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FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

COMPARABILITY OF IN-SITU GAMMA SPECTROMETRY AND LABORATORY MEASUREMENTS OF RADIUM-226

ADDENDUM TO JULY, 1997 COMPARABILITY OF IN-SITU GAMMA SPECTROMETRY AND LABORATORY DATA REPORT

INFORMATION ONLY

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LIST OF ACRONYMS AND ABBREVIATIONS

cm	centimeter
FEMP	Fernald Environmental Management Project
ft	feet
HPGe	high purity germanium detector
pCi/g	picocuries per gram
ppm	parts per million
TPU	total propagated uncertainty
WAC	waste acceptance criteria

INTRODUCTION

In July 1997, a report entitled "Comparability of in-Situ Gamma Spectrometry and Laboratory Data" was issued that assessed the comparability of high-purity germanium detector (HPGe) measurements with laboratory data generated from the analysis of physical samples. The analytes measured by both analytical techniques included total uranium, thorium-232, radium-226, potassium-40, and cesium-137.

The data in the above 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 were initiated to help resolve these differences between laboratory and HPGe data. The first of these two studies addressed HPGe measurements of radium-226 in the field in order to assess the degree of radon-222 (radon daughters are measured to quantify radium-226 by gamma spectrometry) emanation from soils as a function of environmental factors. The second investigated the accuracy of laboratory alpha spectrometry for radium-226.

This report documents the results of the study to assess the accuracy of alpha spectrometry. In tandem with that study, additional physical samples and HPGe measurements were collected from six locations to infill data gaps and to extend the range of radium-226 comparability. These new data are also reported in this report. Finally, this report presents an empirical approach to correcting HPGe measurements to compensate for radon-222 emanation from soils so that HPGe radium-226 data agree more closely with laboratory data. The results of the study on environmental influences on radium-226 will be issued as a separate report.

ANALYTICAL METHODS

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 tested 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 involved a vigorous nitric acid leach method, but may not have resulted in complete solution of radium-226, particularly at low concentrations in soils. This is because soils were not totally dissolved, thereby releasing background levels of radium primarily contained in the interiors of mineral grains.

Results of the FEMP and EML analyses on the small subset of samples are shown in Table 1. The original results obtained using a vigorous nitric acid lead 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 leach results for high concentration samples (PBC-03-7, PBC-03-9). Finally, the nitric/hydrofluoric acid total dissolution data agreed well with data generated by EML's fusion flux/radon emanation technique, with the exception of PBC-10-1. The data in Table 1 for PBC-10-1 do not exhibit good agreement, and this is believed to result from heterogeneity in the sample despite grinding and extensive 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 A of this report. Table 2 compares the original data contained in the July, 1997 report with the reanalyzed data contained in Appendix A. 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 2 is defined as:

[(total dissolution data - original data)/original data] x 100,

and the average values in Table 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 result 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 A and Table 2 are the average of these two reanalyses.

Because the nitric/hydrofluoric acid total dissolution method results in a more complete recovery of radium-226, particularly in low concentration samples, it was used in the analysis of additional samples collected from six areas. These additional data are discussed in the section below.

RADIUM-226 DATA FROM THE SOUTH FIELD AREA

The radium-226 data in the July 1997 report were unevenly distributed in concentration range. Eight of ten areas had radium-226 weighted mean concentrations below 1.0 pCi/g; one area had a weighted mean concentration of 3.0 to 3.5 pCi/g; and one area had a weighted mean concentration of 13.6 pCi/g. Six locations in the South Field were selected based upon RI/FS data to provide infill data points. The locations of these six areas are shown in Figure 1. The areas are labeled PBC-12, -13, -14, -15, -16, and -17. Based upon estimations from RI/FS data as to their degree of contamination, either 10 samples (and one duplicate) or 15 samples (and one duplicate) were taken at a given location. Fifteen samples were taken at the more highly contaminated (and presumably more heterogeneous) areas and ten samples were collected at the less highly contaminated (and presumably less heterogeneous) areas. The data for these six areas show that the estimates as to the degree of contamination were correct for five of the six sample areas. PBC-12 turned out to be more highly contaminated and heterogeneous than expected, so 10 samples may have been inadequate to characterize it adequately.

The rationale for 10 or 15 samples is provided in Section 2.2.2.3 of the July 1997 report. Figure 2-5 of that same report presents the sample numbering scheme, which was also used in this study. The

location of the HPGe measurements were at physical sample location 1, the very center point in the concentric circular rings. HPGe measurements were made at 1.0 m detector height only. Rather than taking a second set of measurements at 31 cm (1.0 ft) detector height, two sets of measurements were taken, one in the morning and one in the afternoon. In the July 1997 comparability study, Section 5.7 (Figure 5-7) indicated that radium-226 concentrations in the morning could be significantly higher than radium-226 concentrations in the afternoon. This results, in certain instances, from atmospheric conditions favoring the retention of radon-222 in the soil. By taking morning and afternoon HPGe measurements in the South Field, the data could be evaluated to see if environmental conditions caused significant differences between morning and afternoon measurements.

ANALYTICAL DATA

Appendix A contains laboratory alpha 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, or "as is," basis to provide a common ground for comparing the two data sets. An "AM" or "PM" designation is provided for all HPGe data to indicate whether the data were taken in the morning or afternoon. The "AM" data do not appear to be significantly higher than the "PM" data for any of the locations. Two sets of alpha spectrometry data are provided. The data entitled "original result" are the nitric acid leach data contained in the July 1997 report. The data entitled "total dissolution result" are the data obtained by nitric/hydrofluoric acid total dissolution. Because the samples from PBC-12 through PBC-17 had not been analyzed prior to issuance of the July 1997 report, they were only analyzed using the nitric/hydrofluoric acid method.

Total propagated uncertainty (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 are greater than HPGe 1.96 σ counting errors because the former represents total system uncertainty, while the latter represents only one component of system uncertainty.

COMPARISON OF HPGe AND LABORATORY DATA

Table 3 summarizes the total dissolution data in Appendix A. Using the weighting factors shown in Table 2-4 of the July 1997 HPGe comparability report and the computational method described in Section 3.2.2 of the same report, weighted means and weighted standard deviations for each sample collection area are shown in Table 3. There are fewer 31 cm points than 100 cm data points in Table 3

because 31 cm HPGe measurements were not performed in areas PBC-12 through PBC-17 for reasons described above. For each sample area from which sample duplicates were collected, the average of the data for the duplicates was used in the weighted mean/standard deviation calculations. By comparing the weighted average of the laboratory data for each area with the HPGe data for that same area, an assessment of the degree of closeness of the data sets can be made. The section below contains such assessments.

Table 4 summarizes the closeness between laboratory data weighted means (Table 3) and HPGe data. The closeness between weighted means and HPGe data is expressed as the percent relative deviation:

$$\%\,RelativeDeviation = [\frac{(\bar{x}_1 - \bar{x}_2)}{\bar{x}}]x100$$

where:

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

$\bar{x}_2$ is the mean of all HPGe measurements (including both "AM" and "PM" measurements) at a given detector height

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

The percent relative deviations shown in Table 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 4 are calculated based upon the absolute value of the relative deviations.

Adopting criteria proposed in the July 1997 HPGe comparability report (Section 3.2.2) 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 4 indicates that the absolute values of almost all percent relative deviations exceed 20% and a majority exceed 35%. Not surprisingly, then, the average of the absolute values of the percent relative deviations are 37.0 and

54.1, respectively, for 31 cm and 100 cm detector height data. Based upon the criteria presented above, HPGe and alpha spectrometry data are defined as dissimilar, or not comparable.

Further inspection of Tables 3 and 4 indicates that the weighted mean of alpha spectrometry radium-226 data for a given area is almost always higher than the corresponding HPGe measured radium-226 data for that area. Further, the difference between alpha 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 the 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 data reflect loss of radon-222 relative to laboratory data which measures radium-226 in soil directly.

Correlation of Laboratory and HPGe Data

Figures 2 and 3 show x,y scatter plots of the data in Tables 3. These figures show the minimum and maximum HPGe measurements for each area. Error bars for the HPGe measurements are not derived from standard deviations in Table 3, but rather represent the 1.96 σ counting errors listed for HPGe measurements in Appendix A. Error bars for laboratory data represent upper and lower 97.5% confidence limits based upon the weighted standard deviations in Table 3.

Four points are particularly noteworthy based upon examination of Figures 2 and 3. First, comparison of Figure 3 (100 cm data) with the corresponding Figure 3-6 (100 cm data) in the July 1997 HPGe Comparability Report 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 2 is for 31 cm data which has no additional points.) In this regard, the range of data has been extended to radium concentrations in excess of 18.0 pCi/g. Second, the data clearly indicate a positive bias in alpha spectrometry data relative to HPGe data. Thus, all of the data, with the exception of PBC-02, fall below the perfect correlation line (line with a slope of 1.0 bisecting the figure). 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 A) relative to TPUs for individual data points. Fourth, the difference between the plotted points and the perfect correlation line increases as a function of radium-226 (as measured by alpha spectrometry). Thus, the degree of correlation of alpha spectrometry data with HPGe data worsens as the concentration of radium-226 increases in the soil. However, as discussed in the section below, a curve can be fitted through the plotted points in Figures 2 and 3 with a very high degree of correlation, as demonstrated in Figures 4 through 6. This can be inferred to mean that HPGe is probably very accurately measuring residual radon-222 daughters in the soil. This accuracy forms the basis for derivation of a correction algorithm that empirically compensates for radon emanation from soils.

CORRECTION ALGORITHM FOR HPGe RADIUM-226 MEASUREMENTS

The data in Figures 2 and 3 have been replotted in Figures 4, 5, and 6. In these figures, though, HPGe data constitute the x-axis and alpha spectrometry 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.

A series of different curves were fitted on a trial basis to the data points--linear regressions, polynomial regressions, and power regressions. All regressions were fitted two ways: forced through the origin and not forced through the origin. Second order polynomials consistently yielded the highest correlation coefficients. 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 polynomial forced through the origin was utilized to give the best fit to the data points. These curves are shown in Figures 4 through 6.

From the curves in Figures 4 through 6, a series of correction factors were calculated as shown below in an example.

Step 1

For a given HPGe concentration, an average calculated alpha spectrometry concentration was determined from the polynomial equations in Figures 4 through 6. Thus from Figure 4 (for example) if an HPGe measurement = 2.0 pCi/g, the corresponding alpha spectrometry result is 4.48 pCi/g. Similarly, from Figure 5 if HPGe = 2.0 pCi/g, then alpha spectrometry = 4.07 pCi/g; and from Figure 6 if HPGe = 2.0 pCi/g, then alpha spectrometry = 3.66 pCi/g. By taking the average of the

three calculated alpha spectrometry concentrations. an HPGe measurement of 2.0 pCi/g equates to an average alpha spectrometry value of 4.07 pCi/g.

Step 2

The difference is then calculated between the average calculated alpha spectrometry concentration from equations in Figures 4-6 and the concentration that would exist if there were a perfect correlation between HPGe and alpha spectrometry data (i.e., a straight line going through the origin with a slope of 1.0). If there were a perfect correlation between HPGe and alpha spectrometry data. a measured HPGe concentration of 2.0 pCi/g would correlate to an alpha spectrometry concentration of 2.0 pCi/g.

The difference between the alpha spectrometry concentrations in Step 1 and Step 2 is 4.07 pCi/g - 2.0 pCi/g = 2.07 pCi/g. The difference of 2.07 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 (16) of HPGe concentrations between 0 and 6 pCi/g. These correction factors are then plotted against HPGe concentrations as shown in Figure 7. These data points are described very well by an equation having the form:

$$\text{Correction factor} = 0.4369\,(\text{HPGe concentration})^2 + 0.167\,(\text{HPGe concentration}) + 0.0001$$

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 and added to the HPGe measured radium-226 concentration. For example, an HPGe measurement of 3.0 pCi/g yields a correction factor of 4.42 pCi/g. The "corrected" radium-226 concentration is then 3.0 pCi/g + 4.42 pCi/g = 7.42 pCi/g.

Corrected HPGe Data

The HPGe data in Table 3 have been "corrected" as described in Step 4 above. Tables 5A and 5B show measured HPGe data contained in Table 3, measured alpha spectrometry data contained in Table 3, and corrected HPGe data. Table 6 shows the closeness of corrected HPGe data and alpha spectrometry data. Based upon criteria described earlier in this report, corrected HPGe and alpha spectrometry data would be assessed as having good comparability. Particularly noteworthy in this regard is the fact that the average percent relative deviations are 14.8% and 14.5%, respectively, for

31 cm and 100 cm data. This compares to average percent relative deviations of 37.0% and 54.1% without correction.

Caveat

The HPGe correction process described above to compensate for radon-222 loss from soils should be regarded as preliminary. A large body of data have been obtained from repeated morning and afternoon HPGe measurements at the same Field Quality Control Station since April 1997. These data will provide a good data set to test the applicability of the correction process described above. A report containing all of the Field Quality Control Station data should be issued in November.

SUMMARY

1. Improvements have been made to the FEMP alpha spectrometry method for analyzing radium-226. A method employing concentrated nitric 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. 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.

4. When these correction factors were applied to HPGe measurements made at 16 locations, the corrected data were very comparable with alpha spectrometry data obtained from analysis of physical samples.

5. The HPGe radium-226 correction process described in this report should be regarded as preliminary. Data collected since April 1997 at a Field Quality Control Station should provide a good test of the process.

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

Sample I.D.	FEMP HNO_3 Leach		FEMP HNO_3-HF Total Dissolution		EML Fusion Dissolution	
	Result (pCi/g)	1.96 Sigma TPU (pCi/g)	Result (pCi/g)	1.96 Sigma TPU (pCi/g)	Result (pCi/g)	1.96 Sigma TPU (pCi/g)
PBC-03-7	24.0	5.4	24.7	5.5	22.9	0.6
PBC-03-9	13.5	3.0	14.1	3.1	12.4	1.6
PBC-05-6	0.45	0.11	1.1	0.2	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 2
COMPARISON OF ORIGINAL AND TOTAL DISSOLUTION RADIUM-226 DATA

Sample ID	Original Data (pCi/g)	Total Dissolution Data (pCi/g)	Percent Difference
PBC-01-1	0.48	0.79	64.6
PBC-01-2	0.57	0.8	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	0.6	17.6
PBC-02-4	0.54	0.56	3.7
PBC-02-5	0.59	0.8	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

TABLE 2
(continued)

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Sample ID	Original Data (pCi/g)	Total Dissolution Data (pCi/g)	Percent Difference
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
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

TABLE 2
(continued)

Sample ID	Original Data (pCi/g)	Total Dissolution Data (pCi/g)	Percent Difference
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
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	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

TABLE 2
(continued)

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Sample ID	Original Data (pCi/g)	Total Dissolution Data (pCi/g)	Percent Difference
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
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	0.8	142.4
PBC-08-3	0.54	0.94	74.1
PBC-08-4	0.38	0.73	92.1
PBC-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

TABLE 2
(continued)

Sample ID	Original Data (pCi/g)	Total Dissolution Data (pCi/g)	Percent Difference
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	50.0
PBC-10-9	2.3	4.6	100.0
PBC-10-10	3.4	2.7	-20.6
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 3
COMPARISON OF ALPHA SPECTROMETRY AND HPGe RADIUM-226 DATA

HPGe Setting	Area	Alpha Spectrometry		HPGe	
		Weighted Mean (pCi/g)	Weighted Std. Dev. (pCi/g)	Mean* (pCi/g)	Std. Dev. (pCi/g)
31 cm(1 ft)	PBC-01	0.80	0.01	0.64	0.01
	PBC-02	0.63	0.02	0.66	0.01
	PBC-03	11.4	1.3	4.2	0.15
	PBC-04	1.09	0.06	0.82	0.03
	PBC-05	1.2	0.02	0.72	0.04
	PBC-06	1.2	0.02	0.80	0.01
	PBC-07	1.24	0.04	0.80	0.01
	PBC-08	0.87	0.04	0.65	0.01
	PBC-09	0.78	0.02	0.73	0.03
	PBC-10	3.3	0.03	1.9	0.04
1.0 m (3.28 ft.)	PBC-01	0.81	0.02	0.6	0.01
	PBC-02	0.61	0.03	0.68	0.02
	PBC-03	13.1	1.6	4.3	0.05
	PBC-04	1.1	0.06	0.8	0.02
	PBC-05	1.2	0.02	0.73	0.01
	PBC-06	1.2	0.02	0.8	0.01
	PBC-07	1.26	0.06	1.03	0.08
	PBC-08	0.81	0.04	0.61	0.02
	PBC-09	0.77	0.02	0.69	0.002
	PBC-10	3.5	0.40	1.7	0.01
	PBC-12	6.8	0.09	2.1	0.04
	PBC-13	1.5	0.07	0.94	0.06
	PBC-14	1.2	0.05	0.78	0.03
	PBC-15	1.6	0.20	0.78	0.01
	PBC-16	18.4	2.9	5.1	0.06
	PBC-17	11.2	1.4	3.8	0.06

* Average of "AM" and "PM" measurements.

TABLE 4
CLOSENESS OF ALPHA SPECTROMETRY AND HPGe RADIUM-226 DATA

Area	% Relative Deviation of Means (31 cm)*	% Relative Deviation of Means (100 cm)*
PBC-01	22.22	29.79
PBC-02	-4.65	-10.85
PBC-03	92.31	101.15
PBC-04	28.27	31.58
PBC-05	50.00	48.70
PBC-06	40.00	40.00
PBC-07	43.14	20.09
PBC-08	28.95	28.17
PBC-09	6.62	10.96
PBC-10	53.85	69.23
PBC-12		105.62
PBC-13		45.90
PBC-14		42.42
PBC-15		68.91
PBC-16		113.19
PBC-17		98.67

Average = 37.00 **Average= 54.08**

* Negative signs indicate that alpha spectrometry data are less tha HPGe data; positive signs Indicate that alpha spectrometry data are greater than HPGe data. Signs are not taken into Account in the computation of the above averages.

TABLE 5A
CORRECTED 31 cm HPGe RADIUM-226 DATA

Area	Measured HPGe Concentration (pCi/g)	Correction Factor (pCi/g)	Corrected HPGe Concentration (pCi/g)	Measured Alpha Spectrometry Concentration (pCi/g)
PBC-01	0.64	0.28	0.92	0.8
PBC-02	0.66	0.30	0.96	0.63
PBC-03	4.2	8.39	12.59	11.4
PBC-04	0.82	0.43	1.25	1.09
PBC-05	0.72	0.34	1.06	1.2
PBC-06	0.8	0.41	1.21	1.2
PBC-07	0.8	0.41	1.21	1.24
PBC-08	0.65	0.29	0.94	0.87
PBC-09	0.73	0.35	1.08	0.78
PBC-10	1.9	1.88	3.78	3.3

TABLE 5B
CORRECTED 100 cm HPGe RADIUM-226 DATA

Area	Measured HPGe Concentration (pCi/g)	Correction Factor (pCi/g)	Corrected HPGe Concentration (pCi/g)	Measured Alpha Spectrometry Concentration (pCi/g)
PBC-01	0.6	0.25	0.85	0.81
PBC-02	0.68	0.31	0.99	0.61
PBC-03	4.3	8.77	13.1	13.1
PBC-04	0.8	0.41	1.2	1.1
PBC-05	0.73	0.35	1.1	1.2
PBC-06	0.8	0.41	1.2	1.2
PBC-07	1.03	0.63	1.66	1.26
PBC-08	0.61	0.26	0.87	0.81
PBC-09	0.69	0.32	1.01	0.77
PBC-10	1.7	1.54	3.2	3.5
PBC-12	2.1	2.27	4.4	6.8
PBC-13	0.94	0.54	1.5	1.5
PBC-14	0.78	0.39	1.2	1.2
PBC-15	0.78	0.39	1.2	1.6
PBC-16	5.1	12.19	17.3	18.4
PBC-17	3.8	6.92	10.7	11.2

TABLE 6
CLOSENESS OF ALPHA SPECTROMETRY AND CORRECTED HPGe RADIUM-226 DATA

Area	% Relative Deviation of Means (31 cm)*	% Relative Deviation of Means (100 cm)*
PBC-01	-14.23	-5.34
PBC-02	-41.22	-47.70
PBC-03	-9.89	0.20
PBC-04	-13.39	-9.45
PBC-05	12.11	10.44
PBC-06	-0.75	-0.75
PBC-07	2.53	-27.41
PBC-08	-7.71	-7.29
PBC-09	-32.35	-26.94
PBC-10	-13.68	7.79
PBC-12		43.59
PBC-13		1.47
PBC-14		2.36
PBC-15		30.88
PBC-16		6.23
PBC-17		4.35

Average = 14.79 **Average= 14.51**

* Negative signs indicate that alpha spectrometry data are less tha HPGe data; positive signs Indicate that alpha spectrometry data are greater than HPGe data. Signs are not taken into Account in the computation of the above averages.

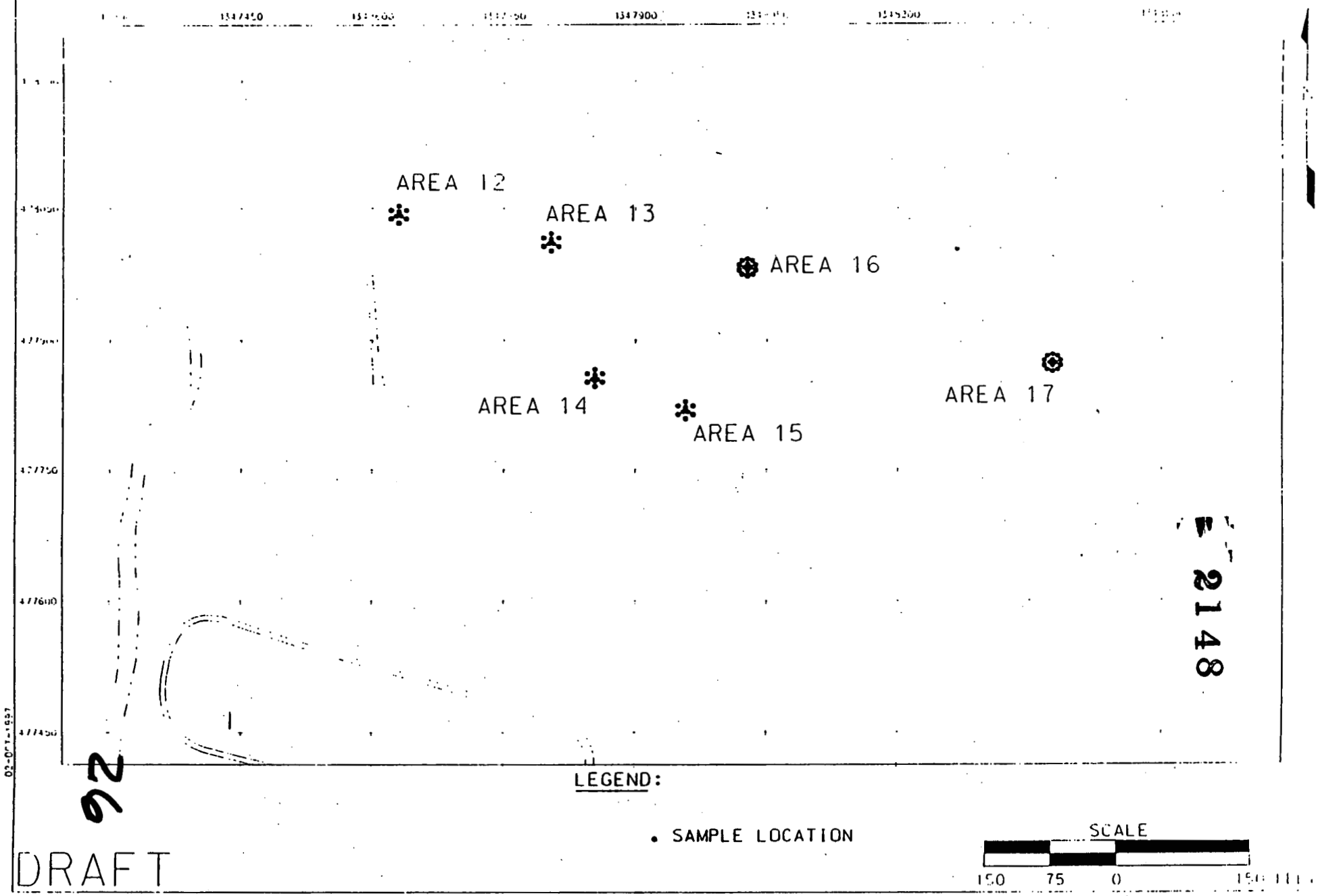

FIGURE 1. COMP. STUDY LOCATIONS AND SAMPLE PATTERNS

Figure 2

Correlation Between HPGe (31 cm) and Alpha Spectrometry Data for Radium-226

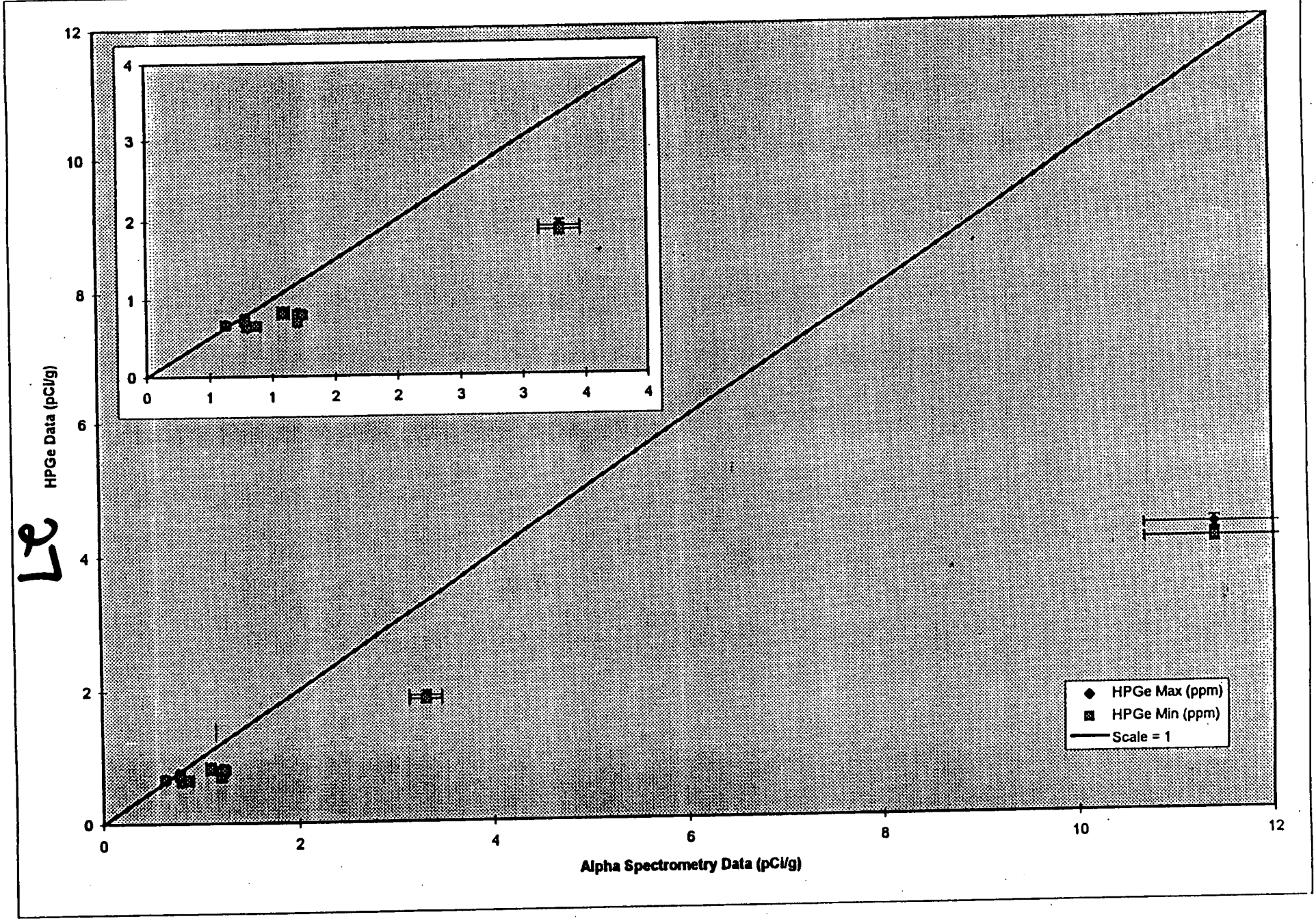

Figure 3
Correlation Between HPGe (100 cm) and Alpha Spectrometry Data for Radium-226

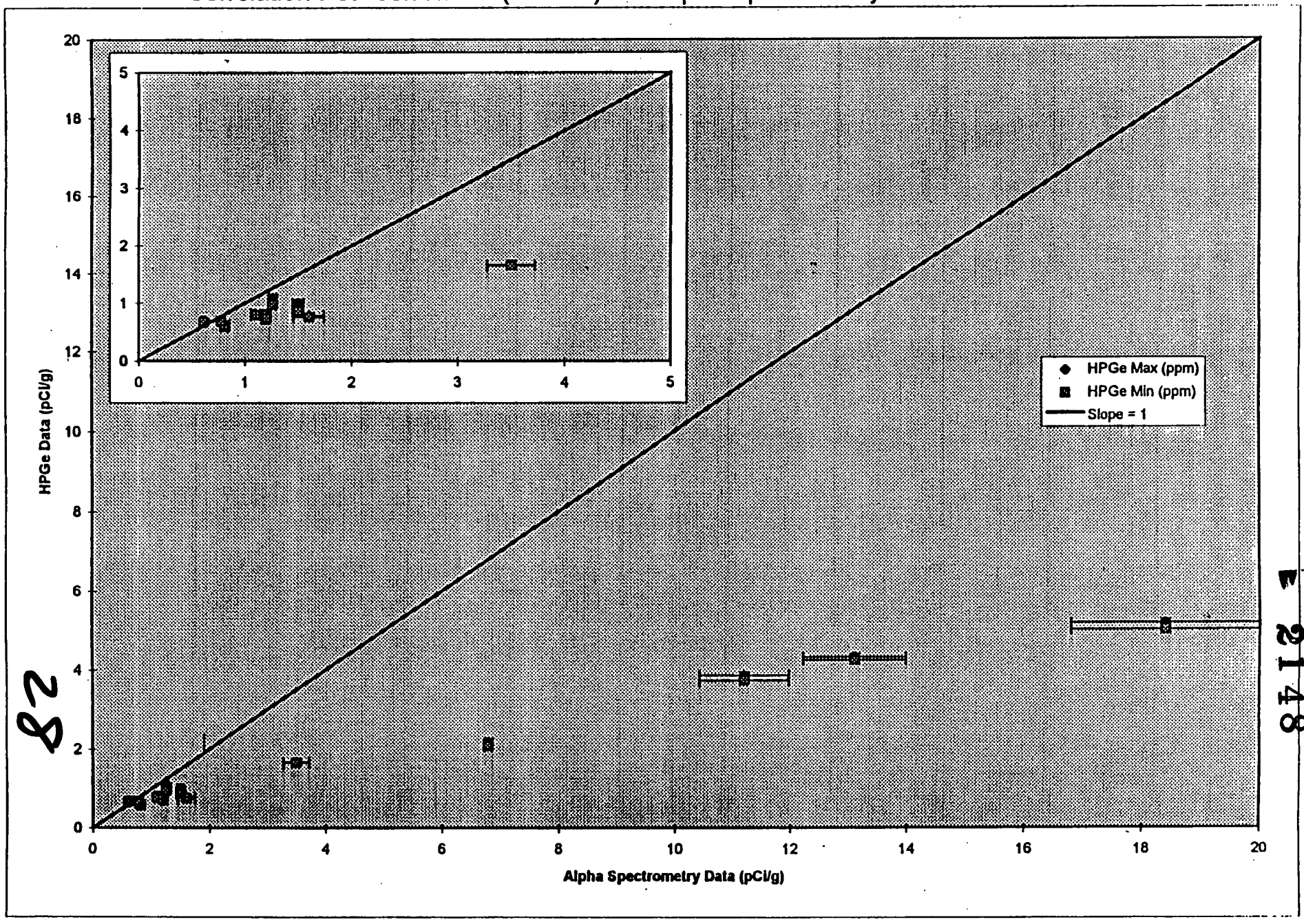

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Figure 4

100 cm HPGe vs Alpha spectrometry Data for Radium-226 (including PBC-12) (forced through origin)

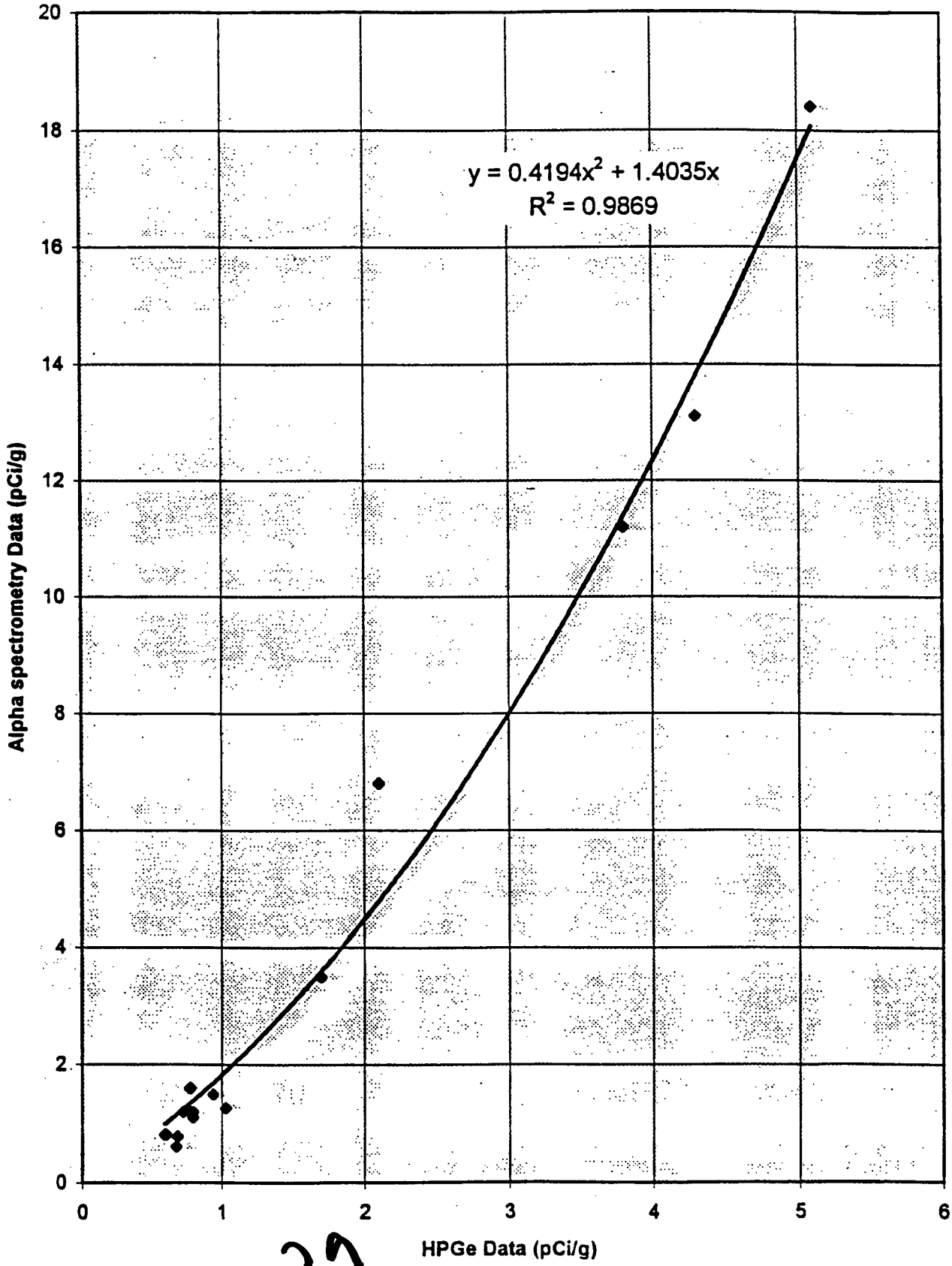

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Figure 5 E 2148

100 cm HPGe vs Alpha spectrometry Data
for Radium-226 (excluding PBC-12)
(forced through origin)

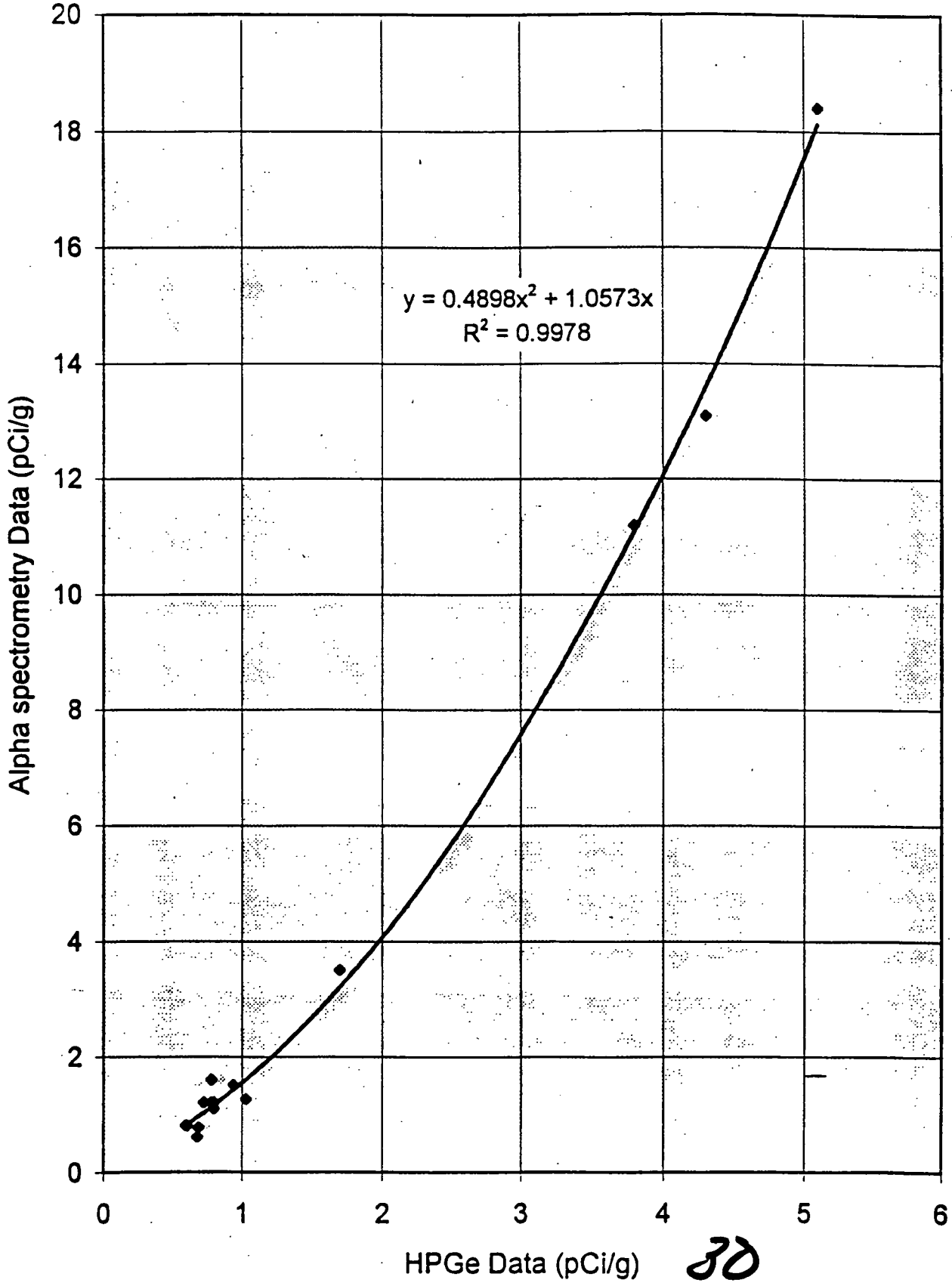

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Figure 6

31 cm HPGe vs Alpha Spectrometry Data for Radium-226
(forced through origin)

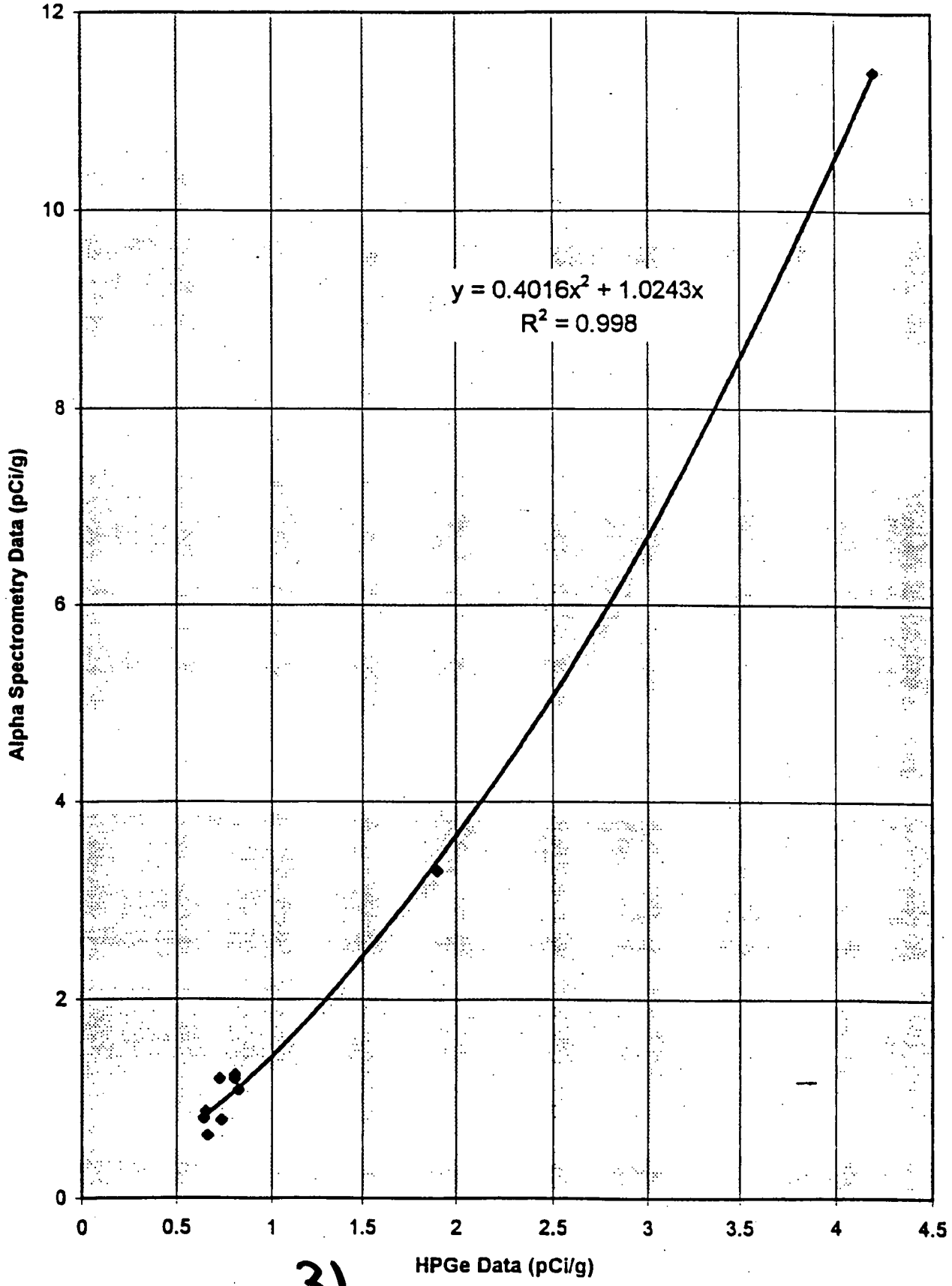
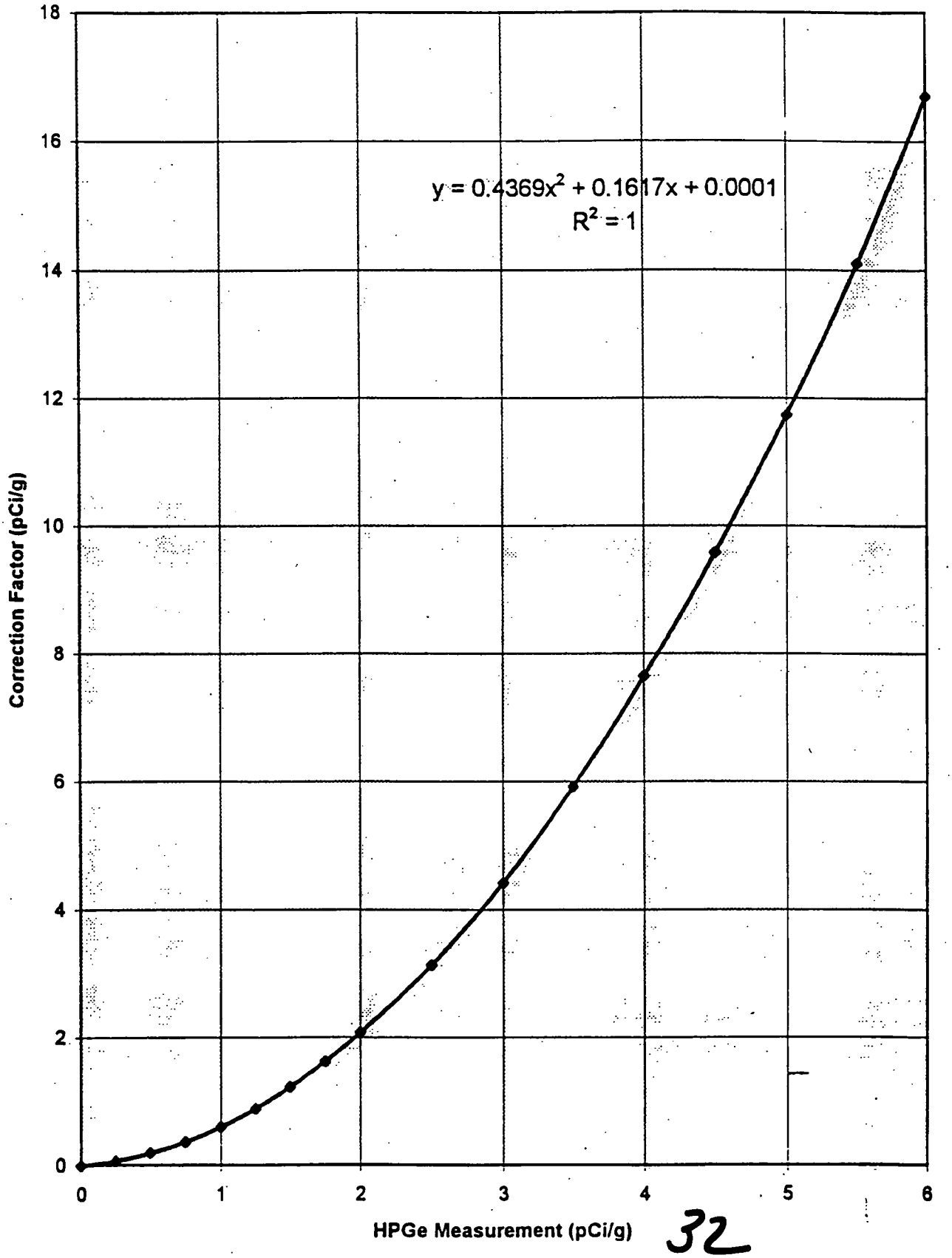


Figure 7

Correction Factor as a Function of HPGe Measurement



APPENDIX A

RADIUM-226 RESULTS DETERMINED BY HPGe AND ALPHA SPECTROMETRY

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

					HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht		AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA01-PBC									
PBC-1-1	1	m	PM	24.1	.59	.04				
PBC-1-1	1	m	PM	24.1	.60	.04				
PBC-1-1	.31	m	PM	24.1	.65	.04				
PBC-1-1	.31	m	PM	24.1	.63	.04				
PBC-1-1				24.1			.48	.14	.79	.20
PBC-1-2				23.6			.57	.13	.80	.20
PBC-1-3				20.6			.40	.12	.81	.20
PBC-1-4				20.4			.47	.11	.77	.20
PBC-1-5				24.4			.72	.17	.79	.20
PBC-1-6	*			20.6			.40	.12	.89	.22
PBC-1-7	*			22.1			.49	.11	.91	.22

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* Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

					HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht		AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA02-PBC									
PBC-2-1	1	m	PM	21.9	.67	.04				
PBC-2-1	1	m	PM	21.9	.70	.04				
PBC-2-1	.31	m	PM	21.9	.67	.04				
PBC-2-1	.31	m	PM	21.9	.66	.04				
PBC-2-1				21.9			.68	.16	.65	.12
PBC-2-2				24.2			.68	.16	.68	.12
PBC-2-3				19.1			.51	.15	.60	.11
PBC-2-4				22			.54	.13	.56	.10
PBC-2-5				24.3			.59	.14	.80	.14
PBC-2-6				22.2			.61	.14	.59	.11
PBC-2-7				18.5			.51	.12	.45	.080
PBC-2-8	*			19			.51	.15	.53	.095
PBC-2-9				19			.60	.14	.63	.11
PBC-2-10				30.1			.58	.14	.58	.10
PBC-2-11	*			18.6			.81	.19	.51	.098

* Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

					HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht		AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA03-PBC									
PBC-3-1	1	m	PM	21.2	4.25	.09				
PBC-3-1	1	m	PM	21.2	4.32	.09				
PBC-3-1	.31	m	PM	21.2	4.09	.09				
PBC-3-1	.31	m	PM	21.2	4.30	.09				
PBC-3-1				21.2			12	2.8	8.4	1.4
PBC-3-2				25.9			11	2.5	11	2.6
PBC-3-3				26.1			13	3.0	13	3.0
PBC-3-4				25			25	5.6	15	2.4
PBC-3-5				17.4			20	4.4	23	5.2
PBC-3-6				22			7.1	1.7	14	2.2
PBC-3-7				21.7			24	5.4	25	5.6
PBC-3-8				24.1			22	5.0	23	5.2
PBC-3-9				22			14	3.0	13	3.0
PBC-3-10				17.3			15	3.3	16	3.6
PBC-3-11				18.2			9.5	2.1	7.6	1.2
PBC-3-12				23.1			8.3	1.9	7.4	1.7
PBC-3-13				27.3			5.0	1.1	7.6	1.3
PBC-3-14				28.6			4.8	1.1	4.6	1.00
PBC-3-15	•			24.4			5.4	1.2	5.7	1.3
PBC-3-16	•			21.1			5.1	1.2	4.3	.99

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• Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

					HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht		AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA04-PBC									
PBC-4-1	1	m	PM	27.3	.79	.04				
PBC-4-1	1	m	PM	27.3	.82	.04				
PBC-4-1	.31	m	PM	27.3	.80	.04				
PBC-4-1	.31	m	PM	27.3	.85	.04				
PBC-4-1				27.3			.44	.13	1.00	.25
PBC-4-2 *				24.9			.71	.16	1.2	.28
PBC-4-3				26.3			.67	.15	1.1	.28
PBC-4-4				26.6			.66	.15	.99	.24
PBC-4-5				23.1			.53	.12	.97	.24
PBC-4-6				26.3			.62	.15	.98	.24
PBC-4-7				25.3			.68	.16	1.1	.26
PBC-4-8				29.5			.51	.12	1.00	.25
PBC-4-9				26.7			.52	.12	.96	.23
PBC-4-10				24.6			.50	.12	1.6	.38
PBC-4-11 *				25			.58	.14	.99	.24

* Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

				HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht	AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA05-PBC								
PBC-5-1	1 m	PM	21.8	.72	.04				
PBC-5-1	1 m	PM	21.8	.74	.04				
PBC-5-1	.31 m	PM	21.8	.69	.04				
PBC-5-1	.31 m	PM	21.8	.74	.04				
PBC-5-1			21.8			.60	.14	1.2	.26
PBC-5-2			24			.60	.14	1.2	.27
PBC-5-3			24.9			.55	.13	1.1	.25
PBC-5-4			23.9			.58	.14	1.1	.26
PBC-5-5			25.7			.67	.15	1.2	.28
PBC-5-6			27.8			.45	.11	1.2	.27
PBC-5-7			25.4			.47	.11	1.2	.28
PBC-5-8			22.3			.48	.11	1.1	.25
PBC-5-9			21.5			.60	.14	1.3	.29
PBC-5-10	*		26			.45	.11	1.1	.25
PBC-5-11	*		27.6			.50	.12	1.2	.26

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* Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

					HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht		AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA06-PBC									
PBC-6-1	1	m	AM	26.7	.79	.04				
PBC-6-1	1	m	AM	26.7	.81	.04				
PBC-6-1	1	m	AM	26.7	.80	.04				
PBC-6-1	1	m	AM	26.7	.80	.04				
PBC-6-1	1	m	AM	26.7	.79	.04				
PBC-6-1	1	m	AM	26.7	.79	.04				
PBC-6-1	.31	m	PM	26.7	.80	.04				
PBC-6-1	.31	m	AM	26.7	.79	.04				
PBC-6-1	.31	m	PM	26.7	.81	.04				
PBC-6-1	.31	m	PM	26.7	.82	.04				
PBC-6-1	.31	m	AM	26.7	.79	.04				
PBC-6-1	.31	m	PM	26.7	.80	.04				
PBC-6-1				26.7			.60	.16	1.2	.28
PBC-6-2				27.5			.60	.14	1.3	.28
PBC-6-3				27			.67	.15	1.1	.26
PBC-6-4				24.3			.59	.14	1.2	.26
PBC-6-5				24.7			.70	.16	1.2	.29
PBC-6-6				28.1			.69	.16	1.2	.28
PBC-6-7				26.8			.73	.17	1.1	.26
PBC-6-8				25.3			.70	.16	1.2	.28
PBC-6-9	•			24.1			.56	.13	1.1	.27
PBC-6-10				26.5			.76	.18	.98	.17
PBC-6-11	•			24.4			.57	.13	1.2	.26

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• Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

				HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht	AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA07-PBC								
PBC-7-1	1 m	AM	28.4	1.09	.05				
PBC-7-1	1 m	AM	28.4	.97	.04				
PBC-7-1	.31 m	PM	28.4	.81	.04				
PBC-7-1	.31 m	AM	28.4	.79	.04				
PBC-7-1			28.4			.69	.16	1.2	.30
PBC-7-2			29.5			.78	.18	1.2	.28
PBC-7-3			28.4			.64	.15	1.1	.27
PBC-7-4			26.6			.73	.17	1.3	.30
PBC-7-5			27.5			1.0	.23	1.6	.37
PBC-7-6			27			.79	.18	1.5	.35
PBC-7-7	•		27.2			.87	.20	1.5	.36
PBC-7-8			25			.74	.17	1.3	.31
PBC-7-9			28.7			.61	.14	1.5	.36
PBC-7-10			27			.67	.15	1.1	.26
PBC-7-11			27.7			.68	.16	.91	.23
PBC-7-12			28.5			1.0	.26	1.3	.31
PBC-7-13			28.6			.62	.14	.88	.22
PBC-7-14			23.7			1.3	.29	1.7	.39
PBC-7-15			28.9			.83	.19	.94	.23
PBC-7-16	•		27			.20	.050	1.1	.27

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• Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

					HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht		AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA08-PBC									
PBC-8-1	1	m	AM	29.9	.60	.04				
PBC-8-1	1	m	AM	29.9	.62	.04				
PBC-8-1	.31	m	AM	29.9	.64	.04				
PBC-8-1	.31	m	AM	29.9	.66	.04				
PBC-8-1				29.9			.42	.13	.94	.23
PBC-8-2 *				35.1			.33	.079	.80	.20
PBC-8-3				26.3			.54	.12	.94	.22
PBC-8-4				30.9			.38	.091	.73	.18
PBC-8-5				28.2			.42	.097	.74	.19
PBC-8-6				34			.36	.11	.71	.18
PBC-8-7 *				32.6			.45	.10	.95	.24

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* Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

				HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht	AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA09-PBC								
PBC-9-1	1 m	PM	29.3	.69	.04				
PBC-9-1	1 m	PM	29.3	.69	.04				
PBC-9-1	.31 m	PM	29.3	.71	.04				
PBC-9-1	.31 m	PM	29.3	.75	.04				
PBC-9-1			29.3			.37	.087	.79	.14
PBC-9-2			27.3			.46	.11	.79	.13
PBC-9-3			26.3			.40	.094	.73	.13
PBC-9-4	*		26.3			.37	.086	.65	.12
PBC-9-5			26.4			.43	.099	.69	.12
PBC-9-6			24.8			.42	.097	.84	.15
PBC-9-7	*		25.6			.41	.099	.89	.16

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* Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

				HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht	AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area: AREA10-PBC									
PBC-10-1	1 m	PM	20.8	1.66	.07				
PBC-10-1	1 m	PM	20.8	1.67	.07				
PBC-10-1	.31 m	PM	20.8	1.85	.07				
PBC-10-1	.31 m	PM	20.8	1.90	.07				
PBC-10-1			20.8			3.3	.74	2.8	.65
PBC-10-2			19.1			4.9	1.1	4.7	1.1
PBC-10-3			17.4			6.4	1.4	5.9	1.4
PBC-10-4			18.8			2.1	.46	4.3	1.00
PBC-10-5			21.8			1.9	.42	2.3	.53
PBC-10-6			16.7			3.9	.91	4.6	1.00
PBC-10-7			18.8			5.0	1.1	3.9	.90
PBC-10-8			18.8			2.0	.44	3.0	.68
PBC-10-9			16.8			2.3	.52	4.6	1.00
PBC-10-10 *			20.5			3.4	.77	2.7	.63
PBC-10-11			19.3			3.4	.76	3.1	.73
PBC-10-12			20.4			1.5	.34	1.5	.37
PBC-10-13			16.6			1.4	.32	1.7	.41
PBC-10-14			17.8			1.7	.38	1.7	.40
PBC-10-15			18.4			2.0	.45	2.2	.53
PBC-10-16 *			15.2			6.2	1.4	6.2	1.4

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* Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

					HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht		AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA12-PBC									
PBC-12-1	1	m	AM	22.8	2.09	.06				
PBC-12-1	1	m	AM	22.8	2.17	.06				
PBC-12-1	1	m	AM	22.8	2.15	.06				
PBC-12-1	1	m	PM	22.8	2.13	.06				
PBC-12-1	1	m	PM	22.8	2.07	.06				
PBC-12-1	1	m	PM	22.8	2.14	.06				
PBC-12-1				22.8					5.8	.92
PBC-12-2				18.3					4.9	1.1
PBC-12-3				13.9					10	1.7
PBC-12-4				15.7					11	1.7
PBC-12-5 *				21.1					3.2	.74
PBC-12-6				17.7					8.1	1.3
PBC-12-7				13.8					7.7	1.2
PBC-12-8				10.3					7.1	1.6
PBC-12-9				23.5					5.1	1.2
PBC-12-10				22.1					3.3	.76
PBC-12-11 *				19.4					3.5	.80

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* Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

					HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det	Ht	AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA13-PBC									
PBC-13-1	1	m	PM	19.7	.96	.05				
PBC-13-1	1	m	AM	19.7	1.01	.05				
PBC-13-1	1	m	PM	19.7	.91	.05				
PBC-13-1	1	m	AM	19.7	.89	.05				
PBC-13-1	1	m	PM	19.7	.86	.05				
PBC-13-1	1	m	AM	19.7	1.01	.05				
PBC-13-1				19.7					1.7	.40
PBC-13-2				20.6					1.7	.39
PBC-13-3				16.2					1.3	.31
PBC-13-4				18.1					1.2	.29
PBC-13-5				17.9					1.2	.29
PBC-13-6				23.7					1.7	.40
PBC-13-7	•			16.3					1.6	.38
PBC-13-8				18.1					1.4	.34
PBC-13-9				18.9					1.8	.42
PBC-13-10				23.7					1.7	.40
PBC-13-11	•			14.3					1.5	.37

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• Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

					HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht		AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA14-PBC									
PBC-14-1	1	m	PM	15.1	.74	.04				
PBC-14-1	1	m	PM	15.1	.76	.04				
PBC-14-1	1	m	PM	15.1	.76	.04				
PBC-14-1	1	m	AM	15.1	.77	.04				
PBC-14-1	1	m	AM	15.1	.80	.04				
PBC-14-1	1	m	AM	15.1	.82	.04				
PBC-14-1	•			15.1					1.5	.36
PBC-14-2				12.9					1.00	.25
PBC-14-3				14.6					1.2	.30
PBC-14-4				14.1					1.5	.35
PBC-14-5				13					1.1	.27
PBC-14-6				13.5					1.1	.26
PBC-14-7				13.8					1.4	.34
PBC-14-8				15.7					1.2	.29
PBC-14-9				13.6					1.2	.29
PBC-14-10				13					1.2	.30
PBC-14-11	•			16					1.3	.32

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• Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

					HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht		AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA15-PBC									
PBC-15-1	1	m	PM	23	.78	.04				
PBC-15-1	1	m	AM	23	.78	.04				
PBC-15-1	1	m	AM	23	.78	.04				
PBC-15-1	1	m	PM	23	.76	.04				
PBC-15-1	1	m	PM	23	.79	.04				
PBC-15-1				23					1.3	.30
PBC-15-2				17.5					1.3	.32
PBC-15-3				16.3					2.6	.42
PBC-15-4	•			18.8					1.3	.22
PBC-15-5				20.2					1.2	.29
PBC-15-6				16.2					2.8	.46
PBC-15-7				13.1					1.1	.28
PBC-15-8				17.9					1.2	.21
PBC-15-9				22.4					1.4	.24
PBC-15-10				14.8					1.1	.27
PBC-15-11	•			17.9					1.4	.33

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• Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

				HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht	AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA16-PBC								
PBC-16-1	1 m	AM	12.1	5.02	.09				
PBC-16-1	1 m	AM	12.1	5.09	.09				
PBC-16-1	1 m	PM	12.1	5.12	.08				
PBC-16-1	1 m	AM	12.1	5.13	.09				
PBC-16-1	1 m	PM	12.1	5.19	.09				
PBC-16-1			12.1					7.7	1.8
PBC-16-2			12.9					9.7	2.2
PBC-16-3			10.6					27	6.1
PBC-16-4			12.9					29	6.4
PBC-16-5			17.6					23	5.1
PBC-16-6			18.7					25	5.6
PBC-16-7			16.1					3.0	.70
PBC-16-8			13.8					14	3.3
PBC-16-9			21.2					16	3.6
PBC-16-10 *			12.5					12	2.7
PBC-16-11			13.2					16	3.5
PBC-16-12			15.4					11	2.4
PBC-16-13			12.1					17	3.8
PBC-16-14			24					15	3.4
PBC-16-15			18					50	11.0
PBC-16-16 *			16.2					11	2.5

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* Duplicates

APPENDIX 1 - RADIUM-226 RESULTS DETERMINED BY HPGE AND ALPHA

					HPGE (pCi/g)		ALPHA (pCi/g)			
Sample Id	Det Ht		AM PM	Moisture %	Result	TPU	Original Result	Original TPU	Total Dissolution Result	Total Dissolution TPU
Area:	AREA17-PBC									
PBC-17-1	1	m	AM	21.2	3.81	.07				
PBC-17-1	1	m	PM	21.2	3.86	.08				
PBC-17-1	1	m	AM	21.2	3.77	.08				
PBC-17-1	1	m	AM	21.2	3.73	.08				
PBC-17-1	1	m	PM	21.2	3.73	.07				
PBC-17-1				21.2					6.7	1.5
PBC-17-2				21.7					14	3.1
PBC-17-3				24.5					14	3.1
PBC-17-4				28.8					11	2.4
PBC-17-5				21.1					16	3.5
PBC-17-6				21.8					18	4.1
PBC-17-7				15.4					13	2.9
PBC-17-8				19.9					2.3	.54
PBC-17-9				19.8					1.2	.29
PBC-17-10				18.9					4.4	.99
PBC-17-11				17.6					7.6	1.7
PBC-17-12				17.5					10.0	2.3
PBC-17-13				25.4					14	3.2
PBC-17-14				21.6					12	2.8
PBC-17-15 *				25					20	4.5
PBC-17-16 *				27.4					22	4.9

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* Duplicates