanalyzed data contained in Appendix D-3. For areas containing low concentrations of radium-226 (PBC-01, PBC-04, PBC-05, PBC-06, PBC-08 and PBC-09), the reanalyzed data based upon total dissolution of soil are clearly significantly higher. In this regard, the percent difference column in Table 7-2 is defined as:

$$[(\text{total dissolution data} - \text{original data})/\text{original data}] \times 100,$$

and the average values in Table 7-2 represent the average percent differences for a given area. The average percent differences for the six low concentration areas listed above range from 70 to 120. Conversely, the average percent differences for high concentration radium-226 areas (PBC-03, PBC-10) range from 3.6 to 15.4. The negative percent differences for certain individual samples probably result both from analytical variability as well as from sample heterogeneity. Similarly, some of the more extreme positive percent differences probably would result primarily from sample heterogeneity.

Area PBC-02 is anomalous relative to other low radium-226 concentration areas. Although it, too, is a low radium-226 concentration area, relatively little increase in the radium-226 concentrations occurred as a result of reanalysis using the nitric/hydrofluoric acid total dissolution. Accordingly, PBC-02 was reanalyzed a second time to serve as a check on the validity of the first reanalysis. The data in Appendix D-3 and Table 7-2 are the average of these two reanalyses.

Because the nitric/hydrofluoric acid total dissolution method resulted in a more complete recovery of radium-226, particularly in low concentration samples, it was used in the analysis of additional samples collected from areas PBC-12 through PBC-17. Thus, the analytical alpha spectrometry data in Appendix D-3 for samples from these areas are derived from the nitric/hydrofluoric acid total dissolution method.

7.3 ANALYTICAL DATA

Appendix D-3 contains laboratory alpha spectrometry (total dissolution method), laboratory gamma spectrometry, HPGe and soil moisture data. The soil moisture data were used to calculate laboratory results on a wet weight basis. HPGe data are also shown on a wet weight basis to provide a common ground for comparing the two data sets. Two data sets collected at different times are represented in Appendix D-3. One data set represents the original 10 locations, PBC-1 through PBC-10. The second data set contains locations PBC-12 through PBC-17 and was obtained to help infill data gaps in the first data set. An "AM" or "PM" designation is provided for all HPGe data taken from locations PBC-12 through PBC-17 to indicate whether the data were taken in the morning or afternoon. Instead of making HPGe measurements at 31 cm, "AM" and "PM" measurements were made to serve as a check on possible radon disequilibrium effects. The "AM" data do not appear to be consistently much higher than the "PM" data for any of these six locations; consequently, all of the "AM" and "PM" HPGe data were averaged for each location.

Total propagated uncertainties (TPUs) are displayed for each analytical method. The laboratory TPUs are presented as 1.96 σ values while the HPGe uncertainties reflect 1.96 σ counting errors. Laboratory TPUs for alpha and gamma spectrometry are often greater than HPGe 1.96 σ counting errors for two reasons. First, alpha and gamma spectrometry have likely measured far fewer counts than the HPGe detector. Second, laboratory data represent total system uncertainty, while HPGe data represents only one component of system uncertainty. In this regard, however, the data in Table 2-3 suggest that the

HPGe total system uncertainty is about 9.5% of the measured value. Lastly, Appendix D-3 contains a column representing the average for each sample of the concentrations determined by the two analytical methods. The standard deviations listed are the 1.0 σ standard deviations associated with the average of the two methods.

7.4 COMPARISON OF HPGe AND LABORATORY RADIUM-226 DATA

Tables 7-3 and 7-4 summarize the data in Appendix D-3. Using the weighting factors shown in Tables 3-2 through 3-4 and the computational method described in Section 4.3.2, weighted means and standard deviations for each sample collection area are shown in Tables 7-3 and 7-4. Propagated counting errors in Tables 7-3 and 7-4 for HPGe are derived from standard propagation of error calculations (Taylor 1990) applied to the HPGe data in Appendix D-3. By comparing the weighted average of laboratory data for each area with the HPGe data for the same area, an assessment of the degree of closeness and the degree of correlation between the data sets can be made. The sections below contains such assessments for radium-226 data.

7.4.1 Closeness of Laboratory and HPGe Data

Tables 7-5 and 7-6 summarize the closeness between laboratory data weighted means and HPGe data. The closeness between weighted means and HPGe data is expressed as the percent relative deviations per Section 4.3.2. The percent relative deviations shown in Tables 7-5 and 7-6 are shown as negative and positive values in order to provide a sense of possible bias. However, the averages of the relative deviations shown at the bottom of Tables 7-5 and 7-6 are calculated based upon the absolute value of the relative deviations.

Adopting criteria from Section 4.3.3 for interpreting percent relative deviations, when the relative deviation between HPGe and laboratory data is less than 20%, the data are defined as being very similar; when the relative deviation is greater than 20% but less than 35%, the data are defined as having acceptable similarity. When the relative deviation is greater than 35%, the data are defined as dissimilar.

Examination of Table 7-5 for the 31 cm detector height indicates that the average of the absolute values of the percent relative deviations are 29.44 and 21.69 for alpha spectrometry and the two method average, respectively. Based upon the criteria given above, these data sets are defined as acceptably

similar. Conversely, based upon an average percent relative deviation of 13.41, gamma spectrometry and HPGe 31 cm data would be defined as very similar.

Table 7-6 for 100 cm data shows that a large majority of individual absolute values of percent relative deviations exceed 20%, and a large number exceed 35%. Based upon the averages of the absolute values of the percent relative deviations of 49.91 and 40.08, HPGe data are considered to be dissimilar to alpha spectrometry and two-method average data. Based upon an average percent relative deviation of 30.14, HPGe data are considered to be acceptably similar to gamma spectrometry data.

Further inspection of Tables 7-5 and 7-6 indicates that the weighted means of alpha spectrometry radium-226 data for a given area are almost always higher than the corresponding HPGe measured radium-226 data for that area. Further, the difference between alpha and gamma spectrometry data and HPGe data appears to increase with increasing radium-226 concentration in the soil (this increase is shown more explicitly in a graphical mode later in the report).

The fact that laboratory data is biased high relative to field data for radium-226 is entirely consistent with theory. In-situ gamma spectrometry measures activities of daughters of radon-222, a gas. Because radon-222 diffuses, or emanates, from the soil, it is not in equilibrium with radium-226. Thus, the lower in-situ gamma spectrometry data reflect the loss of radon-222 from soil relative to laboratory data (which, for alpha spectrometry, measures radium-226 in soil directly).

7.4.2 Correlation of Laboratory and HPGe Radium-226 Data

Figures 7-1 and 7-2 show x,y scatter plots for the two method average data in Tables 7-3 and 7-4. These figures show the average of the HPGe measurements for each area. Error bars for the HPGe measurements represent the 1.96 σ propagated counting errors listed for HPGe measurements in Appendix D-3. Error bars for laboratory data represent upper and lower 97.5% confidence limits based upon the weighted standard deviations in Tables 7-3 and 7-4. The large error bars for certain laboratory data points in Figures 7-1 and 7-2 result from heterogeneity in radium-226 contamination. The error bars do not reflect poor precision in analytical data.

Figures 7-1 and 7-2 clearly demonstrate that a high degree of linear correlation between HPGe and laboratory data can be achieved spanning a range of 0.6 pCi/g to 15 pCi/g. Figure 6-1 indicates that

gaps exist in the data between 1.0 and 2.5 pCi/g and between 2.5 and 8.0 pCi/g. In an attempt to acquire additional data to infill the gaps, gamma spectrometry measurements were performed on samples in areas PBC-12 through PBC-17. HPGe measurements were performed only at 1.0 m detector height.

Four points are particularly noteworthy based upon examination of Figures 7-1 and 7-2. First, comparison of Figure 7-2 (100 cm data) with Figure 7-1 clearly shows that data are much more evenly distributed along the range of radium-226 concentrations with the addition of data from the South Field. (Note that Figure 7-1 is for 31 cm data which has no additional points.) In this regard, the range of data has been extended to radium concentrations of 15.0 pCi/g. Second, the data in both figures indicate a positive bias in the laboratory data relative to HPGe data as shown by the regression lines having slopes of 0.32 to 0.38 (a perfect correlation as defined here would yield a regression line having a slope of 1.0). Third, the large error bars for the three data points having the highest radium-226 concentrations do not reflect analytical error, but rather result from analyte heterogeneity, as can be inferred from the spread of data values in given areas (Appendix D3) relative to TPUs for individual data points. Fourth, because of the regression slopes of 0.32 to 0.38, the difference between the plotted points and a perfect correlation line (slope of 1.0) increases as a function of radium-226 (as measured by laboratory methods). Thus, the degree of comparability of alpha spectrometry data with HPGe data worsens as the concentration of radium-226 increases in the soil.

7.4.3 Sewage Treatment Plant Samples

One problem with the scatter plots of two method average vs. HPGe data in Figures 7-1 and 7-2 is the lack of data near the FRL for radium-226 of 1.7 pCi/g (a wet weight analysis would have radium-226 concentrations less than 1.7 pCi/g depending on the soil moisture content). Information from pre-design HPGe measurements near the Sewage Treatment Plant (STP) indicated that soil west of the Sewage Treatment Plant could have radium-226 concentrations in the range of the FRL. Inasmuch as a series of 1.0 meter HPGe measurements were co-located with the locations from which physical samples had been obtained during the A1PII pre-design investigation survey, it was decided to analyze the physical samples for radium-226 in the laboratory (in the pre-design investigation the samples were only analyzed for total uranium) in order to see how the co-located HPGe and laboratory data related to the data in Figure 7-2.

The physical samples were analyzed by both alpha and gamma spectrometry as discussed in Section 7.2. HPGe data were processed using GammaVision. The co-located data are shown in Figure 7-3. Two method average data error bars represent upper and lower 97.5% confidence limits. HPGe error bars represent 1.96 σ propagated errors for the average of alpha and gamma spectrometry.

As can be seen from Figure 7-3, the HPGe measurements tend to be higher relative to laboratory measurements than in the method validation study. Generally, the HPGe measurements were taken at the STP in the mid to late morning and early afternoon. Some of the morning measurements could, therefore, be high because radon-222 had not completely dissipated.

7.4.4 Linear Regression Analysis

Linear regression analyses of the data in Tables 7-3 and 7-4 were carried out using the regression tools built into a commercial spreadsheet, Excel. Table 7-7 contains the correlation coefficients (expressed as R^2 values), slopes and intercepts calculated from these regression analyses. Linear regressions have been performed for:

- HPGe vs alpha spectrometry data at 31 cm and 100 cm detector heights
- HPGe vs gamma spectrometry data at 31 cm and 100 cm detector heights
- HPGe vs two method average data at 31 cm and 100 cm detector heights

For each regression analysis, HPGe data comprised "y" coordinates while laboratory data comprised "x" coordinates.

Using criteria outlined in Table 4-2, both the 31 cm and 100 cm data display an unacceptable degree of comparability with laboratory data. Although correlation coefficients (R^2) are high, the low regression line slopes combined with the relatively large intercepts as percents of the FRL lead to the unacceptable designation of comparability. In this regard, the correlation of laboratory and HPGe data is consistent with conclusions drawn from the degree of closeness of laboratory and HPGe data.

7.5 COMPARISON OF GAMMAVISION AND EGAS DATA

As noted in the introduction (Section 7.1), all HPGe data were processed using GammaVision, a commercially available software package. Previously, all HPGe data were processed using a proprietary HPGe detector software package called EGAS. Table 7-8 compares HPGe data processed by both EGAS and GammaVision. Examination of Table 7-8 reveals that GammaVision consistently

generates radium-226 concentrations larger than those generated by EGAS. 31 cm radium-226 concentrations processed by GammaVision average 9% larger than those processed by EGAS, while 100 cm radium-226 concentrations processed by GammaVision average 5.5% larger than those processed by EGAS.

Reasons for the differences between EGAS and GammVision are primarily two-fold for radium-226 data:

1. GammaVision has a slightly better curve fitting program and therefore produces a better (and higher) efficiency curve.

2. GammaVision employs a search and fitting process called "Directed Fit" to aid in fitting the small net peak areas frequently seen. This process is very efficient in peak fitting and generally produces net peak areas larger (3-4%) than the net peak areas produced by EGAS.

7.6 CORRECTION ALGORITHM FOR HPGe RADIUM-226 MEASUREMENTS

Radium-226 concentrations in soil are determined by in-situ gamma spectrometry by measuring gamma photons emitted by radioactive daughters of radon-222. An abbreviated decay series is shown below for radium-226:

$_{88}Ra^{226}$ ----- -α -------> $_{86}Rn^{222}$ ----- -α -----> $_{84}Po^{218}$ -----> -α -----> $_{82}Pb^{214}$
|
|
$_{82}Pb^{206}$ <------- <---------- <-------- $_{83}Bi^{214}$ <--------- -β ----------

As noted in Section 2.7 of this report, the problem with measuring radium-226 concentrations in soil is that its daughter, radon-222, is a gas. Radon-222 may build up in soils, accumulate near the surface of soils, etc., in response to a number of weather and climate conditions. Therefore, in-situ gamma spectrometry measurements of radium-226 also reflect processes which lead to the accumulation or depletion of radon-222 in soils, as well as reflecting the true concentration of radium-226 in soils.

7.6.1 Compensation for Radon-222 Disequilibrium

Table 2-3 and Figure 2-5C indicate that morning radium-226 measurements at a given location average 25% higher than afternoon measurements at the same location and have a larger (relative) standard deviation. Afternoon radium-226 measurements represent steady-state dissipation of radon-222 from

soils, and lead to consistent values for the concentration of radium-226. Sections 7.4 and 7.5 demonstrate that afternoon in-situ gamma spectrometry data are consistently lower than laboratory data, and that the difference between in-situ gamma spectrometry measurements and laboratory measurements increases as the concentration of radium-226 in soils increases. Based upon these observations, a correction algorithm can be derived that empirically compensates for radon emanation from soils, thereby allowing radium-226 concentrations to be calculated from in-situ gamma spectrometry measurements that would be comparable to concentrations derived from laboratory analysis of physical samples. The derivation of this algorithm is explained below.

7.6.2 Correction Algorithms

The data in Figures 7-1 and 7-2 have been replotted in Figures 7-4 and 7-5. In these figures, though, HPGe data constitute the x-axis and laboratory data constitute the y-axis. The axis switch allows for computational ease in calculating correction factors for radium-226 to compensate for radon-222 emanation from soil. Two method average data were used because they are believed to be most representative of the true radium-226 concentration. Second order polynomial equations were fitted to the data in Figures 7-4 and 7-5. All regressions were fitted two ways: forced through the origin and not forced through the origin. Because little difference appeared in the coefficients of the second order polynomial equations and in the correlation coefficients regardless of whether the curves were forced through the origin or not, a second order ploynomial forced through the origin was utilized to give the best fit to the data points.

From the curves in Figures 7-4 and 7-5, a series of correction factors were calculated as shown below in an example.

Step 1

For a given HPGe concentration, an average calculated two-method average concentration was determined from the polynomial equations in Figures 7-4 and 7-5. Thus, from Figure 7-4 (for example), if an HPGe measurement = 2.0 pCi/g, the corresponding two method average result is 2.94 pCi/g. Similarly, from Figure 7-5, if HPGe = 2.0 pCi/g, then the two method average = 3.77 pCi/g. By taking the average of the two calculated alpha spectrometry concentrations, an HPGe measurement of 2.0 pCi/g equates to an average two method average value of 3.35 pCi/g.

Step 2

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The difference is then calculated between the average calculated two method average concentration from equations in Figures 7-4 and 7-5 and the concentration that would exist if there were a perfect correlation between HPGe and two method average data (i.e., a correlation between HPGe and two method average data, a measured HPGe concentration of 2.0 pCi/g would correlate to a two method average concentration of 2.0 pCi/g.

The difference between the two method average concentrations in Step 1 and Step 2 is 3.35 pCi/g - 2.0 pCi/g = 1.28 pCi/g. The difference of 1.28 pCi/g is a radium-226 correction factor and represents radium-226 that is "lost" to HPGe measurements due to radon-222 emanation from soils.

Step 3

Correction factors are calculated as described above for a number (20) of HPGe concentrations between 0 and 7 pCi/g. These correction factors are then plotted against HPGe concentrations as shown in Figure 7-6. These data points are described very well by an equation having the form:

$$\text{Correction factor} = 0.34651\ (\text{HPGe concentration})^2 - 0.01562\ (\text{HPGe concentration})$$

Step 4

To obtain a "correct' radium-226 concentration (i.e., a concentration that would be measured in the laboratory) from an HPGe measurement, a correction factor is simply calculated from the equation in Figure 7-5 and added to the HPGe measured radium-226 concentration. For example, an HPGe measurement of 3.0 pCi/g yields a correction factor of 3.07 pCi/g. The "corrected" radium-226 concentration is then 3.0 pCi/g + 3.07 pCi/g = 6.07 pCi/g.

Step 5

The counting error (one sigma) associated with HPGe radium-226 must also be corrected. This is accomplished by standard propagation of error techniques. When the counting error associated with the correction process in steps four and five above are propagated, the following expression for the propagated counting error is derived:

$$\text{propagated CE} = \text{CE}[0.9849 + 0.34651\ (\text{HPGe concentration})]$$

Table 7-9 shows the effect of error propagation on radium-226 correction. The effect is not significant with respect to intended data usage for radium-226 concentrations under 10 pCi/g.

For simplicity, 31 cm and 100 cm HPGe vs laboratory data curves were averaged to give a single correction factor as opposed to having a correction factor for each individual detector height. The diffusion of radon from soil and its subsequent disequilibrium with radium-226 should not cause differences in measured concentrations at different detector heights. However, the accumulation of radium-226 near the ground surface could result in different radium-226 concentrations measured at

different detector heights. This is why Section 5.3.2.1 of the User's Manual specifies that the radon monitor should be set at the same height as the HPGe detector making the field measurement.

Section 8.0 of this report presents a validation of the above correction algorithm. In that section, the mean of the afternoon radium-226 measurements at the Field Quality Control station is compared to laboratory data. When the Field Quality Control Station data are corrected as described above, excellent agreement with laboratory data occurs.

The radium correction factor that has been developed is empirical and hence is only valid for use at Fernald. It is a site-specific correction factor and should not be used universally. Other sites may use the methodology outlined here to develop their own site-specific correction factors.

7.7 SUMMARY

1. Improvements have been made to the FEMP alpha spectrometry method for analyzing radium-226. A method employing concentrated nitric acid and hydrofluoric acid enables soils to be totally dissolved. This allows more complete recovery of radium-226, yielding concomitantly higher radium-226 concentrations – particularly for low concentration samples.

2. All samples described in the July 1997 comparability report were reanalyzed using the improved soil dissolution method for radium-226. Additionally, physical sample analyses and HPGe measurements from six locations in the South Field allowed a more even distribution of data points from 0.5 pCi/g to over 18 pCi/g.

3. All samples described in the July 1997 Comparability Study and in the October 1997 radium-226 report were reanalyzed using gamma spectrometry. The rationale for this reanalysis was that the average of several laboratory methods should be more representative than data generated by each method individually.

4. A process for obtaining correction factors for HPGe measured radium-226 concentrations was derived to compensate for "loss" of radium-226 due to radon-222 emanation from soils.

5. Data collected from April 7, 1997 through March 31, 1998 at the Field Quality Control Station provide a good test of the radium-226 correction algorithm, as shown in the next section.

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TABLE 7-1
COMPARISON OF DIFFERENT SAMPLE PREPARATION METHODS
ON RADIUM-226 DATA

Sample ID	FEMP HNO_3 Leach		FEMP HNO3-HF Total Dissolution		EML Fusion Dissolution	
	Result (pCi/g)	1.96 σ TPU (pCi/g)	Result (pCi/g)	1.96 σ TPU (pCi/g)	Result (pCi/g)	1.96 σ TPU (pCi/g)
PBC-03-7	24.0	5.4	24.7	5.5	22.9	0.60
PBC-03-9	13.5	3.0	14.1	3.1	12.4	1.6
PBC-05-6	0.45	0.11	1.1	0.20	0.92	0.03
PBC-09-1	0.37	0.09	0.98	0.22	0.86	0.01
PBC-10-1	3.3	0.74	5.3	1.2	2.62	0.01

TABLE 7-2
COMPARISON OF ORIGINAL AND TOTAL DISSOLUTION RADIUM-226 DATA

Sample ID	Original Data (pCi/g)	Total Dissolution Data (pCi/g)	% Difference
PBC-01-1	0.48	0.79	64.6
PBC-01-2	0.57	0.80	40.4
PBC-01-3	0.40	0.81	102.5
PBC-01-4	0.47	0.77	63.8
PBC-01-5	0.72	0.79	9.7
PBC-01-6	0.40	0.89	122.5
PBC-01-7	0.49	0.91	85.7
			Average = 69.9
PBC-02-1	0.68	0.65	-4.4
PBC-02-2	0.68	0.68	0.0
PBC-02-3	0.51	0.60	17.6
PBC-02-4	0.54	0.56	3.7
PBC-02-5	0.59	0.80	35.6
PBC-02-6	0.61	0.59	-3.3
PBC-02-7	0.51	0.45	-11.8
PBC-02-8	0.51	0.53	3.9
PBC-02-9	0.60	0.63	5.0
PBC-02-10	0.58	0.58	0.0
PBC-02-11	0.81	0.51	-37.0
			Average = 0.9
PBC-03-1	12	8.4	-30.0
PBC-03-2	11	11	0.0
PBC-03-3	13	13	0.0
PBC-03-4	25	15	-40.0
PBC-03-5	20	23	15.0
PBC-03-6	7.1	14	97.2
PBC-03-7	24	25	4.2
PBC-03-8	22	23	4.5
PBC-03-9	14	13	-7.1

TABLE 7-2
(continued)

Sample ID	Original Data (pCi/g)	Total Dissolution Data (pCi/g)	% Difference
PBC-03-10	15	16	6.7
PBC-03-11	9.5	7.6	-20.0
PBC-03-12	8.3	7.4	-10.8
PBC-03-13	5.0	7.6	52.0
PBC-03-14	4.8	4.6	-4.2
PBC-03-15	5.4	5.7	5.6
PBC-03-16	5.1	4.3	-15.7
			Average = 3.6
PBC-04-1	0.44	1.0	127.3
PBC-04-2	0.71	1.2	69.0
PBC-04-3	0.67	1.1	64.2
PBC-04-4	0.66	0.99	50.0
PBC-04-5	0.53	0.97	83.0
PBC-04-6	0.62	0.98	58.1
PBC-04-7	0.68	1.1	61.8
PBC-04-8	0.51	1.1	115.7
PBC-04-9	0.52	0.96	84.6
PBC-04-10	0.50	1.6	220.0
PBC-04-11	0.58	0.99	70.7
			Average = 91.3
PBC-05-1	0.60	1.2	100.0
PBC-05-2	0.60	1.2	100.0
PBC-05-3	0.55	1.1	100.0
PBC-05-4	0.58	1.1	89.7
PBC-05-5	0.67	1.2	79.1
PBC-05-6	0.45	1.2	166.7
PBC-05-7	0.47	1.2	155.3
PBC-05-8	0.48	1.1	129.2
PBC-05-9	0.60	1.3	116.7

TABLE 7-2
(continued)

Sample ID	Original Data (pCi/g)	Total Dissolution Data (pCi/g)	% Difference
PBC-05-10	0.45	1.1	144.4
PBC-05-11	0.50	1.2	140.0
			Average = 120.1
PBC-06-1	0.60	1.2	100.0
PBC-06-2	0.60	1.3	116.7
PBC-06-3	0.67	1.1	64.2
PBC-06-4	0.59	1.2	103.4
PBC-06-5	0.70	1.2	71.4
PBC-06-6	0.69	1.2	73.9
PBC-06-7	0.73	1.1	50.7
PBC-06-8	0.70	1.2	71.4
PBC-06-9	0.56	1.1	96.4
PBC-06-10	0.76	1.2	57.9
PBC-06-11	0.57	1.2	110.5
			Average 83.3
PBC-07-1	0.69	1.2	73.9
PBC-07-2	0.78	1.2	53.8
PBC-07-3	0.64	1.1	71.9
PBC-07-4	0.73	1.3	78.1
PBC-07-5	1.0	1.6	60.0
PBC-07-6	0.79	1.5	89.9
PBC-07-7	0.87	1.5	72.4
PBC-07-8	0.74	1.3	75.7
PBC-07-9	0.61	1.5	145.9
PBC-07-10	0.67	1.1	64.2
PBC-07-11	0.68	0.91	33.8
PBC-07-12	1.0	1.3	30.0
PBC-07-13	0.62	0.88	41.9
PBC-07-14	1.3	1.7	30.8

TABLE 7-2
(continued)

Sample ID	Original Data (pCi/g)	Total Dissolution Data (pCi/g)	% Difference
PBC-07-15	0.83	0.94	13.3
PBC-07-16	0.20	1.1	450.0
			Average 86.6
PBC-08-1	0.42	0.94	123.8
PBC-08-2	0.33	0.80	142.4
PBC-08-3	0.54	0.94	74.1
PBC-08-4	0.38	0.73	92.1
[BC-08-5	0.42	0.74	76.2
PBC-08-6	0.36	0.71	97.2
PBC-08-7	0.45	0.95	111.1
			Average = 102.4
PBC-09-1	0.37	0.79	113.5
PBC-09-2	0.46	0.79	71.7
PBC-09-3	0.40	0.73	82.5
PBC-09-4	0.37	0.65	75.7
PBC-09-5	0.43	0.69	60.5
PBC-09-6	0.42	0.84	100.0
PBC-09-7	0.41	0.89	117.1
			Average = 88.7
PBC-10-1	3.3	2.8	-15.2
PBC-10-2	4.9	4.7	-4.1
PBC-10-3	6.4	5.9	-7.8
PBC-10-4	2.1	4.3	104.8
PBC-10-5	1.9	2.3	21.1
PBC-10-6	3.9	4.6	17.9
PBC-10-7	5.0	3.9	-22.0
PBC-10-8	2.0	3.0	50.0
PBC-10-9	2.3	4.6	100.0
PBC-10-10	3.4	2.7	-20.6

TABLE 7-2
(continued)

Sample ID	Original Data (pCi/g)	Total Dissolution Data (pCi/g)	% Difference
PBC-10-11	3.4	3.1	-8.8
PBC-10-12	1.5	1.5	0.0
PBC-10-13	1.4	1.7	21.4
PBC-10-14	1.7	1.7	0.0
PBC-10-15	2.0	2.2	10.0
PBC-10-16	6.2	6.2	0.0
			average = 15.4

TABLE 7-3
COMPARISON OF LABORATORY AND 31 cm HPGe RADIUM-226 DATA

HPGe Setting	Area	Alpha Spectrometry (pCi/g)		Gamma Spectrometry (pCi/g)		Two Method Average (pCi/g)		HPGe (pCi/g)	
		Weighted Mean	Weighted Std. Dev.	Weighted Mean	Weighted Std. Dev.	Weighted Mean	Weighted Std. Dev.	Mean	Propagated CE
31 cm (1 ft)	PBC-01	0.80	0.01	0.68	0.02	0.74	0.01	0.74	0.06
	PBC-02	0.63	0.02	0.66	0.03	0.65	0.02	0.70	0.05
	PBC-03	11	1.4	10	1.2	11	1.2	4.6	0.12
	PBC-04	1.0	0.04	0.89	0.04	0.96	0.03	0.86	0.05
	PBC-05	1.2	0.02	0.84	0.03	1.0	0.02	0.81	0.06
	PBC-06	1.2	0.02	0.92	0.04	1.1	0.02	0.86	0.03
	PBC-07	1.2	0.04	0.95	0.03	1.1	0.03	0.86	0.06
	PBC-08	0.89	0.04	0.69	0.07	0.79	0.04	0.71	0.04
	PBC-09	0.78	0.02	0.78	0.06	0.78	0.03	0.82	0.05
	PBC-10	3.3	0.03	2.4	0.24	2.8	0.26	2.1	0.10

TABLE 7-4
COMPARISON OF LABORATORY AND 100 cm HPGe RADIUM-226 DATA

HPGe Setting	Area	Alpha Spectrometry (pCi/g)		Gamma Spectrometry (pCi/g)		Two Method Average (pCi/g)		HPGe (pCi/g)	
		Weighted Mean	Weighted Std. Dev.	Weighted Mean	Weighted Std. Dev.	Weighted Mean	Weighted Std. Dev.	Mean	Propagated CE
100 cm (3.28 ft)	PBC-01	0.81	0.02	0.69	0.02	0.75	0.02	0.70	0.06
	PBC-02	0.61	0.03	0.69	0.04	0.65	0.03	0.70	0.06
	PBC-03	13	1.6	10	1.4	12	1.5	4.5	0.14
	PBC-04	1.1	0.06	0.94	0.04	1.0	0.04	0.86	0.06
	PBC-05	1.2	0.02	0.81	0.03	0.99	0.02	0.77	0.06
	PBC-06	1.2	0.02	0.98	0.03	1.1	0.02	0.86	0.03
	PBC-07	1.3	0.06	0.99	0.04	1.1	0.05	1.1	0.06
	PBC-08	0.81	0.04	0.70	0.07	0.77	0.05	0.62	0.04
	PBC-09	0.76	0.03	0.86	0.07	0.81	0.03	0.78	0.05
	PBC-10	3.5	0.35	2.3	0.28	2.9	0.30	1.7	0.09
	PBC-12	6.8	0.85	4.6	0.62	5.7	0.73	2.2	0.05
	PBC-13	1.5	0.07	1.2	0.06	1.3	0.06	0.98	0.04
	PBC-14	1.2	0.05	1.0	0.04	1.1	0.04	0.80	0.03
	PBC-15	1.6	0.20	1.4	0.16	1.5	0.18	0.83	0.03
	PBC-16	18	2.9	12	2.0	15	2.4	5.2	0.06
	PBC-17	11	1.4	8.4	0.92	9.8	1.1	3.9	0.05

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TABLE 7-5
CLOSENESS OF LABORATORY AND HPGe 31 cm RADIUM-226 DATA

Area	Alpha Spectrometry % Relative Deviation of Means*	Gamma Spectrometry % Relative Deviation of Means*	Two Method Average % Relative Deviation of Means*
PBC-01	7.79	-8.45	0.00
PBC-02	-10.53	-5.88	-7.41
PBC-03	82.96	74.91	82.96
PBC-04	15.05	3.43	10.99
PBC-05	39.40	4.26	21.61
PBC-06	33.01	6.74	24.49
PBC-07	33.01	9.94	24.49
PBC-08	23.20	-2.15	11.37
PBC-09	-5.0	-5.00	-5.00
PBC-10	44.44	13.33	28.57
	Average = 29.44	Average = 13.41	Average = 21.69

*Negative signs indicate that laboratory signs are less than HPGe data; positive signs indicate that laboratory data are greater than HPGe data. Signs are not taken into account in the computation of the above averages.

TABLE 7-6
CLOSENESS OF LABORATORY AND HPGe 100 cm RADIUM-226 DATA

Area	Alpha Spectrometry % Relative Deviation of Means	Gamma Spectrometry % Relative Deviation of Means	Two Method Average % Relative Deviation of Means
PBC-01	14.57	-1.44	6.90
PBC-02	-13.03	-0.72	-6.69
PBC-03	97.99	76.82	91.79
PBC-04	25.06	9.47	15.63
PBC-05	43.65	5.06	25.00
PBC-06	33.01	13.04	24.49
PBC-07	20.34	-6.83	3.70
PBC-08	26.57	12.12	21.58
PBC-09	-1.95	10.40	4.42
PBC-10	69.23	30.00	52.17
PBC-12	102.22	70.59	88.61
PBC-13	41.94	20.18	28.07
PBC-14	40.0	22.22	31.58
PBC-15	63.37	51.12	57.51
PBC-16	110.34	79.07	97.03
PBC-17	95.30	73.17	86.13
	Average = 49.91	Average = 30.14	Average = 40.08

*Negative signs indicate that laboratory signs are less than HPGe data; positive signs indicate that laboratory data are greater than HPGe data. Signs are not taken into account [illegible] computation of the above averages.

TABLE 7-7
LINEAR REGRESSION PARAMETERS FOR RADIUM-226

Analyte	HPGe Detector Height	Correlation Coefficient (R^2)	Slope of Regression Line	Intercept of Regression Line (pCi/g)	Intercept as % of FRL*
Alpha Spectrometry	31 cm	0.986	0.379	0.466	27.41
	100 cm	0.986	0.279	0.528	31.06
Gamma Spectrometry	31 cm	0.971	0.413	0.523	30.76
	100 cm	0.993	0.399	0.462	27.18
Two-Method Average	31 cm	0.975	0.376	0.513	30.18
	100 cm	0.992	0.324	0.506	29.76

* FRL = 1.7 pCi/g

TABLE 7-8
COMPARISON OF EGAS AND GAMMAVISION HPGe DATA FOR RADIUM-226

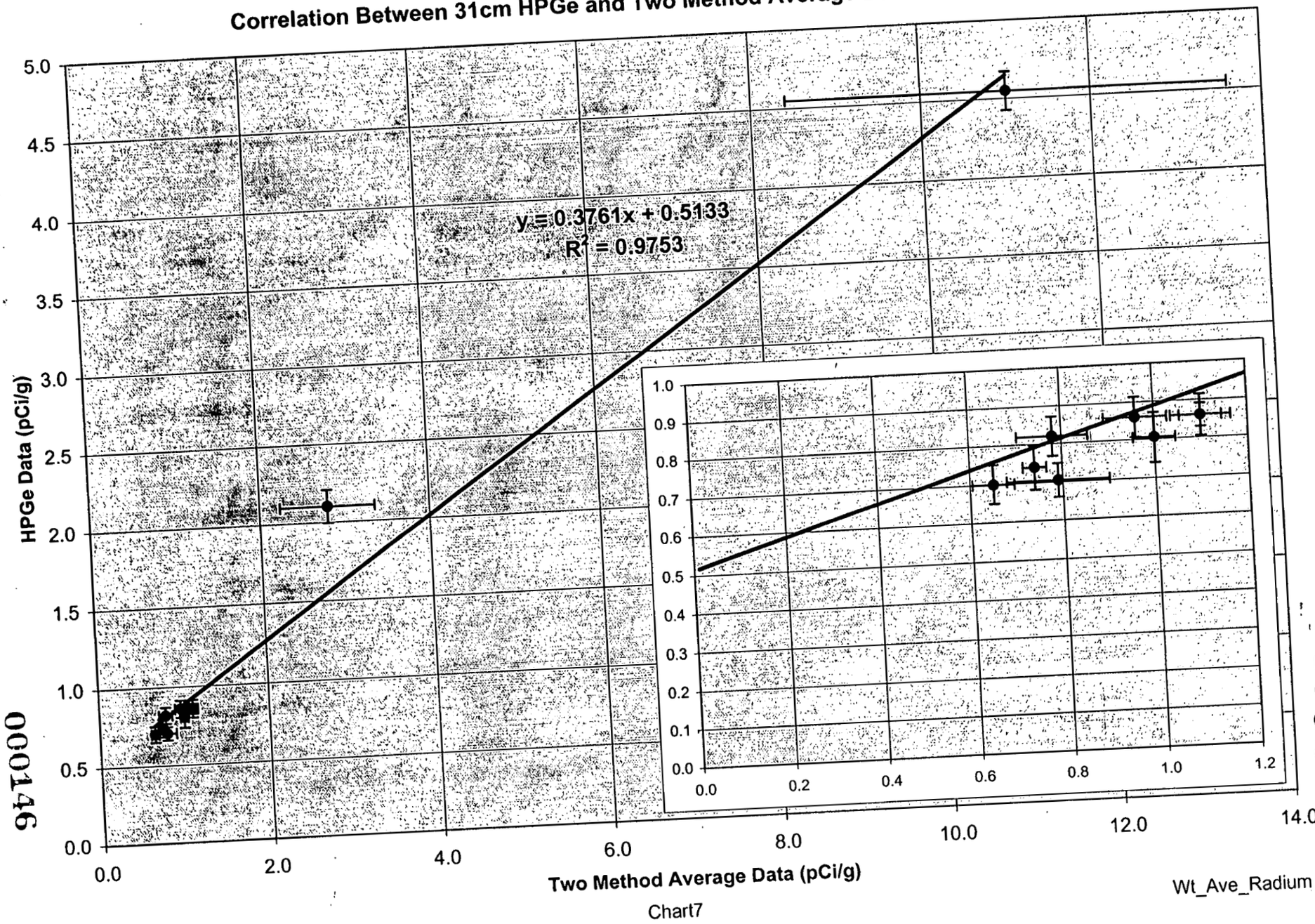
Area	EGAS 31 cm Radium-226 Data (ppm)	GammaVision 31 cm Radium-226 Data (ppm)	% Relative Deviation	Absolute Value of % Relative Deviation
PBC-1	0.64	0.74	-14.49	14.49
PBC-2	0.66	0.70	-5.88	5.88
PBC-3	4.2	4.6	-9.09	9.09
PBC-4	0.82	0.86	-4.76	4.76
PBC-5	0.72	0.81	-11.76	11.76
PBC-6	0.80	0.86	-7.23	7.23
PBC-7	0.80	0.86	-7.23	7.23
PBC-8	0.65	0.71	-8.82	8.82
PBC-9	0.73	0.82	-11.61	11.61
PBC-10	1.9	2.1	-10.00	10.00
		Average RPD =	-9.09	9.09
Area	**EGAS 100 cm Radium-226 Data (ppm)**	**GammaVision 100 cm Radium-226 Data (ppm)**	**% Relative Deviation**	**Absolute Value of % Relative Deviation**
PBC-1	0.60	0.70	-15.38	15.38
PBC-2	0.68	0.70	-2.90	2.90
PBC-3	4.3	4.5	-4.55	4.55
PBC-4	0.81	0.86	-7.23	7.23
PBC-5	0.73	0.77	-5.33	5.33
PBC-6	0.80	0.86	-7.23	7.23
PBC-7	1.0	1.1	-9.52	9.52
PBC-8	0.61	0.62	-1.63	1.63
PBC-9	0.69	0.78	-12.24	12.24
PBC-10	1.7	1.7	0.00	0.00
PBC-12	2.1	2.2	-4.65	4.65
PBC-13	0.94	0.98	-4.17	4.17
PBC-14	0.78	0.80	-2.53	2.53
PBC-15	0.78	0.83	-6.21	6.21
PBC-16	5.1	5.2	-1.94	1.94
PBC-17	3.8	3.9	-2.60	2.60
		Average RPD =	-5.51	5.51

TABLE 7-9
EFFECT OF ERROR PROPAGATION ON COUNTING ERRORS ASSOCIATED WITH RADIUM-226 CORRECTIONS

Parameter	Example #1		Example #2		Example #3		Example #4	
	Uncorrected Value	Corrected Value	Uncorrected Value	Corrected Value	Uncorrected Value	Corrected Value	Uncorrected Value	Corrected Value
HPGe Wet Weight Ra-226 Concentration (pCi/g)	1.0	1.33	2.0	3.35	5.0	13.6	10.0	44.5
HPGe Wet Weight Ra-226 One Sigma Counting Error (pCi/g)	0.10	0.17	0.20	0.47	0.50	2.2	1.0	7.9
Ratio of One Sigma Counting Error to Ra-226 Concentration	0.10	0.13	0.10	0.14	0.10	0.16	0.10	0.18

Figure 7-1

Correlation Between 31cm HPGe and Two Method Average Data for Ra-226



Wt_Ave_Radium

Chart7

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Figure 7-2

Correlation Between 100 cm HPGe and Two Method Average Data for Ra-226

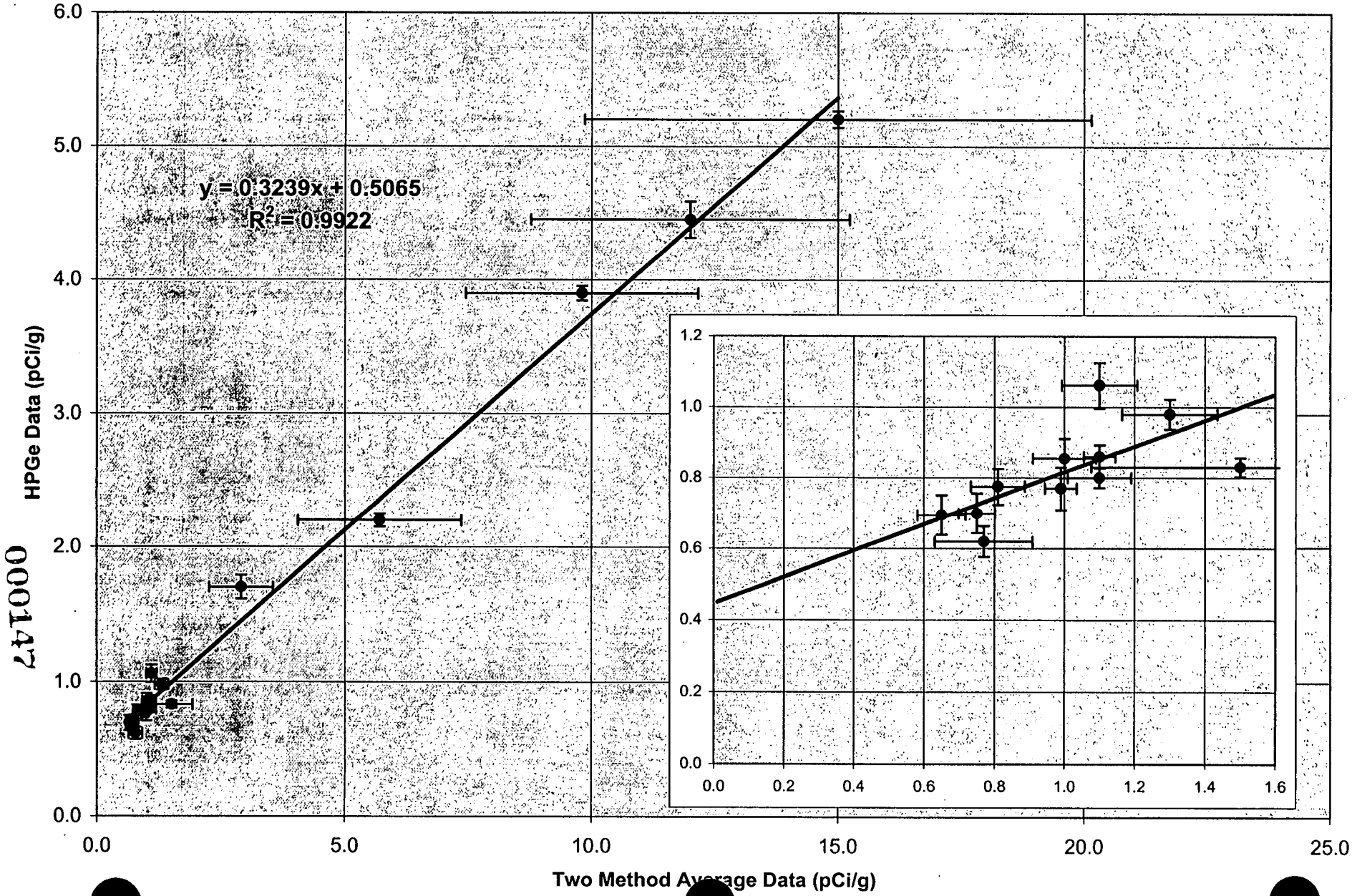

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Figure 7-3

Superposition of 100 cm HPGe and Two Method Average Data from Sewage Treatment Plant Samples upon Linear Regression Line for Comparability Data

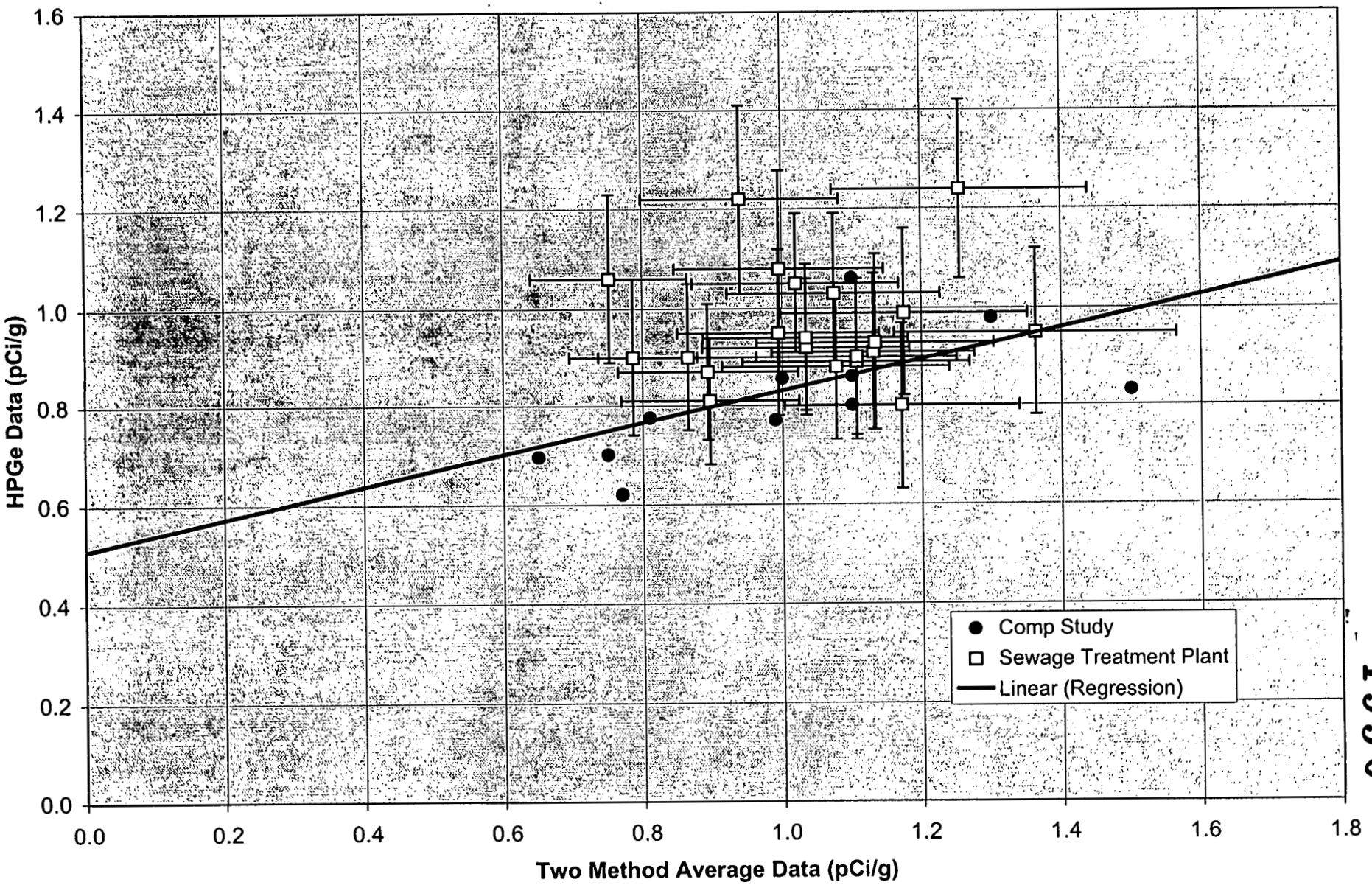


Figure 7-4
Two Method Average vs 31 cm HPGe Data for Ra-226
(forced through origin)

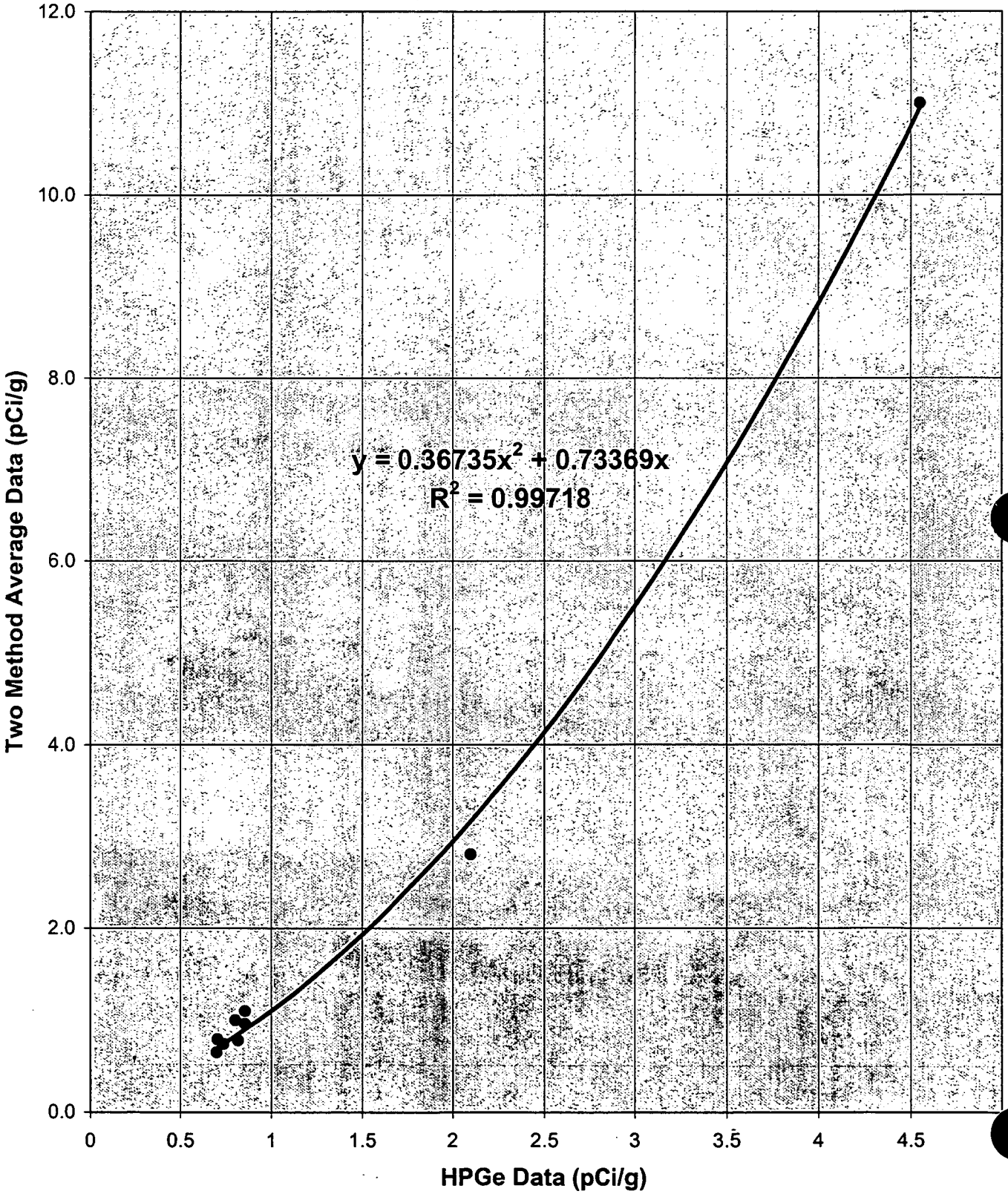


Figure 7-5
Two Method Average vs 100 cm HPGe Data for Ra-226
(forced through origin)

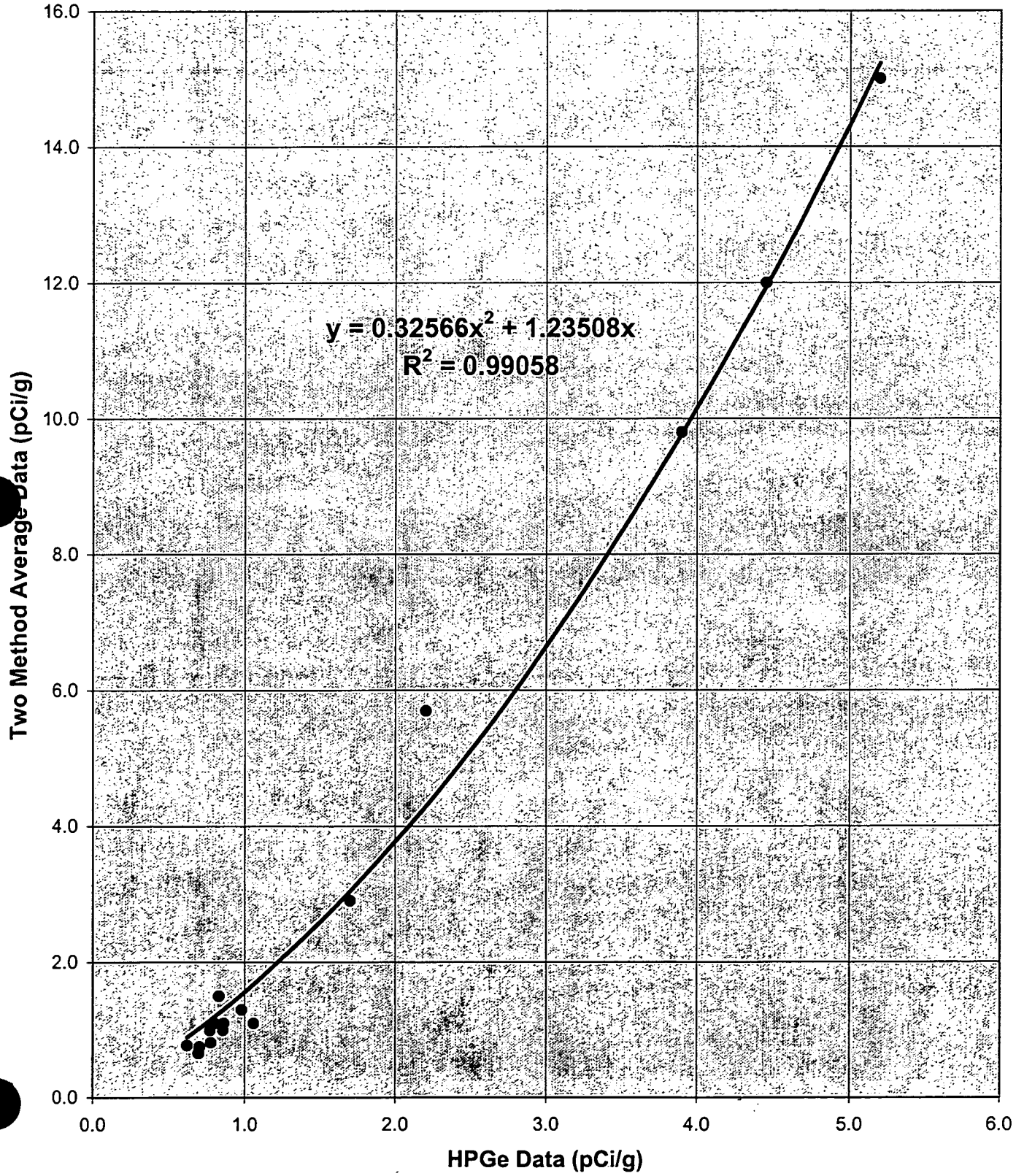
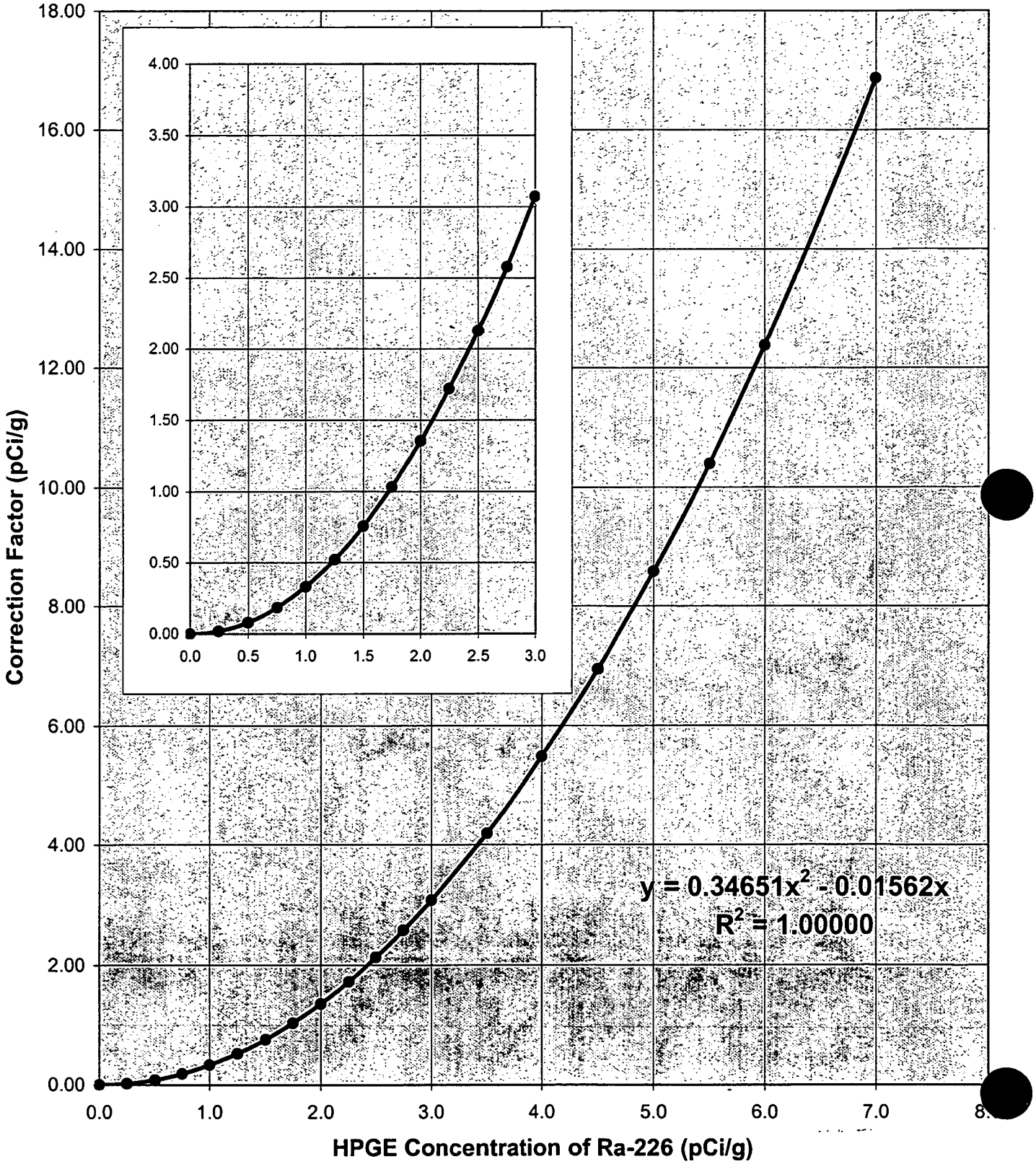


Figure 7-6

Correction Factor(based upon two measurement average data) as a Function of HPGe Concentration of Ra-226



8.0 INDEPENDENT VERIFICATION OF HPGe ACCURACY

8.1 INTRODUCTION

Three independent studies provide verification of HPGe comparability (with laboratory analyses) and/or accuracy. The first of these comprises a set of HPGe measurements and physical sample analyses performed by scientsts from DOE's Environmental Measurements Laboratory (EML) in tandem with the FEMP comparability study described in Sections 3.0 through 7.0. The second is an intercomparison study involving six different organizations using in-situ gamma spectrometry that was carried out a Brookhaven National Laboratory from September 29 through October 3, 1997. The third involves the comparison of laboratory data to the means of HPGe measurements carried out at the FCS from April 7, 1997 through March 31, 1998. Each of these studies is briefly described below.

8.2 DOE-EML COMPARABILITY STUDY

In tandem with the FEMP HPGe measurement and sample collection study described in Section 2, EML scientists performed HPGe measurements and collected samples from the same areas as FEMP scientists. The EML study served as an independent quality assurance check with respect to sampling, applicability of theory, HPGe field measurements, and laboratory analyses.

This section uses data and conclusions from the EML study to complement and reinforce data and conclusions from the FEMP study, which were presented in Sections 5, 6 and 7. In particular, the EML study is used to demonstrate:

- Comparability of HPGe and laboratory data
- Comparability of HPGe data collected by two different groups (EML and the FEMP) with two different instruments
- Validity of a uniform, vertical source distribution in FEMP soils.

The EML comparability study is presented in Appendix J in the form of a memorandum dated April 9, 1997 and contains all data and data interpretations.

8.2.1 Comparability of EML Laboratory and HPGe Data

The figures contained in the EML report (Appendix J) present graphs of laboratory measurements vs. HPGe measurements. The dark, solid lines in the graphs represent perfect agreement between laboratory and HPGe data in that they are straight lines through the origin with a slope of 1.0. Using the 20% relative percent difference (RPD) criterion between laboratory and HPGe measurements as a

measure of good comparability (Section 4.3.3), bounding lines representing ±20 percent difference from the perfect agreement line have been drawn in the graphs to represent zones of good comparability.

A majority of the EML data fall well within the good agreement ±20 percent zone for the analytes measured: uranium-238, total uranium, potassium-40, radium-226 and thorium-232. The observed agreement between concentrations inferred from soil sample analysis and in-situ measurements is consistent with similar studies performed by EML over the past 30 years. Further, the EML comparability of HPGe and laboratory data are not dependent upon the laboratory performing the analysis of physical samples.

8.2.2 Comparability of HPGe Data

Both EML and the FEMP performed HPGe measurements at the same locations with different instruments and crews. Tables 8-1 and 8-2 compare HPGe measurements made by EML and FEMP crews for total uranium, thorium-232 and radium-226. The degree of closeness between the data is expressed by the relative percent deviation, as defined in Section 4.3.3 and as given at the bottom of each table. The EML data are contained in Appendix J and the FEMP data are presented in Sections 5, 6, and 7 of this report.

A very large majority of all pairs fall well within the 20 percent criterion for good comparability. In this regard, the average of the absolute values of the percent RPDs were all well under 20 percent, and by this criterion the EML and FEMP data are considered to be very comparable.

A Wilcoxon Signed Ranks Test was performed on EML vs. FEMP HPGe measurements to help assess possible bias between the two data sets. Test results are provided in Appendix I, Table I-1. The results of these tests are mixed in that FEMP data appear biased high relative to EML data for total uranium and thorium-232 at 31 cm detector heights. Conversely, they are not biased relative to EML data at 100 cm detector heights and are not biased for radium-226 at either detector height.

8.3 BROOKHAVEN NATIONAL LABORATORY COMPARABILITY STUDY

On September 29 through October 3, 1997, six groups routinely using in-situ gamma spectrometry gathered at Brookhaven National Laboratory for a comparability study. The objectives were to

compare HPGe measurements made at two field locations among the six participants and to compare those measurements to laboratory analyses of soil samples. The six participants included Canberra, EG&G Ortec, Yankee Atomic, R.T. Reiman, US EPA, and EML. The measurement data of R.T. Reiman can be taken as representative of what the FEMP would have measured as the FEMP uses the same calibration method and software system (EGAS) developed by Reiman. (Note that GammaVision has been customized to yield as similar results as possible to EGAS.) Of the two measurement locations at Brookhaven, only one contains analytes of interest to the FEMP: radium-226 and thorium-232. Consequently, only results for this location are reported here.

Nineteen soil samples (0 to 10 cm in depth) were collected on a 5-meter triangular grid. All samples were analyzed by gamma spectrometry at DOE's EML laboratory. Analytical results are reported in Table 8-3. One sigma counting uncertainties were 3 percent or less for radium-226 and thorium-232. The total uncertainty (1σ) is estimated to be ± 5 percent based principally on the estimate of the systematic error in the calibration.

All participants used HPGe detectors at a 1.0 meter detector height with a 1.0 hour count time. Six measurement locations were staked out within the measurement test site and each participant made measurements at two of the six locations. (Each of the six locations were bounded by physical samples.) The data in Table 8-4 shows each participant's measured concentrations (expressed as relative percent differences from the measured soil concentrations) relative to the soil data.

Participant E was R.T. Reiman, and his results can be considered as very comparable to soil data using the criteria outlined in Section 4.0 of this report. Participant C is DOE-EML, and their results can also be considered as very comparable to the soil results. Because Section 8.2.2 shows good comparability between FEMP and EML HPGe measurements, and because the FEMP uses the calibration method and certain software developed by R.T. Reiman, R.T. Reiman's results and EML's results are representative of what the FEMP would have measured at Brookhaven.

8.4 COMPARABILITY OF FEMP LABORATORY ANALYTICAL DATA WITH FCS HPGe MEASUREMENTS

As noted in Section 2.1, physical samples were collected at the FCS in order to compare laboratory analytical data to HPGe measurements. The laboratory analytical data are contained in Appendices E1 and E2. Appendix E1 contains laboratory analytical data on a wet weight basis, while Appendix E2 contains the laboratory analytical data on a dry weight basis. In addition to analytical data, Appendices E1 and E2 contain % moisture data, which provides the basis for converting laboratory dry weight concentrations to wet weight concentrations. Appendices E1 and E2 also contain total propagated uncertainties (TPUs) for each type of analysis. The TPUs are shown as 1.96σ values.

Lastly, Appendices E1 and E2 contain a column representing the average total uranium concentration for each sample calculated from the total uranium concentrations determined by the four different analytical methods. For example, for RBS-11-1 in Appendix E1, the average of 76.1 ppm in the last column is the average of 83 ppm (alpha spectrometry), 67 ppm (gamma spectrometry), 78 ppm (bromoPADAP), and 76.4 ppm (ICP/MS). Similarly, the standard deviation (6.7 ppm) in the last column is derived from the four measurements contributing to the average. The averages and standard deviations for gamma spectrometry data for thorium-232 and radium-226 are similarly computed in Appendices E1 and E2.

8.4.1 Comparison of Laboratory Data and HPGe Measurements

Tables 8-5A and 8-5B summarize the data in Appendices E1 and E2. Using the weighting factors shown in Table 3-3 and the computational method described in Section 4.3, weighted means and weighted standard deviations of laboratory analyses for sample area RBS-11 are shown in Tables 8-5A and 8-5B. Duplicate samples were collected (as noted in Appendices E1 and E2), and the average of those duplicate concentrations was used in the weighted mean/standard deviation calculations for laboratory data.

The HPGe total uranium and thorium-232 means and standard deviations in Tables 8-5A and 8-5B are the means and standard deviations of all data collected from April 8, 1997 through March 31, 1998. These data appear in Table 2-1. However, radium-226 means and standard deviation in Tables 8-5A and 8-5B are means and standard deviations of morning and afternoon measurements, respectively, as are shown in Table 2-3.

Inspection of Tables 8-5A and 8-5B shows excellent agreement between the four method average laboratory and HPGe measurements for total uranium. Thorium-232 HPGe measurements are a little lower than the two method average data, but are still in good agreement. Laboratory radium-226 measurements are either a little higher than HPGe radium-226 measurements (a.m. HPGe data) or considerably higher than HPGe radium-226 measurements (p.m. HPGe data). However, when the radon-222 correction algorithm described in Section 7.0 is applied to the HPGe p.m. data, the agreement with laboratory two method average data is excellent.

To better assess the closeness of laboratory and HPGe data, the percent relative deviation between the two sets of measurements for each analyte is calculated as indicated in Section 4.3.2. The percent relative deviations shown in Tables 8-6A and 8-6B are shown as negative and positive values in order to provide a sense of possible bias. Adopting criteria proposed in Section 4.3 for interpreting percent relative deviations, when the relative deviation between HPGe and laboratory data is less than 20%, the data are defined as being very similar; when the relative deviation is greater than 20% but less than 35%, the data are defined as having acceptable similarity. When the relative deviation is greater than 35%, the data are defined as dissimilar.

Examination of Tables 8-6A and 8-6B indicates that the degree of closeness of total uranium and thorium-232 data meet the criteria for being very similar for all comparisons with laboratory data, irrespective of the analytical data. The sole exception is that on a dry weight basis, thorium-232 is acceptably similar to gamma spectrometry data. When the correction algorithm defined in Section 7.6.2 is applied to the afternoon HPGe radium-226 data, the afternoon HPGe measurements are corrected so as to be very similar to the laboratory data.

In summary, comparison of laboratory analytical data at the FCS for total uranium, thorium-232, and radium-226 with 12-month averages of HPGe measurements at the FCS indicates a high degree of similarity. The % relative deviations of the two sets of measurements are within 20% of one another. Such good relative deviations satisfy the accuracy acceptance criteria specified in Table 9-1.

8.5 CONCLUSIONS

The following conclusions are the most important ones to be drawn from the data and discussion in this section:

1. Based upon HPGe measurements at the same time and same locations, FEMP results are very comparable to those obtained by DOE-EML.

2. In an intercomparison study performed at Brookhaven National Laboratory involving six groups using in-situ gamma spectrometry, two groups using the same type of calibration method and similar software as used by the FEMP obtained results for radium-226 and thorium-232 that were very comparable to laboratory-measured concentrations in soil.

3. Comparison of the means of HPGe measurements for total uranium, thorium-232, and radium-226 at the Field Quality Control Station with the weighted average of laboratory measurements demonstrated very good comparability of data.

4. Taken together, these three independent studies provide an excellent affirmation of the comparability data, discussions, and conclusions in Sections 5, 6, and 7 of this report.

TABLE 8-1
COMPARISON OF FEMP AND EML 31 cm HPGe DATA

Area	Total Uranium (ppm)			Thorium-232 (pCi/g)			Radium-226 (pCi/g)		
	FEMP	EML	%RPD	FEMP	EML	%RPD	FEMP	EML	%RPD
PBC-01	9.2	10	-8.33	0.66	0.62	6.25	0.74	0.58	24.24
PBC-02	33.5	32	4.58	0.74	0.75	-1.34	0.70	0.60	15.38
PBC-04	60.8	55	10.02	0.85	0.86	-1.17	0.86	0.87	-1.16
PBC-05	42.6	38	11.41	0.94	0.86	8.89	0.81	0.68	17.45
PBC-06	81.4	75	8.18	0.91	0.91	0.00	0.86	0.88	-2.30
PBC-07	154	153	0.65	1.14	1.11	2.67	0.86	0.78	9.76
PBC-08	3.8	3	23.53	0.64	0.62	3.17	0.71	0.71	0.00
PBC-09	5.9	7	-17.50	0.73	0.67	8.57	0.82	0.82	0.00
PBC-10	85.9	80	7.11	6.7	6.26	6.79	2.1	1.77	17.05
Mean % RPD =			**4.41**			**3.76**			**8.94**
Mean Absolute Value of %RPD =			**10.15**			**4.32**			**9.71**

TABLE 8-2
COMPARISON OF FEMP AND EML 100 cm HPGe DATA

Area	Total Uranium (ppm)			Thorium-232 (pCi/g)			Radium-226 (pCi/g)		
	FEMP	EML	%RPD	FEMP	EML	%RPD	FEMP	EML	%RPD
PBC-01	8.4	14	-50.00	0.61	0.60	1.65	0.70	0.56	22.22
PBC-02	27.4	24	13.23	0.74	0.75	-1.34	0.70	0.75	-6.90
PBC-04	63.4	56	12.40	0.84	0.85	-1.18	0.86	0.81	5.99
PBC-05	46.6	50	-7.04	0.86	0.92	-6.74	0.77	0.68	12.41
PBC-06	85.1	77	9.99	0.89	0.88	1.13	0.86	0.82	4.76
PBC-07	158	152	3.87	1.0	1.05	-4.88	1.1	0.80	31.58
PBC-08	4.2	4	4.88	0.61	0.61	0.00	0.62	0.67	-7.75
PBC-09	6.0	4.5	28.57	0.68	0.66	2.99	0.78	0.80	-2.53
PBC-10	76.2	73.1	4.15	8.1	7.64	5.84	1.7	1.73	-1.75
Mean % RPD =			**2.23**			**-0.28**			**6.45**
Mean Absolute Value of %RPD =			**14.90**			**2.86**			**10.65**

TABLE 8-3
WET WEIGHT RADIONUCLIDE CONCENTRATIONS IN BROOKHAVEN SOIL AT HPGe INTERCOMPARISON TEST SITE

Statistic	Ra-226 (pCi/g)	Th-232 (pCi/g)
mean	0.57	0.78
Median	0.57	0.77
Standard Deviation	0.03	0.05
Maximum	0.64	0.86
Minimum	0.52	0.69

TABLE 8-4
PERCENT DIFFERENCES OF IN-SITU HPGe RESULTS FROM SOIL SAMPLE RESULTS AT BROOKHAVEN INTERCOMPARISON TEST SITE

Participant	Ra-226	Th-232
A	-20	-25
B	-1	-6
C	-4	-12
D	-17	-22
E	+2	-11
F	-10	-11
Group Mean ±Std. Dev. Of Mean	-9±3	-14±3

TABLE 8-5A
COMPARISON OF WET WEIGHT LABORATORY AND HPGe DATA

HPGe Setting	Analyte	Laboratory Method	Weighted Mean	Weighted Std. Dev.	HPGe Data	
					Mean*	Std.Dev.*
100 cm (3.28 ft)	Total Uranium (ppm)	Alpha Spec.	80	3.1	74.4	7.7
		Gamma Spec.	67	3.6		
		BromoPADAP	77	3.6		
		ICP/MS	75.2	4.2		
		4 Method Ave	75.3	3.4		
	Thorium-232 (pCi/g)	Alpha Spec.	0.89	0.02	0.91	0.09
		Gamma Spec.	1.1	0.04		
		2 Method Ave	1.0	0.02		
	Radium-226 (pCi/g)	Alpha Spec.	1.2	0.04	1.04 am	0.28 am
		Gamma Spec.	1.0	0.04	0.84 pm	0.08 pm
		2 Method Ave	1.1	0.03	1.07 pm**	

* HPGe means and standard deviations are taken from tables in control chart section of report. Radium data are from morning and afternoon measurements.

** Corrected mean of pm data.

TABLE 8-5B
COMPARISON OF DRY WEIGHT LABORATORY AND HPGe DATA

HPGe Setting	Analyte	Laboratory Method	Weighted Mean	Weighted Std. Dev.	HPGe Data	
					Mean*	Std.Dev.*
100 cm (3.28 ft)	Total Uranium (ppm)	Alpha Spec.	103	3.8	93.4	5.56
		Gamma Spec.	86	4.4		
		BromoPADAP	99	4.4		
		ICP/MS	97	5.2		
		4 Method Ave	97.3	4.1		
	Thorium-232 (pCi/g)	Alpha Spec.	1.14	0.03	1.14	0.07
		Gamma Spec.	1.5	0.06		
		2 Method Ave.	1.3	0.03		
	Radium-226 (pCi/g)	Alpha Spec.	1.6	0.04	1.30 am	0.31 am
		Gamma Spec.	1.3	0.05	1.05 pm	0.10 pm
		2 Method Ave.	1.4	0.03	1.42 pm**	

* HPGe means and standard deviations are taken from Table 2-1. Radium data are from morning and afternoon measurements (Table 2-2).

** Corrected mean of pm data.

TABLE 8-6A
CLOSENESS OF LABORATORY AND HPGe DATA (WET WT. BASIS)

Analyte	Laboratory Method	Relative Deviation of Means (%)
Total Uranium (ppm)	Alpha Spectrometry	7.25
Total Uranium (ppm)	Gamma Spectrometry	-10.5
Total Uranium (ppm)	BromoPADAP	3.43
Total Uranium (ppm)	ICPMS	1.10
Total Uranium (ppm)	4 Method Average	1.20
Thorium-232 (pCi/g)	Alpha Spectrometry	-2.22
	Gamma Spectrometry	18.9
	2 Method Average	9.42
Corrected pm Radium-226 (pCi/g)	Alpha Spectrometry	11.4
	Gamma Spectrometry	-6.76
	2 Method Average	2.76

TABLE 8-6B
CLOSENESS OF LABORATORY AND HPGe DATA (DRY WT. BASIS)

Analyte	Laboratory Method	Relative Deviation of Means (%)
Total Uranium (ppm)	Alpha Spectrometry	9.78
Total Uranium (ppm)	Gamma Spectrometry	-8.25
Total Uranium (ppm)	BromoPADAP	5.82
Total Uranium (ppm)	ICPMS	3.78
Total Uranium (ppm)	4 Method Average	4.09
Thorium-232 (pCi/g)	Alpha Spectrometry	-3.57
	Gamma Spectrometry	27.3
	2 Method Average	13.1
Corrected pm Radium-226 (pCi/g)	Alpha Spectrometry	11.9
	Gamma Spectrometry	-8.8
	2 Method Average	-1.42

9.0 HPGe MEASUREMENTS AND DATA QUALITY LEVELS

9.1 INTRODUCTION

In September 1993, the US Environmental Protection Agency (EPA) issued the interim final guidance document for the data quality objectives process for Superfund projects (EPA 1993). The document defines two categories of data: 1) screening data with definitive confirmation and 2) definitive data. Screening data with definitive confirmation are defined as data generated by rapid, less precise methods of analysis. These data provide identification and quantification, although the data may be relatively imprecise. Definitive data are defined as data generated using rigorous analytical methods, such as approved EPA reference methods. Methods produce tangible raw data such as spectra in the form of paper printouts or computer-generated electronic files. For the data to be definitive, either analytical or total measurement errors must be determined. The QA/QC elements defined for these two data categories match the requirements of the SCQ for ASLs B and D, respectively. ASL B corresponds to screening data with definitive confirmation and ASL D corresponds to definitive data. Because the HPGe is envisioned to be used to provide either ASL B or ASL D quality data, this section of the report demonstrates that HPGe data meet acceptance criteria for key quality control elements for ASL B and ASL D data.

Procedure ADM-16, entitled "In-Situ Gamma Spectrometry Quality Control," summarizes the HPGe field measurement quality control requirements in Attachment A of that procedure. (ADM-16 also comprises part of the in-situ gamma spectrometry addendum to the SCQ.) Relevant portions of Attachment A of procedure ADM-16 are reproduced in this report as Table 9-1. Of the QC elements listed in Table 9-1, accuracy, bias, MDCs, and precision are discussed below.

9.2 ACCURACY AND BIAS

Accuracy of a measurement is the closeness of a measurement to its accepted true value. Bias is a systematic error of a measurement relative to its accepted values. The closeness of HPGe and laboratory measurements will be considered a measure of accuracy, and systematic differences between HPGe and laboratory measurements will indicate a bias. Because of the nature of the experiments as explained in Section 4.2, an absolute bias cannot be definitively assigned to either HPGe or laboratory measurements without independent evidence.

9.2.1 Accuracy

Currently, four quality control parameters are routinely used by environmental analytical laboratories to provide information on accuracy and precision. These are: relative percent deviation (RPD) of duplicates, matrix spikes, matrix spike duplicates, and laboratory control standards. Table 9-2 is the basis of the link between comparability as defined in Section 4.3.3 and the acceptance criteria for accuracy in Table 9-1. Accuracy is defined for both ASL D and ASL B quality levels: when the relative deviation between HPGe and the average of laboratory data is less than 20 percent, HPGe data are considered accurate for ASL D data quality levels. When the relative deviation between HPGe and the average of laboratory data is greater than 20 percent but less than 35 percent, HPGe data are considered accurate for ASL B purposes. These definitions implicitly assume that the weighted average of laboratory data from discrete samples represent the "true" value. In reality, as discussed in Section 4.2, this may not be the case. Therefore, the mean of HPGe data and laboratory data is used in the denominator of the relative precision calcuation.

Using these definitions of accuracy, total uranium measurements by HPGe are accurate for both ASL B and ASL D purposes (Tables 5-2A, 5-2B), irrespective of the laboratory analytical method used as the basis of comparison. Thorium-232 data (Tables 6-3 and 6-4) are also accurate for ASL D and ASL B when compared against the average of laboratory alpha and gamma spectrometry.

Uncorrected radium-226 data at a 31 cm detector height are accurate at ASL B, irrespective of the analytical method used as the basis of comparison. Conversely, uncorrected radium-226 data at a 100 cm detector height are not accurate at either ASL B or ASL D. The situation is different, however, when radium-226 data are corrected for radon-222 disequilibria as explained in Section 7.6. Using the correction algorithm in Section 7.6.2 on the FCS data (Tables 8-6A and 8-6B), the corrected radium-226 data clearly meet the accuracy criteria for both ASL B and ASL D. Therefore, corrected radium-226 data are considered accurate for both ASL B and ASL D purposes.

9.2.2 Bias

Systematic differences between HPGe and weighted laboratory data can indicate biases. Table 9-3, reporting 1.0 meter HPGe data for illustrative purposes, indicates that some systematic differences do exist (the method of calculating biases is explained at the bottom of Table 9-3). For total uranium and thorium-232, HPGe measurements appear to yield relatively unbiased results relative to the weighted

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four method and two method average laboratory data, respectively. Conversely, a clear bias appears in the HPGe data relative to laboratory data for radium-226. In this regard, HPGe data are consistently lower than laboratory and the difference averages almost 40 percent.

Wilcoxon Signed Ranks Tests (discussed in Appendix I) were performed on laboratory vs. HPGe measurements to assess bias. Test results are provided in Appendix I, Table I-2. These tests suggest that, based upon laboratory and HPGe methods, measurements of total uranium and thorium-232 do not exhibit consistent bias. Conversely, measurements of radium-226 do exhibit bias between laboratory and HPGe methods, with uncorrected HPGe measurements being biased low relative to laboratory measurements.

9.3 PRECISION OF DUPLICATE HPGe MEASUREMENTS

Precision is the measure of the closeness of replicate measurements for purposes of this study. Two HPGe measurements were performed at each detector height above the ground at each location for areas PBC-1 through PBC-5 and PBC-7 through PBC-10. Other areas have more than two replicates. Precision and acceptance criteria can be determined from these data. Tables 9-4 and 9-5 show the high degree of closeness between duplicates for almost all duplicate measurements irrespective of detector height.

Precision of duplicates is a standard quality control parameter for environmental analytical chemistry (Table 9-2). Standard practice is to accept data when the percent relative difference between duplicates is less than 20 percent for data greater than five times MDC. For data less than five times MDC, the precision requirements are $\pm$ MDC. Tables 9-4 and 9-5 show the percent relative precision between duplicates of HPGe measurements for all analytes for measurements at 31 cm and 1.0 meter height, respectively.

Of all the pairs of duplicates, only three have percent relative precisions exceeding 20 percent. These three pairs all occur for HPGe measurements at 31 cm for total uranium. All three pairs of duplicates occur at low concentrations of total uranium which are less than 5 x MDC (Table 9-6). Therefore, per Table 9-2, the 20 percent criterion is invalid for these three pairs of duplicates. Instead, the difference between the pairs of measurements is less than the MDC, and therefore the acceptance criterion for this case is met.

In summary, precision of duplicates data in Tables 9-4 and 9-5 demonstrate that HPGe measurements meet the precision requirements specified in Table 9-1 for ASL D and ASL B. In this regard, note that ASL B and ASL D have the same precision criteria.

9.4 MINIMUM DETECTABLE CONCENTRATION

MDC refers to the statistically determined quantity of a radionuclide that can be measured at a preselected confidence level. The magnitude of the MDC is a function of instrument parameters, radiological background levels, and the procedure used to make the measurement. While any confidence level could be chosen to calculate the MDC, it is traditionally defined as the activity level above which there is less than 5 percent probability that activity will be reported as present when it is really absent (Type I error, or false detection) or reported as absent when it is in fact present (Type II error, or false non-detection). This confidence level has been adopted for the purposes of this study.

The concept of using the MDC for measurements of radionuclides was first proposed by L. Currie in 1968. It is intended to be an *a priori* estimate of the activity level that a system or technique can reliably measure under a given set of conditions. The MDC is not intended to be used *a posteriori* to evaluate individual measurements.

The MDC indicates the ability of a detection system to differentiate between the activity of a radionuclide being analyzed and the background activity. It is given by the expression:

$$\text{MDC (pCi/g)} = K(2.71 + 4.65s_b)$$

where:

K = constants relating the instrument response (in counts) to an activity concentration

s_b = the standard deviation of the number of background counts detected during a measurement period. For measurements of radioactivity, this is typically assumed to be equivalent to the square root of the background counts.

The equation assumes that the acceptable probabilities for Type I and Type II errors are equal to or less than 5 percent. Where background counts are large, such as that at the FEMP, the 2.71 term is often omitted. In addition, the equation applies when the background and sample are counted for the same amount of time.

MDCs for a radiation measurement system are usually determined by using the system to take a sample measurement for which the radionuclides of interest are present or absent at background radiation levels. Gamma spectrometry measurement techniques, in a gamma ray spectrum such as the in-situ HPGe, are complicated by the fact that the counts of interest are contained in photopeaks that are superimposed on a continuum that results from other gamma emissions present in the background. This continuum is a major component of the background counts used to determine a MDC for a gamma detection system. Consequently, the MDC for a given radionuclide is affected by the presence of other radionuclides in the sample or at the measurement location, as well as upon the actual background radiation levels. The acutal MDC for the HPGe will be a function of the total gamma activity present in the measurement area.

For the HPGe system, the MDCs were determined by making measurements in locations as unaffected by FEMP activities as possible. These locations were in the blacktop parking area near Building 305, the In-Situ Gamma Spectroscopy Group Building. A gamma spectrum was accumulated for both 900 and 1800 second count times. The number of counts in a spectrum continuum was determined at each position where a photopeak of interest would be found. MDCs were calculated for the photopeaks using the equation provided above. For those radionuclides which are quantified using an average of multiple peaks, the MDCs were weight averaged (by one over the counting error squared) to give a representative value for that nuclide.

Table 9-6 lists the average of replicate MDCs on a dry weight basis, calculated for total uranium, thorium-232 and radium-226 for a 1.0 m HPGe detector height at both 900 and 1800 seconds. The 95% upper confidence limits of all measured MDCs are less than the FRLs (Table 9-7) for the analyte of interest as required by the QC criterion in Table 9-1.

9.5 LINEARITY

Although there is no QC requirement per se in Table 9-1 for linearity, best analytical practices dictate that the detector response should be linear over the activity range of interest for an analyte. For soil remediation, linearity should be demonstrable from approximately the MDC to well beyond the FRL or other regulatory limit for a given analyte. In practice, this means that linearity should be observed over as much as three orders of magnitude for activities measured by HPGe at the FEMP.

All radiation detectors, including the HPGe systems used in this comparability study, function by absorbing some or all of the energy impinging on them as a result of exposure to a radiation field. The energy absorption process liberates free charges in the detector material, resulting in small surges of current which are counted as pulses by electronic modules coupled to the detector. This detection and counting process is accomplished in 50 microsecond or less time intervals, so a modern detector can easily process thousands of radiation events per second. The counts detected are proportional to the number of photons incident upon the detector; this, in turn, is proportional to the radioactivity concentration in the "sample" being analyzed. Over many decades of use, it has been firmly established that there is a linear relationship between the true sample activity and the HPGe detector response, i.e., the counts the detector registers regardless of the radioisotope or the gamma photon energy.

Linearity of the HPGe detector can be demonstrated by invoking the inverse square law of radiation transport. In its simplest form, it relates the fluence rate (ϕ) at a detector to a point source (S_0 of gamma photons) separated by distance r:

$$\phi = S_0/4\pi r^2 \quad \text{photons/sec} \bullet \text{cm}^2$$

With respect to linearity of detector response, moving a source of given strength further from the detector is equivalent to decreasing the source strength at a given distance from the detector. In each case, the detector "sees" a weaker source, and the detector response will decrease. Thus, for a given source, a graph of detector response (net counts) as a function of $1/r^2$ should be linear over a large range of counts. Figure 9-1 demonstrates such linearity for two sources: a cesium-137 source and a cobalt-60 source. Table 9-8 contains the data used to construct Figure 9-1.

9.6 SUMMARY

Table 9-9 summarizes important quality control elements discussed in this section, their acceptance criteria for ASL D and ASL B data quality levels, and whether or not HPGe measurements meet those acceptance criteria. Table 9-9 shows that HPGe measurements for all analytes investigated in this study meet all of the QC acceptance criteria for both ASL D and ASL B for all QC elements. However, for HPGe measurements for radium-226, the measurements must be corrected for radon disequilibrium in order to met the ASL D criterion for accuracy. Otherwise, radium-226 measurements may only be used for ASL B purposes.

TABLE 9-1
HPGe DETECTOR FIELD QC MEASUREMENT CRITERIA AND REQUIREMENTS

QC Element	Gamma Energy Nuclide or Basis	QC Acceptance Criteria	Frequency	Control Chart
Field Measurement Interference	1460.8 keV	keV = 1460.8 FWHM ≤ 3.0 keV or Channel = 3895.0 FWHM ≤ 8 Channels	each time measurements are made	No
Field Control Station	Total U Th-232 Ra-226 K-40	ASL D measured value ± 3σ measured value ± 3σ measured value ± 3σ	each day measurements are made	Yes
Field Control Station	Temperature Humidity Soil Moisture	No Criteria	each day measurements are made	No
MDC	FRLs for nuclides of concern	for ASL D 95% UCL[1] < FRLs for ASL B 90% UCL[1] < FRLs	quarterly	No
Measurement Accuracy	Compared to weighted average of physical samples	ASL D - weighted average of physical sample ± 20% ASL B - weighted average of physical sample ± 35%	annually	No
Measurement Bias	Compared to weighted average of physical samples	Bias acceptable unless it produces errors resulting in accuracy being exceeded	annually	No
Precision of Duplicates	At least one per 20 HPGe measurements	measured value > (5 x MDC) then RPD ≤ ± 20% measured value < (5 x MDC) then measurement difference ≤ ± MDC	at least one per 20 HPGe measurements	No
Detector Counting Efficiency Determination	Determination of conversion (efficiency) factors	initial conversion factor ± 10% for each gamma energy[2]	annually	No

1 UCL = upper confidence limit for the MDC

2

Cs-137	32.2	Eu-152	344.3	Eu-152	964.0
Eu-152	39.5	Eu-152	411.1	Eu-152	1173.7
Am-241	59.5	Eu-152	444.0	Co-60	1332.5
Eu-152	121.8	Cs-137	778.9	Co-60	1408.0
Eu-152	244.7	Eu-152	661.6		

TABLE 9-2
SW-846 AND CLP-SOW CRITERIA FOR ACCURACY AND PRECISION OF METALS

	% RPD	Data Validation Crieria to "J" Data	Laboratory Control Standard	Data Validation Criteria to "J" Data	Matrix Spike	Data Validation Crieria to "J" Data	Matrix Spike Duplicates	Data Validation Crieria to "J" Data
CLP-SOW for Inorganics	0-20% if result is greater than 5 x CRDL. If result is less than 5 x CRDL, %RPD is ± CRDL.	21-35% if result is greater than 5 x CRDL. If result is less than 5 x CRDL, %RPD is ± 2 x CRDL	80-120% recovery (aqueous). Not specified for solids	50-79% recovery or > 120% recovery	75-125% recovery	30-74% recovery or > 125%	%RPD < 20	Not specified
SW-846 for Metals	< 20%	FEMP specifies same as for CLP	75-125% or lab may set own limits based upon mean recovery ± 3 standard deviations	FEMP specifies same as for CLP	75-125% recovery	FEMP specifies same as for CLP	%RPD < 20	Not specified

TABLE 9-3
BIAS BETWEEN HPGe (1.0 m) AND LABORATORY DATA

Parameter	No. Times HPGe data are greater than weighted four method or two method average data	No. Times HPGe data are less than weighted four method or two method average data	No. Times HPGe data are equal to weighted four method or two method average data	Average % bias of HPGe data[a] relative to laboratory data
Total Uranium[b]	5	7	0	+1.07
Thorium-232	4	6	1	+1.83
Radium-226	1	14	1	+39.25

[a] Average percent bias is calculated by averaging the percent relative deviation for the data in Tables 5-2B, 6-4, and 7-6. Unlike the average percent relative deviation data, the absolute value of the difference between laboratory and HPGe data is not used in the bias calculation. Thus, negative biases tend to cancel out positive biases. Negative biases indicate HPGe data are greater than weighted lab data and positive biases indicate the reverse.

[b] Excluding sample PBC-03-01

TABLE 9-4
PERCENT RELATIVE PRECISION FOR HPGe DUPLICATE MEASUREMENTS AT 31 cm DETECTOR HEIGHT

Area	Total Uranium RPDs (ppm)				Thorium-232 RPDs (pCi/g)				Radium-226 RPDs (pCi/g)			
	31 cm HPGe Max	31 cm HPGe Min	31 cm HPGe Avg	31 cm %RPD* (Absolute value)	31 cm HPGe Max	31 cm HPGe Min	31 cm HPGe Avg	31 cm %RPD* (Absolute value)	31 cm HPGe Max	31 cm HPGe Min	31 cm HPGe Avg	31 cm %RPD* (Absolute value)
PBC-01	10.9	7.5	9.2	36.96	0.70	0.63	0.665	10.53	0.79	0.69	0.74	13.51
PBC-02	34.0	33.0	33.5	2.99	0.76	0.73	0.745	4.03	0.70	0.70	0.70	0.00
PBC-03	328	310	319	5.64	2.4	2.4	2.4	0.00	4.6	4.5	4.55	2.20
PBC-04	61.6	60.0	60.8	2.63	0.86	0.84	0.85	2.35	0.88	0.84	0.86	4.65
PBC-05	44.0	41.1	42.6	6.82	0.95	0.92	0.935	3.21	0.83	0.78	0.805	6.21
PBC-07	154	153	154	0.65	1.2	1.1	1.14	3.51	0.86	0.86	0.86	0.00
PBC-08	5.0	2.5	3.8	66.67	0.67	0.62	0.645	7.75	0.72	0.69	0.705	4.26
PBC-09	7.5	4.3	5.9	54.24	0.77	0.69	0.73	10.96	0.83	0.81	0.82	2.44
PBC-10	86.8	84.9	85.9	2.21	6.8	6.6	6.7	2.99	2.2	2.0	0.21	9.52
PBC-18	1163	1146	1155	1.47			Average =	5.04			Average =	4.75
			Average =	18.03								

* %RPD = % Relative Precision

TABLE 9-5
PERCENT RELATIVE PRECISION FOR HPGe DUPLICATE MEASUREMENTS AT 100 cm DETECTOR HEIGHT

Area	Total Uranium RPDs (ppm)				Thorium-232 RPDs (pCi/g)				Radium-226 RPDs (pCi/g)			
	100 cm HPGe Max	100 cm HPGe Min	100 cm HPGe Avg	100 cm %RPD* (Absolute value)	100 cm HPGe Max	100 cm HPGe Min	100 cm HPGe Avg	100 cm %RPD* (Absolute value)	100 cm HPGe Max	100 cm HPGe Min	100 cm HPGe Avg	100 cm %RPD* (Absolute value)
PBC-01	8.8	8.0	8.4	9.52	0.74	0.66	0.70	11.43	0.64	0.58	0.61	9.84
PBC-02	27.9	26.9	27.4	3.65	0.72	0.67	0.695	7.19	0.76	0.72	0.74	5.41
PBC-03	336	324	330	3.64	4.5	4.4	4.45	2.25	2.8	2.7	2.75	3.64
PBC-04	64.2	62.5	63.35	2.68	0.86	0.85	0.855	1.17	0.86	0.81	0.835	5.99
PBC-05	46.9	46.3	46.6	1.29	0.78	0.76	0.77	2.60	0.90	0.82	0.86	9.30
PBC-07	162	153	158	5.71	1.13	0.99	1.1	13.21	1.0	1.0	1.0	0.00
PBC-08	4.4	4.0	4.2	9.52	0.62	0.62	0.62	0.00	0.62	0.29	0.61	4.96
PBC-09	6	5.9	5.95	1.68	0.81	0.74	0.78	9.03	0.71	0.64	0.68	10.37
PBC-10	78.6	73.7	76.2	6.43	1.7	1.7	1.7	0.00	8.7	7.5	8.1	14.81
PBC-18	927	916	922	1.19			Average =	5.21			Average =	7.15
PBC-19	871	855	863	1.85								
			Average =	4.29								

* %RPD = % Relative Precision

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TABLE 9-6
DRY WEIGHT HPGe *A PRIORI* MINIMUM DETECTABLE CONCENTRATIONS

Count Time	Replicate Number	Total Uranium MDC (ppm)	Thorium-232 MDC (pCi/g)	Radium-226 MDC (pCi/g)
900 Seconds	1	6.7	0.101	0.16
	2	6.6	0.096	0.15
	3	6.2	0.098	0.16
	4	6.9	0.097	0.16
	5	6.0	0.101	0.16
	6	6.9	0.100	0.17
	7	6.8	0.096	0.16
	Average	6.59	0.098	0.160
	Std. Dev.	0.35	0.002	0.006
1800 Seconds	1	5.0	0.073	0.14
	2	5.3	0.072	0.14
	3	5.0	0.070	0.12
	4	5.1	0.070	0.12
	5	4.9	0.071	0.12
	6	4.9	0.069	0.12
	7	4.8	0.070	0.13
	Average	5.00	0.071	0.127
	Std. Dev.	0.16	0.0014	0.010

TABLE 9-7
HPGe MINIMUM DETECTABLE CONCENTRATIONS COMPARED TO FRLs

Analyte	Count Time (sec.)	MDC	Std. Dev.	95% UCL[a]	90% UCL[b]	FRL[c]
Total Uranium	900	6.59 ppm	0.35 ppm	6.85 ppm	6.78 ppm	82 ppm
	1800	5.00 ppm	0.16 ppm	5.12 ppm	5.09 ppm	82 ppm
Thorium-232	900	0.098 pCi/g	0.002 pCi/g	0.099 pCi/g	0.099 pCi/g	1.50 pCi/g
	1800	0.071 pCi/g	0.0014 pCi/g	0.072 pCi/g	0.072 pCi/g	1.50 pCi/g
Radium-226	900	0.160 pCi/g	0.006 pCi/g	0.164 pCi/g	0.164 pCi/g	1.70 pCi/g
	1800	0.127 pCi/g	0.010 pCi/g	0.134 pCi/g	0.134 pCi/g	1.70 pCi/g

[a] upper confidence limit (UCL) of the MDC is given by:

$$UCL = \bar{x} + \frac{ts}{\sqrt{n}}$$

where

t = 1.943 at 6 degrees of freedom for a one-sided 95% confidence interval,
s = standard deviation from Table 9-6, n = 7, and $\bar{x}$ is given in Table 9-7.

[b] where

t = 1.440 at 6 degrees of freedom for a one-sided 90% confidence interval.

[c] FRL for total uranium will be 20 ppm in production area

TABLE 9-8
DATA USED TO DEMONSTRATE LINEARITY OF HPGe DETECTOR RESPONSE

Source to Detector Distance (R), meters	Factor $1/R^2$ (m^{-2})	Detector Response (net counts)	
		Cs-137*	Co-60**
0.5	4	470544	277184
1	1	117636	69296
2	0.25	29409	17324
4	0.0625	7352	4331
6	0.0278	3268	1924
8	0.0156	1838	1083
11.3	0.00784	987	--

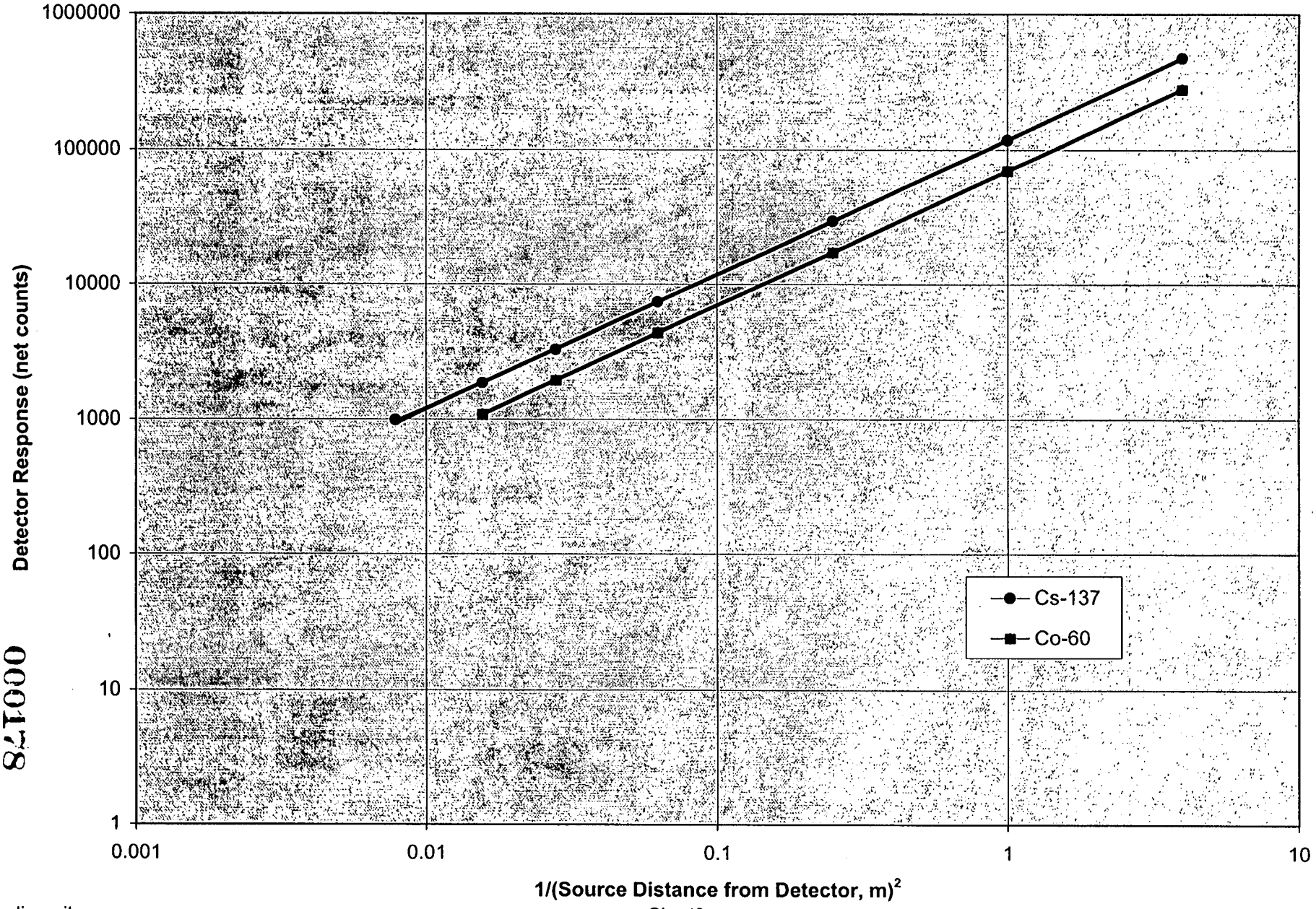
* 661.6 keV gamma photon
** 1332.5 keV gamma photon

TABLE 9-9
HPGe QUALITY CONTROL ELEMENTS [a]

QC Element	Acceptance Criteria	Does HPGe Meet Acceptance Criteria?
Accuracy	±20% RPD from the weighted average of laboratory measurements[b]	Yes
	± 35% RPD from the weighted average of laboratory measurements[b] (ASL B)	Yes
Precision of Duplicates	±20% of the relative deviation[c]	Yes
MDC	95% UCL[d] < FRL 90% UCL < FRL (ASL B)	Yes
Bias	bias acceptable unless it produces errors resulting in accuracy not being met	Yes

[a] all QC elements and acceptance criteria are for ASL D unless otherwise specified. QC elements and acceptance criteria are for total uranium, thorium-232, and radium-226.
[b] location should be the FCS.
[c] the 20% criterion is for activities greater than 5 times the MDC. For activities less than five times the MDA, the criterion for precision of duplicates is ± MDC.
[d] UCL = upper confidence limit

Figure 9-1
HPGe Detector Response Linearity



linearity

Chart3

12/2/98

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APPENDIX A

WEATHER AND SOIL MOISTURE DATA

Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
4/1/97				0.00			--	--	--
4/2/97				0.00			--	--	--
4/3/97				0.00			--	--	--
4/4/97				0.00			--	--	--
4/5/97				0.28			--	--	--
4/6/97				0.00			--	--	--
4/7/97				0.00			--	--	--
4/8/97	0846	32	--	0.00	20.95		--	--	--
4/8/97	1517	--	--		20.26				
4/9/97	0844	23	--	0.00	21.32		--	--	--
4/9/97	1541	39	--		18.96				
4/10/97	0741	20	58	0.00	19.61		--	--	--
4/10/97	1527	48	27		19.03				
4/11/97				0.11			--	--	--
4/12/97				0.62			--	--	--
4/13/97				0.01			--	--	--
4/14/97	0812	24	69	0.00	25.60		--	--	--
4/14/97	1603	52	34		23.78				
4/15/97	0802	34	83	0.00	22.12		--	--	--
4/15/97	1534	55	34		21.07				
4/16/97	0924	50	42	0.01	21.94		--	--	--
4/16/97	1552	59	57		21.94				
4/17/97	0833	35	70	tr*	20.89		--	--	--
4/17/97	1514	39	74		20.82				
4/18/97				0.00			--	--	--
4/19/97				0.01			--	--	--
4/20/97				0.00			--	--	--
4/21/97				0.26			--	--	--
4/22/97	0743	47	88	0.00	22.36		--	--	--
4/22/97	1455	60	34		20.45				

Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
4/23/97	1126	57	66	0.00	20.51		--	--	--
4/23/97	1505	62	46		19.74				
4/24/97	0728	51	87	0.00	20.19		--	--	--
4/24/97	1356	57	47		19.55				
4/25/97				0.00			--	--	--
4/26/97				0.00			--	--	--
2/27/97				0.23			--	--	--
4/28/97	0730	47	87	0.00	23.08		--	--	--
4/28/97	1521	58	55		21.26				
4/29/97	0810	54	74	0.00	20.89		--	--	--
4/29/97	1455	65	29		19.55				
4/30/97	0635	35	71	0.76	19.55		--	--	--
4/30/97	1515	75	49		19.03				
5/1/97	0817	47	63	0.00	24.47		58	44	Mostly cloudy am, partly cloudy by afternoon
5/1/97	1437	49	60		23.49				
5/2/97				1.89			62	42	Evening thunderstorms
5/3/97				0.11			59	45	Mostly cloudy, mid-afternoon cold front
5/4/97				0.00			62	45	Partly cloudy all day
5/5/97	1022	59	36	0.03	20.63		68	37	Mostly cloucy, thundershowers after sunset
5/5/97	1600	62	44		21.26				
5/6/97	0853	63	60	0.00	19.35		64	47	Mostly sunny all day
5/6/97	1534	69	36		20.00				
5/7/97	0903	50	49	0.00	20.51		69	36	Partly cloudy, cloudy during evening hours
5/7/97	1509	72	26		20.00				
5/8/97	0841	50	49	0.46		20.45	65	52	Cloudy, showers, afternoon clearing
5/9/97				tr			58	47	Cloudy with a sprinkle or two
5/10/97				0.00			60	42	Partly cloudy
5/11/97				0.00			72	32	Mostly sunny
5/12/97	0902	46	63	tr	21.81		63	49	Cloudy am, sprinkles, partly cloudy pm
5/12/97	1613	62	37		19.48				

Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
5/13/97	0754	51	59	tr	19.16		61	38	Variable cloudiness, a few light pm sprinkles
5/13/97	1500	61	32		19.42				
5/14/97				0.00			68	40	Variable cloudiness, a few light pm sprinkles
5/15/97	0933	53	59	0.00	17.56		56	40	Variable cloudiness, windy, light pm showers
5/16/97				0.00			61	34	Mostly sunny
5/17/97				0.00			77	55	Light sprinkles in am, otherwise partly cloudy
5/18/97				0.00			83	62	Variable cloudiness, thundershowers in area
5/19/97	0802	70	68	0.14	17.70		82	59	Early am showers, cloudy pm with showers thundershowers showers
5/19/97	1437	82	58		18.23				
5/20/97	0638	47	70	0.00	16.87		64	47	Mostly sunny
5/20/97	1525	63	24		17.15				
5/21/97	0800	47	61	0.00	18.10		61	43	Mostly sunny
5/21/97	1615	60	24		16.46				
5/22/97	0753	42	51	0.00	16.04		66	35	Mostly sunny
5/22/97	1556	66	22		16.04				
5/23/97				0.00			72	40	Mostly sunny
5/24/97				0.09			81	45	Partly cloudy, a few pm thundershowers
5/25/97				1.63			71	54	Cloudy, rain, heavy at times
5/26/97				0.29			63	51	Partly cloudy am, cloudy with showers in pm
5/27/97	0747	52	63	0.00	24.13		69	51	Partly cloudy
5/27/97	1500	66	57		22.30				
5/28/97				0.22			62	54	Cloudy, light rain and drizzle in pm
5/29/97				0.24			63	52	Cloudy, rain in the am
5/30/97				0.01			70	53	Mostly cloudy, brief am shower
5/31/97				2.11			60	55	Heavy rain, thundershowers
6/1/97				1.41			69	54	Cloudy, rain until mid-day, clearing in pm
6/2/97				0.00			72	51	Heavy am fog, partly cloudy pm
6/3/97				0.05			65	55	Overcast all day, light showers in late pm
6/4/97				0.00			67	51	Overcast
6/5/97				0.43			72	46	Variable cloudiness, brief heavy pm shower

Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
6/6/97				0.38			65	52	Mostly, cloudy. Occasional light rain
6/7/97				0.23			60	52	Cloudy. Occasional light rain
6/8/97				1.79			56	52	Cloudy. Rain
6/9/97				0.37			72	53	Variable Coudiness, rain very early in am
6/10/97	0749	50	73	0.00	24.81		78	46	Heavy am fog, mostly sunny
6/10/97	1452	78	47		22.66				
6/11/97	0755	53	86	0.00	24.64		73	51	Light am fog, mostly cloudy, hazy
6/11/97	1432	72	65		23.90				
6/12/97	0858	65	92	0.00	24.47		77	55	Light am fog, mostly cloudy, hazy
6/12/97	1400	75	64		23.02				
6/13/97				tr			76	59	Light am fog, cloudy am, evening sprinkles
6/14/97				0.00			76	55	Heavy dew am, partly cloudy, less humid
6/15/97				0.00			78	45	Very cool am. Sunny, warm pm
6/16/97	0852	71	65	1.22	18.50		76	58	Afternoon thunderstorms, heavy fog late pm
6/17/97	0845	61	91	0.07	24.76		75	54	Heavy am fog, late evening showers
6/17/97	1552	75	62		24.53				
6/18/97				0.37			75	61	Fog in am. Showers and thundershowers
6/19/97	0908	65	87	tr	24.81		85	58	Cloudy early am. Sprinkles. Sunny mid am on
6/19/97	1520	85	41		26.69				
6/20/97				0.00			87	60	Light am fog. Mostly sunny
6/21/97				0.03			87	64	Partly cloudy. Thunderstorms late pm
6/22/97				0.07			84	65	Cloudy early am. Partly cloudy by noon
6/23/97	0918	70	92	0.00	28.93	25.43	88	58	Heavy am fog. Otherwise mostly sunny
6/23/97	1545	89	30		30.36	25.43			
6/24/97	0900	74	93	0.00	30.26	24.92	88	59	Fog. Otherwise partly to mostly sunny
6/24/97	1410	87	32		26.74	24.92			
6/25/97	0840	78	89	0.13	31.65	24.92	89	71	Mostly sunny. Late night thundershowers
6/25/97	1458	89	63		29.92	24.92			
6/26/97				0.06			82	63	Early am showers. Partly cloudy in pm.
6/27/97				0.00			84	52	Sunny

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Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
6/28/97				0.02			83	56	Partly cloudy. Late pm shower
6/29/97				0.12			80	59	Mostly cloudy. Scattered pm showers
6/30/97				0.00			80	66	Partly cloudy
7/1/97	0900	75	92	0.00	29.13	22.68	85	67	Mostly cloudy am. Partly cloudy rest of day
7/1/97	1400	89	65		27.43	22.68			
7/2/97				0.00			90	59	Heavy am fog. Hot/humid/hazy
7/3/97	0731	67	73	0.00	19.81		82	66	Clear, pleasant
7/3/97	1409	80	48		18.23				
7/4/97				0.00			73	62	Variable cloudiness, cooler
7/5/97				0.00			73	51	Partly cloudy, pleasant
7/6/97				0.00			78	47	Partly cloudy, pleasant
7/7/97	0814	60	53	0.00	17.01		82	53	Partly Cloudy
7/7/97	1521	83	33		17.01				
7/8/97	0810	62	91	0.00	16.04		85	58	Fog in am. Mostly sunny
7/8/97	1440	85	35		16.67				
7/9/97	0828	71	90	0.00	17.01		74	62	Cloudy. Scattered showers around area
7/9/97	1455	79	71		17.36				
7/10/97	0750	55	73	0.00	16.32		77	50	Sunny, pleasant
7/10/97	1541	77	48		16.39				
7/11/97				0.00			83	50	Mostly sunny
7/12/97				0.00			85	55	Partly cloudy, some haze
7/13/97				0.00			87	57	Mostly sunny
7/14/97	0741	68	83	0.23	14.09		88	62	Variable cloudiness, thundershowers
7/15/97	0735	65	90	0.00	17.36		85	64	Partly cloudy
7/15/97	1615	85	46		14.09	17.36			
7/16/97	0751	63	77	0.00	18.30	15.59	88	55	Fog in am. Mostly sunny
7/16/97	1448	87	41		17.22	15.59			
7/17/97	0859	73	92	0.00	15.97		89	60	Light am fog. Mostly sunny, some haze
7/17/97	1353	88	44		14.97				
7/18/97				0.00			91	61	Mostly sunny. Cloudy late pm

Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
7/19/97				0.00			86	68	Variable cloudiness am. Partly cloudy in pm
7/20/97				0.00			87	63	Mostly sunny
7/21/97	0748	67	91	0.04	12.97		90	61	Variable cloudiness. Scattered pm showers
7/21/97	1436	89	57		19.74	12.97			
7/22/97				0.54			74	68	Fog in am. Cloudy with scattered showers
7/23/97	0840	70	92	0.02	17.63		82	68	Cloudy, am fog. Late afternoon shower
7/23/97	1357	93	53		16.67				
7/24/97	0821	70	93	0.00	17.15		82	68	Cloudy with fog and haze. Late pm sun
7/24/97	1520	79	61		16.25				
7/25/97				0.00			85	64	Fog in am. Mostly sunny
7/26/97				0.00			94	65	Mostly sunny
7/27/97				0.11			96	72	Mostly sunny. Pm thunderstorms
7/28/97	0750	70	92	tr	13.94		89	65	Light am fog. Scattered showers
7/28/97	1530	90	85		12.82				
7/29/97	0651	70	91	0.00	12.74		81	69	Mostly sunny am, mostly cloudy pm
7/29/97	1520	84	36		13.19				
7/30/97	0750	61	69	0.00	11.11		79	61	Mostly sunny
7/30/97	1551	81	48		13.72				
7/31/97	0840	62	71	--	14.16		--	--	--
7/31/97	1634	83	42		11.97				
8/1/97				0.00			85	53	Light am fog. Mostly to partly cloudy
8/2/97				tr			81	54	Variable cloudiness. Light afternoon showers
8/3/97				0.00			90	59	Mostly sunny
8/4/97	0820	67	84	0.00	14.02		85	65	--
8/4/97	1507	85	47		13.57				
8/5/97	0855	67	62	0.00	13.57		76	61	Mostly sunny
8/5/97	1512	72	43		9.83	13.57			
8/6/97	0832	54	60	0.00	13.34		73	46	Mostly sunny
8/6/97	1426	73	29		12.97				

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Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
8/7/97	0942	65	79	0.00	9.67	12.74	79	45	--
8/7/97	1630	80	24		12.51				
8/8/97				0.00			84	47	--
8/9/97				0.00			76	65	Mostly sunny
8/10/97				0.01			74	63	Mostly cloudy, occasional sprinkles
8/11/97	0844	65	90	0.00	11.82		86	58	Heavy am fog. Mostly cloudy
8/11/97	1453	86	61		21.57	11.82			
8/12/97	0847	67	78	0.25	12.20		87	65	Fog in am. Variable cloudiness, pm showers
8/13/97				0.96			79	66	Fog in am. Thundershowers. Cloudy pm
8/14/97	0808	65	78	0.00	22.00		80	65	Cloudy am. Mostly sunny pm
8/14/97	1505	79	49		19.81				
8/15/97				0.81			85	65	Light rain and fog am. Cloudy, breezy pm
8/16/97				0.00			90	76	Mostly sunny, breezy
8/17/97				2.31			80	64	Thundershowers am. Thunderstorms pm
8/18/97	0901	63	88	0.00	30.89	27.71	81	59	Light am fog. Partly cloudy by afternoon
8/18/97	1447	80	67		24.53	27.71			
8/19/97	0913	69	77	0.17	29.33	26.02	73	60	Light am fog. Light rain in afternoon/evening
8/19/97	1457	72	61		22.72	26.02			
8/20/97	1223	67	83	0.30	25.54		71	58	Early am rain, fog, drizzle. Mostly cloudy pm
8/21/97	0930	64	68	0.00	25.32	25.32	70	59	Variable cloudiness
8/21/97	1530	71	62		29.43	25.32			
8/22/97				0.00			71	50	Partly cloudy
8/23/97				0.00			73	46	Variable cloudiness
8/24/97				0.00			74	51	Mostly cloudy
8/25/97	0820	69	77	0.00	23.49		78	62	Mostly cloudy am. Partly cloudy pm
8/25/97	1440	78	72		23.14				
8/26/97				0.00			81	57	Heavy am fog
8/27/97	1000	62	85	0.03	24.13		84	61	am fog, showers. Partly cloudy pm
8/27/97	1435	84	80		24.36				
8/28/97	1448	84	48	0.00	21.57		84	60	Heavy am fog. Otherwise mostly sunny

Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
8/29/97	0924	62	76	0.00	20.70		75	56	Mostly sunny
8/29/97	1547	74	39		20.70				
8/30/97				0.00			76	52	Heavy am fog. Mostly sunny by mid am
8/31/97				0.00			83	58	Mostly sunny
9/1/97				0.00			85	62	Mostly sunny
9/2/97	1053	84	67	0.02	19.03		87	60	Dense am fog. Sunny pm. Showers after dark
9/2/97	1616	87	45		19.03				
9/3/97	1345	67	28	0.01	18.57		70	52	Overcast am. Partly cloudy pm
9/4/97	1048	55	50	0.00	17.15		69	40	Mostly sunny. New record lows in area
9/4/97	1555	69	36		17.15				
9/5/97				0.00			74	41	Mostly sunny. New record lows in area
9/6/97				tr			78	50	Variable coudiness. Isolated showers in
9/7/97				0.21			83	58	Mostly cloudy. pm
9/8/97	0900	63	91	0.03	14.75		80	63	Partly cloudy. Showers very late pm
9/8/97	1524	81	55		13.87				
9/9/97				0.46			72	64	Mostly cloudy. Showers/thundershowers
9/10/97	0845	62	92	0.00	17.87		71	61	Mostly cloudy. Scattered showers in area
9/10/97	1457	69	70		17.87				
9/11/97				tr			69	52	Light am fog,am sprinkles,some pm
9/12/97				0.00			73	47	Dense am fog. Clear am. Partly cloudy pm
9/13/97				0.00			75	46	Mostly sunny
9/14/97				0.00			77	54	Mostly sunny
9/15/97	0927	61	91	0.00	16.67		80	57	Light am fog. Otherwise variable cloudiness
9/15/97	1727	85	48		15.90				
9/16/97	0822	64	95	0.00	16.87		82	54	Dense am fog. Sunny am. Partly cloudy pm
9/16/97	1524	82	42		14.68				
9/17/97	0908	64	95	tr	15.40		77	56	Cloudy. Occasional showers
9/17/97	1420	74	42		14.31				
9/18/97	0936	58	85	0.00	15.54		80	44	Fog am. Clear in am. Partly cloudy pm
9/19/97				0.00			88	47	Mostly sunny am. Mostly cloudy pm

Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
9/20/97				0.02			76	56	Showers before sunup. Mostly cloudy in pm
9/21/97				0.00			66	46	Variable cloudiness am. Mostly sunny pm
9/22/97	0830	58	85	0.00	13.94		68	39	Mostly cloudy with high thin overcast
9/22/97	1450	67	83		13.42				
9/23/97				0.03			60	49	Cloudy with light rain/rainshowers
9/24/97				0.00			67	45	Cloudy am. Mostly sunny by late afternoon
9/25/97	0958	52	89	0.00	13.49		76	36	Some am fog. Otherwise mostly sunny/clear
9/26/97				0.00			73	44	Mostly sunny
9/27/97				0.00			76	44	Mostly sunny
9/28/97				0.01			78	46	Sunny. Cloudy evening, cold front/light rain
9/29/97				0.01			78	49	Very early am rain
9/30/97	1015	64	51	0.00	12.28		69	51	Clear am. Mostly cloudy pm
9/30/97	1515	71	47		11.97				
10/1/97	0854	52	79	0.00	11.82		64	41	Mostly sunny am. Partly cloudy pm
10/2/97	0825	52	79	0.00	12.28		69	32	Fog/patchy frost in am. Partly/mostly cloudy
10/3/97				0.00			81	51	Mostly sunny
10/4/97				0.00			84	63	Mostly sunny
10/5/97				0.00			84	54	Mostly sunny
10/6/97	0935	63	82	0.00	11.74		83	52	Light am fog. Otherwise mostly sunny
10/6/97	1451	82	49		11.50				
10/7/97	0843	68	75	0.00	11.43		82	57	Mostly cloudy/hazy. Late afternoon clearing
10/7/97	1435	81	50		10.95				
10/8/97				0.00			83	52	Some am fog. Otherwise mostly sunny/hazy
10/9/97	1050	68	94	tr	10.87		81	57	Mostly cloudy/hazy. Rain showers in evening
10/9/97	1420	67	67		10.87				
10/10/97				0.00			76	50	Cloudy early am. Otherwise mostly sunny
10/11/97				0.00			75	39	Mostly sunny
10/12/97				0.00			84	43	Mostly sunny
10/13/97	0907	70	70	0.49	10.95		79	48	Mostly cloudy/windy. Rain in evening

Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
10/14/97	0830	41	88	0.01	19.35		61	44	Mostly cloudy early am. Mostly sunny pm
10/14/97	1513	61	40		18.30				
10/15/97	0850	43	73	0.00	17.22		56	31	am frost. Clear am. Mostly sunny pm
10/15/97	1537	56**	40		16.94				
10/16/97	829	38	85	0.00	14.31	16.77	56	38	Variable cloudiness
10/16/97	1415	55**	--		16.60				
10/17/97				0.00			53	42	Mostly cloudy
10/18/97				0.00			60	35	Mostly sunny
10/19/97				0.00			64	31	Mostly sunny
10/20/97	0907	47	78	0.00	14.31		60	36	Mostly cloudy am. Mostly cloudy pm
10/21/97	0750	37	86	0.00	13.72		56	33	Variable cloudiness
10/21/97	1531	57	40		13.27				
10/22/97	0845	30	92	0.00	13.49		47	25	Killing frost. Variable cloudiness
10/22/97	1551	46	78		13.49				
10/23/97	0910	27	83	0.00	12.97		51	22	Variable cloudiness
10/24/97				0.34			48	33	Overcast. Rain began about 10 am. Fog
10/25/97				0.00			57	46	Mostly cloudy
10/26/97				0.87			52	44	Overcast Rain and drizzle. Fog
10/27/97	0848	38	86	0.02	24.18		43	34	Mostly cloudy. Gradual clearing by evening
10/27/97	1547	42	61		23.43				
10/28/97	0740	23	38	0.00	23.49		49	24	Mostly sunny
10/29/97	0809	33**	--	0.00	22.66		59	31	Mostly sunny
10/30/97				0.00			64	27	Dense am fog. Otherwise mostly sunny
10/31/97				0.02			64	44	Early am showers. Mostly cloudy
11/1/97				0.30			61	46	Occasional rain. Thunderstorm at 1pm
11/2/97				0.07			49	40	Mostly cloudy. Morning shower
11/3/97				0.12			43	34	Overcast am. Rain/snow showers mixed
11/4/97	0900	29	86	tr	24.59		40	34	Overcast with a snow flurry or two
11/4/97	1430	42	72		24.18				

Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
11/5/97	0833	40	67	0.00	24.36		54	38	Mostly sunny. Cloudy in evening
11/5/97	1415	54	51		23.20				
11/6/97	0837	43	63	0.09	21.51		50	42	Cloudy. Some light rain/showers in evening
11/7/97				0.05			48	37	Mostly cloudy. Evening showers
11/8/97				0.01			50	39	Overcast. Rain shower very early am
11/9/97				0.00			50	33	Mostly sunny. Clouds in late afternoon
11/10/97				0.01			46	39	Cloudy with sprinkles. Light rain in evening
11/11/97				0.00			44	36	am sun. Clouds in by mid- afternoon
11/12/97	0800	27	--	0.00	21.20		36	24	Mostly cloudy
11/13/97	0905	32	--	0.58	19.68		39	25	Rain by mid-afternoon through evening. Fog
11/14/97	1038	32	--	0.01	25.32		35	32	Overcast, cold. Light, early am rain
11/14/97	1412	32	--		24.07				
11/15/97				0.02			34	29	Light snow/fog. About 0.33 in. accumulation
11/16/97				tr			32	23	Overcast. Flurries and light snow showers
11/17/97	1003	15	--	0.00	24.53		36	16	Mostly sunny
11/17/97	1335	28	--		25.43				
11/18/97	1400	44	42	0.00	24.36		44	14	Dense am fog. Otherwise, sunny
11/19/97	0953	33	66	0.00	25.26		53	30	Mostly sunny am. Variable cloudiness pm
11/19/97	1335	50	72		25.04				
11/20/97	0950	36	84	0.00	24.36		57	24	Fog in am, otherwise partly to mostly cloudy
11/20/97	1440	58	48		24.47				
11/21/97				0.44			43	36	Overcast. Rain
11/22/97				0.01			42	37	Overcast. Early am rain
11/23/97				0.00			40	27	Mostly cloudy am. Partly cloudy pm
11/24/97	1124	33	62	0.00	26.25		38	22	Early am clouds. Otherwise, mostly sunny
11/25/97				0.00			56	21	Early am clouds. Otherwise, mostly sunny
11/26/97	1030	50	78	0.00	24.53		58	42	Overcast to occasional mostly cloudy. Windy
11/27/97				0.00			51	23	Mostly cloudy
11/28/97				0.00			65	52	Mostly cloudy

Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
11/29/97				0.00			64	52	Mostly cloudy
11/30/97				0.87			58	41	Overcast. Rain. Windy
12/1/97	0852	37**	--	0.00	16.25	25.25	42	36	Cloudy
12/1/97	1525	41	72		21.69	25.25			
12/2/97	0844	38	75	0.00	25.21		46	34	Cloudy early am. Partly cloudy to cloudy pm
12/3/97				0.20			54	40	Periods of light rain. Moderate evening rain
12/4/97				tr			44	33	Overcast. Occasional drizzle. Some fog
12/5/97				0.02			32	24	Occasional snow/flurries/showers. 0.2 in..
12/6/97	1150	26	--	tr	26.09		27	21	Overcast with flurries. 0.1 in. Some fog
12/7/97				0.00			31	27	Overcast
12/8/97	0820	25	--	tr	26.36		34	26	am sun. Cloudy pm. Evening snow, 0.1 in.
12/9/97				0.23			37	28	am snow, 0.2 in. Dense am fog. Rain in pm
12/10/97				0.45			43	35	Overcast. Early am rain. Mid-day shower
12/11/97	0928	34	81	tr	26.25		36	31	Overcast, fog and drizzle. Light snow in pm
12/11/97	1548	35	68		26.47				
12/12/97				tr			34	27	early am light snow. Sunny am. Coudy pm
12/13/97				0.00			37	28	Mostly sunny
12/14/97				0.00			36	22	Mostly sunny
12/15/97				0.00			47	17	Mostly sunny
12/16/97	0908	23	--	0.00	25.21		51	20	Mostly sunny
12/17/97				0.00			50	24	Mostly sunny
12/18/97				0.00			51	19	Ice fog w/heavy frost until noon
12/19/97				0.00			57	34	Mostly sunny
12/20/97				0.00			42	27	Mostly cloudy
12/21/97				0.04			42	34	Mostly cloudy. Rain after dark
12/22/97				0.45			51	31	Overcast with fog, rain, and drizzle
12/23/97				tr			40	35	Overcast with fog and drizzle
12/24/97				0.69			46	36	Overcast with fog and rain
12/25/97				0.02			46	34	Overcast with fog, light rain, and drizzle
12/26/97				0.00			35	33	Overcast
12/27/97				0.00			33	27	Mostly cloudy. Some mid-day sun
12/28				0.00			35	18	Mostly sunny

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Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
12/29/97	0839	21	94	0.06	23.14	25.54	36	22	Cloudy, light fog. 0.6 in. snow after 3 pm
12/29/97	1502	28	--		25.54				
12/30/97	0840	27	84	0.01	27.27		29	22	Cloudy. Snow showers/flurries. 0.2 in.
12/30/97	1502	28	73		27.27				
12/31/97				0.01			27	10	Light am snow. Snow showers pm. 0.1 in.
1/1/98				0.00			40	7	Variable cloudiness
1/2/98				0.00			51	41	Mostly cloudy
1/3/98				0.04			58	50	Cloudy. Mid-morning showers
1/4/98				0.00			64	52	Mostly cloudy
1/5/98	0828	53	76	0.16	25.93		60	52	Cloudy. Light rain in afternoon and evening
1/6/98	0814	47**	--	0.42	26.52		58	46	Dense fog am/pm. Showers am/pm
1/6/98	1429	58**	--		26.69				
1/7/98				1.96			57	39	Overcast with rain, fog. Dense fog at times
1/8/98				0.17			54	37	Cloudy, fog.
1/9/98				0.09			45	33	--
1/10/98				0.00			39	29	--
1/11/98				0.00			32	19	--
1/12/98				0.02			49	31	--
1/13/98	0855	28	74	0.01	26.74		42	22	--
1/13/98	1524	30	53		26.74				
1/14/98	0810	19	--	0.00	25.87		38	19	--
1/15/98	1508	35	89	0.00	27.01		38	29	--
1/16/98				0.00			32	30	--
1/17/98				0.03			33	27	--
1/18/98				0.02			30	21	--
1/19/98				0.00			33	23	--
1/20/98	0748	27	77	0.00	25.04		34	20	--
1/20/98	1527	34	63		25.04				
1/21/98	0951	33	66	0.00	28.32	25.00	38	27	--
1/21/98	1456	38	61		28.32	25.00			
1/22/98	0919	38	80	0.34	26.58		45	33	--

Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
1/23/98				0.06			35	32	--
1/24/98				0.01			35	26	--
1/25/98				0.00			35	31	--
1/26/98	0827	26**	--	0.00	26.09		47	23	--
1/26/97	1500	47**	--		20.51	26.0			
1/27/98	0821	28	95	0.00	25.54		50	27	--
1/27/98	1513	50	46		26.58				
1/28/98	1443	51	43	0.00	26.25		53	20	--
1/29/98	0814	40	78	0.00	25.76		44	31	--
1/29/98	1508	38	80		25.26				
1/30/98				0.00			35	31	--
1/31/98				0.00			41	24	--
2/1/98				0.00			53	27	--
2/2/98	0927	48	51	0.00	24.07		52	35	--
2/2/98	1427	51**	--		23.25				
2/3/98	0836	33	78	0.00	23.43		42	32	--
2/3/98	1451	42	52		22.66				
2/4/98				0.31			34	28	--
2/5/98				0.54			32	27	--
2/6/98				0.00			38	26	--
2/7/98				0.00			40	23	--
2/8/98				0.00			43	20	--
2/9/98				0.00			46	22	--
2/10/98				0.00			50	30	--
2/11/98	0818	45	70	0.36	28.77		48	35	--
2/12/98	0933	33	78	0.01		28.70	39	33	--
2/13/98				0.00			42	30	--
2/14/98				0.00			47	28	--
2/15/98				0.00			52	24	--
2/16/98				0.18			51	37	--

Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
2/17/98				0.30			49	41	--
2/18/98				0.19			42	35	--
2/19/98	0838	39	88	0.05		28.00	42	39	--
2/19/98	1441	43	75			28.00			
2/20/98				0.08			42	40	Fog, drizzle, and occasional light rain
2/21/98				0.00			44	29	Cloudy
2/22/98				0.00			51	31	Mostly cloudy
2/23/98				tr			46	32	Cloudy. Morning sprinkles
2/24/98	1440	56	29.3	0.01		25.00	58	21	Early am showers. Cloudy am. Sunny pm
2/25/98				0.00			57	25	Dense am "ice" fog. Mostly sunny pm
2/26/98	0902	44	71	0.00	24.36		67	41	Mostly cloudy. A few breaks to partly cloudy
2/27/98				tr			61	40	Early am sprinkles. Variable cloudiness
2/28/98				0.01			59	33	Variable cloudiness. Some afternoon
3/1/98				0.00			45	29	Mostly cloudy
3/2/98	0853	34	84	tr	23.25		38	31	Some early am sun. Otherwise, cloudy
3/3/98	0833	27	91	0.02	22.42		39	32	Light am snow/flurries. Otherwise cloudy
3/3/98	1506	41	83		22.84				
3/4/98				0.14			37	28	Cloudy. Periods of light snow(1.5 inces).
3/5/98	0847	28	95	0.00		25.32	38	24	Mostly cloudy. Some light fog.
3/5/98	1443	38**	--		25.32				
3/6/98				0.00			48	30	Variable cloudiness
3/7/98				0.00			52	36	Mostly cloudy
3/8/98				0.62			68	43	Mostly cloudy. Late night thundershowers
3/9/98				0.52			57	28	Windy. Rain am. Light snow pm().1 in.)
3/10/98				tr			26	20	Partly to mostly cloudy. Some light flurries
3/11/98				tr			24	15	Mostly cloudy. Afternoon snow showers
3/12/98				0.00			28	10	Clear
3/13/98				0.00			40	16	Breezy variable cloudiness
3/14/98				0.00			44	29	Sunny
3/15/98				0.00			40	21	Mostly sunny
3/16/97	0811	32	63	0.00	25.37		43	32	Mostly cloudy
3/16/98	1357	40	43		25.37				

Date	Time	Air Temp. (F)	% Humidity	Rainfall (inches)	Soil Moisture (%)	Corrected Soil Moisture (%)	Daily High Temp. (F)	Daily Low Temp. (F)	Comments
3/17/98				0.38			52	36	Cloudy. Occasional light rain/showers
3/18/98				0.12			60	49	Cloudy. Occasional light rain/fog
3/19/98	0714	48	95	0.00	28.26		62	48	Variable cloudiness
3/19/98	1545	62	57		27.95				
3/20/98				0.42			49	36	Cloudy/very windy. Occasional rain/showers
3/21/98				0.12			36	30	Cloudy/windy. Light snow. 1.2 in.
3/22/98				0.00			42	34	Mostly cloudy. Breezy
3/23/98	0748	26	95	0.05	29.38		43	24	Scattered afternoon/evening rain showers
3/24/98	0852	31	96	0.00	27.95		47	25	Dense am fog. Otherwise mostly sunny
3/24/98	1512	47	35		27.22				
3/25/98				0.01			61	40	am rain showers. Partly cloudy to sunny pm
3/26/98	0926	66	47	0.00	26.58		76	58	Sunny and windy
3/26/98	1315	72	42		24.76	26.40			
3/27/98				0.00			78	66	Partly cloudy
3/28/98				0.00			77	67	Mostly cloudy
3/29/98				0.00			82	53	Sunny
3/30/98	0908	73	52	0.00	20.38		81	66	Mostly sunny
3/30/98	1530	80	36		21.14				
3/31/98	0652	69	58	0.30	18.77		81	52	Variable cloudiness. Evening showers/rain
3/31/98	1519	80	34		19.16				

* tr = trace

** Temperatures estimated from daily highs and lows.

000198

APPENDIX B

HPGe MEASUREMENTS (WET WEIGHT BASIS) OF TOTAL URANIUM, THORIUM-232, RADIUM-226 AND POTASSIUM-40

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
4/1/97	41					0.00					
4/2/97	42					0.00					
4/3/97	43					0.00					
4/4/97	44					0.00					
4/5/97	45					0.28					
4/6/97	46					0.00					
4/7/97	47					0.00					
4/8/97	48a	0846	32		20.95	0.00	30716	73.74	0.89	1.04	10.50
4/8/97	48p	1517			20.26	0.00	30716	76.42	0.87	0.78	10.80
4/9/97	49a	0844	23		21.32	0.00	30687	74.93	0.83	0.78	10.10
4/9/97	49p	1541	39		18.96	0.00	30687	74.38	0.87	0.74	10.80
4/10/97	410a	0741	20	58	19.61	0.00	31108	78.53	0.91	1.07	10.80
4/10/97	410p	1527	48	27	19.03	0.00	31108	74.97	0.92	0.77	10.60
4/11/97	411					0.11					
4/12/97	412					0.62					
4/13/97	413					0.01					
4/14/97	414a	0812	24	69	25.60	0.00	30687	68.95	0.85	0.97	10.10
4/14/97	414p	1603	52	34	23.78	0.00	30687	74.32	0.87	0.76	10.10
4/15/97	415a	0802	34	83	22.12	0.00	30716	71.32	0.88	1.36	10.60
4/15/97	415p	1534	55	34	21.07	0.00	30716	76.12	0.87	0.75	10.70
4/16/97	416a	0924	50	42	21.94	0.01	30904	71.94	0.87	0.84	9.53
4/16/97	416p	1552	59	57	21.94	0.00	30904	75.83	0.88	0.87	9.72
4/17/97	417a	0833	35	70	20.89	0.00	31108	74.33	0.88	0.79	10.70
4/17/97	417p	1514	39	74	20.82	0.00	31108	74.04	0.86	0.81	10.80
4/18/97	418					0.00					
4/19/97	419					0.01					
4/20/97	420					0.00					
4/21/97	421					0.26					
4/22/97	422a	0743	47	88	22.36	0.00	30687	71.63	0.85	0.98	10.30
4/22/97	422p	1455	60	34	20.45	0.00	30687	72.22	0.86	0.74	10.50
4/23/97	423a	1126	57	66	20.51	0.00	30904	76.13	0.89	0.77	10.10
4/23/97	423p	1505	62	46	19.74	0.00	30904	63.28	0.81	0.74	10.10
4/24/97	424a	0728	51	87	20.19	0.00	31108	76.43	0.92	0.86	10.50

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
4/24/97	424p	1356	57	47	19.55	0.00	31108	77.03	0.89	0.74	10.70
4/25/97	425					0.00					
4/26/97	426					0.00					
4/27/97	427					0.23					
4/28/97	428a	0730	47	87	23.08	0.00	30687	69.59	0.87	0.72	10.20
4/28/97	428p	1521	58	55	21.26	0.00	30687	74.07	0.87	0.75	10.30
4/29/97	429a	0810	54	74	20.89	0.00	30687	73.45	0.85	0.98	10.30
4/29/97	429p	1455	65	29	19.55	0.00	30687	74.39	0.87	0.73	10.50
4/30/97	430a	0635	35	71	19.55	0.00	30904	75.83	0.90	1.27	10.50
4/30/97	430p	1515	75	49	19.03	0.76	30904	77.36	0.91	0.75	10.30
5/1/97	51a	0817	47	63	24.47	0.00	31108	71.04	0.85	0.73	10.70
5/1/97	51p	1437	49	60	23.49	0.00	31108	73.74	0.84	0.74	10.40
5/2/97	52					1.89					
5/3/97	53					0.11					
5/4/97	54					0.00					
5/5/97	55a	1022	59	36	20.63	0.00	30687	73.74	0.84	0.76	10.30
5/5/97	55p	1600	62	44	21.26	0.03	30687	74.07	0.83	0.76	10.10
5/6/97	56a	0853	63	60	19.35	0.00	30904	73.73	0.89	0.72	9.72
5/6/97	56p	1534	69	36	20.00	0.00	30904	73.76	0.84	0.71	10.20
5/7/97	57a	0903	50	49	20.51	0.00	30904	75.84	0.88	0.92	9.77
5/7/97	57p	1509	72	26	20.00	0.00	30904	77.04	0.85	0.79	10.20
5/8/97	58a	0841	50	49	20.45	0.46	31108	74.35	0.93	0.87	10.80
5/9/97	59					0.00					
5/10/97	510					0.00					
5/11/97	511					0.00					
5/12/97	512a	0902	46	63	21.81	0.00	30687	75.25	0.92	0.77	10.60
5/12/97	512p	1613	62	37	19.48	0.00	30687	74.66	0.89	0.74	10.70
5/13/97	513a	0754	51	59	19.16	0.00	31108	78.21	0.91	1.14	10.90
5/13/97	513p	1500	61	32	19.42	0.00	31108	80.92	0.91	0.80	11.20
5/14/97	514					0.00					
5/15/97	515a	0933	53	59	17.56	0.00	31108	77.34	0.95	0.81	10.80
5/16/97	516					0.00					
5/17/97	517					0.00					

000201

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
5/18/97	518					0.00					
5/19/97	519a	0802	70	68	17.70	0.00	30687	77.39	0.92	0.80	11.50
5/19/97	519p	1437	82	58	18.23	0.14	30687	80.65	0.98	0.80	11.20
5/20/97	520a	0638	47	70	16.87	0.00	31108	78.29	0.91	0.81	11.00
5/20/97	520p	1525	63	24	17.15	0.00	31108	80.98	1.00	0.75	11.70
5/21/97	521a	0800	47	61	18.10	0.00	30904	82.48	0.94	0.80	11.00
5/21/97	521p	1615	60	24	16.46	0.00	30687	79.13	0.99	0.80	11.70
5/22/97	522a	0753	42	51	16.04	0.00	31108	83.60	1.01	1.38	11.50
5/22/97	522p	1556	66	22	16.04	0.00	31108	84.25	0.98	0.87	11.50
5/23/97	523					0.00					
5/24/97	524					0.09					
5/25/97	525					1.63					
5/26/97	526					0.29					
5/27/97	527a	0747	52	63	24.13	0.00	30687	69.24	0.82	0.80	9.51
5/27/97	527p	1500	66	57	22.30	0.00	30687	67.17	0.86	0.73	9.36
5/28/97	528					0.22					
5/29/97	529					0.24					
5/30/97	530					0.01					
5/31/97	531					2.11					
6/1/97	61					1.41					
6/2/97	62					0.00					
6/3/97	63					0.05					
6/4/97	64					0.00					
6/5/97	65					0.43					
6/6/97	66					0.38					
6/7/97	67					0.23					
6/8/97	68					1.79					
6/9/97	69					0.37					
6/10/97	610a	0749	50	73	24.81	0.00	30687	65.32	0.77	0.95	9.95
6/10/97	610p	1452	78	47	22.66	0.00	30687	67.16	0.80	0.82	9.73
6/11/97	611a	0755	53	86	24.64	0.00	31108	63.26	0.76	0.98	9.01
6/11/97	611p	1432	72	65	23.90	0.00	31108	66.58	0.78	0.71	8.89
6/12/97	612a	0858	65	92	24.47	0.00	30904	70.41	0.85	0.90	10.00

000202

1950

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
6/12/97	612p	1400	75	64	23.02	0.00	30904	69.56	0.83	0.74	9.67
6/13/97	613					0.00					
6/14/97	614					0.00					
6/15/97	615					0.00					
6/16/97	616a	0852	71	65	18.50	1.22	30687	73.18	0.90	0.80	10.70
6/17/97	617a	0845	61	91	24.76	0.00	40743	65.65	0.80	0.83	9.54
6/17/97	617p	1552	75	62	24.53	0.07	40743	65.37	0.81	0.68	9.84
6/18/97	618					0.37					
6/19/97	619a	0908	65	87	24.81	0.00	30716	62.05	0.77	0.76	9.34
6/19/97	619p	1520	85	41	26.96	0.00	30716	63.56	0.71	0.70	9.45
6/20/97	620					0.00					
6/21/97	621					0.03					
6/22/97	622					0.07					
6/23/97	623a	0918	70	92	25.43	0.00	30687	73.15	0.90	1.00	10.50
6/23/97	623p	1545	89	30	25.43	0.00	30687	72.87	0.87	0.77	11.10
6/24/97	624a	0900	74	93	24.92	0.00	30716	68.08	0.89	1.18	10.70
6/24/97	624p	1410	87	32	24.92	0.00	30716	70.78	0.90	0.76	10.40
6/25/97	625a	0840	78	89	24.92	0.00	40743	75.25	0.95	0.87	10.60
6/25/97	625p	1458	89	63	24.92	0.13	40743	74.97	0.95	0.77	11.00
6/26/97	626					0.06					
6/27/97	627					0.00					
6/28/97	628					0.02					
6/29/97	629					0.12					
6/30/97	630					0.00					
7/1/97	71a	0900	75	92	22.68	0.00	30687	78.86	0.89	0.81	10.80
7/1/97	71p	1400	89	65	22.68	0.00	30687	77.08	0.93	0.81	11.20
7/2/97	72					0.00					
7/3/97	73a	0731	67	73	19.81	0.00	31108	79.44	0.97	0.93	11.50
7/3/97	73p	1409	80	48	18.23	0.00	31108	82.46	0.97	0.83	11.80
7/4/97	74					0.00					
7/5/97	75					0.00					
7/6/97	76					0.00					
7/7/97	77a	0814	60	53	17.01	0.00	30687	82.14	1.01	1.26	11.60

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
7/7/97	77p	1521	83	33	17.01	0.00	30687	85.48	0.97	0.83	11.90
7/8/97	78a	0810	62	91	16.04	0.00	30716	80.38	1.01	1.20	11.40
7/8/97	78p	1440	85	35	16.67	0.00	30716	78.58	0.99	0.85	11.40
7/9/97	79a	0828	71	90	17.01	0.00	30904	86.91	0.98	0.92	11.50
7/9/97	79p	1455	79	71	17.36	0.00	30904	82.77	0.99	0.93	11.90
7/10/97	710a	0750	55	73	16.32	0.00	30716	82.15	0.97	0.96	11.80
7/10/97	710p	1541	77	48	16.39	0.00	30716	81.54	1.01	0.79	11.70
7/11/97	711					0.00					
7/12/97	712					0.00					
7/13/97	713					0.00					
7/14/97	714a	0741	68	83	14.09	0.23	30687	84.21	1.06	1.53	11.60
7/15/97	715a	0735	65	90	17.36	0.00	30716	76.78	0.97	0.88	11.20
7/15/97	715p	1615	85	46	17.36	0.00	30716	77.97	0.97	0.86	11.60
7/16/97	716a	0751	63	77	15.59	0.00	30904	77.08	0.99	1.38	11.40
7/16/97	716p	1448	87	41	15.59	0.00	30904	86.34	1.04	0.89	12.30
7/17/97	717a	0859	73	92	15.97	0.00	31108	85.13	1.03	1.26	12.00
7/17/97	717p	1353	88	44	14.97	0.00	31108	82.16	1.01	0.94	12.40
7/18/97	718					0.00					
7/19/97	719					0.00					
7/20/97	720					0.00					
7/21/97	721a	0748	67	91	12.97	0.00	30687	89.02	1.07	1.46	12.50
7/21/97	721p	1436	89	57	12.97	0.04	30687	83.67	1.05	0.93	12.30
7/22/97	722					0.54					
7/23/97	723a	0840	70	92	17.63	0.00	30904	77.06	0.97	1.11	11.50
7/23/97	723p	1357	93	53	16.67	0.02	30904	78.28	0.93	0.93	11.70
7/24/97	724a	0821	70	93	17.15	0.00	31108	76.12	0.95	1.14	11.50
7/24/97	724p	1520	79	61	16.25	0.00	31108	80.63	0.98	0.96	11.40
7/25/97	725					0.00					
7/26/97	726					0.00					
7/27/97	727					0.11					
7/28/97	728a	0750	70	92	13.94	0.00	40743	81.87	0.99	1.04	11.50
7/28/97	728p	1530	90	85	12.82	0.00	40743	80.07	0.93	1.11	11.90
7/29/97	729a	0651	70	91	12.74	0.00	40743	84.84	1.00	1.14	12.00

000204

1950

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
7/29/97	729p	1520	84	36	13.19	0.00	40743	84.29	1.00	0.87	12.00
7/30/97	730a	0750	61	69	11.11	0.00	30904	86.06	1.02	1.00	12.50
7/30/97	730p	1551	81	48	13.72	0.00	30904	85.50	1.06	0.83	12.30
7/31/97	731a	0840	62	71	14.16		31108	84.85	1.06	1.05	12.10
7/31/97	731p	1634	83	42	11.97		31108	86.37	1.04	0.87	12.30
8/1/97	81					0.00					
8/2/97	82					0.00					
8/3/97	83					0.00					
8/4/97	84a	0820	67	84	14.02	0.00	40743	76.51	1.03	1.21	12.30
8/4/97	84p	1507	85	47	13.57	0.00	40743	86.99	1.08	0.94	12.30
8/5/97	85a	0855	67	62	13.57	0.00	30687	88.44	1.06	1.05	12.80
8/5/97	85p	1512	72	43	13.57	0.00	30687	89.94	1.09	0.89	13.00
8/6/97	86a	0832	54	60	13.34	0.00	30716	87.51	1.06	1.47	12.30
8/6/97	86p	1426	73	29	12.97	0.00	30716	83.10	1.00	0.89	12.40
8/7/97	87a	0942	65	79	12.74	0.00	30904	89.61	1.08	1.44	12.40
8/7/97	87p	1630	80	24	12.51	0.00	30904	91.75	1.11	0.87	12.20
8/8/97	88					0.00					
8/9/97	89					0.00					
8/10/97	810					0.01					
8/11/97	811a	0844	65	90	11.82	0.00	30716	85.45	1.05	1.33	12.30
8/11/97	811p	1453	86	61	11.82	0.00	30716	86.05	1.06	1.00	12.30
8/12/97	812a	0847	67	78	12.20	0.25	31108	90.51	1.11	1.20	12.40
8/13/97	813					0.96					
8/14/97	814a	0808	65	78	22.00	0.00	31108	73.76	0.91	1.05	11.20
8/14/97	814p	1505	79	49	19.81	0.00	31108	77.94	0.97	0.82	11.20
8/15/97	815					0.81					
8/16/97	816					0.00					
8/17/97	817					2.31					
8/18/97	818a	0901	63	88	27.71	0.00	40743	64.80	0.83	0.76	10.00
8/18/97	818p	1447	80	67	27.71	0.00	40743	72.26	0.86	0.79	10.50
8/19/97	819a	0913	69	77	26.02	0.00	30904	71.38	0.92	0.97	10.60
8/19/97	819p	1457	72	61	26.02	0.17	30904	70.17	0.90	0.85	10.50
8/20/97	820p	1223	67	83	25.54	0.30	31108	72.56	0.85	0.87	10.20

000205

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
8/21/97	821a	0930	64	68	25.32	0.00	31108	68.06	0.82	0.80	10.20
8/21/97	821p	1530	71	62	25.32	0.00	31108	73.15	0.90	0.76	10.90
8/22/97	822					0.00					
8/23/97	823					0.00					
8/24/97	824					0.00					
8/25/97	825a	0820	69	77	23.49	0.00	30716	74.36	0.90	1.08	11.00
8/25/97	825p	1440	78	72	23.14	0.00	30716	72.92	0.91	0.81	10.80
8/26/97	826					0.00					
8/27/97	827a	1000	62	85	24.13	0.03	31108	76.10	0.92	1.82	11.20
8/27/97	827p	1435	84	80	24.36	0.00	31108	77.33	0.96	0.91	11.30
8/28/97	828p	1448	84	48	21.57	0.00	31108	79.15	0.90	0.84	11.80
8/29/97	829a	0924	62	76	20.70	0.00	30687	79.40	1.01	1.15	11.60
8/29/97	829p	1547	74	39	20.70	0.00	30687	80.69	0.96	0.81	11.60
8/30/97	830					0.00					
8/31/97	831					0.00					
9/1/97	91					0.00					
9/2/97	92a	1053	84	67	19.03	0.00	30687	79.74	1.00	1.17	11.80
9/2/97	92p	1616	87	45	19.03	0.02	30687	83.93	0.99	0.90	11.80
9/3/97	93p	1345	67	28	18.57	0.01	30687	83.08	1.01	0.92	12.00
9/4/97	94a	1048	55	50	17.15	0.00	30716	80.08	0.95	0.97	11.70
9/4/97	94p	1555	69	36	17.15	0.00	30716	78.27	0.98	0.83	11.90
9/5/97	95					0.00					
9/6/97	96					0.00					
9/7/97	97					0.21					
9/8/97	98a	0900	63	91	14.75	0.00	30687	77.62	0.97	1.25	11.40
9/8/97	98p	1524	81	55	13.87	0.03	30687	80.62	0.98	0.94	11.30
9/9/97	99					0.46					
9/10/97	910a	0845	62	92	17.87	0.00	30716	67.74	0.83	0.87	10.40
9/10/97	910p	1457	69	70	17.87	0.00	30716	71.05	0.89	0.82	10.90
9/11/97	911					0.00					
9/12/97	912					0.00					
9/13/97	913					0.00					
9/14/97	914					0.00					

002006

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DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
9/15/97	915a	0927	61	91	16.67	0.00	30687	77.36	0.98	1.35	11.60
9/15/97	915p	1727	85	48	15.90	0.00	30687	81.55	0.97	0.87	11.80
9/16/97	916a	0822	64	95	16.87	0.00	31108	77.97	0.96	1.99	11.90
9/16/97	916p	1524	82	42	14.68	0.00	31108	83.04	1.03	0.90	12.10
9/17/97	917a	0908	64	95	15.40	0.00	30687	82.14	1.03	1.06	12.30
9/17/97	917p	1420	74	42	14.31	0.00	30687	78.86	1.01	0.94	11.30
9/18/97	918a	0936	58	85	15.54	0.00	30716	75.55	1.00	1.50	11.30
9/19/97	919					0.00					
9/20/97	920					0.02					
9/21/97	921					0.00					
9/22/97	922a	0830	58	85	13.94	0.00	30687	82.43	1.05	1.70	12.40
9/22/97	922p	1450	67	83	13.42	0.00	30687	80.98	1.01	0.92	12.10
9/23/97	923					0.03					
9/24/97	924					0.00					
9/25/97	925a	0958	52	89	13.49	0.00	40743	83.06	0.98	1.51	11.50
9/26/97	926					0.00					
9/27/97	927					0.00					
9/28/97	928					0.01					
9/29/97	929					0.01					
9/30/97	930a	1015	64	51	12.28	0.00	31108	84.28	1.04	0.97	12.30
9/30/97	930p	1515	71	47	11.97	0.00	31108	83.09	1.02	0.96	12.30
10/1/97	1001a	0854	52	79	11.82	0.00	30687	81.88	1.04	1.01	12.00
10/2/97	1002a	0825	52	79	12.28	0.00	30716	77.39	1.05	1.77	12.00
10/3/97	1003					0.00					
10/4/97	1004					0.00					
10/5/97	1005					0.00					
10/6/97	1006a	0935	63	82	11.74	0.00	31108	89.93	1.09	1.38	12.70
10/6/97	1006p	1451	82	49	11.50	0.00	31108	86.35	1.09	0.91	12.50
10/7/97	1007a	0843	68	75	11.43	0.00	30687	82.45	1.03	1.92	12.20
10/7/97	1007p	1435	81	50	10.95	0.00	30687	87.26	1.03	0.89	12.00
10/8/97	1008					0.00					
10/9/97	1009a	1050	68	94	10.87	0.00	30716	81.88	1.05	1.01	12.20
10/9/97	1009p	1420	67	67	10.87	0.00	30716	85.45	1.03	0.97	12.10

000307

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
10/10/97	1010					0.00					
10/11/97	1011					0.00					
10/12/97	1012					0.00					
10/13/97	1013a	0907	70	70	10.95	0.49	30904	87.24	1.09	1.00	12.30
10/14/97	1014a	0830	41	88	19.35	0.01	31108	72.25	0.87	0.88	11.30
10/14/97	1014p	1513	61	40	18.30	0.00	31108	76.13	0.88	0.90	11.50
10/15/97	1015a	0850	43	73	17.22	0.00	30904	76.45	0.99	1.39	11.40
10/15/97	1015p	1537	56	40	16.94	0.00	30904	77.09	0.96	0.90	11.00
10/16/97	1016a	0829	38	85	16.77	0.00	31108	74.97	0.99	1.14	11.60
10/16/97	1016p	1415	55		16.60	0.00	31108	78.84	0.99	0.94	11.70
10/17/97	1017					0.00					
10/18/97	1018					0.00					
10/19/97	1019					0.00					
10/20/97	1020a	0907	47	78	14.31	0.00	30904	81.85	1.01	1.28	12.00
10/21/97	1021a	0750	37	86	13.72	0.00	31108	81.51	1.02	1.51	12.30
10/21/97	1021p	1531	57	40	13.27	0.00	31108	83.98	1.05	1.01	12.50
10/22/97	1022a	0845	30	92	13.49	0.00	30904	81.55	1.07	1.65	11.60
10/22/97	1022p	1551	46	78	13.49	0.00	30904	83.95	1.05	0.89	11.80
10/23/97	1023a	0910	27	83	12.97	0.00	30716	77.35	1.00	1.97	11.80
10/24/97	1024					0.34					
10/25/97	1025					0.00					
10/26/97	1026					0.87					
10/27/97	1027a	0848	38	86	24.18	0.02	30904	66.28	0.88	0.83	10.20
10/27/97	1027p	1547	42	61	23.43	0.00	40743	70.15	0.86	0.75	10.40
10/28/97	1028a	0740	23		23.49	0.00	40743	73.15	0.89	1.01	10.80
10/29/97	1029a	0809	33		22.66	0.00	31108	70.15	0.90	1.21	10.70
10/30/97	1030					0.00					
10/31/97	1031					0.02					
11/1/97	1101					0.30					
11/2/97	1102					0.07					
11/3/97	1103					0.12					
11/4/97	1104a	0900	29	86	24.59	0.00	31108	68.07	0.84	0.86	10.10
11/4/97	1104p	1430	42	72	24.18	0.00	31108	70.16	0.90	0.85	10.40

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
11/5/97	1105a	0833	40	67	24.36	0.00	30716	47.97	0.61	0.76	8.93
11/5/97	1105p	1415	54	51	23.20	0.00	30716	69.24	0.85	0.80	10.10
11/6/97	1106a	0837	43	63	21.51	0.09	31108	75.22	0.86	1.04	10.90
11/7/97	1107					0.05					
11/8/97	1108					0.01					
11/9/97	1109					0.00					
11/10/97	1110					0.01					
11/11/97	1111					0.00					
11/12/97	1112a	0800	27		21.20	0.00	31108	74.93	0.85	0.99	10.70
11/13/97	1113a	0905	32		19.68	0.58	30904	74.63	0.91	1.02	11.10
11/14/97	1114a	1038	32		25.32	0.01	30716	60.28	0.80	0.95	9.77
11/14/97	1114p	1412	32		24.07	0.00	30716	64.46	0.81	0.83	10.10
11/15/97	1115					0.02					
11/16/97	1116					0.00					
11/17/97	1117a	1003	15		24.53	0.00	30716	66.84	0.84	0.81	10.20
11/17/97	1117p	1335	28		25.43	0.00	30716	63.28	0.81	0.83	9.84
11/18/97	1118p	1400	44	42	24.36	0.00	30716	66.24	0.81	1.01	10.10
11/19/97	1119a	0953	33	66	25.26	0.00	30716	66.55	0.84	1.04	9.76
11/19/97	1119p	1335	50	72	25.04	0.00	30716	67.75	0.85	1.04	10.10
11/20/97	1120a	0950	36	84	24.36	0.00	30716	63.58	0.84	1.43	10.10
11/20/97	1120p	1440	58	48	24.47	0.00	30716	67.19	0.85	0.88	10.00
11/21/97	1121					0.44					
11/22/97	1122					0.01					
11/23/97	1123					0.00					
11/24/97	1124a	1124	33	62	26.25	0.00	30716	66.82	0.84	1.05	10.30
11/25/97	1125					0.00					
11/26/97	1126a	1030	50	78	24.53	0.00	31108	73.12	0.89	0.89	10.70
11/27/97	1127					0.00					
11/28/97	1128					0.00					
11/29/97	1129					0.00					
11/30/97	1130					0.87					
12/1/97	1201a	0852	37		25.25	0.00	31108	65.40	0.85	0.83	10.20
12/1/97	1201p	1525	41	72	25.25	0.00	31108	65.04	0.85	0.77	10.20

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
12/2/97	1202a	0844	38	75	25.21	0.00	31108	66.25	0.83	0.76	10.00
12/3/97	1203					0.20					
12/4/97	1204					0.00					
12/5/97	1205					0.02					
12/6/97	1206a	1150	26		26.09	0.00	30716	64.14	0.82	0.85	9.74
12/7/97	1207					0.00					
12/8/97	1208a	0820	25		26.36	0.00	30716	64.74	0.81	0.83	9.99
12/9/97	1209					0.23					
12/10/97	1210					0.45					
12/11/98	1211a	0928	34	81	26.25	0.00	30904	65.66	0.83	0.81	9.66
12/11/97	1211p	1548	35	68	26.47	0.00	30904	65.98	0.78	0.82	9.69
12/12/97	1212					0.00					
12/13/97	1213					0.00					
12/14/97	1214					0.00					
12/15/07	1215					0.00					
12/16/97	1216a	0908	23		25.21	0.00	30716	68.02	0.86	1.45	10.30
12/17/97	1217					0.00					
12/18/97	1218					0.00					
12/19/97	1219					0.00					
12/20/97	1220					0.00					
12/21/97	1221					0.04					
12/22/97	1222					0.45					
12/23/97	1223					0.00					
12/24/97	1224					0.69					
12/25/97	1225					0.02					
12/26/97	1226					0.00					
12/27/97	1227					0.00					
12/28/97	1228					0.00					
12/29/97	1229a	0839	21	94	25.54	0.00	40743	68.06	0.84	0.95	10.10
12/29/97	1229p	1502	28		25.54	0.06	40743	68.34	0.87	0.85	10.40
12/30/97	1230a	0840	27	84	27.27	0.00	40743	66.53	0.83	0.97	9.66
12/30/97	1230p	1502	28	73	27.27	0.01	40743	62.65	0.79	0.76	9.53
12/31/97	1231					0.01					

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
1/1/98	11					0.00					
1/2/98	12					0.00					
1/3/98	13					0.04					
1/4/98	14					0.00					
1/5/98	15a	0828	53	76	25.93	0.16	40743	68.31	0.81	0.80	10.20
1/6/98	16a	0814	47		26.52	0.00	30904	65.65	0.81	0.94	9.96
1/6/98	16p	1429	58		26.69	0.42	30904	67.15	0.83	0.80	9.42
1/7/98	17					1.96					
1/8/98	18					0.17					
1/9/98	19					0.09					
1/10/98	110					0.00					
1/11/98	111					0.00					
1/12/98	112					0.02					
1/13/98	113a	0855	28	74	26.74	0.01	30904	67.72	0.82	0.88	9.43
1/13/98	113p	1524	30	53	26.74	0.00	30904	67.15	0.87	0.87	9.99
1/14/98	114a	0810	19		25.87	0.00	40743	67.44	0.80	0.80	9.79
1/15/98	115p	1508	35	89	27.01	0.00	40743	67.76	0.83	0.88	9.81
1/16/98	116					0.00					
1/17/98	117					0.03					
1/18/98	118					0.02					
1/19/98	119					0.00					
1/20/98	120a	0748	27	77	25.04	0.00	30716	66.25	0.80	0.80	9.66
1/20/98	120p	1527	34	63	25.04	0.00	30716	65.09	0.82	0.84	9.89
1/21/98	121a	0951	33	66	25.00	0.00	30904	66.87	0.81	0.77	9.75
1/21/98	121p	1456	38	61	25.00	0.00	30904	68.11	0.87	0.88	9.98
1/22/98	122a	0919	38	80	26.58	0.34	30904	65.66	0.82	1.02	9.78
1/23/98	123					0.06					
1/24/98	124					0.01					
1/25/98	125					0.00					
1/26/98	126a	0827	26		26.09	0.00	30904	67.76	0.83	0.94	10.10
1/26/98	126p	1500	47		26.00	0.00	30904	70.74	0.81	0.85	9.74
1/27/98	127a	0821	28	95	25.54	0.00	31108	66.86	0.80	1.11	10.20
1/27/98	127p	1513	50	46	26.58	0.00	31108	65.99	0.86	0.83	10.50

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
1/28/98	128p	1443	51	43	26.25	0.00	30904	73.69	0.85	0.82	10.10
1/29/98	129a	0814	40	78	25.76	0.00	40743	68.05	0.82	0.80	9.72
1/29/98	129p	1508	38	80	25.26	0.00	40743	68.36	0.83	0.99	10.10
1/30/98	130					0.00					
1/31/98	131					0.00					
2/1/98	21					0.00					
2/2/98	22a	0927	48	51	24.07	0.00	30904	73.43	0.84	0.83	10.40
2/2/98	22p	1427	51		23.25	0.00	30904	71.67	0.86	0.84	10.40
2/3/98	23a	0836	33	78	23.43	0.00	30716	67.76	0.84	0.88	10.20
2/3/98	23p	1451	42	52	22.66	0.00	30716	68.69	0.84	0.91	9.89
2/4/98	24					0.31					
2/5/98	25					0.54					
2/6/98	26					0.00					
2/7/98	27					0.00					
2/8/98	28					0.00					
2/9/98	29					0.00					
2/10/98	210					0.00					
2/11/98	211a	0818	45	70	28.77	0.36	31108	43.74	0.56	0.78	7.55
2/12/98	212a	0933	33	78	28.70	0.01	31108	61.72	0.78	0.92	9.30
2/13/98	213					0.00					
2/14/98	214					0.00					
2/15/98	215					0.00					
2/16/98	216					0.18					
2/17/98	217					0.30					
2/18/98	218					0.19					
2/19/98	219a	0838	39	88	28.00	0.05	40743	61.48	0.79	0.78	9.54
2/19/98	219p	1441	43	75	28.00	0.00	40743	61.79	0.85	0.77	9.76
2/20/98	220					0.08					
2/21/98	221					0.00					
2/22/98	222					0.00					
2/23/98	223					0.00					
2/24/98	224p	1440	56	29.3	25.00	0.01	30716	63.29	0.82	0.92	9.60
2/25/98	225					0.00					

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
2/26/98	226a	0902	44	71	24.36	0.00	40743	65.92	0.79	0.81	9.42
2/27/98	227					0.00					
2/28/98	228					0.01					
3/1/98	31					0.00					
3/2/98	32a	0853	34	84	23.25	0.00	30904	72.83	0.85	0.96	10.60
3/3/98	33a	0833	27	91	22.42	0.02	40743	73.16	0.82	0.82	10.20
3/3/98	33p	1506	41	83	22.84	0.00	40743	72.27	0.83	0.80	10.30
3/4/98	34					0.14					
3/5/98	35a	0847	28	95	25.32	0.00	40743	66.87	0.80	0.81	10.10
3/5/98	35p	1443	38		25.32	0.00	40743	65.95	0.79	0.76	9.99
3/6/98	36					0.00					
3/7/98	37					0.00					
3/8/98	38					0.62					
3/9/98	39					0.52					
3/10/98	310					0.00					
3/11/98	311					0.00					
3/12/98	312					0.00					
3/13/98	313					0.00					
3/14/98	314					0.00					
3/15/98	315					0.00					
3/16/98	315a	0811	32	63	25.37	0.00	30904	72.23	0.87	0.77	10.40
3/16/98	316p	1357	40	43	25.37	0.00	40743	68.95	0.81	0.76	10.20
3/17/98	317					0.38					
3/18/98	318					0.12					
3/19/98	319a	0714	48	95	28.26	0.00	30716	62.64	0.76	0.76	9.00
3/19/98	319p	1545	62	57	27.95	0.00	30716	63.24	0.78	0.73	9.63
3/20/98	320					0.42					
3/21/98	321					0.12					
3/22/98	322					0.00					
3/23/98	323a	0748	26	95	29.38	0.05	30687	59.40	0.74	0.89	9.49
3/24/98	324a	0852	31	96	27.95	0.00	40743	63.54	0.81	0.89	9.70
3/24/98	324p	1512	47	35	27.22	0.00	40743	66.53	0.76	0.77	9.49
3/25/98	325					0.01					

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DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM WET WT. (PPM)	TH-232 WET WT. (PCI/G)	RA-226 WET WT. (PCI/G)	K-40 WET WT. (PCI/G)
3/26/98	326a	0926	66	47	26.58	0.00	31108	67.16	0.81	0.82	10.00
3/26/98	326p	1315	72	42	26.40	0.00	31108	65.37	0.80	0.79	10.00
3/27/98	327					0.00					
3/28/98	328					0.00					
3/29/98	329					0.00					
3/30/98	330a	0908	73	52	20.38	0.00	30716	73.17	0.85	0.74	10.60
3/30/98	330p	1530	80	36	21.14	0.00	30716	72.27	0.86	0.74	11.10
3/31/98	331a	0652	69	58	18.77	0.00	30687	74.35	0.89	0.77	10.60
3/31/98	331p	1519	80	34	19.16	0.30	30687	76.17	0.89	0.73	11.10

000214

1950

APPENDIX C

HPGe MEASUREMENTS (DRY WEIGHT BASIS) OF TOTAL URANIUM, THORIUM-232, RADIUM-226, AND POTASSIUM-40

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
4/1/97	41					0.00					
4/2/97	42					0.00					
4/3/97	43					0.00					
4/4/97	44					0.00					
4/5/97	45					0.28					
4/6/97	46					0.00					
4/7/97	47					0.00					
4/8/97	48a	0846	32		20.95	0.00	30716	93.28	1.13	1.32	13.28
4/8/97	48p	1517			20.26	0.00	30716	95.84	1.09	0.98	13.54
4/9/97	49a	0844	23		21.32	0.00	30687	95.23	1.05	0.99	12.84
4/9/97	49p	1541	39		18.96	0.00	30687	91.78	1.07	0.91	13.33
4/10/97	410a	0741	20	58	19.61	0.00	31108	97.69	1.13	1.33	13.43
4/10/97	410p	1527	48	27	19.03	0.00	31108	92.59	1.14	0.95	13.09
4/11/97	411					0.11					
4/12/97	412					0.62					
4/13/97	413					0.01					
4/14/97	414a	0812	24	69	25.60	0.00	30687	92.67	1.14	1.30	13.58
4/14/97	414p	1603	52	34	23.78	0.00	30687	97.51	1.14	1.00	13.25
4/15/97	415a	0802	34	83	22.12	0.00	30716	91.58	1.13	1.75	13.61
4/15/97	415p	1534	55	34	21.07	0.00	30716	96.44	1.10	0.95	13.56
4/16/97	416a	0924	50	42	21.94	0.01	30904	92.16	1.11	1.08	12.21
4/16/97	416p	1552	59	57	21.94	0.00	30904	97.14	1.13	1.11	12.45
4/17/97	417a	0833	35	70	20.89	0.00	31108	93.96	1.11	1.00	13.53
4/17/97	417p	1514	39	74	20.82	0.00	31108	93.51	1.09	1.02	13.64
4/18/97	418					0.00					
4/19/97	419					0.01					
4/20/97	420					0.00					
4/21/97	421					0.26					
4/22/97	422a	0743	47	88	22.36	0.00	30687	92.26	1.09	1.26	13.27
4/22/97	422p	1455	60	34	20.45	0.00	30687	90.79	1.08	0.93	13.20
4/23/97	423a	1126	57	66	20.51	0.00	30904	95.77	1.12	0.97	12.71
4/23/97	423p	1505	62	46	19.74	0.00	30904	78.84	1.01	0.92	12.58
4/24/97	424a	0728	51	87	20.19	0.00	31108	95.76	1.15	1.08	13.16

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
4/24/97	424p	1356	57	47	19.55	0.00	31108	95.75	1.11	0.92	13.30
4/25/97	425					0.00					
4/26/97	426					0.00					
4/27/97	427					0.23					
4/28/97	428a	0730	47	87	23.08	0.00	30687	90.47	1.13	0.94	13.26
4/28/97	428p	1521	58	55	21.26	0.00	30687	94.07	1.10	0.95	13.08
4/29/97	429a	0810	54	74	20.89	0.00	30687	92.85	1.07	1.24	13.02
4/29/97	429p	1455	65	29	19.55	0.00	30687	92.47	1.08	0.91	13.05
4/30/97	430a	0635	35	71	19.55	0.00	30904	94.26	1.12	1.58	13.05
4/30/97	430p	1515	75	49	19.03	0.76	30904	95.54	1.12	0.93	12.72
5/1/97	51a	0817	47	63	24.47	0.00	31108	94.06	1.13	0.97	14.17
5/1/97	51p	1437	49	60	23.49	0.00	31108	96.38	1.10	0.97	13.59
5/2/97	52					1.89					
5/3/97	53					0.11					
5/4/97	54					0.00					
5/5/97	55a	1022	59	36	20.63	0.00	30687	92.91	1.06	0.96	12.98
5/5/97	55p	1600	62	44	21.26	0.03	30687	94.07	1.05	0.97	12.83
5/6/97	56a	0853	63	60	19.35	0.00	30904	91.42	1.10	0.89	12.05
5/6/97	56p	1534	69	36	20.00	0.00	30904	92.20	1.05	0.89	12.75
5/7/97	57a	0903	50	49	20.51	0.00	30904	95.41	1.11	1.16	12.29
5/7/97	57p	1509	72	26	20.00	0.00	30904	96.30	1.06	0.99	12.75
5/8/97	58a	0841	50	49	20.45	0.46	31108	93.46	1.17	1.09	13.58
5/9/97	59					0.00					
5/10/97	510					0.00					
5/11/97	511					0.00					
5/12/97	512a	0902	46	63	21.81	0.00	30687	96.24	1.18	0.98	13.56
5/12/97	512p	1613	62	37	19.48	0.00	30687	92.72	1.11	0.92	13.29
5/13/97	513a	0754	51	59	19.16	0.00	31108	96.75	1.13	1.41	13.48
5/13/97	513p	1500	61	32	19.42	0.00	31108	100.42	1.13	0.99	13.90
5/14/97	514					0.00					
5/15/97	515a	0933	53	59	17.56	0.00	31108	93.81	1.15	0.98	13.10
5/16/97	516					0.00					
5/17/97	517					0.00					

000216

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
5/18/97	518					0.00					
5/19/97	519a	0802	70	68	17.70	0.00	30687	94.03	1.12	0.97	13.97
5/19/97	519p	1437	82	58	18.23	0.14	30687	98.63	1.20	0.98	13.70
5/20/97	520a	0638	47	70	16.87	0.00	31108	94.18	1.09	0.97	13.23
5/20/97	520p	1525	63	24	17.15	0.00	31108	97.74	1.21	0.91	14.12
5/21/97	521a	0800	47	61	18.10	0.00	30904	100.71	1.15	0.98	13.43
5/21/97	521p	1615	60	24	16.46	0.00	30687	94.72	1.19	0.96	14.01
5/22/97	522a	0753	42	51	16.04	0.00	31108	99.57	1.20	1.64	13.70
5/22/97	522p	1556	66	22	16.04	0.00	31108	100.35	1.17	1.04	13.70
5/23/97	523					0.00					
5/24/97	524					0.09					
5/25/97	525					1.63					
5/26/97	526					0.29					
5/27/97	527a	0747	52	63	24.13	0.00	30687	91.26	1.08	1.05	12.53
5/27/97	527p	1500	66	57	22.30	0.00	30687	86.45	1.11	0.94	12.05
5/28/97	528					0.22					
5/29/97	529					0.24					
5/30/97	530					0.01					
5/31/97	531					2.11					
6/1/97	61					1.41					
6/2/97	62					0.00					
6/3/97	63					0.05					
6/4/97	64					0.00					
6/5/97	65					0.43					
6/6/97	66					0.38					
6/7/97	67					0.23					
6/8/97	68					1.79					
6/9/97	69					0.37					
6/10/97	610a	0749	50	73	24.81	0.00	30687	86.87	1.02	1.26	13.23
6/10/97	610p	1452	78	47	22.66	0.00	30687	86.84	1.03	1.06	12.58
6/11/97	611a	0755	53	86	24.64	0.00	31108	83.94	1.01	1.30	11.96
6/11/97	611p	1432	72	65	23.90	0.00	31108	87.49	1.02	0.93	11.68
6/12/97	612a	0858	65	92	24.47	0.00	30904	93.22	1.13	1.19	13.24

000217

1950

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
6/12/97	612p	1400	75	64	23.02	0.00	30904	90.36	1.08	0.96	12.56
6/13/97	613					0.00					
6/14/97	614					0.00					
6/15/97	615					0.00					
6/16/97	616a	0852	71	65	18.50	1.22	30687	89.79	1.10	0.98	13.13
6/17/97	617a	0845	61	91	24.76	0.00	40743	87.25	1.06	1.10	12.68
6/17/97	617p	1552	75	62	24.53	0.07	40743	86.62	1.07	0.90	13.04
6/18/97	618					0.37					
6/19/97	619a	0908	65	87	24.81	0.00	30716	82.52	1.02	1.01	12.42
6/19/97	619p	1520	85	41	26.69	0.00	30716	86.70	0.97	0.95	12.89
6/20/97	620					0.00					
6/21/97	621					0.03					
6/22/97	622					0.07					
6/23/97	623a	0918	70	92	25.43	0.00	30687	98.10	1.21	1.34	14.08
6/23/97	623p	1545	89	30	25.43	0.00	30687	97.72	1.17	1.03	14.89
6/24/97	624a	0900	74	93	24.92	0.00	30716	90.68	1.19	1.57	14.25
6/24/97	624p	1410	87	32	24.92	0.00	30716	94.27	1.20	1.01	13.85
6/25/97	625a	0840	78	89	24.92	0.00	40743	100.23	1.27	1.16	14.12
6/25/97	625p	1458	89	63	24.92	0.13	40743	99.85	1.27	1.03	14.65
6/26/97	626					0.06					
6/27/97	627					0.00					
6/28/97	628					0.02					
6/29/97	629					0.12					
6/30/97	630					0.00					
7/1/97	71a	0900	75	92	22.68	0.00	30687	101.99	1.15	1.05	13.97
7/1/97	71p	1400	89	65	22.68	0.00	30687	99.69	1.20	1.05	14.49
7/2/97	72					0.00					
7/3/97	73a	0731	67	73	19.81	0.00	31108	99.06	1.21	1.16	14.34
7/3/97	73p	1409	80	48	18.23	0.00	31108	100.84	1.19	1.02	14.43
7/4/97	74					0.00					
7/5/97	75					0.00					
7/6/97	76					0.00					
7/7/97	77a	0814	60	53	17.01	0.00	30687	98.98	1.22	1.52	13.98

000218

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
7/7/97	77p	1521	83	33	17.01	0.00	30687	103.00	1.17	1.00	14.34
7/8/97	78a	0810	62	91	16.04	0.00	30716	95.74	1.20	1.43	13.58
7/8/97	78p	1440	85	35	16.67	0.00	30716	94.30	1.19	1.02	13.68
7/9/97	79a	0828	71	90	17.01	0.00	30904	104.72	1.18	1.11	13.86
7/9/97	79p	1455	79	71	17.36	0.00	30904	100.16	1.20	1.13	14.40
7/10/97	710a	0750	55	73	16.32	0.00	30716	98.17	1.16	1.15	14.10
7/10/97	710p	1541	77	48	16.39	0.00	30716	97.52	1.21	0.94	13.99
7/11/97	711					0.00					
7/12/97	712					0.00					
7/13/97	713					0.00					
7/14/97	714a	0741	68	83	14.09	0.23	30687	98.02	1.23	1.78	13.50
7/15/97	715a	0735	65	90	17.36	0.00	30716	92.91	1.17	1.06	13.55
7/15/97	715p	1615	85	46	17.36	0.00	30716	94.35	1.17	1.04	14.04
7/16/97	716a	0751	63	77	15.59	0.00	30904	91.32	1.17	1.63	13.51
7/16/97	716p	1448	87	41	15.59	0.00	30904	102.29	1.23	1.05	14.57
7/17/97	717a	0859	73	92	15.97	0.00	31108	101.31	1.23	1.50	14.28
7/17/97	717p	1353	88	44	14.97	0.00	31108	96.62	1.19	1.11	14.58
7/18/97	718					0.00					
7/19/97	719					0.00					
7/20/97	720					0.00					
7/21/97	721a	0748	67	91	12.97	0.00	30687	102.29	1.23	1.68	14.36
7/21/97	721p	1436	89	57	12.97	0.04	30687	96.14	1.21	1.07	14.13
7/22/97	722					0.54					
7/23/97	723a	0840	70	92	17.63	0.00	30904	93.55	1.18	1.35	13.96
7/23/97	723p	1357	93	53	16.67	0.02	30904	93.94	1.12	1.12	14.04
7/24/97	724a	0821	70	93	17.15	0.00	31108	91.88	1.15	1.38	13.88
7/24/97	724p	1520	79	61	16.25	0.00	31108	96.27	1.17	1.15	13.61
7/25/97	725					0.00					
7/26/97	726					0.00					
7/27/97	727					0.11					
7/28/97	728a	0750	70	92	13.94	0.00	40743	95.13	1.15	1.21	13.36
7/28/97	728p	1530	90	85	12.82	0.00	40743	91.84	1.07	1.27	13.65
7/29/97	729a	0651	70	91	12.74	0.00	40743	97.23	1.15	1.31	13.75

000219

1950

dry wt.

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
7/29/97	729p	1520	84	36	13.19	0.00	40743	97.10	1.15	1.00	13.82
7/30/97	730a	0750	61	69	11.11	0.00	30904	96.82	1.15	1.12	14.06
7/30/97	730p	1551	81	48	13.72	0.00	30904	99.10	1.23	0.96	14.26
7/31/97	731a	0840	62	71	14.16		31108	98.85	1.23	1.22	14.10
7/31/97	731p	1634	83	42	11.97		31108	98.11	1.18	0.99	13.97
8/1/97	81					0.00					
8/2/97	82					0.00					
8/3/97	83					0.00					
8/4/97	84a	0820	67	84	14.02	0.00	40743	88.99	1.20	1.41	14.31
8/4/97	84p	1507	85	47	13.57	0.00	40743	100.65	1.25	1.09	14.23
8/5/97	85a	0855	67	62	13.57	0.00	30687	102.33	1.23	1.21	14.81
8/5/97	85p	1512	72	43	13.57	0.00	30687	104.06	1.26	1.03	15.04
8/6/97	86a	0832	54	60	13.34	0.00	30716	100.98	1.22	1.70	14.19
8/6/97	86p	1426	73	29	12.97	0.00	30716	95.48	1.15	1.02	14.25
8/7/97	87a	0942	65	79	12.74	0.00	30904	102.69	1.24	1.65	14.21
8/7/97	87p	1630	80	24	12.51	0.00	30904	104.87	1.27	0.99	13.94
8/8/97	88					0.00					
8/9/97	89					0.00					
8/10/97	810					0.01					
8/11/97	811a	0844	65	90	11.82	0.00	30716	96.90	1.19	1.51	13.95
8/11/97	811p	1453	86	61	11.82	0.00	30716	97.58	1.20	1.13	13.95
8/12/97	812a	0847	67	78	12.20	0.25	31108	103.09	1.26	1.37	14.12
8/13/97	813					0.96					
8/14/97	814a	0808	65	78	22.00	0.00	31108	94.56	1.17	1.35	14.36
8/14/97	814p	1505	79	49	19.81	0.00	31108	97.19	1.21	1.02	13.97
8/15/97	815					0.81					
8/16/97	816					0.00					
8/17/97	817					2.31					
8/18/97	818a	0901	63	88	27.71	0.00	40743	89.64	1.15	1.05	13.83
8/18/97	818p	1447	80	67	27.71	0.00	40743	99.96	1.19	1.09	14.52
8/19/97	819a	0913	69	77	26.02	0.00	30904	96.49	1.24	1.31	14.33
8/19/97	819p	1457	72	61	26.02	0.17	30904	94.85	1.22	1.15	14.19
8/20/97	820p	1223	67	83	25.54	0.30	31108	97.45	1.14	1.17	13.70

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
8/21/97	821a	0930	64	68	25.32	0.00	31108	91.14	1.10	1.07	13.66
8/21/97	821p	1530	71	62	25.32	0.00	31108	97.95	1.21	1.02	14.60
8/22/97	822					0.00					
8/23/97	823					0.00					
8/24/97	824					0.00					
8/25/97	825a	0820	69	77	23.49	0.00	30716	97.19	1.18	1.41	14.38
8/25/97	825p	1440	78	72	23.14	0.00	30716	94.87	1.18	1.05	14.05
8/26/97	826					0.00					
8/27/97	827a	1000	62	85	24.13	0.03	31108	100.30	1.21	2.40	14.76
8/27/97	827p	1435	84	80	24.36	0.00	31108	102.23	1.27	1.20	14.94
8/28/97	828p	1448	84	48	21.57	0.00	31108	100.92	1.15	1.07	15.05
8/29/97	829a	0924	62	76	20.70	0.00	30687	100.13	1.27	1.45	14.63
8/29/97	829p	1547	74	39	20.70	0.00	30687	101.75	1.21	1.02	14.63
8/30/97	830					0.00					
8/31/97	831					0.00					
9/1/97	91					0.00					
9/2/97	92a	1053	84	67	19.03	0.00	30687	98.48	1.24	1.44	14.57
9/2/97	92p	1616	87	45	19.03	0.02	30687	103.66	1.22	1.11	14.57
9/3/97	93p	1345	67	28	18.57	0.01	30687	102.03	1.24	1.13	14.74
9/4/97	94a	1048	55	50	17.15	0.00	30716	96.66	1.15	1.17	14.12
9/4/97	94p	1555	69	36	17.15	0.00	30716	94.47	1.18	1.00	14.36
9/5/97	95					0.00					
9/6/97	96					0.00					
9/7/97	97					0.21					
9/8/97	98a	0900	63	91	14.75	0.00	30687	91.05	1.14	1.47	13.37
9/8/97	98p	1524	81	55	13.87	0.03	30687	93.60	1.14	1.09	13.12
9/9/97	99					0.46					
9/10/97	910a	0845	62	92	17.87	0.00	30716	82.48	1.01	1.06	12.66
9/10/97	910p	1457	69	70	17.87	0.00	30716	86.51	1.08	1.00	13.27
9/11/97	911					0.00					
9/12/97	912					0.00					
9/13/97	913					0.00					
9/14/97	914					0.00					

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
9/15/97	915a	0927	61	91	16.67	0.00	30687	92.84	1.18	1.62	13.92
9/15/97	915p	1727	85	48	15.90	0.00	30687	96.97	1.15	1.03	14.03
9/16/97	916a	0822	64	95	16.87	0.00	31108	93.79	1.15	2.39	14.31
9/16/97	916p	1524	82	42	14.68	0.00	31108	97.33	1.21	1.05	14.18
9/17/97	917a	0908	64	95	15.40	0.00	30687	97.09	1.22	1.25	14.54
9/17/97	917p	1420	74	42	14.31	0.00	30687	92.03	1.18	1.10	13.19
9/18/97	918a	0936	58	85	15.54	0.00	30716	89.45	1.18	1.78	13.38
9/19/97	919					0.00					
9/20/97	920					0.02					
9/21/97	921					0.00					
9/22/97	922a	0830	58	85	13.94	0.00	30687	95.78	1.22	1.98	14.41
9/22/97	922p	1450	67	83	13.42	0.00	30687	93.53	1.17	1.06	13.98
9/23/97	923					0.03					
9/24/97	924					0.00					
9/25/97	925a	0958	52	89	13.49	0.00	40743	96.01	1.13	1.75	13.29
9/26/97	926					0.00					
9/27/97	927					0.00					
9/28/97	928					0.01					
9/29/97	929					0.01					
9/30/97	930a	1015	64	51	12.28	0.00	31108	96.08	1.19	1.11	14.02
9/30/97	930p	1515	71	47	11.97	0.00	31108	94.39	1.16	1.09	13.97
10/1/97	101a	0854	52	79	11.82	0.00	30687	92.86	1.18	1.15	13.61
10/2/97	102a	0825	52	79	12.28	0.00	30716	88.22	1.20	2.02	13.68
10/3/97	103					0.00					
10/4/97	104					0.00					
10/5/97	105					0.00					
10/6/97	106a	0935	63	82	11.74	0.00	31108	101.89	1.23	1.56	14.39
10/6/97	106p	1451	82	49	11.50	0.00	31108	97.57	1.23	1.03	14.12
10/7/97	107a	0843	68	75	11.43	0.00	30687	93.09	1.16	2.17	13.77
10/7/97	107p	1435	81	50	10.95	0.00	30687	97.99	1.16	1.00	13.48
10/8/97	108					0.00					
10/9/97	109a	1050	68	94	10.87	0.00	30716	91.87	1.18	1.13	13.69
10/9/97	109p	1420	67	67	10.87	0.00	30716	95.87	1.16	1.09	13.58

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DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
10/10/97	1010					0.00					
10/11/97	1011					0.00					
10/12/97	1012					0.00					
10/13/97	1013a	0907	70	70	10.95	0.49	30904	97.97	1.22	1.12	13.81
10/14/97	1014a	0830	41	88	19.35	0.01	31108	89.58	1.08	1.09	14.01
10/14/97	1014p	1513	61	40	18.30	0.00	31108	93.18	1.08	1.10	14.08
10/15/97	1015a	0850	43	73	17.22	0.00	30904	92.35	1.20	1.68	13.77
10/15/97	1015p	1537	56	40	16.94	0.00	30904	92.81	1.16	1.08	13.24
10/16/97	1016a	0829	38	85	16.77	0.00	31108	90.08	1.19	1.37	13.94
10/16/97	1016p	1415	55		16.60	0.00	31108	94.53	1.19	1.13	14.03
10/17/97	1017					0.00					
10/18/97	1018					0.00					
10/19/97	1019					0.00					
10/20/97	1020a	0907	47	78	14.31	0.00	30904	95.52	1.18	1.49	14.00
10/21/97	1021a	0750	37	86	13.72	0.00	31108	94.47	1.18	1.75	14.26
10/21/97	1021p	1531	57	40	13.27	0.00	31108	96.83	1.21	1.16	14.41
10/22/97	1022a	0845	30	92	13.49	0.00	30904	94.27	1.24	1.91	13.41
10/22/97	1022p	1551	46	78	13.49	0.00	30904	97.04	1.21	1.03	13.64
10/23/97	1023a	0910	27	83	12.97	0.00	30716	88.88	1.15	2.26	13.56
10/24/97	1024					0.34					
10/25/97	1025					0.00					
10/26/97	1026					0.87					
10/27/97	1027a	0848	38	86	24.18	0.02	30904	87.42	1.16	1.09	13.45
10/27/97	1027p	1547	42	61	23.43	0.00	40743	91.62	1.12	0.98	13.58
10/28/97	1028a	0740	23		23.49	0.00	40743	95.61	1.16	1.32	14.12
10/29/97	1029a	0809	33		22.66	0.00	31108	90.70	1.16	1.56	13.84
10/30/97	1030					0.00					
10/31/97	1031					0.02					
11/1/97	1101					0.30					
11/2/97	1102					0.07					
11/3/97	1103					0.12					
11/4/97	1104a	0900	29	86	24.59	0.00	31108	90.27	1.11	1.14	13.39
11/4/97	1104p	1430	42	72	24.18	0.00	31108	92.53	1.19	1.12	13.72

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
11/5/97	1105a	0833	40	67	24.36	0.00	30716	63.42	0.81	1.00	11.81
11/5/97	1105p	1415	54	51	23.20	0.00	30716	90.16	1.11	1.04	13.15
11/6/97	1106a	0837	43	63	21.51	0.09	31108	95.83	1.10	1.33	13.89
11/7/97	1107					0.05					
11/8/97	1108					0.01					
11/9/97	1109					0.00					
11/10/97	1110					0.01					
11/11/97	1111					0.00					
11/12/97	1112a	0800	27		21.20	0.00	31108	95.09	1.08	1.26	13.58
11/13/97	1113a	0905	32		19.68	0.58	30904	92.92	1.13	1.27	13.82
11/14/97	1114a	1038	32		25.32	0.01	30716	80.72	1.07	1.27	13.08
11/14/97	1114p	1412	32		24.07	0.00	30716	84.89	1.07	1.09	13.30
11/15/97	1115					0.02					
11/16/97	1116					0.00					
11/17/97	1117a	1003	15		24.53	0.00	30716	88.56	1.11	1.07	13.52
11/17/97	1117p	1335	28		25.43	0.00	30716	84.86	1.09	1.11	13.20
11/18/97	1118p	1400	44	42	24.36	0.00	30716	87.57	1.07	1.34	13.35
11/19/97	1119a	0953	33	66	25.26	0.00	30716	89.04	1.12	1.39	13.06
11/19/97	1119p	1335	50	72	25.04	0.00	30716	90.38	1.13	1.39	13.47
11/20/97	1120a	0950	36	84	24.36	0.00	30716	84.06	1.11	1.89	13.35
11/20/97	1120p	1440	58	48	24.47	0.00	30716	88.96	1.13	1.17	13.24
11/21/97	1121					0.44					
11/22/97	1122					0.01					
11/23/97	1123					0.00					
11/24/97	1124a	1124	33	62	26.25	0.00	30716	90.60	1.14	1.42	13.97
11/25/97	1125					0.00					
11/26/97	1126a	1030	50	78	24.53	0.00	31108	96.89	1.18	1.18	14.18
11/27/97	1127					0.00					
11/28/97	1128					0.00					
11/29/97	1129					0.00					
11/30/97	1130					0.87					
12/1/97	1201a	0852	37		25.25	0.00	31108	87.49	1.14	1.11	13.65
12/1/97	1201p	1525	41	72	25.25	0.00	31108	87.01	1.14	1.03	13.65

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DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
12/2/97	1202a	0844	38	75	25.21	0.00	31108	88.58	1.11	1.02	13.37
12/3/97	1203					0.20					
12/4/97	1204					0.00					
12/5/97	1205					0.02					
12/6/97	1206a	1150	26		26.09	0.00	30716	86.78	1.11	1.15	13.18
12/7/97	1207					0.00					
12/8/97	1208a	0820	25		26.36	0.00	30716	87.91	1.10	1.13	13.57
12/9/97	1209					0.23					
12/10/97	1210					0.45					
12/11/97	1211a	0928	34	81	26.25	0.00	30904	89.03	1.13	1.10	13.10
12/11/97	1211p	1548	35	68	26.47	0.00	30904	89.73	1.06	1.12	13.18
12/12/97	1212					0.00					
12/13/97	1213					0.00					
12/14/97	1214					0.00					
12/15/07	1215					0.00					
12/16/97	1216a	0908	23		25.21	0.00	30716	90.95	1.15	1.94	13.77
12/17/97	1217					0.00					
12/18/97	1218					0.00					
12/19/97	1219					0.00					
12/20/97	1220					0.00					
12/21/97	1221					0.04					
12/22/97	1222					0.45					
12/23/97	1223					0.00					
12/24/97	1224					0.69					
12/25/97	1225					0.02					
12/26/97	1226					0.00					
12/27/97	1227					0.00					
12/28/97	1228					0.00					
12/29/97	1229a	0839	21	94	25.54	0.00	40743	91.40	1.13	1.28	13.56
12/29/97	1229p	1502	28		25.54	0.06	40743	91.78	1.17	1.14	13.97
12/30/97	1230a	0840	27	84	27.27	0.00	40743	91.48	1.14	1.33	13.28
12/30/97	1230p	1502	28	73	27.27	0.01	40743	86.14	1.09	1.04	13.10
12/31/97	1231					0.01					

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
1/1/98	11					0.00					
1/2/98	12					0.00					
1/3/98	13					0.04					
1/4/98	14					0.00					
1/5/98	15a	0828	53	76	25.93	0.16	40743	92.22	1.09	1.08	13.77
1/6/98	16a	0814	47		26.52	0.00	30904	89.34	1.10	1.28	13.55
1/6/98	16p	1429	58		26.69	0.42	30904	91.60	1.13	1.09	12.85
1/7/98	17					1.96					
1/8/98	18					0.17					
1/9/98	19					0.09					
1/10/98	110					0.00					
1/11/98	111					0.00					
1/12/98	112					0.02					
1/13/98	113a	0855	28	74	26.74	0.01	30904	92.44	1.12	1.20	12.87
1/13/98	113p	1524	30	53	26.74	0.00	30904	91.66	1.19	1.19	13.64
1/14/98	114a	0810	19		25.87	0.00	40743	90.98	1.08	1.08	13.21
1/15/98	115p	1508	35	89	27.01	0.00	40743	92.83	1.14	1.21	13.44
1/16/98	116					0.00					
1/17/98	117					0.03					
1/18/98	118					0.02					
1/19/98	119					0.00					
1/20/98	120a	0748	27	77	25.04	0.00	30716	88.38	1.07	1.07	12.89
1/20/98	120p	1527	34	63	25.04	0.00	30716	86.83	1.09	1.12	13.19
1/21/98	121a	0951	33	66	25.00	0.00	30904	93.29	1.13	1.07	13.60
1/21/98	121p	1456	38	61	25.00	0.00	30904	95.02	1.21	1.23	13.92
1/22/98	122a	0919	38	80	26.58	0.34	30904	89.43	1.12	1.39	13.32
1/23/98	123					0.06					
1/24/98	124					0.01					
1/25/98	125					0.00					
1/26/98	126a	0827	26		26.09	0.00	30904	91.68	1.12	1.27	13.67
1/26/98	126p	1500	47		26.00	0.00	30904	95.59	1.09	1.15	13.16
1/27/98	127a	0821	28	95	25.54	0.00	31108	89.79	1.07	1.49	13.70
1/27/98	127p	1513	50	46	26.58	0.00	31108	89.88	1.17	1.13	14.30

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
1/28/98	128p	1443	51	43	26.25	0.00	30904	99.92	1.15	1.11	13.69
1/29/98	129a	0814	40	78	25.76	0.00	40743	91.66	1.10	1.08	13.09
1/29/98	129p	1508	38	80	25.26	0.00	40743	91.46	1.11	1.32	13.51
1/30/98	130					0.00					
1/31/98	131					0.00					
2/1/98	21					0.00					
2/2/98	22a	0927	48	51	24.07	0.00	30904	96.71	1.11	1.09	13.70
2/2/98	22p	1427	51		23.25	0.00	30904	93.38	1.12	1.09	13.55
2/3/98	23a	0836	33	78	23.43	0.00	30716	88.49	1.10	1.15	13.32
2/3/98	23p	1451	42	52	22.66	0.00	30716	88.82	1.09	1.18	12.79
2/4/98	24					0.31					
2/5/98	25					0.54					
2/6/98	26					0.00					
2/7/98	27					0.00					
2/8/98	28					0.00					
2/9/98	29					0.00					
2/10/98	210					0.00					
2/11/98	211a	0818	45	70	28.77	0.36	31108	61.41	0.79	1.10	10.60
2/12/98	212a	0933	33	78	28.70	0.01	31108	86.56	1.09	1.29	13.04
2/13/98	213					0.00					
2/14/98	214					0.00					
2/15/98	215					0.00					
2/16/98	216					0.18					
2/17/98	217					0.30					
2/18/98	218					0.19					
2/19/98	219a	0838	39	88	28.00	0.05	40743	85.39	1.10	1.08	13.25
2/19/98	219p	1441	43	75	28.00	0.00	40743	85.82	1.18	1.07	13.56
2/20/98	220					0.08					
2/21/98	221					0.00					
2/22/98	222					0.00					
2/23/98	223					0.00					
2/24/98	224p	1440	56	29.3	25.00	0.01	30716	84.39	1.09	1.23	12.80
2/25/98	225					0.00					

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
2/26/98	226a	0902	44	71	24.36	0.00	40743	87.15	1.04	1.07	12.45
2/27/98	227					0.00					
2/28/98	228					0.01					
3/1/98	31					0.00					
3/2/98	32a	0853	34	84	23.25	0.00	30904	94.89	1.11	1.25	13.81
3/3/98	33a	0833	27	91	22.42	0.02	40743	94.30	1.06	1.06	13.15
3/3/98	33p	1506	41	83	22.84	0.00	40743	93.66	1.08	1.04	13.35
3/4/98	34					0.14					
3/5/98	35a	0847	28	95	25.32	0.00	40743	89.54	1.07	1.08	13.52
3/5/98	35p	1443	38		25.32	0.00	40743	88.31	1.06	1.02	13.38
3/6/98	36					0.00					
3/7/98	37					0.00					
3/8/98	38					0.62					
3/9/98	39					0.52					
3/10/98	310					0.00					
3/11/98	311					0.00					
3/12/98	312					0.00					
3/13/98	313					0.00					
3/14/98	314					0.00					
3/15/98	315					0.00					
3/16/98	316a	0811	32	63	25.37	0.00	30904	96.78	1.17	1.03	13.94
3/16/98	316p	1357	40	43	25.37	0.00	40743	92.39	1.09	1.02	13.67
3/17/98	317					0.38					
3/18/98	318					0.12					
3/19/98	319a	0714	48	95	28.26	0.00	30716	87.32	1.06	1.06	12.55
3/19/98	319p	1545	62	57	27.95	0.00	30716	87.77	1.08	1.01	13.37
3/20/98	320					0.42					
3/21/98	321					0.12					
3/22/98	322					0.00					
3/23/98	323a	0748	26	95	29.38	0.05	30687	84.11	1.05	1.26	13.44
3/24/98	324a	0852	31	96	27.95	0.00	40743	88.19	1.12	1.24	13.46
3/24/98	324p	1512	47	35	27.22	0.00	40743	91.41	1.04	1.06	13.04
3/25/98	325					0.01					

DATE	INDEX	TIME	TEMP (F)	HUMIDITY (%)	SOIL MOISTURE (%)	RAIN (INCHES)	DETECTOR NUMBER	TOTAL URANIUM DRY WT. (PPM)	TH-232 DRY WT. (PCI/G)	RA-226 DRY WT. (PCI/G)	K-40 DRY WT. (PCI/G)
3/26/98	326a	0926	66	47	26.58	0.00	31108	91.47	1.10	1.12	13.62
3/26/98	326p	1315	72	42	26.40	0.00	31108	88.82	1.09	1.07	13.59
3/27/98	327					0.00					
3/28/98	328					0.00					
3/29/98	329					0.00					
3/30/98	330a	0908	73	52	20.38	0.00	30716	91.90	1.07	0.93	13.31
3/30/98	330p	1530	80	36	21.14	0.00	30716	91.64	1.09	0.94	14.08
3/31/98	331a	0652	69	58	18.77	0.00	30687	91.53	1.10	0.95	13.05
3/31/98	331p	1519	80	34	19.16	0.30	30687	94.22	1.10	0.90	13.73

APPENDIX D

HPGe AND LABORATORY MEASUREMENT DATA FOR TOTAL URANIUM, THORIUM-232, AND RADIUM-226

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-01

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-1-1	1 m	24.1	8.8	5.0										
PBC-1-1	1 m	24.1	8.0	4.7										
PBC-1-1	.31 m	24.1	10.9	4.5										
PBC-1-1	.31 m	24.1	7.5	3.8										
PBC-1-1		24.1			7.4	1.9	6.5	3.4	11.3	.8	5.9	.1	7.8	2.4
PBC-1-2		23.6			6.7	1.7	11	3.7	12.5	.8	8.1	.1	9.6	2.6
PBC-1-3		20.6			8.7	2.2	6.4	4.1	12.4	.8	6.5	.2	8.5	2.8
PBC-1-4		20.4			6.3	1.7	6.8	1.2	12.9	.9	9.1	.1	8.8	3.0
PBC-1-5		24.4			6.9	1.7	9.0	4.0	10.6	.7	11.2	.2	9.4	1.9
PBC-1-6	**	20.6			8.3	2.0	6.8	4.4	11.2	.8	8.2	.1	8.6	1.8
PBC-1-7	**	22.1			8.2	2.0	7.4	5.0	9	.6	9.9	.1	8.6	1.1

** Duplicates

000231

1950

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-02

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-2-1	1 m	21.9	27.9	8.2										
PBC-2-1	1 m	21.9	26.9	8.7										
PBC-2-1	.31 m	21.9	34.0	7.5										
PBC-2-1	.31 m	21.9	33.0	7.0										
PBC-2-1		21.9			33	7.6	41	8.5	33.9	1.6	36.6	.4	36.1	3.6
PBC-2-2		24.2			29	6.7	30	5.2	36.0	1.7	45.5	.7	35.1	7.6
PBC-2-3		19.1			26	6.2	28	5.7	28.5	1.3	35.1	.4	29.4	4.0
PBC-2-4		22			28	6.4	26	5.2	32.0	1.5	34.2	.3	30.1	3.7
PBC-2-5		24.3			28	6.4	27	5.7	32.1	1.5	34.7	.4	30.5	3.6
PBC-2-6		22.2			17	3.9	15	3.1	17.9	.8	21.8	.2	17.9	2.9
PBC-2-7		18.5			29	6.6	17	4.4	17.0	.8	19.5	.2	20.6	5.7
PBC-2-8	**	19			24	6.0	19	4.9	31.1	1.4	29.1	.3	25.8	5.4
PBC-2-9		19			20	4.6	23	5.8	21.3	1.0	21.7	.2	21.5	1.2
PBC-2-10		30.1			25	5.6	27	2.7	27.0	1.2	27.5	.2	26.6	1.1
PBC-2-11	**	18.6			26	5.8	23	6.3	32.0	1.5	32.7	.3	28.4	4.7

** Duplicates

000232

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-03

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-3-1	1 m	21.2	336	19.7										
PBC-3-1	1 m	21.2	324	19.2										
PBC-3-1	.31 m	21.2	328	17.5										
PBC-3-1	.31 m	21.2	310	16.6										
PBC-3-1		21.2			1900	430	2100	190	1700	42.3	1819	16.7	1880	168
PBC-3-2		25.9			270	63	250	23	260	6.1	218	5.3	250	23
PBC-3-3		26.1			240	54	220	22	251	5.9	203	2.2	229	21
PBC-3-4		25			300	68	310	29	314	7.4	253	16.8	294	28
PBC-3-5		17.4			360	81	380	35	386	9.1	403	25.5	382	18
PBC-3-6		22			240	53	250	23	269	6.3	233	3.8	248	16
PBC-3-7		21.7			450	100	460	42	456	11.4	411	6.4	444	23
PBC-3-8		24.1			170	39	160	17	148	3.5	174	2.6	163	12
PBC-3-9		22			250	17	240	24	259	6.1	242	2.3	248	8.7
PBC-3-10		17.3			230	53	260	25	263	6.2	240	2.6	248	16
PBC-3-11		18.2			350	80	500	48	373	8.8	366	3.8	397	69
PBC-3-12		23.1			280	66	340	31	281	6.6	268	2.8	292	32

000233

1950

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-03

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-3-13		27.3			240	56	280	27	246	5.8	217	2.7	246	26
PBC-3-14		28.6			280	64	290	27	278	6.6	246	2.6	274	19
PBC-3-15	**	24.4			320	73	350	32	331	7.8	292	3.1	323	24
PBC-3-16	**	21.1			300	70	296	28	241	5.7	220	1.8	263	38

** Duplicates

000234

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-04

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-4-1	1 m	27.3	64.2	6.5										
PBC-4-1	1 m	27.3	62.5	7.6										
PBC-4-1	.31 m	27.3	61.6	5.8										
PBC-4-1	.31 m	27.3	60.0	6.3										
PBC-4-1		27.3			58	13	50	7.0	62.0	1.6	54.8	.8	56.2	5.1
PBC-4-2	**	24.9			49	11	53	7.3	52.5	1.4	50.8	.6	51.4	1.9
PBC-4-3		26.3			59	14	64	8.7	62.4	1.6	58.1	1	60.9	2.8
PBC-4-4		26.6			63	14	72	9.3	64.1	1.7	61.3	.7	65.1	4.7
PBC-4-5		23.1			38	8.9	40	7.3	41.4	1.1	39.3	.6	39.7	1.4
PBC-4-6		26.3			48	11	44	6.6	46.4	1.2	40.9	.4	44.9	3.1
PBC-4-7		25.3			44	10	53	8.1	45.0	1.2	48.9	.4	47.8	4.2
PBC-4-8		29.5			73	16	74	9.8	75.2	1.8	67	.7	72.3	3.6
PBC-4-9		26.7			64	15	82	11	66.3	1.7	62.7	.6	68.8	9.0
PBC-4-10		24.6			55	12	55	7.1	58.1	1.5	60.2	.7	57.0	2.7
PBC-4-11	**	25			61	14	65	9.0	58.8	1.5	57	1.1	60.5	3.6

** Duplicates

000235

1950

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-05

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-5-1	1 m	21.8	46.9	7.9										
PBC-5-1	1 m	21.8	46.3	8.0										
PBC-5-1	.31 m	21.8	44.0	7.4										
PBC-5-1	.31 m	21.8	41.1	8.1										
PBC-5-1		21.8			30	6.9	33	6.0	37.1	1.7	33.8	.3	33.5	2.9
PBC-5-2		24			37	8.4	36	4	40.4	1.1	37.3	.3	37.6	1.9
PBC-5-3		24.9			36	8.1	34	7	40.6	1.1	37.9	.4	37.1	2.9
PBC-5-4		23.9			32	7.5	33	6.2	40.6	1.1	39.4	.3	36.3	4.4
PBC-5-5		25.7			53	12	61	7.8	57.3	1.5	61.6	.6	58.1	3.9
PBC-5-6		27.8			70	16	63	8.4	65.9	1.7	68.4	.7	66.8	3.2
PBC-5-7		25.4			67	16	68	8.7	64.0	1.7	64.1	.8	65.7	1.9
PBC-5-8		22.3			28	6.3	28	5.9	34.0	1.6	37.0	.3	31.8	4.4
PBC-5-9		21.5			72	17	49	7.1	50.5	1.3	52.0	.5	56.0	11
PBC-5-10	**	26			36	8.5	41	6.9	43.9	1.1	44.2	.4	41.3	3.8
PBC-5-11	**	27.6			48	11	54	7.1	53.1	1.4	55.9	.8	52.7	3.3

** Duplicates

000236

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-06

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-6-1	1 m	26.7	89.6	7.8										
PBC-6-1	1 m	26.7	81.4	7.0										
PBC-6-1	1 m	26.7	86.5	7.4										
PBC-6-1	1 m	26.7	85.9	7.6										
PBC-6-1	1 m	26.7	82.9	8.1										
PBC-6-1	1 m	26.7	84.3	8.0										
PBC-6-1	.31 m	26.7	77.6	5.8										
PBC-6-1	.31 m	26.7	84.5	6.2										
PBC-6-1	.31 m	26.7	84.1	6.8										
PBC-6-1	.31 m	26.7	82.0	6.8										
PBC-6-1	.31 m	26.7	79.9	6.6										
PBC-6-1	.31 m	26.7	80.2	6.2										
PBC-6-1		26.7			80	18	71	8.2	78.8	1.9	89.4	1.2	79.7	7.7
PBC-6-2		27.5			84	19	96	11	89.5	2.1	91.6	.9	90.3	5.0
PBC-6-3		27			93	21	110	13	92.3	2.2	115	1.3	103	12. .0

000237

1950

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-06

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-6-4		24.3			85	19	86	10	81.1	1.9	95	1.1	86.8	5.9
PBC-6-5		24.7			110	24	110	12	91.7	2.2	106	1.2	104	9.0
PBC-6-6		28.1			88	20	91	9.9	93.8	2.2	101	.8	93.3	5.6
PBC-6-7		26.8			82	19	97	11	92.1	2.2	101	.8	93.1	8.2
PBC-6-8		25.3			110	24	110	12	108.8	2.6	121	1.4	112	5.7
PBC-6-9	**	24.1			73	16	80	7.8	70.5	1.8	80	.9	75.8	4.8
PBC-6-10		26.5			78	18	88	11	81.6	1.9	94.4	1.1	85.5	7.2
PBC-6-11	**	24.4			76	17	77	8.8	67.6	1.8	84.1	.8	76.3	6.8

** Duplicates

000238

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-07

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-7-1	1 m	28.4	162	10.1										
PBC-7-1	1 m	28.4	153	8.9										
PBC-7-1	.31 m	28.4	154	7.8										
PBC-7-1	.31 m	28.4	153	8.3										
PBC-7-1		28.4			150	38	150	15	139	3.3	149	1.2	147	5.4
PBC-7-2		29.5			170	42	180	17	166	3.9	173	2.1	172	5.9
PBC-7-3		28.4			140	36	160	16	154	3.6	163	2.2	154	10
PBC-7-4		26.6			140	36	150	15	143	3.4	116	3.8	137	15
PBC-7-5		27.5			190	42	190	19	180	4.2	153	4.4	178	17
PBC-7-6		27			210	47	190	18	208	4.9	199	11.4	202	9.2
PBC-7-7	**	27.2			180	41	180	18	183	4.3	162	7.2	176	9.6
PBC-7-8		25			170	38	200	19	182	4.3	199	2.3	188	14
PBC-7-9		28.7			150	38	150	15	156	3.7	165	1.2	155	7.1
PBC-7-10		27			140	32	150	15	151	3.6	166	1.5	152	11
PBC-7-11		27.7			130	30	140	14	137	3.2	144	2.8	138	5.9
PBC-7-12		28.5			210	49	230	22	220	5.2	241	2.2	225	13

**Duplicates

0002239

1950

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-07

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-7-13		28.6			360	80	430	36	396	9.9	352	2.1	385	36
PBC-7-14		23.7			160	37	170	16	160	3.8	179	2.1	167	9.1
PBC-7-15		28.9			180	40	200	16	188	4.4	223	2.0	198	19
PBC-7-16	**	27			170	39	180	18	190	4.5	202	1.6	186	14

** Duplicates

000240

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-08

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-8-1	1 m	29.9	4.4	3.5										
PBC-8-1	1 m	29.9	4.0	4.1										
PBC-8-1	.31 m	29.9	5.0	3.3										
PBC-8-1	.31 m	29.9	2.5	3.2										
PBC-8-1		29.9			4.9	1.2	6.0	3.0	5.3	.4	2.9	.1	4.8	1.3
PBC-8-2	**	35.1			4.3	1.2	5.3	3.4	5.1	.3	3.4	.1	4.5	0.9
PBC-8-3		26.3			7.3	1.9	4.9	4.5	5.5	.4	3.2	.1	5.2	1.7
PBC-8-4		30.9			3.2	1.0	6.6	4.3	4.4	.3	3.5	.2	4.4	1.5
PBC-8-5		28.2			4.0	1.1	3.4	2.9	4.5	.3	3.4	0	3.8	0.5
PBC-8-6		34			6.0	1.6	2.6	1.7	6.7	.5	4.5	.1	4.9	1.8
PBC-8-7	**	32.6			3.7	1.1	4.8	1.2	5.8	.4	3.4	.5	4.4	1.1

** Duplicates

000241

1950

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-09

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-9-1	1 m	29.3	6.0	4.6										
PBC-9-1	1 m	29.3	5.9	4.5										
PBC-9-1	.31 m	29.3	7.5	4.5										
PBC-9-1	.31 m	29.3	4.3	4.0										
PBC-9-1		29.3			5.8	1.8	6.9	3.9	7.1	0.5	6.1	0	6.5	0.6
PBC-9-2		27.3			5.8	1.4	7.3	1.2	6.5	0.4	8.1	0.1	6.9	1.0
PBC-9-3		26.3			5.9	1.4	6.0	2.5	5.9	0.4	5.1	0.1	5.7	0.4
PBC-9-4	**	26.3			7.1	2.1	6.2	3.5	6.6	0.4	6	0.2	6.5	0.5
PBC-9-5		26.4			5.9	1.5	9.2	4.4	6.4	0.4	5.4	0.1	6.7	1.7
PBC-9-6		24.8			7.2	2.1	4.8	3.9	7.5	0.5	6.1	0.1	6.4	1.2
PBC-9-7	**	25.6			5.7	1.4	8.1	4.6	7.6	0.5	7.6	0.1	7.3	1.1

** Duplicates

000242

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-10

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-10-1	1 m	20.8	78.6	11.1										
PBC-10-1	1 m	20.8	73.7	9.5										
PBC-10-1	.31 m	20.8	86.8	9.8										
PBC-10-1	.31 m	20.8	84.9	8.6										
PBC-10-1		20.8			73	16	78	9.5	72.9	1.9	77.2	1.1	75.3	2.7
PBC-10-2		19.1			48	11	30	8.4	48.5	1.3	51.9	0.8	44.5	10.1
PBC-10-3		17.4			62	15	62	8.2	61.5	1.6	64.6	0.5	62.4	1.5
PBC-10-4		18.8			67	15	63	8.5	77.8	2.0	62.8	0.5	67.7	7.0
PBC-10-5		21.8			72	16	89	11	69.1	1.8	68.7	0.9	74.6	9.5
PBC-10-6		16.7			41	9.3	70	10	38.3	1.8	35.4	0.3	46.2	16
PBC-10-7		18.8			30	6.9	38	6.9	39.0	1.8	31.3	0.4	34.6	4.6
PBC-10-8		18.8			31	7.3	65	11	32.9	1.5	27.6	0.2	39.2	18
PBC-10-9		16.8			55	12	100	14	51.6	1.3	40.1	0.5	61.7	26
PBC-10-10	**	20.5			73	16	68	9.6	81.9	1.9	73.9	0.6	74.3	5.6
PBC-10-11		19.3			42	9.4	56	8.4	50.0	1.3	43.5	1.0	47.8	6.3
PBC-10-12		20.4			48	11	62	8.3	49.3	1.3	48.0	0.7	51.8	6.8

**Duplicates

000243

1950

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-10

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-10-13		16.6			51	12	65	8.5	56.7	1.5	62.0	1.0	58.6	6.0
PBC-10-14		17.8			50	11	69	8.7	66.6	1.7	63.3	1.0	62.2	8.4
PBC-10-15		18.4			61	14	84	10	68.8	1.8	67.2	0.8	70.3	9.8
PBC-10-16	**	15.2			56	13	64	8.5	65.1	1.7	75.8	0.6	65.1	8.2

** Duplicates

000244

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-18

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-18-1	1 m	8.9	927	15.9										
PBC-18-1	1 m	8.9	916	16.3										
PBC-18-1	.31 m	8.9	1163	16.7										
PBC-18-1	.31 m	8.9	1146	16.7										
PBC-18-1		8.9			1400	300	1300	120	1240	31	1260	17	1300	71
PBC-18-2		8.9			350	79	670	60	610	15	610	38	560	143
PBC-18-3		9.9			550	120	680	57	750	19	670	12	663	83
PBC-18-4		10.7			520	120	710	62	640	16	660	9	633	81
PBC-18-5	**	15.8			1600	350	1500	130	1390	35	1520	66	1503	87
PBC-18-6		7.5			750	170	650	56	810	20	750	24	740	66
PBC-18-7		10.3			1700	390	1800	150	1960	49	1950	70	1853	125
PBC-18-8		13.8			1500	330	1700	140	1730	41	1480	15	1603	131
PBC-18-9		10.5			570	130	880	73	720	18	860	13	758	144
PBC-18-10		8.6			740	170	850	75	890	22	760	12	810	72
PBC-18-11		20.7			1600	350	2000	900	1760	43	1460	22	1705	232
PBC-18-12		9			1400	320	1700	130	1500	35	1550	19	1538	125

**Duplicates

000245

1950

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-18

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-18-13		14.7			2200	500	2000	170	1930	47	1870	25	2000	144
PBC-18-14		11.8			810	180	1100	91	890	23	930	7	933	122
PBC-18-15		8			860	190	980	86	850	21	780	7	868	83
PBC-18-16	**	16.3			1300	290	1700	140	1480	36	1380	20	1465	173

** Duplicates

000246

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-19

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-19-1	1 m	37.2	871	13.6										
PBC-19-1	1 m	37.2	855	14.1										
PBC-19-1	.31 m	37.2	1095	17.3										
PBC-19-1	.31 m	37.2	1063	16.8										
PBC-19-1	.31 m	37.2	1094	15.6										
PBC-19-1		37.2			1000	230	1100	94	850	26	990	11	985	103
PBC-19-2		9.1			590	130	670	59	590	14	560	5	603	47
PBC-19-3		5.7			1500	340	1800	150	2040	48	1780	26	1780	221
PBC-19-4		22			800	180	860	69	730	20	790	7	795	53
PBC-19-5		14.6			590	130	870	71	570	15	680	8	678	137
PBC-19-6		8.1			460	100	530	50	580	15	410	4	495	75
PBC-19-7		6.3			500	110	600	58	640	15	520	8	565	66
PBC-19-8		16.5			1000	230	1600	130	1360	31	1220	20	1295	252
PBC-19-9		13.6			840	190	1000	95	990	22	770	14	900	113
PBC-19-10		7.2			500	110	630	56	620	15	560	10	578	60
PBC-19-11		12			600	140	670	63	630	16	570	10	618	43

000247

1950

APPENDIX D1 - TOTAL URANIUM WET WEIGHT CONCENTRATIONS DETERMINED BY HPGE AND FOUR DIFFERENT LABORATORY METHODS

AREA-PBC-19

Sample ID	Det Ht	Moisture %	HPGe (ppm)		Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BromoPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
			Result	CE	Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	SD
PBC-19-12	**	6.7			440	100	480	49	480	12	390	6	448	43
PBC-19-13		5.3			340	78	630	60	610	15	500	5	520	133
PBC-19-14		8.1			880	200	860	78	900	22	730	9	843	77
PBC-19-15		7.4			900	200	890	82	940	23	750	13	870	83
PBC-19-16	**	6			500	110	610	58	480	12	340	8	483	111

** Duplicates

000248

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORIUM-232

AREA-PBC-01

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-1-1	.31 m	24.1	0.70	0.10						
PBC-1-1	.31 m	24.1	0.63	0.08						
PBC-1-1	1 m	24.1	0.64	0.10						
PBC-1-1	1 m	24.1	0.58	0.08						
PBC-1-1		24.1			0.58	0.16	0.52	0.12	0.55	0.04
PBC-1-2		23.6			0.82	0.21	0.48	0.11	0.65	0.24
PBC-1-3		20.6			0.74	0.24	0.46	0.11	0.60	0.20
PBC-1-4		20.4			0.80	0.21	0.56	0.13	0.68	0.17
PBC-1-5		24.4			0.62	0.25	0.49	0.11	0.56	0.09
PBC-1-6	**	20.6			0.65	0.22	0.47	0.11	0.56	0.13
PBC-1-7	**	22.1			0.60	0.18	0.49	0.12	0.55	0.08

** Duplicates

000249

1950

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-02

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-2-1	.31 m	21.9	0.76	0.12						
PBC-2-1	.31 m	21.9	0.73	0.10						
PBC-2-1	1 m	21.9	0.76	0.10						
PBC-2-1	1 m	21.9	0.72	0.12						
PBC-2-1		21.9			0.56	0.19	0.48	0.11	0.52	0.06
PBC-2-2		24.2			0.81	0.21	0.58	0.14	0.70	0.16
PBC-2-3		19.1			0.54	0.18	0.36	0.09	0.45	0.13
PBC-2-4		22.0			0.51	0.18	1.2	0.27	0.86	0.49
PBC-2-5		24.3			0.82	0.18	0.60	0.14	0.71	0.16
PBC-2-2		22.2			0.67	0.17	0.39	0.09	0.53	0.20
PBC-2-7		18.5			0.56	0.16	0.41	0.10	0.49	0.11
PBC-2-8	**	19.0			0.56	0.17	0.38	0.09	0.47	0.13
PBC-2-9		19.0			0.48	0.16	0.37	0.09	0.43	0.08
PBC-2-10		30.1			0.79	0.21	0.58	0.13	0.69	0.15
PBC-2-11	**	18.6			0.59	0.20	0.41	0.10	0.50	0.13

** Duplicates

000250

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-03

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-3-1	.31 m	21.2	2.4	0.16						
PBC-3-1	.31 m	21.2	2.4	0.22						
PBC-3-1	1 m	21.2	2.8	0.22						
PBC-3-1	1 m	21.2	2.7	0.14						
PBC-3-1		21.2			2.8	0.52	2.0	0.49	2.4	0.57
PBC-3-2		25.9			2.7	0.55	2.0	0.44	2.4	0.49
PBC-3-3		26.1			3.6	0.65	2.3	0.53	3.0	0.92
PBC-3-4		25.0			2.3	0.46	2.1	0.48	2.2	0.14
PBC-3-5		17.4			3.0	0.61	2.0	0.45	2.5	0.71
PBC-3-6		22.0			2.2	0.44	1.6	0.36	1.9	0.42
PBC-3-7		21.7			2.9	0.48	2.3	0.52	2.6	0.42
PBC-3-8		24.1			2.8	0.53	1.7	0.38	2.3	0.78
PBC-3-9		22.0			NR*	NR*	3.2	0.73	NR*	NR*
PBC-3-10		17.3			3.4	0.45	2.0	0.46	2.7	0.99
PBC-3-11		18.2			2.9	0.61	1.8	0.41	2.4	0.78
PBC-3-12		23.1			3.5	0.63	2.3	0.53	2.9	0.85
PBC-3-13		27.3			4.5	0.78	2.8	0.63	3.7	1.20

* NR = no result

000251

1950

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-03

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-3-14		28.6			2.4	0.43	1.9	0.43	2.2	0.35
PBC-3-15	**	24.4			2.2	0.41	1.8	0.41	2.0	0.28
PBC-3-16	**	21.1			1.6	0.32	1.2	0.29	1.4	0.28

** Duplicates

000252

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-04

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-4-1	.31 m	27.3	0.86	0.08						
PBC-4-1	.31 m	27.3	0.84	0.08						
PBC-4-1	1 m	27.3	0.86	0.10						
PBC-4-1	1 m	27.3	0.81	0.08						
PBC-4-1		27.3			1.1	0.22	0.80	0.18	0.95	0.21
PBC-4-2	**	24.9			1.2	0.32	0.77	0.18	0.99	0.30
PBC-4-3		26.3			1.5	0.33	0.75	0.17	1.1	0.53
PBC-4-4		26.6			1.1	0.33	0.71	0.16	0.91	0.28
PBC-4-5		23.1			1.1	0.25	0.70	0.16	0.90	0.28
PBC-4-6		26.3			0.90	0.20	0.67	0.15	0.79	0.16
PBC-4-7		25.3			1.1	0.22	0.69	0.16	0.90	0.29
PBC-4-8		29.5			1.3	0.32	0.74	0.17	1.02	0.40
PBC-4-9		26.7			1.4	0.36	0.76	0.17	1.1	0.45
PBC-4-10		24.6			1.1	0.28	0.79	0.18	0.95	0.22
PBC-4-11	**	25.0			0.96	0.28	0.79	0.18	0.88	0.12

** Duplicates

000253

1950

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-05

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-5-1	.31 m	21.8	0.95	0.12						
PBC-5-1	.31 m	21.8	0.92	0.08						
PBC-5-1	1 m	21.8	0.90	0.10						
PBC-5-1	1 m	21.8	0.82	0.10						
PBC-5-1		21.8			0.89	0.23	0.74	0.17	0.82	0.11
PBC-5-2		24.0			1.1	0.24	0.75	0.17	0.93	0.25
PBC-5-3		24.9			0.92	0.22	0.75	0.17	0.84	0.12
PBC-5-4		23.9			0.95	0.22	0.72	0.17	0.84	0.16
PBC-5-5		25.7			0.78	0.24	0.91	0.21	0.85	0.09
PBC-5-6		27.8			1.3	0.31	0.55	0.13	0.93	0.53
PBC-5-7		25.4			1.0	0.23	0.86	0.20	0.93	0.10
PBC-5-8		22.3			0.94	0.22	0.68	0.16	0.81	0.18
PBC-5-9		21.5			1.1	0.25	1.0	0.23	1.1	0.07
PBC-5-10	**	26.0			0.99	0.22	0.93	0.21	0.96	0.04
PBC-5-11	**	27.6			1.2	0.25	0.98	0.22	1.1	0.16

** Duplicates

000254

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-06

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-6-1	.31 m	26.7	0.94	0.12						
PBC-6-1	.31 m	26.7	0.90	0.08						
PBC-6-1	.31 m	26.7	0.97	0.10						
PBC-6-1	.31 m	26.7	0.91	0.08						
PBC-6-1	.31 m	26.7	0.88	0.08						
PBC-6-1	.31 m	26.7	0.88	0.08						
PBC-6-1	1 m	26.7	0.91	0.08						
PBC-6-1	1 m	26.7	0.94	0.10						
PBC-6-1	1 m	26.7	0.89	0.10						
PBC-6-1	1 m	26.7	0.85	0.08						
PBC-6-1	1 m	26.7	0.90	0.10						
PBC-6-1	1 m	26.7	0.84	0.08						
PBC-6-1		26.7			1.0	0.23	0.73	0.17	0.87	0.19
PBC-6-2		27.5			1.1	0.31	0.77	0.18	0.94	0.23
PBC-6-3		27.0			1.5	0.36	0.80	0.18	1.2	0.49
PBC-6-4		24.3			1.1	0.25	0.78	0.18	0.94	0.23
PBC-6-5		24.7			0.95	0.23	0.82	0.19	0.89	0.09

000255

1950

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-06

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-6-6		28.1			1.1	0.26	0.88	0.20	1.0	0.16
PBC-6-7		26.8			1.0	0.24	0.79	0.18	0.90	0.15
PBC-6-8		25.3			1.4	0.39	0.80	0.18	1.1	0.42
PBC-6-9	**	24.1			1.2	0.26	0.85	0.20	1.0	0.25
PBC-6-10		26.5			1.3	0.32	0.78	0.19	1.0	0.37
PBC-6-11	**	24.4			1.1	0.25	0.78	0.18	0.94	0.23

** Duplicates

000256

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-07

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-7-1	.31 m	28.4	1.2	0.10						
PBC-7-1	.31 m	28.4	1.1	0.12						
PBC-7-1	1 m	28.4	1.0	0.16						
PBC-7-1	1 m	28.4	1.0	0.12						
PBC-7-1		28.4			1.4	0.28	0.97	0.22	1.2	0.30
PBC-7-2		29.5			1.1	0.30	0.99	0.23	1.0	0.08
PBC-7-3		28.4			1.3	0.26	1.0	0.23	1.2	0.21
PBC-7-4		26.6			1.2	0.25	0.95	0.22	1.1	0.18
PBC-7-5		27.5			1.3	0.28	0.96	0.22	1.1	0.24
PBC-7-6		27.0			1.5	0.30	1.1	0.26	1.3	0.28
PBC-7-7	**	27.2			1.3	0.28	1.1	0.25	1.2	0.14
PBC-7-8		25.0			1.5	0.40	1.2	0.27	1.4	0.21
PBC-7-9		28.7			1.3	0.27	0.91	0.21	1.1	0.28
PBC-7-10		27.0			1.2	0.26	1.0	0.23	1.1	0.14
PBC-7-11		27.7			1.2	0.28	0.96	0.22	1.1	0.17
PBC-7-12		28.5			1.6	0.38	1.3	0.29	1.5	0.21
PBC-7-13		28.6			1.1	0.25	0.85	0.20	1.0	0.18

**Duplicates

000257

1950

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-07

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-7-14		23.7			1.4	0.28	1.2	0.27	1.3	0.14
PBC-7-15		28.9			1.3	0.27	1.1	0.25	1.2	0.14
PBC-7-16	**	27.0			1.3	0.27	0.99	0.23	1.1	0.22

** Duplicates

000258

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-08

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-8-1	.31 m	29.9	0.67	0.08						
PBC-8-1	.31 m	29.9	0.62	0.08						
PBC-8-1	1 m	29.9	0.62	0.06						
PBC-8-1	1 m	29.9	0.59	0.08						
PBC-8-1		29.9			0.72	0.19	0.55	0.13	0.64	0.12
PBC-8-2	**	35.1			0.86	0.26	0.47	0.11	0.67	0.28
PBC-8-3		26.3			1.1	0.27	0.57	0.13	0.84	0.37
PBC-8-4		30.9			0.72	0.19	0.45	0.10	0.59	0.19
PBC-8-5		28.2			NR*	NR*	0.49	0.12	NR*	NR*
PBC-8-6		34.0			0.53	0.17	0.46	0.11	0.50	0.05
PBC-8-7		32.6			0.71	0.18	0.49	0.11	0.60	0.16

* NR = no result
** Duplicates

000259

1950

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-09

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-9-1	.31 m	29.3	0.77	0.08						
PBC-9-1	.31 m	29.3	0.69	0.08						
PBC-9-1	1 m	29.3	0.71	0.10						
PBC-9-1	1 m	29.3	0.64	0.08						
PBC-9-1		29.3			0.86	0.19	0.54	0.13	0.70	0.23
PBC-9-2		27.3			0.78	0.20	0.49	0.12	0.64	0.21
PBC-9-3		26.3			1.0	0.29	0.55	0.13	0.78	0.32
PBC-9-4	**	26.3			0.97	0.31	0.47	0.11	0.72	0.35
PBC-9-5		26.4			0.80	0.18	0.47	0.11	0.64	0.23
PBC-9-6		24.8			0.85	0.21	0.55	0.13	0.70	0.21
PBC-9-7	**	25.6			0.80	0.20	0.55	0.13	0.68	0.18

** Duplicates

0002260

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-10

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-10-1	.31 m	20.8	6.8	0.27						
PBC-10-1	.31 m	20.8	6.6	0.22						
PBC-10-1	1 m	20.8	8.7	0.25						
PBC-10-1	1 m	20.8	7.5	0.25						
PBC-10-1		20.8			6.4	1.0	5.9	1.3	6.2	0.35
PBC-10-2		19.1			7.0	1.1	5.1	1.1	6.1	1.3
PBC-10-3		17.4			6.5	1.0	5.4	1.2	6.0	0.78
PBC-10-4		18.8			3.9	0.64	3.4	0.75	3.7	0.35
PBC-10-5		21.8			6.2	1.0	3.9	0.88	5.1	1.6
PBC-10-6		16.7			14	2.2	15	3.4	15	0.71
PBC-10-7		18.8			11	1.6	4.0	0.90	7.5	4.9
PBC-10-8		18.7			19	3.0	15	3.4	17	2.8
PBC-10-9		16.8			24	3.7	23	5.3	24	0.71
PBC-10-10	**	20.5			2.5	0.44	2.2	0.51	2.4	0.21
PBC-10-11		19.3			5.1	0.84	3.8	0.86	4.5	0.92
PBC-10-12		20.4			6.8	1.1	5.3	1.2	6.1	1.1
PBC-10-13		16.6			8.4	1.3	6.7	1.5	7.5	1.3

**Duplicates

000261

1950

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-10

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-10-14		17.8			5.1	0.84	4.7	1.0	4.9	0.28
PBC-10-15		18.4			9.2	1.4	14	3.2	12	3.4
PBC-10-16	**	15.2			4.2	0.69	3.7	0.84	4.0	0.35

** Duplicates

000262

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-12

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-12-1 (am)	1 m	22.8	1.5	0.10						
PBC-12-1 (am)	1 m	22.8	1.6	0.10						
PBC-12-1 (am)	1 m	22.8	1.5	0.12						
PBC-12-1 (pm)	1 m	22.8	1.5	0.14						
PBC-12-1 (pm)	1 m	22.8	1.5	0.12						
PBC-12-1 (pm)	1 m	22.8	1.6	0.14						
PBC-12-1		22.8			1.2	0.26				
PBC-12-2		18.3			1.1	0.26				
PBC-12-3		13.9			1.6	0.37				
PBC-12-4		15.7			1.4	0.33				
PBC-12-5	**	21.1			1.1	0.25				
PBC-12-6		17.7			1.5	0.32				
PBC-12-7		13.8			2.6	0.50				
PBC-12-8		10.3			1.2	0.31				
PBC-12-9		23.5			1.9	0.37				
PBC-12-10		22.1			5.3	0.94				
PBC-12-11	**	19.4			0.92	0.26				

** Duplicates

000263

1950

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-13

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-13-1 (am)	1 m	19.7	2.8	0.10						
PBC-13-1 (am)	1 m	19.7	2.7	0.14						
PBC-13-1 (am)	1 m	19.7	2.8	0.16						
PBC-13-1 (pm)	1 m	19.7	2.9	0.12						
PBC-13-1 (pm)	1 m	19.7	2.8	0.14						
PBC-13-1 (pm)	1 m	19.7	2.8	0.14						
PBC-13-1		19.7			5.9	1.0				
PBC-13-2		20.6			4.8	0.85				
PBC-13-3		16.2			8.4	1.5				
PBC-13-4		18.1			1.8	0.38				
PBC-13-5		17.9			1.5	0.31				
PBC-13-6		23.7			1.6	0.32				
PBC-13-7	**	16.3			0.99	0.23				
PBC-13-8		18.1			1.1	0.27				
PBC-13-9		18.9			1.1	0.26				
PBC-13-10		23.7			1.6	0.34				
PBC-13-11	**	14.3			0.97	0.23				

** Duplicates

000264

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-14

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-14-1 (am)	1 m	15.1	0.66	0.10						
PBC-14-1 (am)	1 m	15.1	0.68	0.10						
PBC-14-1 (am)	1 m	15.1	0.66	0.10						
PBC-14-1 (pm)	1 m	15.1	0.56	0.06						
PBC-14-1 (pm)	1 m	15.1	0.61	0.08						
PBC-14-1 (pm)	1 m	15.1	0.58	0.04						
PBC-14-1	**	15.1			0.82	0.21				
PBC-14-2		12.9			0.70	0.21				
PBC-14-3		14.6			0.67	0.22				
PBC-14-4		14.1			0.84	0.21				
PBC-14-5		13.0			0.66	0.22				
PBC-14-6		13.5			0.88	0.28				
PBC-14-7		13.8			0.83	0.23				
PBC-14-8		15.7			0.96	0.23				
PBC-14-9		13.6			0.73	0.25				
PBC-14-10		13.0			0.62	0.18				
PBC-14-11	**	16.0			0.87	0.23				

** Duplicates

000265

1950

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-15

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-15-1 (am)	1 m	23.0	0.77	0.10						
PBC-15-1 (am)	1 m	23.0	0.72	0.10						
PBC-15-1 (am)	1 m	23.0	0.75	0.08						
PBC-15-1 (pm)	1 m	23.0	0.71	0.08						
PBC-15-1 (pm)	1 m	23.0	0.76	0.08						
PBC-15-1 (pm)	1 m	23.0	0.84	0.12						
PBC-15-1		23.0			0.79	0.21				
PBC-15-2		17.5			0.92	0.25				
PBC-15-3		16.3			0.91	0.25				
PBC-15-4		18.8			0.98	0.23				
PBC-15-5		20.2			0.92	0.26				
PBC-15-6		16.2			0.99	0.25				
PBC-15-7		13.1			0.89	0.23				
PBC-15-8		17.9			0.90	0.25				
PBC-15-9		22.4			0.69	0.21				
PBC-15-10		14.8			0.61	0.20				
PBC-15-11		17.9			0.81	0.25				

992000

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-16

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-16-1 (am)	1 m	12.1	0.98	0.08						
PBC-16-1 (am)	1 m	12.1	1.2	0.16						
PBC-16-1 (am)	1 m	12.1	0.96	0.08						
PBC-16-1 (pm)	1 m	12.1	0.91	0.08						
PBC-16-1 (pm)	1 m	12.1	1.1	0.08						
PBC-16-1		12.1			0.87	0.25				
PBC-16-2		12.9			0.95	0.26				
PBC-16-3		10.6			1.5	0.35				
PBC-16-4		12.9			1.5	0.37				
PBC-16-5		17.6			1.9	0.45				
PBC-16-6		18.7			1.4	0.36				
PBC-16-7		16.1			0.79	0.23				
PBC-16-8		13.8			0.94	0.26				
PBC-16-9		21.2			1.8	0.41				
PBC-16-10	**	12.5			0.87	0.24				
PBC-16-11		13.2			0.93	0.26				
PBC-16-12		15.4			1.4	0.35				
PBC-16-13		12.1			1.9	0.41				
PBC-16-14		24.0			1.4	0.33				

000267

1950

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-16

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-16-15		18.0			1.6	0.42				
PBC-16-16	**	16.2			1.7	0.39				

**Duplicates

000268

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-17

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-17-1 (am)	1 m	21.2	0.75	0.08						
PBC-17-1 (am)	1 m	21.2	0.50	0.06						
PBC-17-1 (am)	1 m	21.2	0.69	0.08						
PBC-17-1 (pm)	1 m	21.2	0.90	0.08						
PBC-17-1 (pm)	1 m	21.2	0.77	0.10						
PBC-17-1		21.2			1.1	0.34				
PBC-17-2		21.7			1.0	0.29				
PBC-17-3		24.5			1.3	0.33				
PBC-17-4		28.8			1.3	0.35				
PBC-17-5		21.1			0.95	0.28				
PBC-17-6		21.8			0.92	0.29				
PBC-17-7		15.4			1.1	0.28				
PBC-17-8		19.9			0.75	0.21				
PBC-17-9		19.8			0.99	0.25				
PBC-17-10		18.9			0.91	0.22				
PBC-17-11		17.6			1.0	0.33				
PBC-17-12		17.5			0.81	0.24				
PBC-17-13		25.4			0.93	0.26				
PBC-17-14		21.6			1.1	0.26				

000269

1950

APPENDIX D2 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR THORUM-232

AREA-PBC-17

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-17-15	**	25.0			0.94	0.29				
PBC-17-16	**	27.4			0.96	0.33				

** Duplicates

000270

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-01

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-1-1	.31 m	24.1	0.69	0.08						
PBC-1-1	.31 m	24.1	0.79	0.08						
PBC-1-1	1 m	24.1	0.66	0.08						
PBC-1-1	1 m	24.1	0.74	0.08						
PBC-1-1		24.1			0.69	0.11	0.79	0.20	0.74	0.07
PBC-1-2		23.6			0.64	0.12	0.80	0.20	0.72	0.11
PBC-1-3		20.6			0.68	0.12	0.81	0.20	0.75	0.09
PBC-1-4		20.4			0.62	0.11	0.77	0.20	0.70	0.11
PBC-1-5		24.4			0.73	0.12	0.79	0.20	0.76	0.04
PBC-1-6	**	20.6			0.65	0.11	0.89	0.22	0.77	0.17
PBC-1-7	**	22.1			0.90	0.15	0.91	0.22	0.91	0.01

** Duplicates

000271

1950

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-02

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-2-1	.31 m	21.9	0.70	0.07						
PBC-2-1	.31 m	21.9	0.70	0.08						
PBC-2-1	1 m	21.9	0.67	0.08						
PBC-2-1	1 m	21.9	0.72	0.08						
PBC-2-1		21.9			0.66	0.12	0.65	0.12	0.66	0.01
PBC-2-2		24.2			0.73	0.14	0.68	0.12	0.71	0.04
PBC-2-3		19.1			0.52	0.11	0.60	0.11	0.56	0.06
PBC-2-4		22.0			0.65	0.12	0.56	0.10	0.61	0.06
PBC-2-5		24.3			0.79	0.13	0.80	0.14	0.80	0.01
PBC-2-2		22.2			0.88	0.14	0.59	0.11	0.74	0.21
PBC-2-7		18.5			0.51	0.11	0.45	0.08	0.48	0.04
PBC-2-8	**	19.0			0.57	0.10	0.53	0.10	0.55	0.03
PBC-2-9		19.0			0.66	0.13	0.63	0.11	0.65	0.02
PBC-2-10		30.1			0.81	0.13	0.58	0.10	0.70	0.16
PBC-2-11	**	18.6			0.88	0.15	0.58	0.10	0.70	0.26

** Duplicates

000272

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-03

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-3-1	.31 m	21.2	4.6	0.17						
PBC-3-1	.31 m	21.2	4.5	0.18						
PBC-3-1	1 m	21.2	4.4	0.20						
PBC-3-1	1 m	21.2	4.5	0.19						
PBC-3-1		21.2			9.1	1.0	8.4	1.4	8.8	0.49
PBC-3-2		25.9			9.3	0.76	11	2.6	10.2	1.2
PBC-3-3		26.1			8.8	0.72	13	3.0	11	3.0
PBC-3-4		25.0			16	1.7	15	2.4	16	0.71
PBC-3-5		17.4			22	1.7	23	5.2	23	0.71
PBC-3-6		22.0			9.7	1.0	14	2.2	12	3.0
PBC-3-7		21.7			15	0.39	25	5.6	20	7.1
PBC-3-8		24.1			12	1.0	23	5.2	18	7.8
PBC-3-9		22.0			NR*	NR*	13	3.0	NR*	NR*
PBC-3-10		17.3			7.9	0.29	16	3.6	12	5.7
PBC-3-11		18.2			5.4	0.51	7.6	1.2	6.5	1.6
PBC-3-12		23.1			5.9	0.52	7.4	1.7	6.7	1.1
PBC-3-13		27.3			3.9	0.37	7.6	1.3	5.8	2.6

* NR - No Result

000273

1950

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-03

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-3-14		28.6			3.0	0.37	4.6	1.0	3.8	1.1
PBC-3-15	**	24.4			4.2	0.48	5.7	1.3	5.0	1.0
PBC-3-16	**	21.1			3.7	0.44	4.3	0.99	4.0	0.42

** Duplicates

000274

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-04

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-4-1	.31 m	27.3	0.88	0.08						
PBC-4-1	.31 m	27.3	0.84	0.08						
PBC-4-1	1 m	27.3	0.86	0.07						
PBC-4-1	1 m	27.3	0.85	0.09						
PBC-4-1		27.3			0.80	0.12	1.0	0.25	0.90	0.14
PBC-4-2		24.9			1.0	0.16	1.2	0.28	1.1	0.14
PBC-4-3		26.3			0.99	0.16	1.1	0.28	1.0	0.08
PBC-4-4		26.6			1.1	0.16	0.99	0.24	1.1	0.11
PBC-4-5		23.1			0.77	0.13	0.97	0.24	0.87	0.14
PBC-4-6		26.3			0.82	0.13	0.98	0.24	0.90	0.11
PBC-4-7		25.3			0.87	0.14	1.1	0.26	1.0	0.16
PBC-4-8		29.5			1.1	0.17	1.0	0.25	1.1	0.07
PBC-4-9		26.7			1.1	0.18	0.96	0.23	1.0	0.10
PBC-4-10	**	24.6			0.96	0.14	1.6	0.38	1.3	0.45
PBC-4-11	**	25.0			0.68	0.12	0.99	0.24	0.84	0.22

** Duplicates

000275

1950

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-05

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-5-1	.31 m	21.8	0.83	0.09						
PBC-5-1	.31 m	21.8	0.78	0.10						
PBC-5-1	1 m	21.8	0.76	0.08						
PBC-5-1	1 m	21.8	0.78	0.09						
PBC-5-1		21.8			0.88	0.15	1.2	0.26	1.0	0.23
PBC-5-2		24.0			0.66	0.12	1.2	0.27	0.93	0.38
PBC-5-3		24.9			0.83	0.14	1.1	0.25	0.97	0.19
PBC-5-4		23.9			0.87	0.14	1.1	0.26	0.99	0.16
PBC-5-5		18.8			0.73	0.11	1.2	0.28	0.97	0.33
PBC-5-6		27.8			0.79	0.13	1.2	0.27	1.0	0.29
PBC-5-7		25.5			0.96	0.14	1.2	0.28	1.1	0.17
PBC-5-8		22.3			0.66	0.13	1.1	0.25	0.88	0.31
PBC-5-9		21.4			0.87	0.14	1.3	0.29	1.1	0.30
PBC-5-10	**	26.0			0.94	0.14	1.1	0.25	1.0	0.11
PBC-5-11	**	27.6			0.75	0.13	1.2	0.26	0.98	0.32

** Duplicates

002276

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-06

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-6-1	.31 m	26.7	0.86	0.08						
PBC-6-1	.31 m	26.7	0.86	0.09						
PBC-6-1	.31 m	26.7	0.84	0.08						
PBC-6-1	.31 m	26.7	0.86	0.06						
PBC-6-1	.31 m	26.7	0.83	0.07						
PBC-6-1	.31 m	26.7	0.90	0.08						
PBC-6-1	1 m	26.7	0.89	0.09						
PBC-6-1	1 m	26.7	0.87	0.08						
PBC-6-1	1 m	26.7	0.88	0.07						
PBC-6-1	1 m	26.7	0.87	0.07						
PBC-6-1	1 m	26.7	0.83	0.09						
PBC-6-1	1 m	26.7	0.84	0.09						
PBC-6-1		26.7			0.83	0.15	1.2	0.28	1.0	0.26
PBC-6-2		27.5			1.0	0.14	1.3	0.28	1.2	0.21
PBC-6-3		27.0			1.1	0.17	1.1	0.26	1.1	0.0
PBC-6-4		24.3			0.94	0.15	1.2	0.26	1.1	0.18
PBC-6-5		24.7			0.97	0.16	1.2	0.29	1.1	0.16

000277

1950

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-06

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-6-6		28.1			0.83	0.13	1.2	0.28	1.0	0.26
PBC-6-7		26.8			0.97	0.15	1.1	0.26	1.0	0.09
PBC-6-8		25.3			1.2	0.16	1.2	0.28	1.2	0.0
PBC-6-9	**	24.1			0.86	0.14	1.1	0.27	1.0	0.17
PBC-6-10		26.5			1.0	0.15	1.2	0.28	1.1	0.14
PBC-6-11	**	24.4			0.98	0.16	1.2	0.26	1.1	0.16

** Duplicates

000278

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-07

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-7-1	.31 m	28.4	0.86	0.08						
PBC-7-1	.31 m	28.4	0.86	0.08						
PBC-7-1	1 m	28.4	1.1	0.09						
PBC-7-1	1 m	28.4	0.99	0.09						
PBC-7-1		28.4			0.89	0.14	1.2	0.30	1.0	0.22
PBC-7-2		29.5			0.94	0.15	1.2	0.28	1.1	0.18
PBC-7-3		28.4			0.93	0.15	1.1	0.27	1.0	0.12
PBC-7-4		26.6			1.0	0.15	1.3	0.30	1.2	0.21
PBC-7-5		27.5			1.2	0.18	1.6	0.37	1.4	0.28
PBC-7-6		27.0			0.97	0.16	1.5	0.35	1.2	0.37
PBC-7-7	**	27.2			1.0	0.16	1.5	0.36	1.3	0.35
PBC-7-8		25.0			1.0	0.16	1.3	0.31	1.2	0.21
PBC-7-9		28.7			0.76	0.13	1.5	0.36	1.1	0.52
PBC-7-10		27.0			0.96	0.15	1.1	0.26	1.0	0.10
PBC-7-11		27.7			0.87	0.15	0.91	0.23	0.89	0.03
PBC-7-12		28.5			1.2	0.17	1.3	0.31	1.3	0.07
PBC-7-13		28.6			0.89	0.15	0.88	0.22	0.89	0.01

**Duplicates

000279

1950

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-07

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-7-14		23.7			1.4	0.20	1.7	0.39	1.6	0.21
PBC-7-15		28.9			1.0	0.15	0.94	0.23	1.0	0.04
PBC-7-16	**	27.0			0.85	0.14	1.1	0.27	1.0	0.18

** Duplicates

000280

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-08

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-8-1	.31 m	29.9	0.72	0.06						
PBC-8-1	.31 m	29.9	0.69	0.06						
PBC-8-1	1 m	29.9	0.62	0.06						
PBC-8-1	1 m	29.9	0.62	0.06						
PBC-8-1		29.9			0.59	0.12	0.94	0.23	0.77	0.25
PBC-8-2	**	35.1			0.96	0.14	0.80	0.20	0.88	0.11
PBC-8-3		26.3			0.88	0.14	0.94	0.22	0.91	0.04
PBC-8-4		30.9			0.55	0.10	0.73	0.18	0.64	0.13
PBC-8-5		28.2			NR*	NR*	0.74	0.19	NR*	NR*
PBC-8-6		34.0			0.57	0.10	0.71	0.18	0.64	0.10
PBC-8-7	**	32.6			0.80	0.13	0.95	0.24	0.88	0.11

* NR = No Result
** Duplicates

0002281

1950

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-09

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-9-1	.31 m	29.3	0.83	0.08						
PBC-9-1	.31 m	29.3	0.81	0.07						
PBC-9-1	1 m	29.3	0.81	0.08						
PBC-9-1	1 m	29.3	0.74	0.06						
PBC-9-1		29.3			0.68	0.12	0.79	0.14	0.74	0.08
PBC-9-2		27.3			0.78	0.14	0.79	0.13	0.79	0.01
PBC-9-3	**	26.3			1.1	0.16	0.73	0.13	0.92	0.26
PBC-9-4		26.3			1.1	0.18	0.65	0.12	0.88	0.32
PBC-9-5		26.4			0.77	0.12	0.69	0.12	0.73	0.06
PBC-9-6		24.8			0.75	0.12	0.84	0.15	0.80	0.06
PBC-9-7	**	25.6			0.90	0.15	0.89	0.16	0.90	0.01

** Duplicates

000282

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-10

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-10-1	.31 m	20.8	2.2	0.14						
PBC-10-1	.31 m	20.8	2.0	0.16						
PBC-10-1	1 m	20.8	1.7	0.11						
PBC-10-1	1 m	20.8	1.7	0.14						
PBC-10-1		20.8			2.1	0.22	2.8	0.65	2.5	0.49
PBC-10-2		19.1			4.2	0.37	4.7	1.1	4.5	0.35
PBC-10-3		17.4			4.2	0.37	5.9	1.4	5.1	1.2
PBC-10-4		18.8			1.7	0.23	4.3	1.0	3.0	1.8
PBC-10-5		21.8			1.8	0.21	2.3	0.53	2.1	0.35
PBC-10-6		16.7			2.6	0.34	4.6	1.0	3.6	1.4
PBC-10-7		18.8			2.8	0.36	3.9	0.90	3.4	0.78
PBC-10-8		18.7			1.4	0.22	3.0	0.68	2.2	1.1
PBC-10-9		16.8			2.3	0.31	4.6	1.0	3.5	1.6
PBC-10-10	**	20.5			2.1	0.26	2.7	0.63	2.4	0.42
PBC-10-11		19.3			2.3	0.24	3.1	0.73	2.7	0.57
PBC-10-12		20.4			0.99	0.16	1.5	0.37	1.2	0.36
PBC-10-13		16.6			0.95	0.15	1.7	0.41	1.3	0.53

**Duplicate

000283

1950

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-10

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-10-14		17.8			1.3	0.19	1.7	0.40	1.5	0.28
PBC-10-15		18.4			1.3	0.21	2.2	0.53	1.8	0.64
PBC-10-16	**	15.2			3.9	0.46	6.2	1.4	5.1	1.6

** Duplicates

000284

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-12

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-12-1 (am)	1 m	22.8	2.2	0.11						
PBC-12-1 (am)	1 m	22.8	2.2	0.11						
PBC-12-1 (am)	1 m	22.8	2.3	0.12						
PBC-12-1 (pm)	1 m	22.8	2.3	0.15						
PBC-12-1 (pm)	1 m	22.8	2.2	0.12						
PBC-12-1 (pm)	1 m	22.8	2.2	0.10						
PBC-12-1		22.8			3.8	0.46	5.8	0.92	4.8	1.4
PBC-12-2		18.3			2.8	0.36	4.9	1.1	39.	1.5
PBC-12-3		13.9			8.0	0.93	10	1.7	9.0	1.4
PBC-12-4		15.7			6.8	0.79	11	1.7	8.9	3.0
PBC-12-5	**	21.1			2.6	0.33	3.2	0.74	2.9	0.42
PBC-12-6		17.7			5.1	0.61	8.1	1.3	6.6	2.1
PBC-12-7		13.8			5.3	0.63	7.7	1.2	6.5	1.7
PBC-12-8		10.3			4.3	0.52	7.1	1.6	5.7	2.0
PBC-12-9		23.5			2.8	0.36	5.1	1.2	4.0	1.6
PBC-12-10		22.1			2.8	0.36	3.3	0.76	3.1	0.35
PBC-12-11	**	19.4			2.6	0.33	3.5	0.80	3.1	0.64

** Duplicates

000285

1950

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-13

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-13-1 (am)	1 m	19.7	1.0	0.09						
PBC-13-1 (am)	1 m	19.7	0.92	0.09						
PBC-13-1 (am)	1 m	19.7	1.1	0.13						
PBC-13-1 (pm)	1 m	19.7	0.99	0.10						
PBC-13-1 (pm)	1 m	19.7	0.95	0.09						
PBC-13-1 (pm)	1 m	19.7	0.90	0.10						
PBC-13-1		19.7			1.3	0.20	1.7	0.40	1.5	0.28
PBC-13-2		20.6			1.1	0.17	1.7	0.39	1.4	0.42
PBC-13-3		16.2			0.87	0.19	1.3	0.31	1.1	0.30
PBC-13-4		18.1			1.1	0.17	1.2	0.29	1.1	0.07
PBC-13-5		17.9			1.0	0.16	1.2	0.29	1.1	0.14
PBC-13-6		23.7			1.4	0.20	1.7	0.40	1.6	0.21
PBC-13-7	**	16.3			1.2	0.18	1.6	0.38	1.4	0.28
PBC-13-8		18.1			1.1	0.18	1.4	0.34	1.3	0.21
PBC-13-9		18.9			1.3	0.19	1.8	0.42	1.5	0.35
PBC-13-10		23.7			1.4	0.20	1.7	0.40	1.6	0.21
PBC-13-11	**	14.3			1.1	0.17	1.5	0.37	1.3	0.28

** Duplicates

000286

APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-14

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-14-1 (am)	1 m	15.1	0.85	0.07						
PBC-14-1 (am)	1 m	15.1	0.79	0.07						
PBC-14-1 (am)	1 m	15.1	0.86	0.07						
PBC-14-1 (pm)	1 m	15.1	0.77	0.07						
PBC-14-1 (pm)	1 m	15.1	0.74	0.06						
PBC-14-1 (pm)	1 m	15.1	0.79	0.07						
PBC-14-1	**	15.1			1.1	0.18	1.5	0.36	1.3	0.28
PBC-14-2		12.9			0.86	0.16	1.0	0.25	0.93	0.10
PBC-14-3		14.6			1.2	0.17	1.2	0.30	1.2	0.0
PBC-14-4		14.1			1.1	0.17	1.5	0.35	1.3	0.28
PBC-14-5		13.0			0.94	0.15	1.1	0.27	1.0	0.11
PBC-14-6		13.5			0.88	0.15	1.1	0.26	0.99	0.16
PBC-14-7		13.8			1.2	0.19	1.4	0.34	1.3	0.14
PBC-14-8		15.7			0.93	0.16	1.2	0.29	1.1	0.19
PBC-14-9		13.6			0.96	0.16	1.2	0.29	1.1	0.17
PBC-14-10		13.0			1.1	0.16	1.2	0.30	1.2	0.07
PBC-14-11	**	16.0			1.1	0.17	1.3	0.32	1.2	0.14

** Duplicates

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APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-15

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-15-1 (am)	1 m	23.0	0.86	0.07						
PBC-15-1 (am)	1 m	23.0	0.85	0.06						
PBC-15-1 (am)	1 m	23.0	0.80	0.07						
PBC-15-1 (pm)	1 m	23.0	0.81	0.06						
PBC-15-1 (pm)	1 m	23.0	0.86	0.07						
PBC-15-1 (pm)	1 m	23.0	0.79	0.06						
PBC-15-1		23.0			1.4	0.20	1.3	0.30	1.4	0.07
PBC-15-2		17.5			1.2	0.18	1.3	0.32	1.3	0.07
PBC-15-3		16.3			2.2	0.29	2.6	0.42	2.4	0.28
PBC-15-4		18.8			1.6	0.22	1.3	0.22	1.5	0.21
PBC-15-5		20.2			1.1	0.17	1.2	0.29	1.2	0.07
PBC-15-6		16.2			2.4	0.31	2.8	0.46	2.6	0.28
PBC-15-7		13.1			0.98	0.16	1.1	0.28	1.0	0.08
PBC-15-8		17.9			1.1	0.17	1.2	0.21	1.2	0.07
PBC-15-9		22.4			1.2	0.18	1.4	0.24	1.3	0.14
PBC-15-10		14.8			1.0	0.16	1.1	0.27	1.1	0.07
PBC-15-11		17.9			1.3	0.19	1.4	0.33	1.4	0.07

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APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-16

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-16-1 (am)	1 m	12.1	5.1	0.13						
PBC-16-1 (am)	1 m	12.1	5.2	0.14						
PBC-16-1 (am)	1 m	12.1	5.1	0.13						
PBC-16-1 (pm)	1 m	12.1	5.2	0.14						
PBC-16-1 (pm)	1 m	12.1	5.3	0.15						
PBC-16-1		12.1			6.0	0.70	7.7	1.8	6.9	1.2
PBC-16-2		12.9			7.3	0.86	9.7	2.2	8.5	1.7
PBC-16-3		10.6			14	1.5	27	6.1	21	9.2
PBC-16-4		12.9			17	1.9	29	6.4	23	8.5
PBC-16-5		17.6			19	2.2	23	5.1	21	2.8
PBC-16-6		18.7			18	2.1	25	5.6	22	5.0
PBC-16-7		16.1			6.4	0.74	3.0	0.70	4.7	2.4
PBC-16-8		13.8			9.6	1.1	14	3.3	12	3.11
PBC-16-9		21.2			11	1.3	16	3.6	14	3.5
PBC-16-10	**	12.5			5.6	0.65	12	2.7	8.8	4.5
PBC-16-11		13.2			3.5	0.44	16	3.5	10	8.8
PBC-16-12		15.4			6.7	0.78	11	2.4	8.9	3.0
PBC-16-13		12.1			11	1.3	17	3.8	14	4.2
PBC-16-14		24.0			9.8	1.1	15	3.4	12	3.7

**Duplicate

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APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-16

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-16-15		18.0			36	4.1	50	11	43	9.9
PBC-16-16	**	16.2			8.3	0.96	11	2.5	10	1.9

**Duplicates

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APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-17

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-17-1 (am)	1 m	21.2	3.9	0.12						
PBC-17-1 (am)	1 m	21.2	3.9	0.12						
PBC-17-1 (am)	1 m	21.2	3.9	0.11						
PBC-17-1 (pm)	1 m	21.2	3.8	0.13						
PBC-17-1 (pm)	1 m	21.2	3.9	0.12						
PBC-17-1		21.2			9.2	1.0	6.7	1.5	8.0	1.8
PBC-17-2		21.7			10	1.2	14	3.1	12	2.8
PBC-17-3		24.5			8.9	0.72	14	3.1	11	3.6
PBC-17-4		28.8			7.9	0.67	11	2.4	9.5	2.2
PBC-17-5		21.1			11	1.2	16	3.5	14	3.5
PBC-17-6		21.8			12	1.4	18	4.1	15	4.2
PBC-17-7		15.4			8.0	0.93	13	2.9	11	3.5
PBC-17-8		19.9			2.0	0.27	2.3	0.54	2.2	0.21
PBC-17-9		19.8			1.1	0.17	1.2	0.29	1.2	0.07
PBC-17-10		18.9			3.8	0.46	4.4	0.99	4.1	0.42
PBC-17-11		17.6			5.1	0.60	7.6	1.7	6.4	1.8
PBC-17-12		17.5			7.6	0.88	10	2.3	8.8	1.7
PBC-17-13		25.4			10	1.2	14	3.2	12	2.8
PBC-17-14		21.6			9.2	1.0	12	2.8	11	2.0

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APPENDIX D3 - ANALYTICAL WET WEIGHT CONCENTRATIONS FOR RADIUM-226

AREA-PBC-17

Sample ID	Det Ht	Moisture %	HPGe (pCi/g)		Gamma Spectrometry (pCi/g)		Alpha Spectrometry (pCi/g)		2-Method Average (pCi/g)	
			Result	CE	Result	TPU	Result	TPU	Result	Std Dev
PBC-17-15	**	25.0			16	1.9	20	4.5	18	2.8
PBC-17-16	**	27.4			16	1.8	22	4.9	19	4.2

** Duplicates

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APPENDIX E

WET AND DRY WEIGHT LABORATORY DATA AT FIELD QUALITY CONTROL STATION

APPENDIX E1- LABORATORY WET WEIGHT TOTAL URANIUM DATA FOR SAMPLES TAKEN AT FIELD QUALITY CONTROL STATION

AREA RBS-11

Sample ID	Moisture %	Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BrPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
		Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	Std Dev
RBS-11-1	20.9	83	19	67	8.2	78	2.1	76.4	18.	76.1	6.7
RBS-11-2	24.8	63	14	45	7.7	56	1.4	57.1	1.4	55.3	7.5
RBS-11-3	23.8	71	16	63	8.7	68	1.8	68.3	0.8	67.6	3.3
RBS-11-4	25.7	72	16	58	7.2	68	1.8	67.2	0.7	66.3	5.9
RBS-11-5	20.9	89	20	74	9.0	81	1.9	76.6	1.3	80.2	6.6
RBS-11-5-D	21.9	99	22	70	8.4	87	2.0	84.3	1.2	85.0	11.9
RBS-11-6	26.7	87	19	76	8.0	84	2.0	84.3	1.4	82.5	4.6
RBS-11-7	24.2	78	17	66	8.5	79	1.8	73.8	1.1	74.2	5.9
RBS-11-8	19.7	78	17	61	9.2	71	1.8	69.3	.9	69.8	7.0
RBS-11-9	19.5	94	21	88	10	95	2.3	93.4	1.3	92.6	3.1
RBS-11-10	18.1	78	17	69	9.9	83	2.0	77.1	1.3	76.8	5.8

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APPENDIX E1- LABORATORY WET WEIGHT THORIUM-232 DATA FOR SAMPLES TAKEN AT FIELD QUALITY CONTROL STATION

AREA RBS-11

Sample ID	Moisture %	Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		Average (ppm)	
		Result	TPU	Result	TPU	Result	Std Dev
RBS-11-1	20.9	.82	.19	1.1	.20	.98	.22
RBS-11-2	24.8	.81	.19	1.0	.20	.90	.13
RBS-11-3	23.8	.87	.21	0.99	.18	.93	.08
RBS-11-4	25.7	.91	.21	1.1	.22	.99	.11
RBS-11-5	20.9	.88	.21	1.1	.20	.99	.16
RBS-11-5-D	21.9	.96	.22	1.1	.20	1.0	.06
RBS-11-6	26.7	.94	.22	1.1	.18	1.0	.08
RBS-11-7	24.2	.91	.21	0.98	.20	.95	.05
RBS-11-8	19.7	.88	.21	0.95	.19	.92	.05
RBS-11-9	19.5	1.0	.24	1.3	.24	1.2	.21
RBS-11-10	18.1	.82	.19	1.2	.23	1.0	.27

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APPENDIX E1- LABORATORY WET WEIGHT RADIUM-226 DATA FOR SAMPLES TAKEN AT FIELD QUALITY CONTROL STATION

AREA RBS-11

Sample ID	Moisture %	Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		Average (ppm)	
		Result	TPU	Result	TPU	Result	Std Dev
RBS-11-1	20.9	1.3	.32	1.2	.18	1.3	.07
RBS-11-2	24.8	1.1	.26	1.10	.16	1.1	.07
RBS-11-3	23.8	1.2	.29	.93	.14	1.1	.19
RBS-11-4	25.7	1.1	.28	.98	.15	1.0	.08
RBS-11-5	20.9	1.1	.27	1.1	.16	1.1	0.0
RBS-11-5-D	21.9	1.2	.29	1.1	.17	1.2	.07
RBS-11-6	26.7	1.3	.31	.84	.14	1.1	.33
RBS-11-7	24.2	1.1	.28	1.1	.18	1.1	0.0
RBS-11-8	19.7	1.1	.27	1.1	.16	1.1	0.0
RBS-11-9	19.5	1.2	.30	.84	.16	1.0	.25
RBS-11-10	18.1	1.5	.36	.95	.15	1.2	.39

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APPENDIX E2- LABORATORY DRY WEIGHT TOTAL URANIUM DATA FOR SAMPLES TAKEN AT FIELD QUALITY CONTROL STATION

AREA RBS-11

Sample ID	Moisture %	Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		BrPADAP (ppm)		ICP/MS (ppm)		Average (ppm)	
		Result	TPU	Result	TPU	Result	TPU	Result	TPU	Result	Std Dev
RBS-11-1	20.9	105	24	85	10	98	2.6	96.6	2.3	96.2	8.3
RBS-11-2	24.8	84	19	60	10	74	1.9	75.9	1.9	73.5	10.0
RBS-11-3	23.8	93	21	83	11	89	2.3	89.6	1.1	88.7	4.2
RBS-11-4	25.7	97	22	78	10	91	2.4	90.4	1.0	89.1	8.0
RBS-11-5	20.9	113	25	94	11	103	2.4	96.8	1.7	102	8.4
RBS-11-5-D	21.9	127	28	90	11	111	2.6	108	1.6	109	15
RBS-11-6	26.7	119	26	104	11	115	2.7	115	1.9	113	6.4
RBS-11-7	24.2	103	22	87	11	104	2.4	97.3	1.5	97.8	7.8
RBS-11-8	19.7	97	21	76	11	88	2.3	86.3	1.1	86.8	8.6
RBS-11-9	19.5	117	26	109	12	118	2.8	116	1.6	115	4.1
RBS-11-10	18.1	95	21	84	12	101	2.4	94.2	1.6	93.6	7.1

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APPENDIX E2- LABORATORY DRY WEIGHT THORIUM-232 DATA FOR SAMPLES TAKEN AT FIELD QUALITY CONTROL STATION

AREA RBS-11

Sample ID	Moisture %	Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		Average (ppm)	
		Result	TPU	Result	TPU	Result	Std Dev
RBS-11-1	20.9	1.04	.24	1.6	.33	1.2	.28
RBS-11-2	24.8	1.08	.25	1.6	.34	1.2	.17
RBS-11-3	23.8	1.14	.28	1.3	.28	1.2	.11
RBS-11-4	25.7	1.22	.28	1.7	.35	1.4	.18
RBS-11-5	20.9	1.11	.27	1.5	.34	1.3	.20
RBS-11-5-D	21.9	1.23	.28	1.4	.32	1.3	.08
RBS-11-6	26.7	1.28	.30	1.6	.31	1.4	.14
RBS-11-7	24.2	1.20	.28	1.4	.30	1.2	.05
RBS-11-8	19.7	1.10	.26	1.3	.29	1.2	.08
RBS-11-9	19.5	1.24	.30	1.8	.35	1.4	.29
RBS-11-10	18.1	1.00	.23	1.6	.34	1.2	.33

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APPENDIX E2- LABORATORY DRY WEIGHT RADIUM-226 DATA FOR SAMPLES TAKEN AT FIELD QUALITY CONTROL STATION

AREA RBS-11

Sample ID	Moisture %	Alpha Spectrometry (ppm)		Gamma Spectrometry (ppm)		Average (ppm)	
		Result	TPU	Result	TPU	Result	Std Dev
RBS-11-1	20.9	1.6	.40	1.6	.23	1.6	.03
RBS-11-2	24.8	1.5	.35	1.4	.22	1.4	.04
RBS-11-3	23.8	1.6	.38	1.2	.19	1.4	.25
RBS-11-4	25.7	1.5	.38	1.3	.20	1.4	.11
RBS-11-5	20.9	1.4	.34	1.4	.20	1.4	0.0
RBS-11-5-D	21.9	1.5	.37	1.4	.22	1.5	.09
RBS-11-6	26.7	1.8	.42	1.2	.19	1.5	.41
RBS-11-7	24.2	1.5	.37	1.4	.24	1.4	.04
RBS-11-8	19.7	1.4	.34	1.4	.20	1.4	0.0
RBS-11-9	19.5	1.5	.37	1.0	.19	1.3	.32
RBS-11-10	18.1	1.8	.44	1.2	.19	1.5	.47

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APPENDIX F

HPGe DETECTOR INSTRUMENTATION AND THEORY

APPENDIX F
HPGe DETECTOR INSTRUMENTATION AND THEORY

F.1 FIELD DETECTION INSTRUMENTATION

This section provides an overview of the basic principles of High Purity Germanium (HPGe) detectors and in-situ gamma-ray spectrometry. For a more detailed discussion, refer to IRCU Report #53, "Gamma Ray Spectrometry in the Environment."

F.1.1 Types of Detectors

There are three general types of radiation detection devices: gas-filled, scintillation, and semiconductor. Semiconductor detectors, including HPGe or other high energy resolution detectors, are needed for complex gamma and x-ray spectra. Typically "N" type detectors are used when a high degree of resolution is required in energy regions less than 100 keV. "P" type HPGe detectors are used in situations when resolution below 100 keV is not critical. The advantages of semiconductor detectors over scintillation and gas-filled detectors include very low resolving time and a high degree of energy resolution. The major disadvantage of HPGe detectors is sensitivity to thermal excitation (heat). Because of this, HPGe detectors are maintained at liquid nitrogen temperatures during operation. HPGe detectors typically exhibit energy resolution on the order of 1 to 3 keV full width half maximum (FWHM) of detected photopeaks. This high resolution enhances the ability to seperate, identify and quantify photopeaks. This is a desirable feature for in-situ characterization of radionuclides.

Radiation detection devices such as HPGe detectors use products of the ionization or excitation process to produce a measurable output that is proportional to the incident radiation intensity and/or the incident radiation energy. Radiation detectors are coupled to various types of supporting processors, depending on the desired application, to provide a source of power to the detector and to enable the quantity and quality of the radiation interactions to be amplified and processed. The Multichannel Analyzer (MCA) is the device commonly used in high resolution gamma spectrometry.

MCAs are sophisticated instruments designed to measure and record the number of pulses generated by nuclear events in a detector that occur at multiple energy levels. Typical MCAs can separate nuclear events occurring in a detector into a number of energy bands, or channels. MCAs available today are capable of dividing the total observed energy spectrum into as few as 256 channels to as many as

16,384 channels, depending on the desired application. The result is that peaks resolved by an HPGe detector can be viewed as a single energy display. Gamma ray spectrum analysis using MCAs coupled with high speed computers containing gamma analysis software provides a rapid and accurate method to identify and quantify gamma photons impinging on an HPGe detector.

For gamma-ray in-situ measurements of soil, detectors of known angular response and energy calibration are used to measure the gamma or x-ray emission from an unknown distribution of radionuclides in the soil. To determine the detector measurement response (efficiency), the unscattered photon flux above the soil-air interface from radioactive emitters distributed in the soil is mathematically modeled and combined with the detector's calibrated angular response to determine the average source activity in the area and volume of soil within the detector's field of view. The most important consideration when performing in-situ spectrometry is that the accuracy of the analysis depends on the radioactivity distribution with soil depth and, to a lesser extent, on the soil density, soil moisture content, and soil chemical composition. Parameters that must be known or approximated for use in the in-situ model include source activity depth distribution, soil bulk density, soil moisture content, air and soil total photon attenuation coefficients, and detector response functions.

To relate photopeak count rate to activity in the soil, the detector measurement efficiency over the energy range of interest at different detector measurement heights must be determined. For in-situ detectors which rely upon modeling to determine measurement efficiency, this process is called characterization. During characterization, the detector measures point source standards at a known distance (usually 1 meter), at several angles to the detector for a specific period of time. This characterization process produces a conversion factor which permits conversion of the detector net counts for photopeaks to be converted to nuclide concentrations. Table F-1 lists the photopeaks used in this study to determine the radionuclides of concern in soil. Section F.1.2 discusses detector characterization and the determination of conversion factors.

F.1.2 Detector Characterization

Detector characterization is performed by measuring the detector sensitivity to multiple gamma-ray energies at angles ranging from 0 to 90 degrees. Radioactive standards, certified by the United States Department of Commerce, National Institute of Standards and Technology (NIST) are used for detector characterization. Standards used at FEMP are Am-241, Cs-137, Co-60, and Eu-152. These standards

emit gamma and/or x-rays with energies ranging from 32.1 keV to 1408.0 keV that are used for characterization.

To characterize the detector, the standards are placed one at a time in a reproducible configuration at one meter from the detector face while a measurement is made. At the completion of each measurement, the source is moved ten degrees within the configuration and another measurement is made. This is repeated until measurements are made from 0 to 90 degrees for each standard. At the completion of the 90 degree measurement, the source is placed at 0 degrees and a duplicate measurement is made. This duplicate measurement is made to account for determinate errors. The 0 degree measurements are averaged and used to determine the detector's effective area at 0 degrees by solving Equation (1).

$$A_0 = \frac{4\pi r^2 N/T}{S_0} x\, e^{r/\lambda_a} \qquad (1)$$

where:

A_0 = detector effective area at 0 degrees in units of cm^2*cps/γ/s

r = source distance from the detector in units of cm

N = signal or net counts in units of counts

T = count time in units of seconds

S_0 = source strength in units of γ/s

λ_a = mean free path in air for the gamma energy in units of cm

The detector effective area varies as a function of gamma-ray energy and gamma-ray angle of incidence. This relationship for a given energy can expressed as:

$$A = A_0 R(\theta) \qquad (2)$$

where:

$R(\theta)$ = the ratio of the detector response at an angle θ to that at θ = 0 degrees.

The angular response of the detector package is folded into a multiple integration equation to determine conversion factors for the in-situ measurement. The theory of in-situ measurements and the equation are provided in Section F.1.2.1. It is convenient to compute conversion factors for two detector heights with a branching of unity and to plot the results (pCi/g/cps) as a function of energy. These data are used on a spreadsheet to compute the conversion factors for the detector at any measurement height.

The conversion factors computed and loaded into the analysis software for the in-situ detectors reflect the following assumptions:

soil density = 1.5 g/cm^3
soil moisture = 10%
vertical distribution = homogeneous
averaging depth = 3.0 cm
air density = 0.001293 g/cm^3

The detector 'field of view' is defined as that circle on the plane where 90% of the gamma rays originate that contribute to the photopeak counts. The 'field of view' is a function of gamma-ray energy, vertical distribution, and detector height.

F.1.2.1 Measurement Theory

The unscattered flux of gamma-rays of energy E at a height above a smooth air-ground interface due to an emitter distributed in the soil is given by:

$$\Phi = \int_0^\infty \int_0^\infty \frac{S_v}{4\pi r^2} x\, e^{-(\frac{\mu}{\rho})_a \rho_a r_a} e^{-(\frac{\mu}{\rho})_s \rho_s r_s} 2\pi\, x\, (dxdz) \qquad (3)$$

where:

S_v = the activity per unit volume in units of $(\gamma/s)/cm^3$

$r = r_a + r_s$ in units of cm = distance from the activity source to the detector where r_a is the distance in air and r_s is the distance in soil

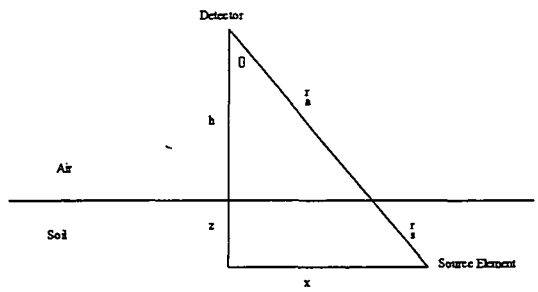
$(\mu/\rho)_a$ = air mass attenuation coefficient in units of cm^2/g

$(\mu/\rho)_s$ = soil mass attenuation coefficient in units of cm^2/g

ρ_a = air density in units of g/cm^3

ρ_s = soil density in units of g/cm^3

This expression assumes a source distribution which varies only with depth. The relationship between source and detector is shown in the diagram below.



Geometry used in the derivation of conversion factors relating *in situ* photopeak count rate data to isotope concentration in the ground.

For fallout activity, the distribution after a period of time can be reasonably approximated by an exponential distribution given by:

$$S_v = S^0_v \, e^{\alpha z} \qquad (4)$$

where:

S = the activity per unit volume at the surface and

α = the reciprocal of the relaxation length in units of cm^{-1}.

Combining Equation (3) with Equation (4) and integrating over z leads to the following expression:

$$\Phi = \frac{S_v^0}{2} \int_0^{\frac{\pi}{2}} \frac{TAN\theta e^{-(\frac{\mu}{\rho})_a \rho_a h \sec\theta}}{\alpha + (\frac{\mu}{\rho})_s \rho_s \sec\theta} d\theta \qquad (5)$$

F.1.2.2 Determining Conversion Factors

The detector response to a given flux of gamma-rays (F) of energy E incident at an angle q can be given in terms of an effective detector area, A, defined by:

$$A = N_p/\Phi \qquad (6)$$

where:

N_p = the net photopeak count rate in units of cps.

The effective area, as stated previously, for a given energy, varies as a function of the gamma-ray angle of incidence and is normally written as:

$$A = A_0 R(\theta) \qquad (2)$$

Both A_0 and $R(\theta)$ can be determined experimentally with point gamma-ray sources.

Combining Equations (6) and (2) with Equation (5) leads to an expression which relates the measured photopeak count rate to source activity in the soil. This is given by:

$$\frac{N_p}{S_v^0} = \frac{A_0}{2}\int_0^{\frac{\pi}{2}} \frac{R\theta \tan\theta e^{-(\frac{\mu}{\rho})_a \rho_a h \sec\theta}}{\alpha + (\frac{\mu}{\rho})_s \rho_s \sec\theta} d\theta \qquad (7)$$

The conversion factor given by Equation (8) is in units of cps/(γ/cm^{3}s)

$$\frac{N_p}{S_v^0} \qquad (8)$$

For a specific isotope, the conversion factor is normally changed to units of cps/(pCi/cm^3). Multiplying Equation (7) by the soil density (γ/cm^3) leads to the conversion factor which is normally given in units of cps (pCi/g).

$$\frac{N_p}{\frac{S_v^0}{\rho}} \tag{9}$$

In general, the average concentration in the top z cm, for a source distributed exponentially with depth is given by:

$$S_v^z = \frac{1}{z}\int_0^z S_v^0\, e^{-\alpha z} dz = \frac{S_v^0}{\alpha z}(1 - e^{-\alpha z}) \tag{10}$$

Combining Equations (7) and (10) leads to the following multiple integration equation used at FEMP to determine detector conversion factors:

$$\frac{S_v^z / \rho}{N_p} = \frac{1 - e^{-\alpha z}}{\alpha z}\beta\,[\frac{A_0\,\rho_s}{2}\int_0^{\pi/2}\frac{R\theta\,\tan\theta\, e^{-(\mu/\rho)_a h \sec\theta}}{\alpha + (\mu/\rho)_s \sec\theta}]^{-1}$$

Where:

S_v^z = the activity per unit volume at some depth z beneath the surface, (γ/s)/cm^3.

N_p = the net photopeak count rate, cps.

β = conversion factor to convert γ/s (dps) to pCi/g for a specific isotope. 1 pCi = 3.7 dps.

A_0 = detector effective area at 0 degrees in units of cm^2 cps/γ/s

$R\theta$ = the ratio of the detector's response at an angle of θ to that at θ = 0 degrees.

$(\mu/\rho)_a$ = air attenuation coefficient, cm^2/g. This term varies with nuclide energy.

$(\mu/\rho)_s$ = soil attenuation coefficient, cm^2/g. This term varies with nuclide energy.

ρ_a = air density, g/cm^3. The value used is 0.001293 g/cm^3.

ρ_s = soil density, g/cm^3. The value used is 1.5 g/cm^3 .

α = the reciprocal of the relaxation length, cm^{-1}. The value used for α is 1 x 10^{-6} for sub-surface deposits and 1 x 10^6 for surface deposits.

z = depth beneath the surface, cm. The value used is 3 cm.

h = detector height above the measurement plane, cm.

Computations have been carried out to determine the conversion factors at various energies using the above equation and EGAS or Fortran geometric programming. The computed conversion factors are used to create an efficiency (conversion factor) curve which is used by analysis software to determine concentrations of nuclides in environmental spectra.

F.1.3 Data Computation and Output

Analysis is performed using EG&G analytical and multi-channel analysis software. An example of the standard GammaVision report is shown in Table F-2. The report is divided into four pages and contains the following information:

Page 1

Page 1 contains general information about the sample (spectrum) the detector and analysis parameters.

Page 2

Page 2 contains the following raw counting information for identified peaks.

Column 1 -	Nuclide name and detector resolution as FWHM.
Column 2 -	The peak channel in the display for the nuclide.
Column 3 -	The (peak) centroid energy in keV.
Column 4 -	The background counts.
Column 5 -	The net area counts. These counts represent the 'activity seen'.
Column 6 -	The intensity (count rate) of the nuclide.
Column 7 -	The counting uncertainty as a sigma percent.

Page 3

Page 3 contains the following quantified information for peaks contained in the analysis library.

Column 1 -	The nuclide identity.
Column 2 -	The average nuclide activity for all the peaks in the library.
Column 3 -	The peak (isotope).
Column 4 -	The activity for each peak (isotope) in the library.
Column 5 -	The minimum detectable activity for each peak (isotope) in the library*.
Column 6 -	Any analyst comments.

* - Sample-specific MDAs (MDCs) are provided for each isotope. These MDCs are "a posteriori," as opposed to MDCs given in Section 5, which are "a priori." These sample-specific MDCs can be used to assess data useability.

Page 4

Page 4 contains the following summary of all identified nuclides and their activities.

Column 1 - The nuclide identity.
Column 2 - The nuclide average weighted activity.
Column 3 - The counting uncertainty as pCi/g.

The gamma photons listed in Table F-1 are used to calculate a weighted average activity concentration for the isotopes in Table F-2. The square of the counting errors are used as the weighting factors. The weighted average activity concentrations for the various isotopes are listed under the "Summary of Nuclides in Sample" heading.

TABLE F-1
GAMMA PHOTONS USED TO QUANTIFY U-238, Th-232, Ra-226, Cs-137, AND K-40 FOR HPGe MEASUREMENTS

Analyte Radionuclide	Radionuclide of Emission	Gamma Photon Energy (keV)	Gamma Photon Abundance (%)
U-238	Th-234 Th-234 Pa-234m	63.2 92.6 1001.0	3.9 5.41 0.845
U-235	U-235	185.7 143.8	54.0 10.5
Th-232	Pb-212 Tl-208 Ac-228	338.3 583.1 911.1	11.4 30.6* 29.0
Cs-137	Ba-137m	661.6	84.62**
K-40	K-40	1460.8	10.7
Ra-226	Pb-214 Bi-214 Bi-214	351.9 609.3 1120.4	35.0 43.0 17.0

* Includes 0.359 branching ratio from decay of Bi-212.
** Includes 0.946 branching ratio from decay of Cs-137.

TABLE F-2

PAGE 1

```
EG&G ORTEC G V - I (3135) WAN32  I4W02.78  27-OCT-98 09:46:27
Gamma Guys Inc.                  Spectrum name: 1681.An1

Sample description
     30687,31cm,900s,A8P1-01-01G,3-30-98,5uR,#1681


Spectrum Filename: 1681.An1

Acquisition information
     Start time          30-Mar-98   11:37:36
     Live time                 900
     Real time                 918
     Dead time               1.98%
     Detector/Geometry IDs        0 &         0

Detector system
     MCB 9

Calibration
     Filename: 1681.An1
     Created: 24-Oct-98 17:36:53 &
     detector # 30687 calibration as of 10/97 at 31 cm.
     Zero offset      .551 keV;  Gain       .375 keV/channel

Library Files
     Main analysis library:           C:\USER\Report.LIB
   Library based peak stripping used.

Analysis parameters
     Start channel             10 for an energy of     4.30keV
     Stop channel            8000 for an energy of  2999.55keV
     Peak rejection level    1000.000%
     Activity scaling factor   1.0000E+00/(  1.0000E+00*  1.0000E+00)
                                                                    =
1.0000E+00
     Detection limit method:
          Y A E C Method
     Additional random error:            1.0000000E+00
     Additional systematic error:        1.0000000E+00
     Background width: best method (based on spectrum).
     Peak acceptance width =   1.0000000E+00

Corrections                          Status          Comments
     Decay correct to date            NO
     Decay during acquisition         NO

     Peaked background correction     NO
     Absorption (Internal)            NO
     Geometry correction              NO
     Random summing                   NO
Energy calibration normalized difference:     .3101
-------------------------------------------------------------
```

PAGE 2

This section based on library: C:\USER\Report.LIB

********** I D E N T I F I E D P E A K S U M M A R Y **********

1 NUCLIDE	2 PEAK CHANNEL	3 CENTROID ENERGY	4 BACKGROUND COUNTS	5 NET AREA COUNTS	6 INTENSITY CTS/SEC	7 UNCERT 1SIGMA%	FWHM
CS-137	82.67	31.54	4445.	60.	.067	157.57	1.125s
U-238	166.69	63.04	14035.	394.	.438	55.70	1.506s
Th-230	180.55	68.23	11668.	61.	.068	294.65	1.445s
U-238	244.03	92.03	13294.	824.	.916	28.20	1.663s
U-235	382.57	143.97	6607.	-10.	-.011	1183.74	1.125s
U-235	492.02	185.00	5304.	602.	.669	26.82	1.486s
Ra-226	492.82	185.30	4288.	417.	.463	22.77	1.125
Th-232	633.94	238.20	3041.	877.	.974	9.51	1.165
Ra-226	936.19	351.51	1773.	764.	.849	14.20	1.508
Th-232	1552.90	582.69	751.	759.	.843	10.47	1.740
Ra-226	1622.93	608.95	624.	916.	1.018	7.65	1.772s
CS-137	1762.62	661.31	622.	1034.	1.149	7.26	1.780s
Th-232	2428.38	910.89	410.	515.	.572	12.09	1.946s
U-238	2667.25	1000.44	297.	85.	.094	50.83	1.974
Ra-226	2986.04	1119.95	246.	277.	.307	14.71	1.906s
CO-60	3133.30	1175.15	291.	78.	.086	59.28	1.693s
CO-60	3553.00	1332.48	17.	1.	.001	279.88	.750s
K-40	3894.67	1460.57	99.	3268.	3.631	1.94	2.411

s Peak fails shape tests.
D Peak area deconvoluted.
A Derived peak area.

***** S U M M A R Y O F L I B R A R Y P E A K U S A G E *****

1 NUCLIDE	2 AVERAGE ACTIVITY pCi/g	3 PEAK ENERGY keV	4 PEAK ACTIVITY pCi/g	CODE	5 MDA VALUE pCi/g	6 COMMENTS
CS-137	3.88534E-01	661.62	3.885E-01	*(	4.4658E-02	
		32.19	3.311E+00	+	1.7284E+01	
CO-60	1.44822E-02	1332.51	4.512E-04	?(	8.2011E-03	
		1173.23	2.853E-02	@(	3.0236E-02	
K-40	1.10737E+01	1460.75	1.107E+01	(	1.6613E-01	
Ra-226	6.13731E-01	351.90	5.734E-01	(	1.4934E-01	
		609.30	6.574E-01	*(	8.5486E-02	
		1120.40	5.864E-01	@(	1.6082E-01	
		186.10	2.712E+00	}	2.0041E+00	
Th-230	5.38114E+00	67.67	5.381E+00	(	4.4352E+01	
Th-232	4.71242E-01	238.60	4.712E-01	(	1.3954E-01	
		583.14	7.695E-01	+	1.3224E-01	
		911.10	5.986E-01	+	1.1283E-01	
U-235	0.00000E+00	185.72	2.467E-01	}	1.4017E-01	
		143.76	0.000E+00	%	7.7644E-01	
U-238	3.72864E+00	63.20	3.460E+00	*(	4.8744E+00	
		92.60	3.962E+00	•(	2.5968E+00	
		1001.00	3.471E+00	(	3.3905E+00	

(- This peak used in the nuclide activity average.
* - Peak is too wide, but only one peak in library.
! - Peak is part of a multiplet and this area went negative during deconvolution.
? - Peak is too narrow.
@ - Peak is too wide at FW25M, but ok at FWHM.
% - Peak fails sensitivity test.
$ - Peak identified, but first peak of this nuclide failed one or more qualification tests.
+ - Peak activity higher than counting uncertainty range.
- - Peak activity lower than counting uncertainty range.
= - Peak outside analysis energy range.
& - Calculated peak centroid is not close enough to the library energy centroid for positive identification.
P - Peakbackground subtraction
} - Peak is too close to another for the activity to be found directly.

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***** S U M M A R Y O F N U C L I D E S I N S A M P L E *****

NUCLIDE		2 ACTIVITY pCi/g	3 COUNTING UNCERTAINTY(1 SIGMA) pCi/g
CS-137	#	3.8853E-01	.03
CO-60	#	1.4482E-02	.01
K-40		1.1074E+01	.21
Ra-226		6.1373E-01	.04
Th-230		5.3811E+00	15.86
Th-232		4.7124E-01	.04
U-235	<	7.76E-01	
U-238		3.7286E+00	1.00

All peaks for activity calculation had bad shape.

---------- S U M M A R Y ----------

TOTAL ACTIVITY (4.3 to 2999.6 keV) 2.1671420E+01 pCi/g

Analyzed by: _____
Tom Cox

Reviewed by: _____
Supervisor

TABLE F-3
GAMMA RAYS UTILIZED FOR COMPARABILITY STUDY
FOR LABORATORY MEASUREMENTS

Analyte Isotope	Half Life (Years)	Energy (KeV)	Abundance (%)	Isotope of Emission
U-238	4.47E+9	63.29	3.8	Th-234
		92.59	5.41	Th-234
		766.41	0.207	Pa-234m
		1001.03	0.845	Pa-234m
U-235	7.04E+8	143.76	10.5	U-235
		185.72	54.0	U-235
Th-232	1.41E+10	238.63	44.6	Pb-212
		583.14	30.6*	Tl-208
		727.17	11.8	Bi-212
		911.07	27.7	Ac-228
Ra-226	1.60E+3	295.21	19.2	Pb-214
		351.92	37.2	Pb-214
		609.31	46.3	Bi-214
		1120.29	15.1	Bi-214
		1764.49	15.8	Bi-214
Cs-137	3.03E+1	661.65	84.62**	Ba-137m
K-40	1.28E+9	1460.81	10.7	K-40

* Includes 0.359 branching ratio from decay of Bi-212
** Includes 0.946 branching ratio from decay of Cs-137

APPENDIX G

USING GAMMAVISION SOFTWARE FOR SPECTRAL ANALYSIS AND QUANTIFICATION

APPENDIX G
THE CARE AND FEEDING OF GAMMAVISION

The EG&G gamma-ray analysis software entitled GammaVision (GV) has been evaluated as a replacement for the Environmental Gamma-Ray Analysis Software (EGAS). EGAS, a FORTRAN program requires manual interaction and input to produce a result. It is desirable to increase analysis speed by automating the analysis process. GV allows this automation by directly interacting with the EG&G multi-channel analysis software through programmable commands.

Information Required for Analysis by GammaVision

In order to evaluate gamma spectra, identify the nuclides present and determine the concentration of each of these nuclides, GV requires spectral information for suspected nuclides, the detector measurement efficiencies for these nuclides over a defined energy range and the analysis criteria desired by the analyst. This information is contained in defined computer files stored in a User directory that can be accessed by GV. These files are:

1. Nuclide Library - a file titled Report.Lib was created which contains gamma photon energy information necessary to identify nuclides of interest and the gamma yield or frequency of decay of each of these nuclides.

2. Calibration Files - calibration files have been created for each detector at measurement distances of 15 cm, 31 cm and 1 meter. These calibration files contain the energy and efficiency (conversion factor) information to permit nuclide identification using the library and for net peak counts to be converted to a concentration in pCi/g. Each calibration file has been assigned a unique name. For example:

   - 30687-1M.Clb is the calibration at 1 meter for detector 30687.
   - 30687-31cm.Clb is the calibration at 31 cm for detector 30687.

3. Analysis File - this file contains information relevant to the analysis which the analyst requires or desires for the analysis. A file titled Quant1.Sdf has been created which contains analysis information used for in-situ spectral analysis and reporting.

The Nuclide Library

The nuclide library titled Report.Lib created for this study contains the following information:

Nuclide of Interest	Nuclide Measured	Energy (keV)	Gamma Yield %
Cs-137	Cs-137	32.19	3.7
		661.62	84.62**
Co-60	Co-60	1173.23	99.86
		1332.51	99.98
K-40	K-40	1460.75	10.7
Ra-226	Pb-214	351.9	35.0
	Bi-214	609.3	43.0
	Bi-214	1120.4	17.0
	Ra-226	186.1	3.4
Th-230	Th-230	67.67	0.373
Th-232	Ac-228	338.32	11.4
	Tl-208	583.1	30.6*
	Ac-228	911.1	29.0
U-235	U-235	143.76	10.5
	U-235	185.72	54.0
U-238	Th-234	63.2	3.9
	Th-234	92.6[1]	5.41[2]
	Th-234	1001.0	0.845

* Includes 0.359 branching ratio from decay of Bi-212
** Includes 0.946 branching ratio from decay of Cs-137

Note 1: This is the average energy of two peaks. The actual peak energies are 92.38 and 92.8 keV.
Note 2: This is the sum of the yields of the two peaks given in note 1.

Calibration Files

Calibration files are created by preparing a measurement efficiency (conversion factor) table which compares energy versus measurement efficiency. Once an efficiency table has been created and saved as a file (an .Eft file in GV), a calibration file can be created by selecting "Save Calibration" which calls up the calibration file directory. When the file is given the same title as the efficiency file that was created, a .Clb is automatically appended indicating that the file is a calibration file.

Programming GammaVision to Perform Analysis

In GV, the analysis program routine is called a Jobfile. These files are prepared using the programming information and commands in Section 9 of "GammaVision-32 Software User's Manual". For this study, which used data previously acquired by several different detectors, individual detector "test" Jobfiles have been prepared to allow programmed analysis by GV. For example, a test Jobfile prepared for detector 30904 measurements reads as follows:

```
SET_DETECTOR_0
LOAD_LIBRARY"C\USER\Report.LIB"
RECALL_CALIB"C:\USER\30904-1M.CLB"
RECALL_OPTIONS"C:\USER\QUANT1.SDF"
SMOOTH
ANALYZE
WAIT 2
```

This program will analyze a spectrum in the buffer using the support files indicated. The spectrum is smoothed one time and then analyzed. After analysis is complete (requires about 5 seconds) the program waits 2 seconds before displaying or printing the report. An example GammaVision Peak Report is included as Attachment 3.

Spectral Measurement Problems

When an analysis is run, quantifying results from peaks of interest in the spectrum is complicated by the presence of other peaks within or near the margins of their region of interest. Interferences encountered are:

Nuclide of Interest	Energy (keV)	Interfering Peak	Energy (keV)
U-238	92.8	Ac-228	89.953
		U-235	89.953
		Ac-228	93.35
		U-235	93.35
U-235	185.7	Ra-226	186.1
Th-232	238.6	U-235	240.9
		Pb-214	241.9

For U-235, the Ra-226 at 186.1 keV falls inside the region of interest of the 185.7 keV peak. When the 186.1 keV peak is included in the nuclide library, GammaVison performs a deconvolution which corrects for the interference.

For the remainder of the nuclides of interest, the interfering peaks are adjacent to the region of interest. These peaks interfere by raising the baseline of the peak of interest, reducing the net peak area and thereby producing a low activity value. Deconvolution will not work for this type of interference, so the interfering peaks are not included in the nuclide library. However, the effect of adjacent peak interference can be reduced somewhat using smoothing. The process of smoothing evens up the "lumps" caused by adjacent peaks and lowers the baseline of the peak of interest. However, smoothing should be used with discretion. Multiple use of smoothing widens and lowers the peak region. As a standard practice, smoothing is performed one time in the Jobfiles written for this study.

GammaVision Smoothing

The smoothing function in GV uses a five-point, area preserving, binomial algorithm. Data in a peak region of interest is replaced channel-by-channel with averaged or smoothed data in accordance with the following equation:

$$S_i = \frac{O_{i+2} + 4 \times O_{i+1} + 6 \times O_{i-1} + O_{i-2}}{16}$$

Where:

S_i = smoothed data in channel i.

O_i = the original data in channel i.

Nuclide Averaging

As illustrated in the nuclide library, nuclides of interest are represented by more than one peak in each spectrum. To determine a single concentration for each nuclide of interest, the peaks are weight averaged as shown in the following equation for three peaks:

$$WA = \frac{\frac{P_1}{UNC_1^2} + \frac{P_2}{UNC_2^2} + \frac{P_3}{UNC_3^2}}{\frac{1}{UNC_1^2} + \frac{1}{UNC_2^2} + \frac{1}{UNC_3^2}}$$

Where:

WA = weight averaged concentration of a nuclide of interest.

$P_{1,2,3...}$ = the concentration of each peak.

$UNC_{1,2,3...}$ = the 1 σ counting uncertainty of each peak.

Minimum Detectable Concentration (MDC)

In ADM-16, In-Situ Gamma Spectrometry Control Quality Control procedure Section 6.7, HPGe MDC is calculated as follows:

$$MDC(pCi / g) = K(2.71 + 4.65\, S_b)$$

Where:

K = the conversion (efficiency) factor for each spectrum region of interest.

s_b = standard deviation of background counts; for MDC, s_b is the square root of the counting background for the region of interest.

In GV, the method used for determining Minimum Detectable Activity (MDA) is the NUREG 4.16 Method which is described in the "GammaVision-32 Software User's Manual" as Method 12. The equation for Method 12 is:

$$P = \frac{2.71 + 4.66\sigma_b}{LT}$$

Where:

P = the count rate for a selected peak of interest.

σ_b = the standard deviation of background counts.

LT = the counting live time.

In GV, the peak count rate is converted to activity (concentration, pCi/g). The program automatically inserts the conversion factor for each peak of interest and any other conversion factors that the analyst

selects for use. The method in which GV computes MDA using Method 12 provides the same result as the Fernald MDC equation.

Data Used in the Efficiency Table

One of the most important elements in gamma-ray analysis is the preparation of an accurate efficiency vs. energy table that contains an adequate number of efficiency measurement points distributed over the energy range of interest to produce a viable efficiency curve. For in-situ measurements, the efficiency table is generated by measuring radioactive standards and then computing conversion factors at various energy points using geometric modeling. This is the technique used by EGAS software and by other investigators performing in-situ measurements. These modeling equations have been in use for many years. The efficiency tables used in GV are produced using the conversion factors computed by EGAS for uniform surface and sub-surface deposits. To adapt the EGAS conversion factors (which are in units of pCi/g/cps) into GV requires using the reciprocal of the EGAS conversion factor because of differences in the activity equations used by EGAS and GV. The EGAS equation used for determining activity is as follows:

$$A_E = \frac{N_E \ x \ CF_E}{t \ x \ Y_E}$$

Where:

A_E = The activity at some gamma energy E, pCi/g

N_E = The net count rate at E, counts.

CF_E = The conversion (efficiency) factor at E, pCi/g/cps

t = The counting time, seconds.

Y_E = The gamma yield at E, gammas/disintegration.

The equation used by GV is the standard form of the activity equation which is:

$$A_E = \frac{N_E}{CF_E \ x \ t \ x \ Y_E}$$

The terms in both equations are the same with the exception of CF_E. CF_E as defined in GammaVision is the inverse of CF_E as defined in EGAS.

The Significance of Efficiency Calibration at Different Heights

As the calibration factor data from the geometric model were being prepared using the spreadsheet (see Attachment 2), differences between the calibration factors at different heights appeared to be small. As a result, columns were added to the Excel Detector Conversion Factor Spreadsheets that display the relative percent difference between the conversion factors for the different heights. These data indicate that within the energy range for FEMP nuclides of concern, the relative percent difference is between 2% and 4% for either 31cm and 15 cm compared to 1 meter. In other words, if one efficiency curve were to be used for all heights, the error introduced would average about 3%.

The Importance of Quality Control

During the course of this study, several spectra caused analysis problems when using GV. EGAS would usually (not always) compute activities for these problem spectra when GV would fail the analysis or produce a different answer from EGAS. At first it was believed that the problem centered around interferences especially the 93 keV peak used for U-238. Interference is sometimes a problem but smoothing usually minimizes interference effects. The major problem when the analysis "blew up" in GV was energy shifted spectra. In several instances, energy shift was in excess of 3 keV, well outside our current QC requirements for using a detector for measurements. EGAS will correct for a great deal of energy shift and will produce a result. GV will correct for some energy shift but fails the analysis if the shift is too great. Shift Happens! Correction for energy shift in a program is good but not a substitute for good QC practice. If a detector which exceeds QC requirements is used to take spectra, the data are ever after suspect no matter how much they are corrected. In the spectra that were badly shifted in this study, correction in GV for the energy shift yielded about the same results as EGAS. **MAKE SURE THE DETECTOR IS WITHIN ENERGY CALIBRATION TOLERANCES BEFORE MEASURING.**

Generation of Data Using a GammaVision Jobfile

Spectrum peak reports can be generated through the GV program. The easiest way to generate these reports is via a GV Jobfile which was described earlier. To run a Jobfile, proceed as follows:

1. Open GV.

2. Select File and then select Recall to bring a previously acquired and stored spectrum into the buffer, <u>or</u>

3. Transfer a just acquired spectra into the buffer.

   Note: GV Jobfiles can be programmed to start the detector, collect a spectra and perform an analysis. When programmed in this fashion, GV automatically transfers the just acquired spectra into the buffer for analysis.

4. Select Services.

5. Select Job Control....

6. A 'Run JOB File' dialog box containing previously prepared Jobfiles will appear.

7. Select the Jobfile appropriate to the detector and analysis height.

8. Press Open.

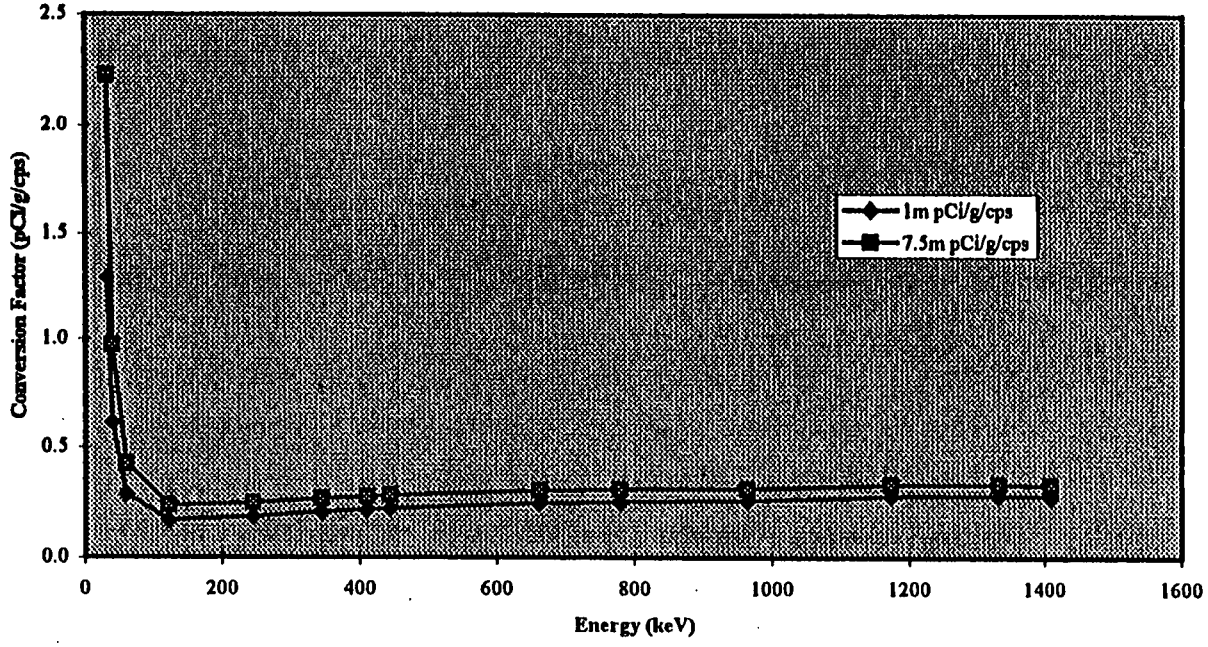
9. Average analysis processing time is about 5 seconds. At the end of the processing time, output goes to the screen, a additional report writer or the printer, depending on the selection in the .Sdf file. All spectrum analysis are automatically saved to file.

An example of a standard GV report is provided in Appendix F as Table F-2. Fernald GammaVision reports can be altered to produce custom reports that may differ from the report in Table F-2.

Attachment 1

Example Detector Homogeneous Conversion Factor Sheet

Energy keV	1m pCi/g/cps	7.5m pCi/g/cps
32.1	1.2900	2.2240
39.5	0.6127	0.9762
59.5	0.2877	0.4277
121.8	0.1675	0.2352
244.7	0.1841	0.2461
344.2	0.2052	0.2670
411.1	0.2148	0.2761
444.0	0.2207	0.2821
661.6	0.2465	0.3056
778.9	0.2536	0.3109
964.0	0.2603	0.3142
1173.2	0.2786	0.3318
1332.5	0.2834	0.3348
1408.0	0.2794	0.3289



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Attachment 2

Example Detector Conversion Factors Spreadsheet

Detector # 30687 Conversion Factors as of 10/97

Energy keV	EGAS 1 Meter Calibration Factor pCi/g/cps	EGAS 7.5 Meter Calibration Factor pCi/g/cps	GV 1 Meter Calibration Factor cps/g/pCi	GV 7.5 Meter Calibration Factor cps/g/pCi	Factor Rate Change x/cm	31 cm Calibration Factor cps/g/pCi	15 cm Calibration Factor cps/g/pCi	Abs. Value of %RPD 1 Meter vs. 31 cm	Abs. Value of %RPD 1 Meter vs. 15 cm
32.1	1.874	3.158	0.5336	0.3167	0.00033379	0.5334	0.5333	0.04	0.05
39.5	0.7153	1.134	1.3980	0.8818	0.00079412	1.3975	1.3973	0.04	0.05
59.5	0.3211	0.4762	3.1143	2.1000	0.00156052	3.1132	3.1130	0.03	0.04
121.8	0.1889	0.2651	5.2938	3.7722	0.00234099	5.2922	5.2918	0.03	0.04
244.7	0.2095	0.2798	4.7733	3.5740	0.00184506	4.7720	4.7717	0.03	0.03
344.2	0.2351	0.3061	4.2535	3.2669	0.00151785	4.2525	4.2522	0.02	0.03
411.1	0.247	0.3178	4.0486	3.1466	0.00138762	4.0476	4.0474	0.02	0.03
444	0.2543	0.3244	3.9324	3.0826	0.00130731	3.9315	3.9313	0.02	0.03
661.6	0.286	0.3546	3.4965	2.8201	0.00104065	3.4958	3.4956	0.02	0.03
778.9	0.2957	0.3625	3.3818	2.7586	0.00095875	3.3811	3.3810	0.02	0.02
964	0.3065	0.3697	3.2626	2.7049	0.00085807	3.2621	3.2619	0.02	0.02
1173.2	0.3308	0.3942	3.0230	2.5368	0.00074799	3.0225	3.0223	0.02	0.02
1332.5	0.3383	0.3991	2.9560	2.5056	0.0006928	2.9555	2.9554	0.02	0.02
1408	0.3311	0.3896	3.0202	2.5667	0.00069769	3.0198	3.0196	0.02	0.02

APPENDIX H

LABORATORY ANALYTICAL METHODS

APPENDIX H
LABORATORY ANALYTICAL METHODS

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H.1 LABORATORY SAMPLE PREPARATION

Upon receipt of the physical sample, the on-site laboratory:

1. Removed, weighed, and recorded all sample material (including any organic matter) in the sample core tube and place it in a disposable aluminum pan. The analyst performing this step described the appearance of each sample.
2. Dried the entire sample at 110° C for 12 hours to constant weight.
3. Calculated and recorded the percent moisture content of the sample.
4. Ground the entire sample until all material passed through a 1-mm sieve.
5. Blended the sample either by hand or machine.
6. Removed the necessary aliquot for analysis and archived the remaining sample material.

Samples were submitted to the lab in 3x6 inch plastic tubes for total uranium analysis. Each sample was frisked by a rad tech to determine the radiation reading. In addition to radiation safety concerns, frisking samples had a practical aspect. For example, Sample 200264208 Area PBC-03-01 frisked 60K on one side of the sample core, but low on the opposite side of the core. When ground, it was discovered the sample core contained a piece of cement which frisked high. This particular sample was passed through the grinder several times to ensure that the cement piece was dispersed evenly throughout the sample. Aliquots were taken from dried and ground samples for alpha and gamma spectrometry analyses. The sample drying procedure for the comparability study soil samples was performed using a Fisher Scientific Drying Oven model 630F at 110°C for 12 hours, and the grinding procedure utilized a Retsch BB-0 Jawed-Tooth Crusher.

H.2 LABORATORY RADIOCHEMICAL METHODS

H.2.1 Isotopic Measurements by Gamma Spectrometry - FDF Method 4518

Many radioactive nuclei decay by the emission of gamma rays with distinct energies that are characteristic of the specific isotope which emitted them. Just as fingerprints can be used to identify a specific individual, detection of gamma rays which have a unique energy can be used to identify the

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presence of specific radionuclides. For example, the technique of gamma spectrometry can be used to identify the presence and quantity of U-235 and U-238, the important uranium isotopes. Since gamma rays are highly penetrating radiation, samples can be analyzed by this technique without any chemical preparation other than homogenizing the samples. HPGe detectors are used in a high resolution gamma spectrometry system to detect the gamma rays emitted from the samples. Samples are placed in a standardized geometry on the HPGe gamma detector and an energy spectrum of the gamma emissions from the sample is collected in a multichannel pulse height analyzer. From the peaks in the accumulated spectrum, the energy of the various gamma emissions detected indicates which isotopes are present. The number of gamma rays counted at a specific energy (i.e. the area under the spectral peak) is used to calculate the amount of that particular radionuclide which is present in the sample. Any radionuclide that emits characteristic gamma rays can be quantified in this manner.

The accuracy of the method is reduced if a sample contains two or more radionuclides which emit characteristic gamma rays of nearly the same energy. Modern gamma spectrometry systems generally will not resolve two gamma rays if their characteristic energies are less than 2 to 3 keV apart. This is especially true if the activity of an interfering radionuclide is more that 5 times greater than that of the other nuclide. A high environmental background or the presence of other gamma emitting radionuclides in a sample can elevate the MDA for a given sample even though the other nuclides are not analytes of concern. To reduce the effects of extraneous background radiation, modern HPGe detectors are generally surrounded by a shield which is typically composed of four inches of lead. Gamma spectrometry is suitable for the analysis of isotopes of uranium, thorium, radium, potassium-40 (K-40), cesium-137 and other gamma emitting or gamma-discernable (based on daughters) radionuclides.

For this method validation study, each soil sample which underwent gamma spectral analysis in the laboratory consisted of approximately 125 grams of dried, ground and homogenized soil. All samples were counted in a standardized container of approximately 125 milliliter volume. They were counted for 3600 seconds on a Canberra Industries Genie gamma spectrometry system coupled to HPGe detectors which were calibrated with an NIST traceable mixed gamma standard containing accurately known quantities of ten radionuclides which emitted thirteen different gamma lines between 59 keV and 1836 keV. The standard was counted in the same type of container as the samples. In some cases, gamma rays from radioactive daughters were used to quantify the activity concentration of the

radioactive parent. This practice was employed in the field gamma measurements as well as in those performed in the lab. The gamma rays important for this study are listed in Table F-3.

Each characteristic peak that appears in a spectrum can be used separately to compute the analyte activity concentration in the sample. When more than one analyte characteristic peak was present in a sample spectrum, the average concentration was reported. The average is a weighted average where the weighting factor is the inverse of the counting error squared for each gamma photon used in the average.

H.2.2 Isotopic Measurements by Alpha Spectrometry

Like gamma rays, alpha emissions from radioactive nuclei are expelled with discreet energies that are characteristic of the isotope emitting them. The technique of alpha spectrometry utilizes this property to identify and quantify the isotopes which are present in a sample. Since alpha particles are very weakly penetrating and can be absorbed by the sample material itself, a chemical extraction must be performed to separate (isolate) the analyte of interest from the sample matrix. This process involves a mineral acid digestion of the sample and separation of the element of interest from other elements utilizing ion exchange resins. Extreme care must be exercised to ensure preparation of a uniform and very thin sample for counting in an alpha spectrometer. A known quantity of a radioactive isotope of the element being analyzed is added to the sample at the start of the chemical preparation process to provide a quantitative measure of the losses that occur during sample preparation. This radio-tracer must be an isotope of the analyzed element which is not present in the samples. The alpha spectrometry technique offers double assurance that only the isotopes of interest are being counted. First, the chemical separation process is designed to separate the element of interest from all others. Secondly, the spectrometric technique ensures that only the alpha emissions from the desired isotopes are used to calculate the activity in the samples. If the chemical separation is not complete for some reason or the chemical losses are greater than normal, the sample spectrum will reveal evidence of these conditions. The chemical processing required for this technique is labor-intensive and time-consuming. While alpha spectrometry is highly selective and extremely sensitive, sample analyses take longer and may be more expensive than other laboratory analysis techniques. It generally takes five to six days to complete the analysis of a batch of 20 soil samples. Laboratory methods involving alpha spectrometry have been developed for all of the important alpha-emitting isotopes of concern in the cleanup of the FEMP. Specifically, this technique is capable of accurately quantifying Ra-226 and the

major isotopes of uranium and thorium. The alpha spectrometry system used in the FDF Analytical Laboratory is a computer controlled system which uses silicon surface barrier detectors and Alpha Management Software available from Canberra Industries Nuclear Products Group.

H.2.2.1 Uranium Analysis Procedure (Alpha Spectrometry) - FDF Method 4508

The samples are dried and ground to homogenize them and the percent moisture is measured. Typically a 0.5 gram aliquot of each sample is heated in a muffle furnace at 550° C for two hours. Approximately 5 pCi of U-232 is added to each sample as a tracer to determine the uranium chemical yield from the preparation process. The samples are dissolved using a mixture of concentrated nitric acid and concentrated hydrofluoric acid to ensure complete digestion of the sample matrix. Uranium is then co-precipitated with iron by making the solution basic with ammonium hydroxide (carbonate free). The hydroxide precipitate is dissolved in 8 molar hydrochloric acid (8 M HCl) with a small amount of hydriodic acid (HI) present. The 8 M HCl/HI solution is passed through an anion exchange resin column. Uranium is absorbed on the resin while iron is eluted with 8 M HCl containing HI. The uranium is eluted from the column with 1 molar HCl. Neodymium fluoride mounting of the uranium extract onto a polypropylene filter paper is performed in accordance with FEMP Analytical Method 256-S-3002. The filters are counted in vacuum chambers to reduce absorption and scattering of the alpha radiation emitted from the mounted sample extract. Silicon surface barrier detectors are used to count the samples. With a typical count time of twenty hours, minimum detectable concentrations of 0.1 pCi/g (dry weight) or lower are obtained.

H.2.2.2 Thorium Analysis Procedure (Alpha Spectrometry) - FDF Method 4512

The samples are dried and ground to homogenize them and the percent moisture is measured. Typically a 3 to 5 gram aliquot is taken for analysis. A thorium-229 (Th-229) tracer is added to each sample and they are digested using a conventional mineral acid dissolution with a mixture of concentrated nitric, hydrofluoric and perchloric acid. The sample digestates are loaded onto an anion exchange resin column in an 8 molar nitric acid medium. The thorium is eluted from the column with a solution of 8 M HCl. The purified thorium fraction is prepared for counting by using the FEMP Analytical Method 256-S-3002, the neodymium fluoride mounting procedure. The samples are counted in vacuum chambers to reduce absorption and scattering of the alpha radiation emitted from the mounted sample extract. Silicon surface barrier detectors are used to count the samples, usually for a

period of twenty hours. Minimum detectable concentrations of 0.1 pCi/g (dry weight) or lower can be obtained with this procedure.

H.2.2.3 Radium Analysis Procedure - FDF Method 4509

The samples are dried and ground to homogenize them and the percent moisture is measured. Typically a 2 to 5 gram aliquot is taken for analysis. Since the element barium behaves chemically like radium, Barium-133 is added as a yield tracer for the Ra-226 and Ra-228 analysis. The soil samples are totally dissolved in a mixture of concentrated nitric acid and concentrated hydrofluoric acid. Radium and barium are separated from interfering elements using a co-precipitation with barium and lead carriers as sulfates. Further purification and separation from lead carrier and radium daughter isotopes are achieved by dissolution of the precipitated sulfates with alkaline EDTA solution and selective recrystalization with barium sulfate using glacial acetic acid. In preparation for counting, the radium/barium sulfate extract is mounted on a polypropylene filter and dried in accordance with the neodymium fluoride mounting procedure, FDF Analytical Method 256-S-3002. Samples are counted for Ra-226 by alpha spectrometry and for Ra-228 and Ba-133 tracer by gamma spectrometry. The gamma emissions from Ac-228, the direct daughter of Ra-228 are used to determine the Ra-228 sample activity. By accurately recording the time interval between the final radium precipitation and the mid point of the gamma count, the degree of equilibrium between Ac-228 and its parent, Ra-228, can be computed, and this factor can be used to derive the parent activity from a count of the daughter gamma emissions. The samples are typically counted for 20 hours in an alpha spectrometer which uses silicon surface barrier detectors. Ra-226 Minimum Detectable Concentrations (MDCs) for samples counted under typical conditions for this project are 0.01 pCi/g (dry). With gamma spectrometry counts from 1 to 6 hours, Ra-228 MDCs are typically in the range of 0.1 to 0.3 pCi/g (dry weight).

H.3 LABORATORY INORGANIC METHODS

Two laboratory inorganic methods were used for the analysis of total uranium, bromoPADAP and ICP/MS. The paragraphs below briefly describe these two analytical methods. Detailed FEMP procedures exist for both methods: for bromoPADAP, the procedure is 5512 ("The Colorimetric (BrPADAP) Determination of Uranium Using an Auto Analyzer") and for ICP/MS, the procedure is 5501 ("Sample Preparation and Analysis for Uranium Determination by ICP/MS").

H.3.1 BromoPADAP - FDF Method 5512

BromoPADAP is used for the colorimetric determination of uranium in a variety of matrices in the concentration range of 1 - 100,000 ppm. The instrument consists of an autosampler, a proportionary pump, a flow cell colorimeter, and a personal computer loaded with peak detection, calibration, response factor, and reporting software.

The bromoPADAP is a classical colorimetric procedure for the determination of total uranium. In this procedure, the sample is rigorously digested with perchloric ($HClO_4$) and nitric (HNO_3) acid. Once solubilized, the uranium is reacted with 2-(5-bromo-2pyridylazo)-5-diethylaminophenol (bromoPADAP) to produce a colored complex which absorbs strongly at 580 nanometers. The amount of absorption is proportional to the concentration of uranium present. Uranium is separated from major interfering metal ions by extraction into trioctylphosphine oxide (TOPO) in cyclohexane. The extracting solution contains F- and PO_4^{-3} ions to inhibit the extraction of Th and Zr along with uranium. Ascorbic acid in the extracting solution reduces V^{+5} to V^{+4}, Ce^{+4} to Ce^{+3}, Cr^{+6} to Cr^{+3}, and Fe^{+3} to Fe^{+2}. The interferences of these cations are much less severe at the lower valence states. A complexing solution is added during color development to prevent interference from traces of interfering elements. Sulfosalicylic acid masks the interferences of Be and Al. NaF reduces Th and Zr interferences and 1,2-diaminocyclohexylenedinitrilotetraacetic acid (Cy DTA) complexes many cations but not UO_2^{+2}. Quantification of uranium is accomplished by comparing the absorbance of the unknown solution to the absorbances of standard uranium solutions.

H.3.2 ICP/MS - FDF Method 5501

Inductively coupled plasma/mass spectrometry (ICP/MS) is a relatively newly developed technique for the determination of total uranium. This procedure is an adaptation of the SW-846 6020 procedure for metals determination. The technique has proven to be a very sensitive and selective method. A soil sample is digested with $HCLO_4$ and HNO_3, along with high heat. The digestate is then brought up in a 1% HNO_3 solution. The uranium in the HNO3 solution is introduced into the ICP/MS instrument where it is nebulized and the resulting aerosol transported by argon gas into a plasma torch. The ions produced are entrained in the plasma gas and introduced, by means of an interface, into a mass spectrometer. The ions produced in the plasma are sorted according to their mass-to-charge ratios and quantified with a channel electron multiplier. Interferences are assessed and valid corrections applied that include compensation for background ions contributed by the plasma gas, reagents, and

constituents of the sample matrix. Standard uranium solutions are used to calibrate for this technique. The total uranium concentration is based on the uranium-238 concentration. However, if concentrations of individual uranium are needed, ICP/MS can easily detect uranium-236, uranium-235, uranium-234, and uranium-233 as well as uranium-238. In this regard, ICP/MS is quite isotope-specific. Other inorganic species with the same mass-to-charge ratio as the target species, such as plutonium-238 and neptunium-235, tend to be rare and unstable.

TABLE H-1
GAMMA RAYS UTILIZED FOR COMPARABILITY STUDY
FOR LABORATORY MEASUREMENTS

Analyte Isotope	Half Life (years)	Energy (keV)	Abundance (%)	Isotope of Emission
U-238	4.47E+9	63.29	3.8	Th-234
		92.59	5.41	Th-234
		766.41	0.207	Pa-234m
		1001.03	0.845	Pa-234m
U-235	7.04E+8	143.76	10.5	U-235
		185.72	54.0	U-235
Th-232	1.41E+10	238.63	44.6	Pb-212
		583.14	30.6*	Tl-208
		727.17	11.8	Bi-212
		911.07	27.7	Ac-228
Ra-226	1.60E+3	295.21	19.2	Pb-214
		351.92	37.2	Pb-214
		609.31	46.3	Bi-214
		1120.29	15.1	Bi-214
		1764.49	15.8	Bi-214
Cs-137	3.03E+1	661.65	84.62**	Ba-137m
K-40	1.28E+9	1460.81	10.7	K-40

* Includes 0.359 branching ratio from decay of Bi-212
** Includes 0.946 branching ratio from decay of Cs-137

APPENDIX I

WILCOXON SIGNED RANKS TESTS

APPENDIX I
WILCOXON SIGNED RANKS TESTS

Wilcoxon signed ranks tests were performed to determine if two sets of measurements differed from one another (i.e., exhibited bias). The process used to perform these tests is in the National Bureau of Standards Handbook 91, entitled "Experimental Statistics" (Natrella 1963), Chapter 16, and is outlined below.

1. Choose a value of $\alpha = 0.05$ for this two-sided test. Discard any observations in which a pair of measurments is equal, and let n = the number of pairs of measurements actually used.

2. The critical value of $T_{0.05}^{(n)} = 4$ for n = 8, 6 for n = 9 and 8 for n = 10 (n = 8, 9 or 10 are the numbers for the most common pairs of measurements tested in Tables I-1 and I-2).

3. For each pair of measurements, compute the difference:

$$x_1 - x_2$$

where x_1 and x_2 are the values of the two measurements.

4. Disregarding signs, rank the differences $x_1 - x_2$ according to the magnitude of their numerical values. Thus, the numerically smallest diffence is ranked one, the next numerically smallest difference is ranked two, etc. Prefix a + or - sign to the assigned ranks to show whether the corresponding difference is positive or negative.

5. Sum the ranks prefixed by a + sign and then sum the ranks prefixed by a - sign. Let T = the smaller of the two sums, ignoring signs.

6. If $T \leq T_{0.05}^{(n)}$, conclude that there is a difference between the two sets of measurements at the 95% confidence level. If $T \geq T_{0.05}^{(n)}$, there is no reason to believe that the two sets of measurements are different (i.e., they exhibit no bias).

Table I-1 presents the results of the Wilcoxon Signed Ranks Tests for pairs of measurements taken by the FEMP HPGe and the EML HPGe. The measurement data are contained in Tables 8-1 and 8-2. Table I-2 presents the results of the Wilcoxon Signed Ranks Tests for pairs of measurements made by the laboratory and FEMP HPGe analyses. These measurement data are contained in Tables 5-1A and 5-1B; 6-1 and 6-2; and 7-3 and 7-4.

TABLE I-1
RESULTS OF WILCOXON SIGNED RANKS TEST ON FEMP AND EML HPGe MEASUREMENTS

Item	Total U, 31 cm		Total U, 1.0 m		Th-232, 31 cm		Th-232 1.0 m	
	Δ* (ppm)	Signed Rank	Δ* (ppm)	Signed Rank	Δ* (ppm)	Signed Rank	Δ* (ppm)	Signed Rank
PBC-01	-0.8	-1.5	-5.6	-6	+0.04	+4	+0.01	+2.5
PBC-02	+1.5	+5	+3.4	+4.5	-0.01	-1.5	-0.01	-2.5
PBC-04	+5.8	+7	+7.4	+8	-0.01	-1.5	-0.01	-2.5
PBC-05	+4.6	+6	-3.4	-4.5	+0.08	+7	-0.06	-7
PBC-06	+6.4	+9	+8.1	+9	0	--	+0.01	+2.5
PBC-07	+1.0	+3	+6	+7	+0.03	+5	-0.05	-6
PBC-08	+0.8	+1.5	+0.2	+1	+0.02	+3	0	--
PBC-09	-1.1	-4	+1.5	+2	+0.06	+6	+0.02	+5
PBC-10	+5.9	+8	+3.1	+3	+0.44	+8	+0.46	+8
Sum Positive Rankings		+39.5		+34.5		+33		18
Sum Negative Rankings		-5.5		-10.5		-3		-18
T		5.5		10.5		3		18
$T_{0.05}$		6		6		4		4
Bias?		Yes		No		Yes		No

* Difference (FEMP - EML)= Δ between FEMP and EML HPGe Measurements
** If $T < T_{0.05}$, conclude that the sets of measurements differ from one another

TABLE I-1
(continued)

Item	Ra-226, 31 cm		Ra-226, 1.0 m	
	Δ* (pCi/g)	Signed Rank	Δ* (pCi/g)	Signed Rank
PBC-01	+0.16	+6	+0.14	+8
PBC-02	0.10	+1.5	-0.05	-5
PBC-04	-0.01	-1.5	+0.05	+5
PBC-05	+0.13	+5	+0.09	+7
PBC-06	-0.02	-3	+0.04	+3
PBC-07	+0.08	+4	+0.30	+9
PBC-08	0	--	-0.05	-5
PBC-09	0	--	-0.02	-1
PBC-10	+3.87	+7	-0.03	-2
Sum Positive Rankings		+23.5		+32
Sum Negative Rankings		-4.5		-13
T		4.5		13
$T_{0.05}$		2		6
Bias?		No		No

* Difference (FEMP - EML)= Δ between FEMP and EML HPGe Measurements
** If $T < T_{0.05}$, conclude that the sets of measurements differ from one another

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TABLE 2
RESULTS OF WILCOXON SIGNED RANKS TEST ON LABORATORY AND HPGe MEASUREMENTS

Item	Total U, Four Method Average - 31 cm		Total U, Four Method Average - 1.0 m		Th-232, Two Method Average - 31 cm		Th-232, Two Method Average - 1.0 m	
	Δ* (ppm)	Signed Rank	Δ* (ppm)	Signed Rank	Δ* (pCi/g)	Signed Rank	Δ* (pCi/g)	Signed Rank
PBC-01	-0.6	-1.5	+0.5	+3	-0.06	-4.5	-0.01	-1.5
PBC-02	-0.9	-3.5	+0.5	+3	-0.17	-8	-0.15	-7
PBC-03	-30	-11	-42	-11	0	0	-0.25	-10
PBC-04	-3.4	-5	-6.2	-6	+0.11	+7	+0.12	+6
PBC-05	-4.2	-6	-0.6	-5	-0.09	-6	+0.04	+4
PBC-06	+5.4	+7	+7.3	+7	+0.02	+1.5	+0.09	+5
PBC-07	+7	+8	+22	+9	+0.06	+4.5	+0.20	+8.5
PBC-08	+0.9	+3.5	+0.4	+1	+0.02	+1.5	+0.03	+3
PBC-09	+0.6	+1.5	+0.5	+3	+0.03	+3	+0.01	+1.5
PBC-10	-18.7	-10	-17	-8	-0.20	-9	-0.20	-8.5
PBC-18	-13	-9	+200	+12				
PBC-19	-155	-12	-32	-10				
Sum Positive Rankings		+20		+38		+17.5		+28
Sum Negative Rankings		-58		-40		-27.5		-27
T		20		38		17.5		27
$T_{0.05}$		14		14		6		8
Bias?***		No		No		No		No

* Difference (laboratory - HPGe) = Δ between laboratory and HPGe Measurements
** If $T < T_{0.05}$, conclude that the sets of measurements differ from one another
*** Excludes sample PBC-03-01

TABLE I-2
(continued)

Item	Ra-226, Two Method Average 31 cm		Ra-226, Two Method Average 1.0 m	
	Δ* (pCi/g)	Signed Rank	Δ* (pCi/g)	Signed Rank
PBC-01	0	0	+0.05	+2.5
PBC-02	-0.05	-2	-0.05	-2.5
PBC-03	+6.4	+9	+7.5	+14
PBC-04	+0.10	+4	+0.14	+4
PBC-05	+0.19	+5	+0.22	+6
PBC-06	+0.24	+6.5	+0.24	+7
PBC-07	+0.24	+6.5	0	0
PBC-08	+0.08	+3	+0.15	+5
PBC-09	+0.04	+1	+0.03	+1
PBC-10	+0.70	+8	+1.2	+10
PBC-12			+2.5	+12
PBC-13			+1.32	+11
PBC-14			+0.30	+8
PBC-15			+0.47	+9
PBC-16			+9.8	+15
PBC-17			+5.9	+13
Sum Positive Rankings		+43		117.5
Sum Negative Rankings		-2		-2.5
T		2		2.5
$T_{0.05}$		6		25
Bias?**		Yes		Yes

* Difference (laboratory - HPGe) = Δ between laboratory and HPGe Measurements
** If $T < T_{0.05}$, conclude that the sets of measurements differ from one another

APPENDIX J

DOE ENVIRONMENTAL MEASUREMENTS LABORATORY COMPARABILITY STUDY

Department of Energy
Environmental Measurements Laboratory
201 Varick Street
New York, NY 10014-4811

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April 9, 1997

Robert J. Janke, Fernald Area Office, FN

RESULTS OF COMPARABILITY STUDY

Enclosed are the results of our analyses of the field and laboratory measurements of total U, ^{238}U, ^{235}U, ^{232}Th, ^{226}Ra, and ^{40}K in surface soils as part of a quality assurance effort associated with the Comparability Study. We have included a comparison of the *in situ* results to an averaged wet concentration derived from the analysis of the soil samples. Also included are the results for the quality control samples which were analyzed concurrently with the laboratory samples associated with this project. All radionuclide concentrations in soil were reported in units of pCi/g. We were successful in obtaining *in situ* concentrations for nine of the ten locations used in this study. We were also able to collect soil samples for seven of the ten locations.

Table 1 reports values of radionuclide concentrations reported in units of pCi/g of dry soil along with soil core parameters. The soil core data consists of a location ID which consistent with the identification scheme established by Fluor Daniel Fernald (FDF) for the purposes of this study (figure C-1 of the Characterization Comparability Study, February 1997, Rev. A). The sample ID pertains to EML's soil samples. The depth column indicates the depth, or depth range, from which the soil samples were obtained. For locations 5 and 6 several sections were taken from a single core to establish a concentration profile . The mass column refers to the mass of the sample and reflects the soil density. The percent water is the percent moisture per unit wet soil (w/w) . In the reporting of radionuclide concentrations, we have included a combined uncertainty in parenthesis and a minimum detectable concentration (MDC). For convenience, we have reported a total uranium concentration in ppm of dry soil. Also included in Table 1 is the activity ratio of $^{235}U/^{238}U$. Table 2 uses the soil moisture data to establish concentrations per unit wet soil. In reporting the uncertainties, we have adopted the recommendations of the BIPM Working Group on the Statement of Uncertainty. The uncertainties reported in tables 1 and 2 are the combined uncertainly of the calibration standard and a one-sigma counting error.
Table 3 shows the results for the *in situ* measurements for the heights of 1 m and 0.305 m (1ft) . Included in the these tables are the results of replicate measurements. Just as in tables 1 and 2, we have included an uncertainty in parenthesis and a MDC. We must point out that the uncertainty in Table 3 reflects only a one-sigma counting error. Figure 1 illustrates the agreement between the two measurements. Most results agree to within the statistical uncertainty of the measurement. At location 10, however, we see a significant difference between the 1ft and the 1m measurements for ^{226}Ra. This difference reflects the heterogeneity of the ^{226}Ra distribution in the soil.

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The top section of Table 4 reports wet concentrations obtained from the laboratory analysis of the soil samples. These values can be compared to the bottom section which reports the *in situ* values. The weighting factors used in the averaging of the wet concentrations reported in Table 2, are consistent with the values in Table C-7 of the Characterization Comparability Study, February 1997, Rev. A. Figure 2 is a plot of the *in situ* concentration as a function of the averaged wet concentrations derived from laboratory sample analysis (AWCLSA) . The dark line represents perfect agreement with the AWCLSA. The two lighter lines represents bands of 20% which has been mentioned as the limit for demonstrating comparability . In a similar fashion, Figures 3, 4, 5, 6, and 7 demonstrate the agreement of the *in situ* concentrations with the AWCLSA for ^{238}U, total U, ^{40}K, ^{226}Ra, and ^{232}Th respectively. In Figures 3, 4 and 6, we have indicted the location ID for each data point. Comparisons of *in situ* concentrations with the AWCLSA for ^{235}U were excluded because many of the measured *in situ* concentrations were at or below the MDC. It was felt that for locations 1, 4, 5, 8, and 9 the 1 foot *in situ* measurement would best reflect the AWCLSA. It should be pointed out it most cases that the concentrations reported for a 1 ft measurement were identical to the 1 m results.

While we believe that the relatively small differences between in the *in situ* and the AWCLSA are a result of real variations within the detector's field of view, we note that for ^{40}K, a naturally occurring radionuclide whose levels should not have been altered by activities at Fernald, the *in situ* concentrations are about 10% lower than the AWCLSA. This effect is most likely a result of the soil moisture profile. We can see from Table 1 that the soil moisture for the 0-5 cm sections are greater that the 10-15 cm sections by almost a factor of two. The corresponding wet concentration for ^{40}K in the 0-5 cm section is lower than for either the 5-10 cm or the 10-15 cm sections. If we realize that well over 50% the fluence rate for a uniformly distributed source comes from the first 5 centimeters of soil, it seems reasonable that the *in situ* values will be lower than the AWCLSA.

As a quality assurance measure for the *in situ* results, we have provided values for the parameters used to establish conversion factors for our instrument. These parameters include gamma ray intensities, mass attenuation coefficients for air and soil, and corresponding fluence rates . For medium to high energy gamma rays, variations in the soil composition have a small effect on the fluence rate. The values of the fluence rate that FDF uses to establish their conversion factors should not differ from the values listed in Table 5 by more than a few percent.

We can also see from Table 5 that the concentration of ^{226}Ra is inferred from its progeny ^{214}Pb and ^{214}Bi . This situation can be problematic when comparing AWCLSA to *in situ* data because the progeny ^{214}Pb and ^{214}Bi occur after ^{222}Rn in the decay chain of ^{226}Ra. ^{222}Rn is a noble gases which can escape from the soil disrupting the radioactive equilibrium existing between parent and progeny. The situation can be acute because the half-life of ^{222}Rn is almost 4 days. Disequilibrium factors for ^{226}Ra vary by soil type but typically fall within the range of 10 to 30%. We can see for locations 1,5, and 6 the disagreement between the AWCLSA and the *in situ* concentrations varies between 17- 28%. Agreement between the AWCLSA and the *in situ* concentrations can be further complicated by precipitation scavenging of ^{222}Rn progeny in the atmosphere. The effects of disequilibrium between ^{226}Ra and its progeny ^{214}Pb and ^{214}Bi can be masked by precipitation. If an *in situ* measurement of ^{226}Ra is made within 3 to 4 hours after a

shower, the levels of ^{214}Pb and ^{214}Bi present in the rain water can sufficiently increase the fluence rate from those nuclides to enhance the reported ^{226}Ra concentration. We suspect that we are seeing this effect in locations 8 and 9. Our measurements were performed in the morning not long after a soaking rain. The agreement between the AWCLSA and the *in situ* concentrations for those locations are much better than for any other location, suggesting that the effects of disequilibrium have been obscured by excess ^{214}Pb and ^{214}Bi present in the rain water. In general, caution must be exercised when interpreting *in situ* data for ^{226}Ra. We do point out, however, that by applying a correction factor for disequilibrium and performing measurements well after a precipitation event, comparability between AWCLSA and the *in situ* concentrations should be established. Moreover, the implications of this for the certification of confirmations units is clear: once a conservative correction is made for disequilibrium, the effects of precipitation will, in the worst case, cause a CU at, or near the FRL to fail.

In general, the observed agreement between concentrations inferred from soil sampling and *in situ* measurements is consistent with similar studies performed by EML over the past 30 years. We believe that the technique is well-suited for this application and will provide accurate and expedient results. Furthermore, we want to emphasize that *in situ* spectrometry should not be thought of as a replacement to standard soil sampling techniques; it should not even be recognized as a alternative. It is a tool to be used to enhance, expand, and expedite standard characterization and certification methodologies used in the decontamination and decommissioning process.

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Enclosure: As stated

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EML: Analytical Results for Comparability Study

Soil Core Data					Dry Concentration (pCi/g)													
Location ID	Sample ID	depth (cm)	mass‡ (g)	% Water	^{238}U	MDC	^{40}K	MDC	^{226}Ra	MDC	^{235}U	MDC	^{232}Th	MDC	Total U (ppm)	MDC	$^{235}U/^{238}U$
1	1L1†	0-15	132.6	20.4%	2.64 (.07)	0.7	17.4 (.1)	0.1	0.88 (.01)	0.06	0.09 (.01)	0.05	0.83 (.03)	0.04	7.9 (.2)	2.2	0.034 (.004)
4	4M2	0-15	131.7	25.5%	25.7 (.2)	1.0	14.3 (.2)	0.2	1.29 (.02)	0.10	0.82 (.03)	0.10	1.29 (.04)	0.08	77.1 (.6)	3.3	0.032 (.001)
	4M3	0-15	133.3	24.6%	22.2 (.2)	1.0	14.3 (.2)	0.2	1.32 (.02)	0.10	0.72 (.03)	0.09	1.25 (.04)	0.07	66.6 (.6)	3.3	0.032 (.001)
	4M4	0-15	128.2	26.9%	24.3 (.2)	1.0	14.2 (.2)	0.2	1.24 (.01)	0.10	0.82 (.03)	0.09	1.23 (.04)	0.07	73.0 (.6)	3.3	0.034 (.001)
5	5M2a	0-5	119.3	30.3%	21.8 (.2)	1.0	16.3 (.2)	0.2	1.14 (.02)	0.10	0.67 (.04)	0.10	1.29 (.05)	0.09	65.5 (.6)	3.3	0.031 (.002)
	5M2b	5-10	141.9	18.1%	13.2 (.2)	1.0	17.0 (.2)	0.2	1.23 (.01)	0.10	0.45 (.03)	0.09	1.17 (.04)	0.08	39.7 (.6)	3.3	0.034 (.002)
	5M2c	10-15	146.2	16.6%	6.0 (.1)	1.0	16.7 (.2)	0.2	1.21 (.01)	0.10	0.21 (.03)	0.08	1.11 (.02)	0.06	18.1 (.3)	3.2	0.035 (.005)
	5M3a	0-5	118.6	30.2%	20.3 (.2)	2.0	16.8 (.3)	0.2	1.21 (.02)	0.10	0.70 (.03)	0.10	1.23 (.05)	0.10	61.0 (.6)	6.3	0.034 (.002)
	5M3b	5-10	137.3	21.7%	16.4 (.2)	1.0	16.9 (.2)	0.2	1.25 (.02)	0.10	0.57 (.04)	0.10	1.38 (.05)	0.10	49.3 (.6)	3.3	0.035 (.002)
	5M3c	10-15	138.3	18.9%	9.0 (.3)	2.0	16.8 (.2)	0.3	1.28 (.03)	0.20	0.35 (.05)	0.20	1.23 (.05)	0.20	27.0 (.9)	6.6	0.039 (.006)
	5M4a	0-5	123.4	30.2%	19.5 (.3)	2.0	16.3 (.3)	0.4	1.09 (.02)	0.20	0.62 (.05)	0.20	1.31 (.05)	0.10	58.6 (.9)	6.6	0.032 (.003)
	5M4b	5-10	136.8	22.7%	17.1 (.1)	0.9	16.6 (.2)	0.1	1.20 (.01)	0.08	0.61 (.02)	0.07	1.27 (.04)	0.06	51.4 (.3)	2.9	0.036 (.001)
	5M4c	10-15	146.1	17.8%	7.40 (.09)	0.6	17.6 (.1)	0.1	1.24 (.01)	0.06	0.24 (.02)	0.05	1.14 (.04)	0.04	22.2 (.3)	1.9	0.032 (.003)
6	6M1a	0-5	116.2	29.2%	31.6 (.2)	1.0	14.4 (.2)	0.2	1.29 (.01)	0.10	1.13 (.03)	0.09	1.29 (.04)	0.08	94.9 (.6)	3.3	0.036 (.001)
	6M1b	5-10	126.5	23.2%	38.5 (.1)	0.8	14.3 (.1)	0.1	1.38 (.01)	0.07	1.29 (.02)	0.07	1.29 (.04)	0.05	115.6 (.3)	2.6	0.034 (.001)
	6M1c	10-15	133.8	19.4%	23.0 (.1)	0.8	14.5 (.1)	0.1	1.36 (.01)	0.07	0.80 (.02)	0.07	1.21 (.04)	0.06	69.1 (.3)	2.6	0.035 (.001)
	6M2a	0-5	115.2	31.5%	41.1 (.2)	1.0	13.9 (.2)	0.2	1.28 (.02)	0.10	1.40 (.04)	0.10	1.25 (.04)	0.09	123.4 (.6)	3.3	0.034 (.001)
	6M2b	5-10	138.8	22.8%	31.3 (.1)	0.7	14.3 (.1)	0.1	1.43 (.01)	0.06	1.04 (.02)	0.06	1.29 (.04)	0.05	93.8 (.3)	2.3	0.033 (.001)
	6M2c	10-15	142.3	19.0%	9.1 (.2)	1.0	14.4 (.2)	0.2	1.28 (.01)	0.10	0.34 (.02)	0.09	1.15 (.04)	0.07	27.3 (.6)	3.3	0.037 (.002)
	6M3	0-15	120.3	27.1%	44.3 (.3)	1.0	14.0 (.2)	0.2	1.38 (.02)	0.10	1.54 (.03)	0.10	1.36 (.05)	0.09	133.0 (.9)	3.3	0.035 (.001)
	6M4	0-15	130.1	24.7%	32.7 (.2)	1.0	14.2 (.2)	0.2	1.37 (.02)	0.10	1.14 (.03)	0.10	1.28 (.04)	0.09	98.2 (.6)	3.3	0.035 (.001)
	6M5a	0-5	116.6	30.9%	37.7 (.3)	1.0	14.0 (.2)	0.2	1.32 (.02)	0.10	1.23 (.03)	0.10	1.28 (.05)	0.09	113.2 (.9)	3.3	0.033 (.001)
	6M5b	5-10	134.1	22.2%	29.8 (.2)	1.0	14.7 (.2)	0.2	1.43 (.02)	0.10	0.99 (.03)	0.10	1.30 (.04)	0.08	89.5 (.6)	3.3	0.033 (.001)
	6M5c	10-15	137.8	19.9%	10.8 (.1)	0.8	14.6 (.1)	0.2	1.29 (.01)	0.07	0.37 (.02)	0.06	1.12 (.04)	0.05	32.4 (.3)	2.6	0.034 (.002)
	6M6	0-15	120.6	29.8%	40.5 (.2)	0.9	14.0 (.1)	0.2	1.36 (.01)	0.07	1.30 (.02)	0.07	1.35 (.04)	0.05	121.6 (.6)	2.9	0.032 (.001)
	6M7	0-15	123.8	27.4%	32.0 (.2)	1.0	13.9 (.2)	0.2	1.26 (.20)	0.10	1.03 (.03)	0.10	1.24 (.04)	0.09	96.1 (.6)	3.3	0.032 (.001)
	6M8	0-15	124.6	26.3%	38.3 (.2)	1.0	14.0 (.2)	0.2	1.29 (.01)	0.10	1.32 (.03)	0.10	1.26 (.04)	0.08	115.0 (.6)	3.3	0.034 (.001)
	6M9	0-15	127.1	24.8%	32.0 (.2)	1.0	14.3 (.2)	0.2	1.36 (.02)	0.10	1.09 (.03)	0.10	1.32 (.05)	0.08	96.1 (.6)	3.3	0.034 (.001)
	6M10	0-15	124.9	28.2%	41.6 (.1)	0.7	14.0 (.1)	0.1	1.38 (.01)	0.06	1.39 (.02)	0.06	1.33 (.04)	0.04	124.9 (.3)	2.3	0.033 (.000)
8	8L1†	0-15	126.4	30.0%	1.70 (.07)	0.8	15.1 (.1)	0.1	1.08 (.01)	0.07	0.06 (.01)	0.05	0.89 (.03)	0.05	5.1 (.2)	2.5	0.035 (.01)
9	9L1†	0-15	124.5	27.0%	2.72 (.06)	0.5	14.2 (.1)	0.09	1.11 (.01)	0.05	0.08 (.01)	0.04	0.98 (.03)	0.04	8.2 (.2)	1.6	0.029 (.004)

† composite core
‡ 90 ml sample volume

Table 1

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EML: Analytical Results for Comparability Study

Soil Core Data					Wet Concentrations (pCi/g)											
Location ID	Sample ID	depth (cm)	mass‡ (g)	% Water	^{238}U	MDC	^{40}K	MDC	^{226}Ra	MDC	^{235}U	MDC	^{232}Th	MDC	Total U (ppm)	MDC
1	1L1†	0-15	132.6	20.4%	2.1 (.1)	0.6	13.9 (.1)	0.1	0.70 (.01)	0.05	0.07 (.01)	0.04	0.66 (.02)	0.03	6.3 (.2)	1.8
4	4M2	0-15	131.7	25.5%	19.2 (.2)	0.7	10.7 (.1)	0.1	0.96 (.01)	0.07	0.61 (.02)	0.07	0.96 (.03)	0.06	57.5 (.4)	2.4
	4M3	0-15	133.3	24.6%	16.7 (.2)	0.8	10.8 (.2)	0.2	1.00 (.02)	0.08	0.54 (.02)	0.07	0.94 (.03)	0.05	50.3 (.5)	2.5
	4M4	0-15	128.2	26.9%	17.8 (.2)	0.7	10.4 (.1)	0.1	0.91 (.01)	0.07	0.60 (.02)	0.07	0.90 (.03)	0.05	53.4 (.4)	2.4
5	5M2a	0-5	119.3	30.3%	15.2 (.2)	0.7	11.4 (.1)	0.1	0.79 (.01)	0.07	0.47 (.03)	0.07	0.90 (.03)	0.06	45.7 (.4)	2.3
	5M2b	5-10	141.9	18.1%	10.8 (.2)	0.8	13.9 (.2)	0.2	1.01 (.01)	0.08	0.37 (.02)	0.07	0.96 (.03)	0.07	32.5 (.5)	2.7
	5M2c	10-15	146.2	16.6%	5.0 (.1)	0.8	13.9 (.2)	0.2	1.01 (.01)	0.08	0.18 (.03)	0.07	0.93 (.02)	0.05	15.1 (.2)	2.7
	5M3a	0-5	118.6	30.2%	14.2 (.1)	1.4	11.7 (.2)	0.1	0.85 (.01)	0.07	0.49 (.02)	0.07	0.86 (.03)	0.07	42.6 (.4)	4.4
	5M3b	5-10	137.3	21.7%	12.8 (.2)	0.8	13.2 (.2)	0.2	0.98 (.02)	0.08	0.45 (.03)	0.08	1.08 (.04)	0.08	38.6 (.5)	2.6
	5M3c	10-15	138.3	18.9%	7.3 (.2)	1.6	13.6 (.2)	0.2	1.04 (.02)	0.16	0.28 (.04)	0.16	1.00 (.04)	0.16	21.9 (.7)	5.3
	5M4a	0-5	123.4	30.2%	13.6 (.2)	1.4	11.4 (.2)	0.3	0.76 (.01)	0.14	0.43 (.03)	0.14	0.91 (.03)	0.07	40.9 (.6)	4.6
	5M4b	5-10	136.8	22.7%	13.2 (.1)	0.7	12.8 (.2)	0.1	0.93 (.01)	0.06	0.47 (.02)	0.05	0.98 (.03)	0.05	39.7 (.2)	2.2
	5M4c	10-15	146.1	17.8%	6.1 (.1)	0.5	14.5 (.1)	0.1	1.02 (.01)	0.05	0.20 (.02)	0.04	0.94 (.03)	0.03	18.3 (.2)	1.6
6	6M1a	0-5	116.2	29.2%	22.4 (.1)	0.7	10.2 (.1)	0.1	0.91 (.01)	0.07	0.80 (.02)	0.06	0.91 (.03)	0.06	67.2 (.4)	2.3
	6M1b	5-10	126.5	23.2%	29.5 (.1)	0.6	11.0 (.1)	0.1	1.06 (.01)	0.05	0.99 (.02)	0.05	0.99 (.03)	0.04	88.7 (.2)	2.0
	6M1c	10-15	133.8	19.4%	18.5 (.1)	0.6	11.7 (.1)	0.1	1.10 (.01)	0.06	0.64 (.02)	0.06	0.98 (.03)	0.05	55.7 (.2)	2.1
	6M2a	0-5	115.2	31.5%	28.2 (.1)	0.7	9.5 (.1)	0.1	0.88 (.01)	0.07	0.96 (.03)	0.07	0.86 (.03)	0.06	84.6 (.4)	2.3
	6M2b	5-10	138.8	22.8%	24.1 (.1)	0.5	11.0 (.1)	0.1	1.10 (.01)	0.05	0.80 (.02)	0.05	1.00 (.03)	0.04	72.4 (.2)	1.8
	6M2c	10-15	142.3	19.0%	7.4 (.2)	0.8	11.7 (.2)	0.2	1.04 (.01)	0.08	0.28 (.02)	0.07	0.93 (.03)	0.06	22.1 (.5)	2.6
	6M3	0-15	120.3	27.1%	32.3 (.2)	0.7	10.2 (.1)	0.1	1.01 (.01)	0.07	1.12 (.02)	0.07	0.99 (.04)	0.07	97.0 (.7)	2.4
	6M4	0-15	130.1	24.7%	24.6 (.2)	0.8	10.7 (.2)	0.2	1.03 (.02)	0.08	0.86 (.02)	0.08	0.96 (.03)	0.07	74.0 (.5)	2.5
	6M5a	0-5	116.6	30.9%	26.0 (.2)	0.7	9.7 (.1)	0.1	0.91 (.01)	0.07	0.85 (.02)	0.07	0.88 (.03)	0.06	78.2 (.6)	2.3
	6M5b	5-10	134.1	22.2%	23.2 (.2)	0.8	11.4 (.2)	0.2	1.11 (.02)	0.08	0.77 (.02)	0.08	1.01 (.03)	0.06	69.6 (.5)	2.6
	6M5c	10-15	137.8	19.9%	8.7 (.1)	0.6	11.7 (.1)	0.2	1.03 (.01)	0.06	0.30 (.02)	0.05	0.90 (.03)	0.04	26.0 (.2)	2.1
	6M6	0-15	120.6	29.8%	28.4 (.1)	0.6	9.8 (.1)	0.1	0.96 (.01)	0.05	0.91 (.01)	0.05	0.95 (.03)	0.04	85.4 (.4)	2.0
	6M7	0-15	123.8	27.4%	23.2 (.1)	0.7	10.1 (.1)	0.1	0.91 (.15)	0.07	0.75 (.02)	0.07	0.90 (.03)	0.07	69.7 (.4)	2.4
	6M8	0-15	124.6	26.3%	28.2 (.1)	0.7	10.3 (.1)	0.1	0.95 (.01)	0.07	0.97 (.02)	0.07	0.93 (.03)	0.06	84.8 (.4)	2.4
	6M9	0-15	127.1	24.8%	24.1 (.2)	0.8	10.8 (.2)	0.2	1.02 (.02)	0.08	0.82 (.02)	0.08	0.99 (.04)	0.06	72.2 (.4)	2.5
	6M10	0-15	124.9	28.2%	29.9 (.1)	0.5	10.1 (.1)	0.1	0.99 (.01)	0.04	1.00 (.01)	0.04	0.95 (.03)	0.03	89.7 (.2)	1.6
8	8L1†	0-15	126.4	30.0%	1.19 (.05)	0.6	10.6 (.1)	0.1	0.76 (.01)	0.05	0.04 (.01)	0.03	0.62 (.02)	0.03	3.6 (.1)	1.8
9	9L1†	0-15	124.5	27.0%	1.99 (.04)	0.4	10.4 (.1)	0.1	0.81 (.01)	0.04	0.06 (.01)	0.03	0.72 (.02)	0.03	6.0 (.1)	1.2

† composite core
‡ 90 ml sample volume

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In Situ Concentrations (pCi/g): (100 cm)

Location ID	^{238}U	MDC	^{40}K	MDC	^{226}Ra	MDC	^{235}U	MDC	^{232}Th	MDC	Total U (ppm)	MDC
1	4.6 (.6)	2.7	12.0 (.2)	0.2	0.56 (.02)	0.06	0.0 (.2)	0.6	0.60 (.02)	0.06	14 (2)	8
2	8.1 (.5)	3.0	8.1 (.2)	0.2	0.75 (.02)	0.07	0.4 (.1)	0.6	0.75 (.02)	0.07	24 (2)	10
4	18.5 (.9)	3.0	9.9 (.2)	0.2	0.81 (.02)	0.06	1.0 (.2)	0.6	0.85 (.02)	0.06	56 (3)	12
5	14.9 (.6)	2.9	11.0 (.2)	0.2	0.69 (.02)	0.07	0.6 (.2)	0.7	0.90 (.02)	0.07	45 (2)	10
Replicate	18.2 (.5)	2.8	11.1 (.2)	0.3	0.67 (.02)	0.07	1.0 (.2)	0.6	0.95 (.03)	0.07	55 (2)	11
6	25.8 (.7)	3.1	9.6 (.2)	0.2	0.87 (.02)	0.06	1.1 (.2)	0.6	0.86 (.02)	0.06	78 (2)	13
Replicate	25.4 (.5)	2.9	9.6 (.2)	0.2	0.77 (.02)	0.06	1.2 (.2)	0.5	0.89 (.02)	0.06	76 (2)	12
7	50.6 (.6)	2.9	9.9 (.2)	0.2	0.80 (.02)	0.07	2.6 (.2)	0.6	1.05 (.03)	0.07	152 (2)	16
8	1.3 (.4)	1.4	9.8 (.2)	0.1	0.67 (.01)	0.04	0.1 (.1)	0.3	0.61 (.01)	0.04	4 (1)	4
9	1.3 (.6)	1.8	9.9 (.2)	0.1	0.87 (.01)	0.04	0.2 (.1)	0.3	0.65 (.01)	0.04	4 (2)	6
Replicate	1.7 (.4)	1.2	9.6 (.2)	0.1	0.72 (.01)	0.04	0.2 (.1)	0.3	0.67 (.02)	0.04	5 (1)	4
10	24.3 (.2)	4.1	10.7 (.2)	0.4	1.73 (.04)	0.14	1.4 (.2)	0.9	7.64 (.06)	0.14	73.1 (.7)	16

(30.5 cm)

Location ID	^{238}U	MDC	^{40}K	MDC	^{226}Ra	MDC	^{235}U	MDC	^{232}Th	MDC	Total U (ppm)	MDC
1	3.3 (.7)	2.4	12.1 (.2)	0.2	0.58 (.02)	0.06	0.3 (.1)	0.4	0.62 (.02)	0.06	10 (2)	8
2	10.8 (.7)	2.4	8.1 (.2)	0.2	0.60 (.02)	0.07	0.3 (.2)	0.7	0.75 (.02)	0.07	32 (2)	8
4	18.1 (.8)	2.8	10.0 (.2)	0.2	0.87 (.02)	0.06	1.4 (.1)	0.5	0.86 (.02)	0.06	55 (2)	12
5	12.7 (.7)	2.9	11.4 (.2)	0.2	0.65 (.02)	0.07	0.7 (.2)	0.6	0.86 (.02)	0.07	38 (2)	11
Replicate	12.3 (.6)	2.5	12.0 (.2)	0.2	0.71 (.02)	0.07	1.1 (.2)	0.6	0.86 (.02)	0.07	37 (2)	11
6	24.8 (.8)	2.7	9.8 (.2)	0.2	0.88 (.02)	0.06	1.1 (.1)	0.4	0.91 (.02)	0.06	75 (2)	11
7	51.0 (.7)	3.0	9.6 (.2)	0.2	0.78 (.02)	0.07	2.0 (.2)	0.6	1.11 (.03)	0.07	153 (2)	15
8	1.0 (.3)	1.3	9.7 (.1)	0.1	0.71 (.01)	0.04	0.2 (.1)	0.3	0.62 (.01)	0.04	3 (1)	4
9	2.3 (.5)	1.7	9.9 (.1)	0.1	0.82 (.01)	0.04	0.2 (.1)	0.3	0.67 (.01)	0.04	7 (1)	6
10	26.6 (.7)	4.5	10.7 (.2)	0.3	1.77 (.03)	0.11	1.2 (.2)	0.8	6.26 (.05)	0.11	80 (2)	17

Table 3

EML: Analytical Results for Comparability Study

Averaged Wet Concentrations from Laboratory Sample Analysis (AWCLSA) (pCi/g)

Location	^{238}U	MDC	^{40}K	^{226}Ra	^{235}U	MDC	^{232}Th	Total U (ppm)	MDC
1	2.1 (.1)	0.6	13.9 (.1)	0.70 (.01)	0.07 (.01)	0.04	0.66 (.02)	6.3 (.2)	1.7
4	18 (1)	1.0	10.6 (.2)	0.95 (.04)	0.58 (.04)	0.07	0.93 (.03)	54 (4)	3
5	10.7 (.1)	1.0	13.0 (.2)	0.94 (.01)	0.36 (.03)	0.08	0.96 (.04)	32.0 (.4)	2.9
6	25.3 (.1)	0.7	10.5 (.1)	0.99 (.02)	0.85 (.02)	0.06	0.95 (.02)	76.0 (.4)	2.1
8	1.19 (.05)	0.6	10.6 (.1)	0.76 (.01)	0.04 (.01)	0.03	0.62 (.02)	3.6 (.1)	1.7
9	1.99 (.04)	0.4	10.4 (.1)	0.81 (.01)	0.06 (.04)	0.03	0.72 (.03)	6.0 (.1)	1.1

In Situ Concentrations (pCi/g)

Location	^{238}U	MDC	^{40}K	^{226}Ra	^{235}U	MDC	^{232}Th	Total U (ppm)	MDC
1†	3.3 (.7)	2.4	12.1 (.2)	0.58 (.02)	0.3 (.1)	0.4	0.62 (.02)	10 (2)	8
4†	18.1 (.8)	2.8	10.0 (.2)	0.87 (.02)	1.4 (.1)	0.5	0.86 (.02)	55 (2)	12
5†	12 (.3)	3	11.1 (.2)	0.68 (.02)	0.8 (.3)	0.6	0.93 (.03)	38 (2)	11
6*	25.6 (.3)	2.9	9.6 (.2)	0.82 (.07)	1.2 (.1)	0.6	0.87 (.02)	77 (2)	13
8†	1.0 (.3)	1.3	9.7 (.1)	0.71 (.01)	0.2 (.1)	0.3	0.62 (.01)	3 (1)	4
9†	2.3 (.5)	1.7	9.9 (.1)	0.82 (.01)	0.2 (.2)	0.3	0.67 (.01)	7 (1)	6

† 30 cm in situ measurement
* 100 cm in situ measurement

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Radionuclide data

Radionuclide Data and Fluence Rate:

Parent Nuclide	Progeny	Energy (keV)	γ/dis.[§] s^{-1} Bq^{-1}	Fluence Rate (cm^{-2} s^{-1} Bq^{-1} g)
U-238				
	Th-234 (24.10 d)	63.3	0.0381	0.0709
	Pa-234m (1.17m)	1001.1	0.00845[†]	0.0622
U-234		143.8	0.105	0.33
Ra-226				
	Pb-214 (26.8 m)	351.9	0.371	0.8134
	Bi-214 (19.9 m)	609.3	0.461	2.67
		1120	0.15	1.172
		1765	0.159	1.578
Th-232				
	Ac-228 (6.13 h)	338.4	0.124	0.5379
		911	0.29	0.2037
	Th-208 (3.07 m)	583	0.306*	1.737
		2614.7	0.359*	4.389
K-40		1460	0.107	0.9607

[§] Gamma emission per disintegration (ICRU-38)

[†] Siemon at al.,1992

* includes 0.359 branching ratio from the decay of ^{212}Bi (ICRU-38)

Soil Composition Data:

Element	Relative Weight Fraction
H	0.028
C	0.0102
O	0.613
Al	0.0595
Si	0.263
Fe	0.0262

Energy (keV)	Mass Attenuation Coefficient (cm^{-2} g) air	soil
63.3	0.246	0.175
143.8	0.147	0.136
338.4	0.105	0.101
351.9	0.103	0.0999
583	0.0837	0.0815
609.3	0.0821	0.08
911	0.0682	0.0665
1001.1	0.0652	0.0636
1120	0.0615	0.06
1460	0.0583	0.0525
1764.9	0.0488	0.0475
2614.7	0.0389	0.0385

QA for LSA

Soil Core Data			Dry Concentration (pCi/g)													
Sample ID	depth (cm)	mass (g)	^{238}U	MDC	^{40}K	MDC	^{226}Ra	MDC	^{235}U	MDC	^{232}Th	MDC	Total U (ppm)	MDC	$^{235}U/^{238}U$
5M3a	0-5	118.6	20.3 (.2)	2.0	16.8 (.3)	0.2	1.21 (.02)	0.10	0.70 (.03)	0.10	1.23 (.05)	0.10	65.5 (.2)	2.2	0.034 (.002)
5M3a*		118.6	19.9 (.2)	1.0	16.5 (.2)	0.2	1.18 (.02)	0.10	0.70 (.04)	0.10	1.27 (.05)	0.09	59.8 (.6)	3.3	0.035 (.002)
5M3a**		120.1	20.3 (.1)	0.8	16.4 (.1)	0.1	1.15 (.01)	0.07	0.70 (.02)	0.06	1.23 (.04)	0.05	61.0 (.3)	2.6	0.034 (.001)
6M2a	0-5	115.2	41.1 (.2)	1.0	13.9 (.2)	0.2	1.28 (.02)	0.10	1.40 (.04)	0.10	1.25 (.04)	0.09	123.4 (.6)	3.3	0.034 (.001)
6M2a*		115.2	41.5 (.2)	1.0	14.2 (.2)	0.2	1.30 (.01)	0.10	1.33 (.03)	0.10	1.27 (.04)	0.09	124.6 (.6)	3.3	0.032 (.001)
6M2a**		113.6	41.4 (.2)	1.0	14.1 (.2)	0.2	1.27 (.02)	0.10	1.43 (.03)	0.10	1.27 (.05)	0.09	124.3 (.6)	3.3	0.035 (.001)
9L1†	0-15	124.5	2.72 (.06)	0.5	14.2 (.1)	0.09	1.11 (.01)	0.05	0.08 (.01)	0.04	0.98 (.03)	0.04	8.2 (.6)	3.3	0.029 (.004)
9L1*		124.5	2.71 (.05)	0.6	14.1 (.1)	0.1	1.11 (.01)	0.05	0.13 (.01)	0.04	0.95 (.03)	0.04	8.2 (.1)	1.9	0.048 (.004)
9L1**		125.1	2.66 (.05)	0.6	14.0 (.1)	0.1	1.05 (.01)	0.05	0.11 (.01)	0.04	0.94 (.03)	0.04	8.0 (.1)	1.9	0.041 (.004)
6M3	0-15	120.3	44.3 (.3)	1.0	14.0 (.2)	0.2	1.38 (.02)	0.10	1.54 (.03)	0.10	1.36 (.05)	0.09	133.0 (.9)	3.3	0.035 (.001)
6M3*		120.3	44.1 (.3)	1.0	13.7 (.2)	0.2	1.36 (.02)	0.10	1.54 (.03)	0.10	1.29 (.05)	0.09	132.5 (.9)	3.3	0.035 (.001)
6M3**		123.3	44.5 (.3)	1.0	14.0 (.2)	0.2	1.30 (.02)	0.10	1.48 (.03)	0.10	1.25 (.04)	0.09	133.6 (.9)	3.3	0.033 (.001)
6M3**		120.3	44.1 (.2)	1.0	14.2 (.2)	0.2	1.32 (.01)	0.10	1.45 (.03)	0.10	1.36 (.05)	0.08	132.4 (.6)	3.3	0.033 (.001)

* QC Sample-recounted
** QC realiquoted

Blank (Deionized water)

^{238}U	MDC	^{40}K	MDC	^{226}Ra	MDC	^{235}U	MDC	^{232}Th	MDC
0.0 (.04)	1.0	0.0 (.1)	0.2	0.00 (.01)	0.09	0.00 (.02)	0.07	0.02 (.02)	0.08

QAP† Reference Soil

	^{238}U	MDC	^{40}K	MDC
QAP	3.8 (.1)	-	16.4 (.1)	-
LSA for comp. study	3.2 (.3)	0.6	16.2 (.1)	0.1

† EML's Quality Assurance Program

NBS‡ Reference Soil

	^{238}U	MDC	^{232}Th	MDC	^{40}K	MDC
NBS	1.1 (.1)	-	1.9 (.1)	-	20 (2)	-
LSA for comp. study	1.2 (.3)	0.6	1.81 (.06)	0.1	18.2 (.3)	0.1

‡ National Bureau of Standards

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Ratio of In situ Concentrations (1 ft/ 1m)

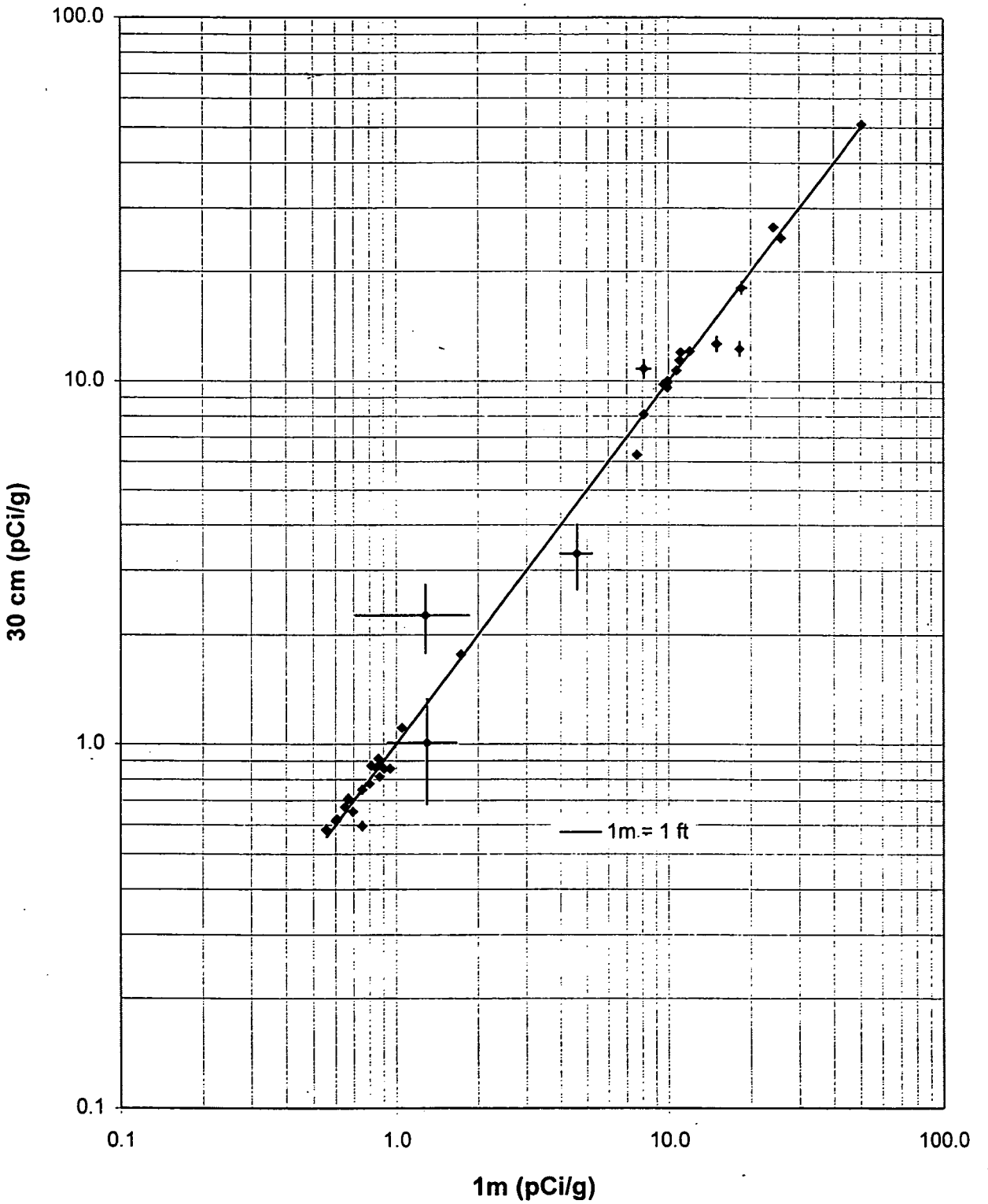

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Figure 1

Comparison of Reported Concentrations for All Nuclides (except ^{235}U) : In Situ vs. AWCLSA

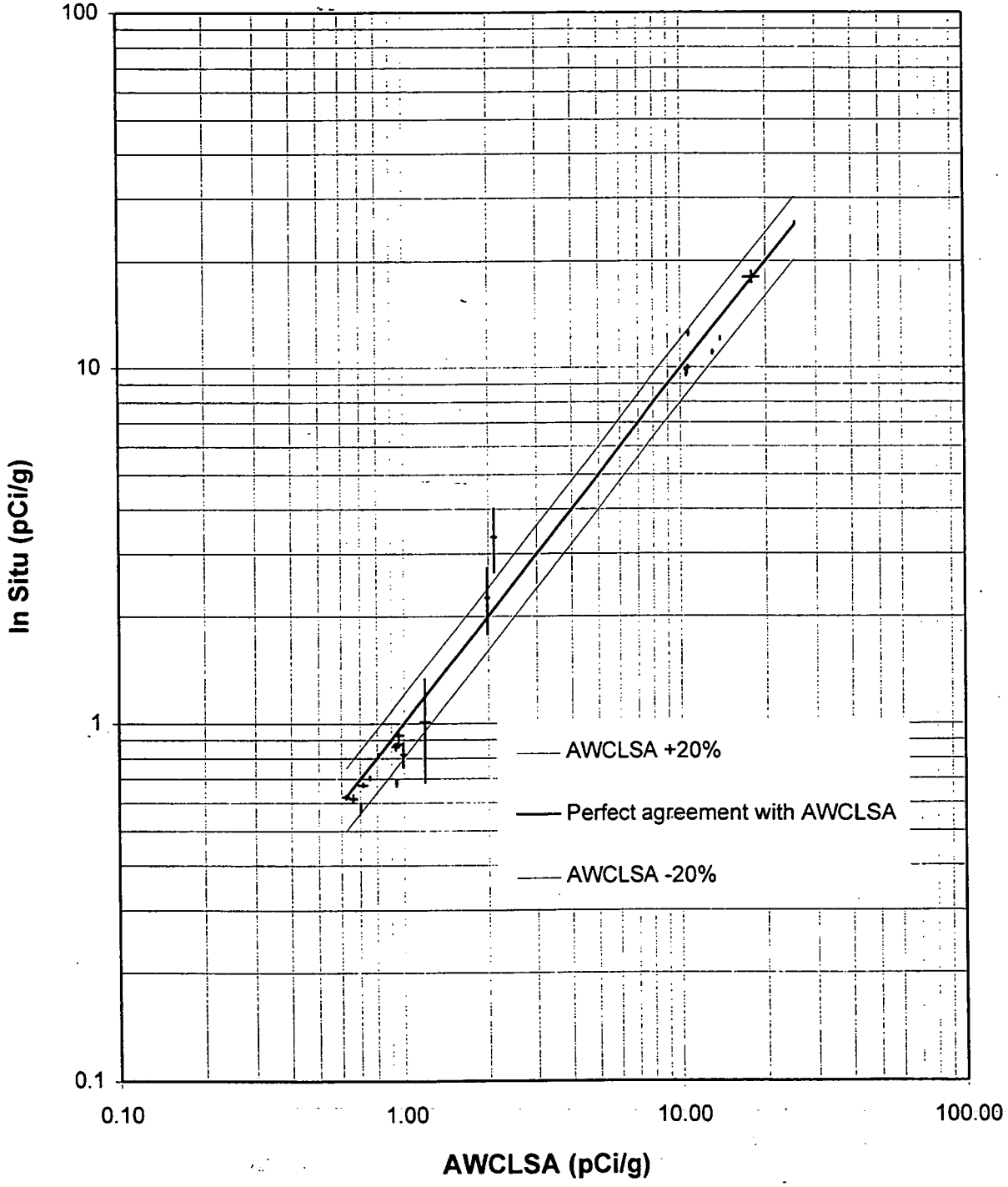

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Figure 2

Comparison of Reported Concentrations for ^{238}U: In Situ vs. AWCLSA

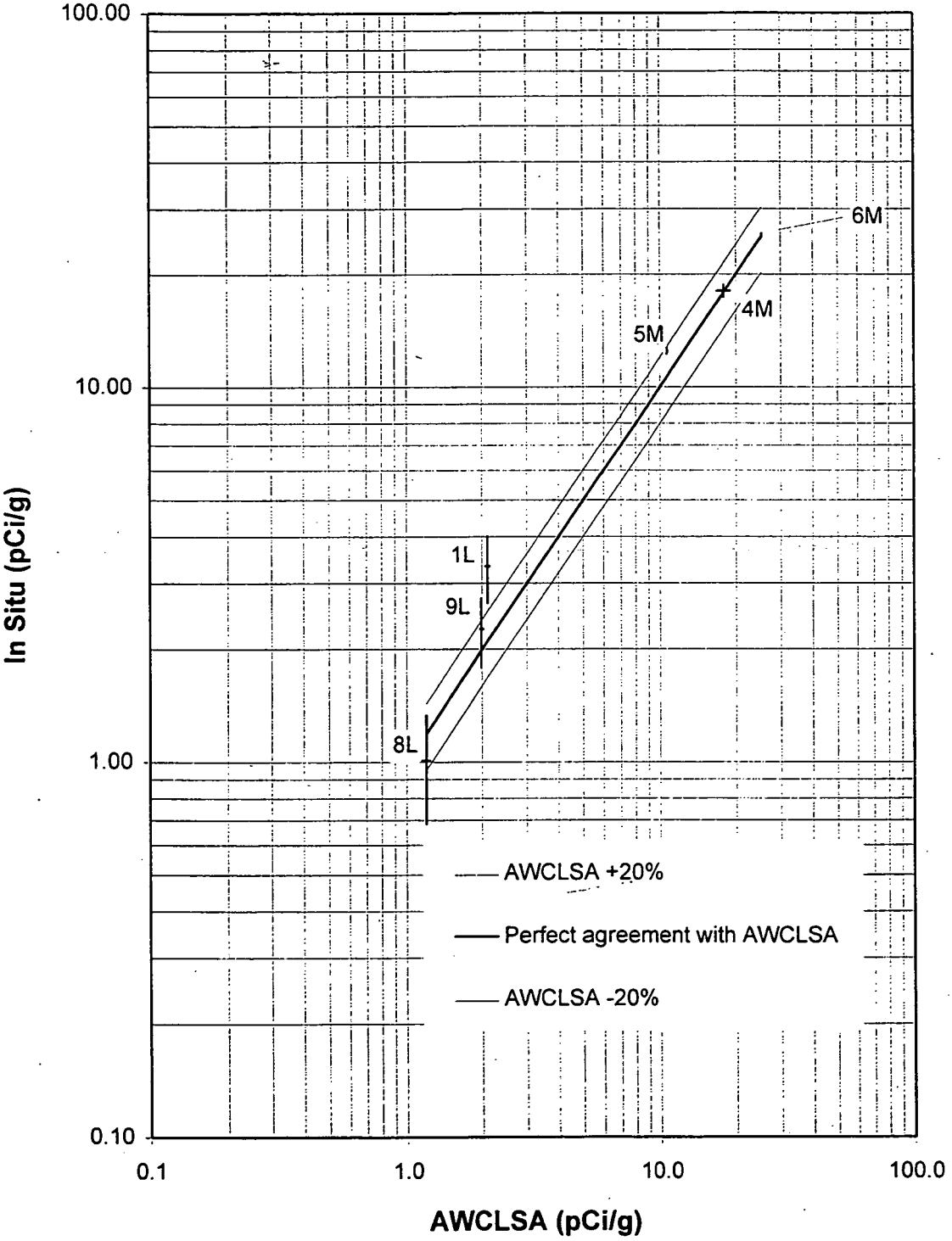

Figure 3

Comparison of Reported Concentrations for Total U: In Situ vs. AWCLSA

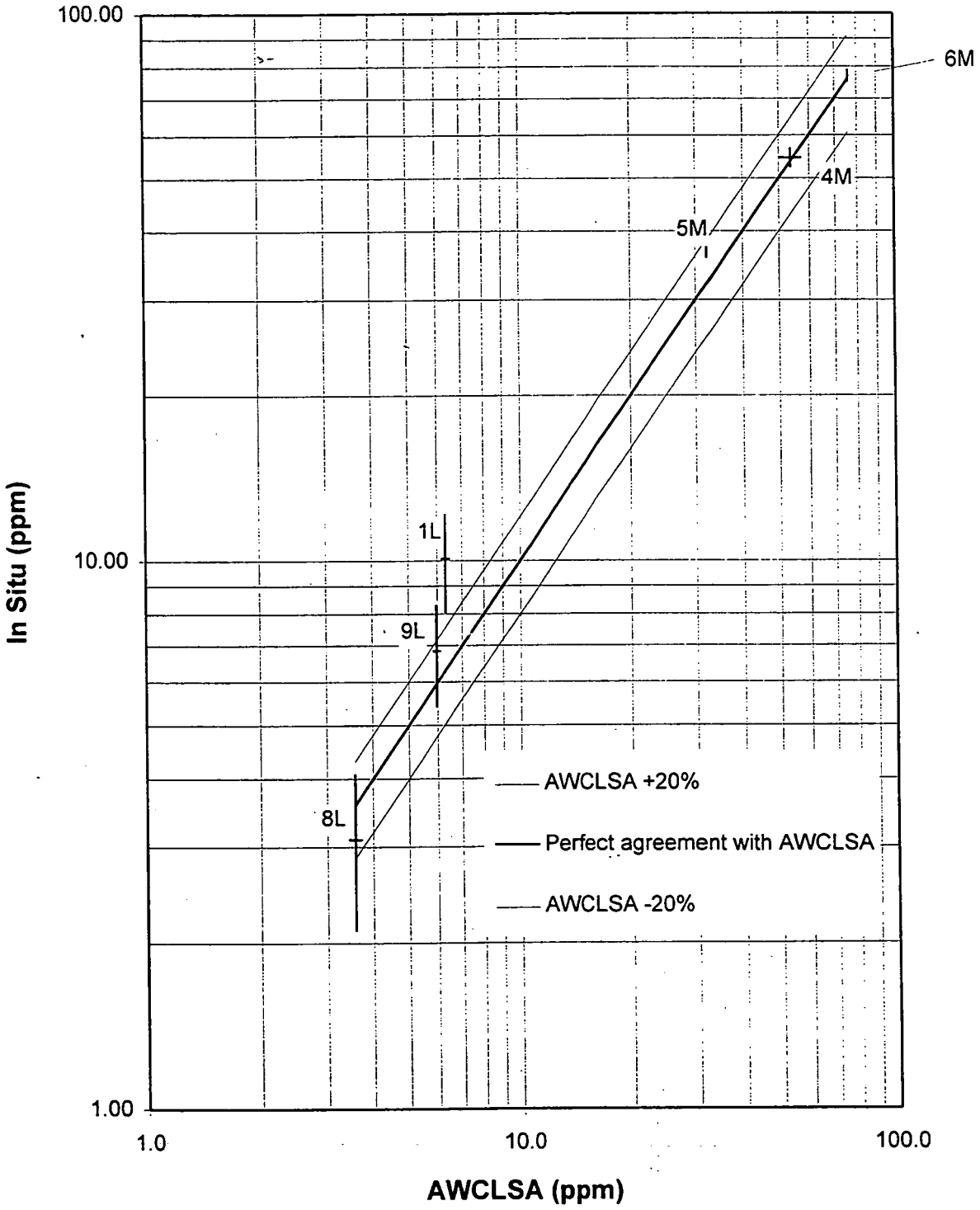

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Figure 4

Comparison of Reported Concentrations for ^{40}K: In Situ vs. AWCLSA

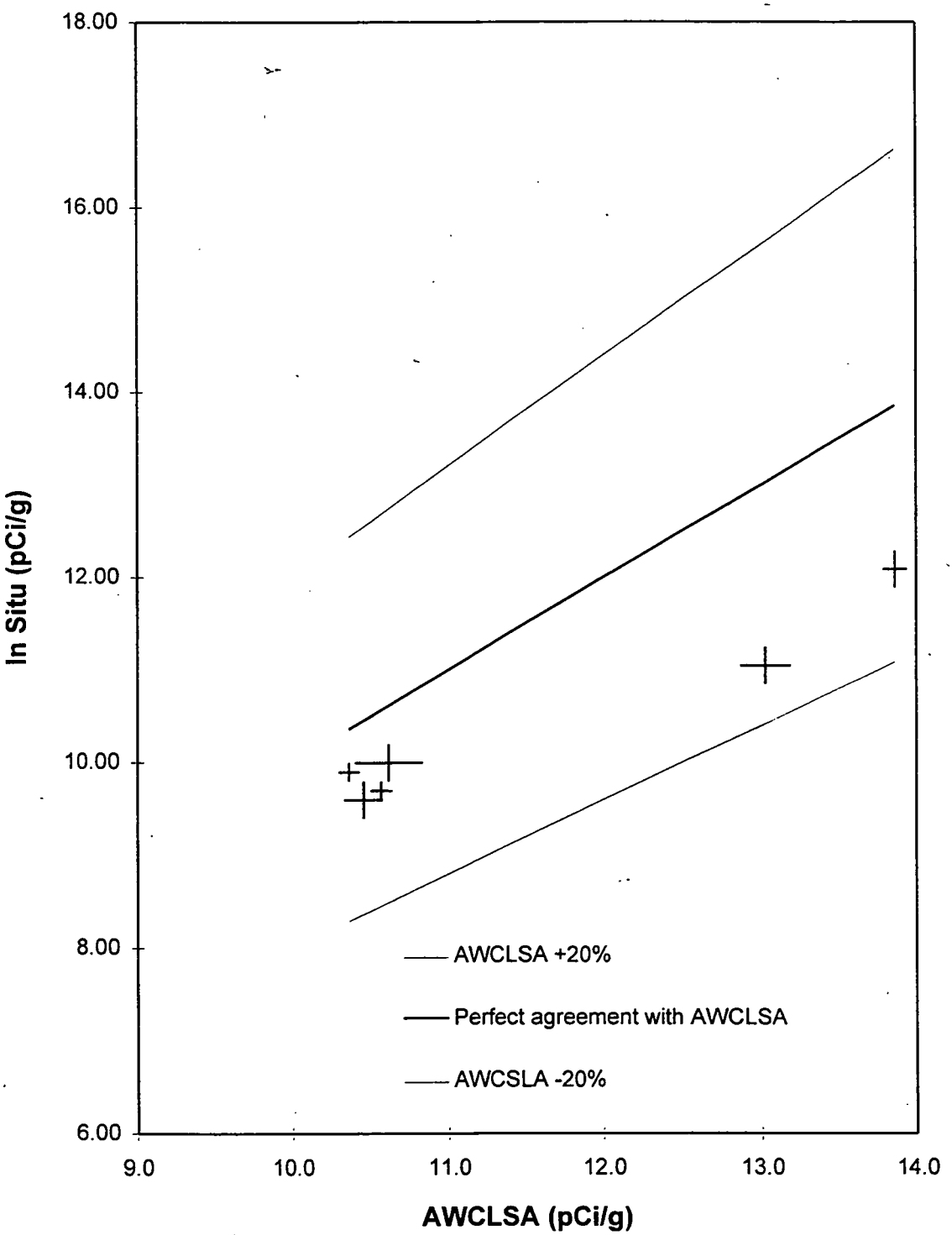

Figure 5

Comparison of Reported Concentrations for ^{226}Ra: In Situ vs. AWCLSA

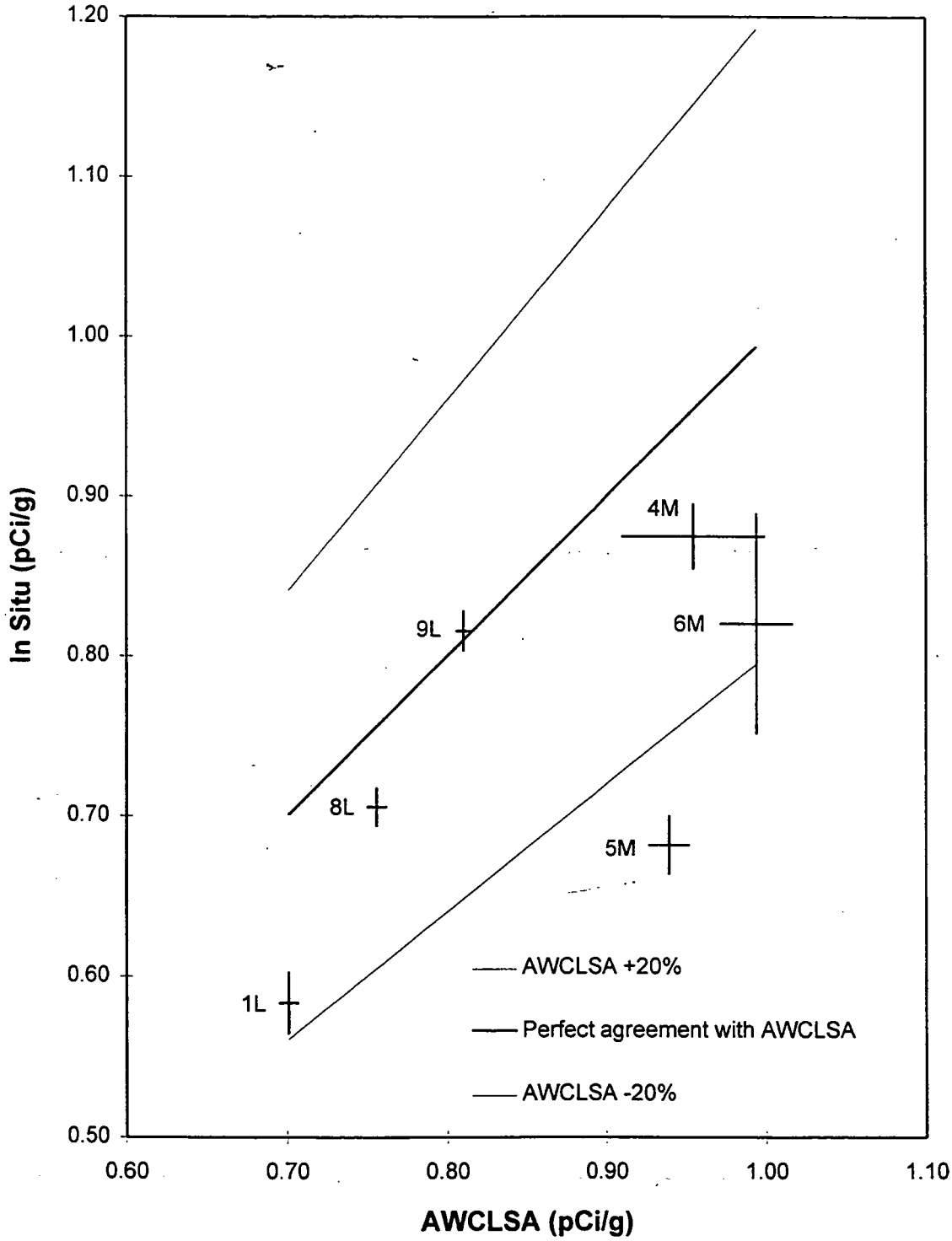

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Figure 6

Comparison of Reported Concentrations for ^{232}Th: In Situ vs. AWCLSA

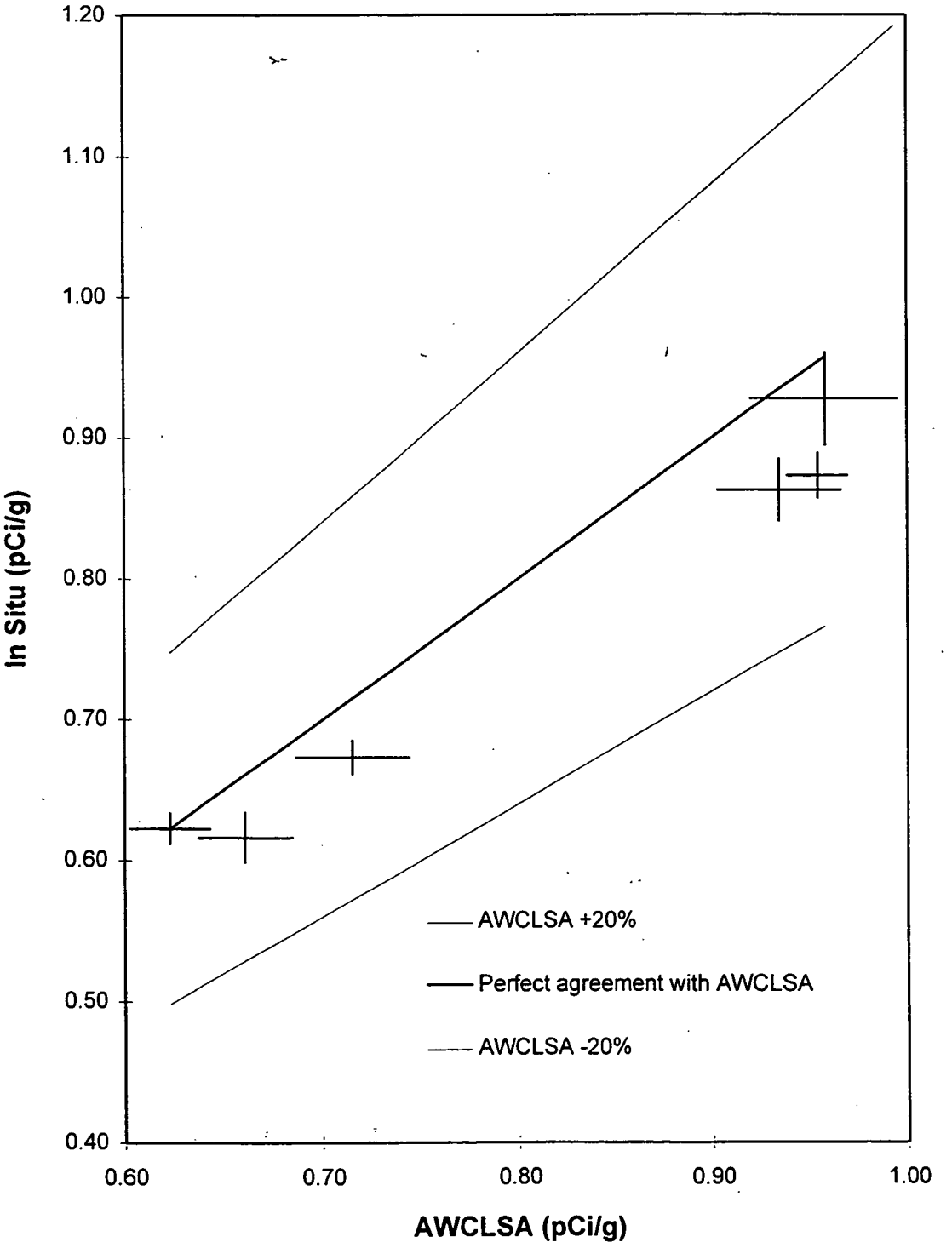

Figure 7

Department of Energy
Environmental Measurements Laboratory
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New York, NY 10014-4811

1950

April 25, 1997

Robert J. Janke, FN

A SUGGESTED SAMPLING PROTOCOL WITH A REVISION OF THE COMPARABILITY STUDY

To avoid any confusion regarding the use of *in situ* spectrometry for characterization and confirmation, we would like to clarify our position and suggest a sampling protocol for *in situ* measurements and discrete soil sampling. One conclusion drawn from our data on the comparability study is that *in situ* measurements can provide accurate, reliable, and reproducible results. The discrete soil sampling approach is a well-documented, time-honored approach; its strength is in the confirmation process because of the many superior analytical techniques which can be performed on the samples. Unfortunately, it suffers in the characterization process because the samples may or may not be representative of the larger soil body, depending on how well the sample is selected and collected. The *in situ* spectrometric approach is also well-documented, but it is relatively new to the characterization and confirmation process; its strength is in characterization because of the detector's large field of view. The approach, however, assumes a uniform horizontal and vertical source distribution which may or may not be consistent with the actual pattern of contamination. This comparability study and other similar studies have demonstrated that deviations from the assumed source distribution do not introduce large systematic errors that would preclude its use in characterization and confirmation activities. Moreover, the assumption of a uniform distribution yields an average that is weighted towards the detector's position.

As suggested in my memo dated 4/9/97, *in situ* measurements are not identical to discrete soil samples for exactly the reasons mentioned above. The goal is to blend the techniques for optimum benefit. We recommend using the *in situ* technique as the primary tool in the characterization and confirmation process for uranium, ^{232}Th, and ^{226}Ra, ^{137}Cs with discrete soil sampling playing a QA/QC role. We therefore suggest that 10 % percent of the measurements be soil samples, with a sampling depth no less than 5 cm or more than 15. We also recommend that some of the soil cores be sectioned to document the depth distribution of the various soil parameters (soil density, soil moisture, etc.) in addition to the COCs. To be sure, a more complete discussion concerning this issue is needed; the approach mentioned above is a reasonable start.

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Enclosed are corrections to the results of our comparability study. Please be aware that a transcription error has caused the ^{226}Ra value for location 10 to change.

Peter Shebell, Physicist
Environmental Science Division

Enclosure: As Stated

cc: Kevin Miller, EME