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# DRAFT
# FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
# FERNALD, OHIO

# RTRAK APPLICABILITY MEASUREMENTS IN LOCATIONS OF ELEVATED RADIONUCLIDE CONCENTRATIONS

## ADDENDUM TO JULY, 1997 RTRAK APPLICABILITY STUDY REPORT

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U.S. DEPARTMENT OF ENERGY
FERNALD AREA OFFICE

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## LIST OF ACRONYMS AND ABBREVIATIONS

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| | |
|---|---|
| DBA | drum baling area |
| FEMP | Fernald Environmental Management Project |
| FRL | final remediation level |
| HPGe | high purity germanium |
| mph | miles per hour |
| pCi/g | picocuries per gram |
| RTRAK | Radiation Tracking System |
| sec | seconds |
| USID | Uranium in Soils Demonstration |
| WAC | waste acceptance criteria |

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## INTRODUCTION

A report entitled "RTRAK Applicability Study" was issued in July, 1997 to address the accuracy, precision, and applications of the Radiation Tracking System (RTRAK) based on data collected in two study areas on the Fernald Environmental Management Project (FEMP) site. The results of the RTRAK Applicability Study were adequate to assess the quality of data generated by the RTRAK for areas in which analyte concentrations are near the Final Remediation Levels (FRLs). However, the report noted that additional data were needed for areas with uranium concentrations approaching or exceeding the Waste Acceptance Criteria (WAC) limit and in locations in which radium and thorium were significantly elevated above background. In addition, it has recently become clear that more specific guidance on the use of the RTRAK for routine data collection is needed.

This report describes studies that were conducted to extend the applicability study to support the use of the RTRAK for WAC screening. In addition, the results of this study and those contained in July 1997 report have been used to develop specific interim guidance for use of the RTRAK.

## STUDY DESIGN

RTRAK measurements were conducted in a location known as the Drum Baling Area (DBA). Past surveys in this area revealed that elevated uranium, radium-226, and thorium-232 activities could be expected. Repeated profile measurements were performed to gain a measure of the method precision (total system precision, not just precision based upon counting statistics), using three combinations of acquisition time and travel speed: 2 sec/2 mph, 4 sec/1 mph, and 8 sec/0.5 mph. The profile paths are shown in Figures 1 through 3. In addition, static RTRAK measurements and high purity germanium (HPGe) measurements were performed at three specific locations within the DBA. The static measurements were made to provide a measure of the accuracy of the RTRAK at higher analyte concentrations. The static data were collected as several series of short measurements which had individual acquisition times of 2 and 8 seconds. The total acquisition period for each series of measurements was 300 seconds (summing a series of individual 2 or 8 second acquisition times for a total of 300 seconds is equivalent to a single 300 second count time).

A description of the RTRAK system and the underlying theory, its operation, and further details of data collection and processing are provided in the July 1997 report.

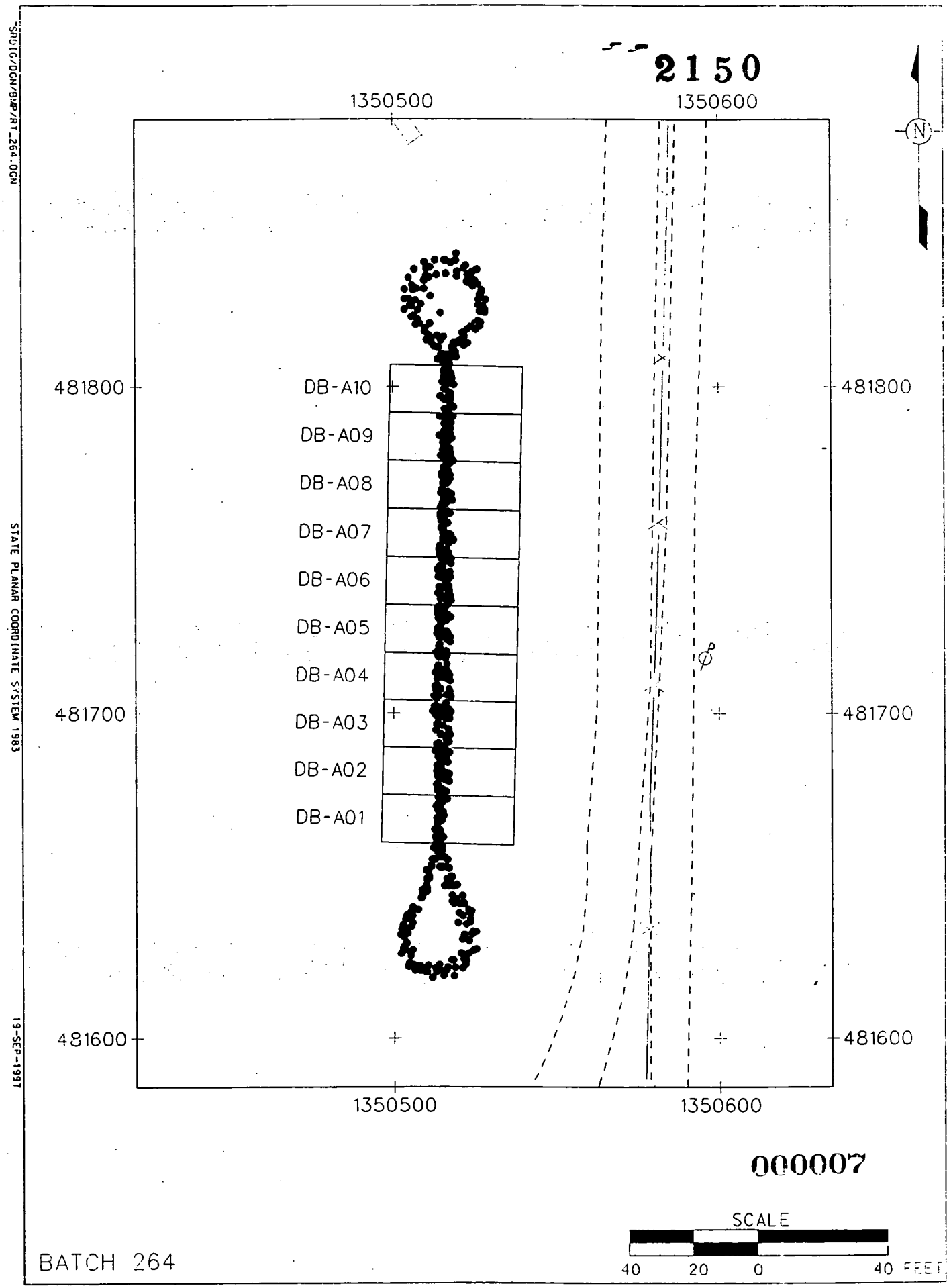



FIGURE 1. CONFIGURATION AND MEASUREMENTS IN PROFILE SEGMENTS FOR DRUM BALING AREA - 2 M.P.H./ 2 SEC. ACQUISITION

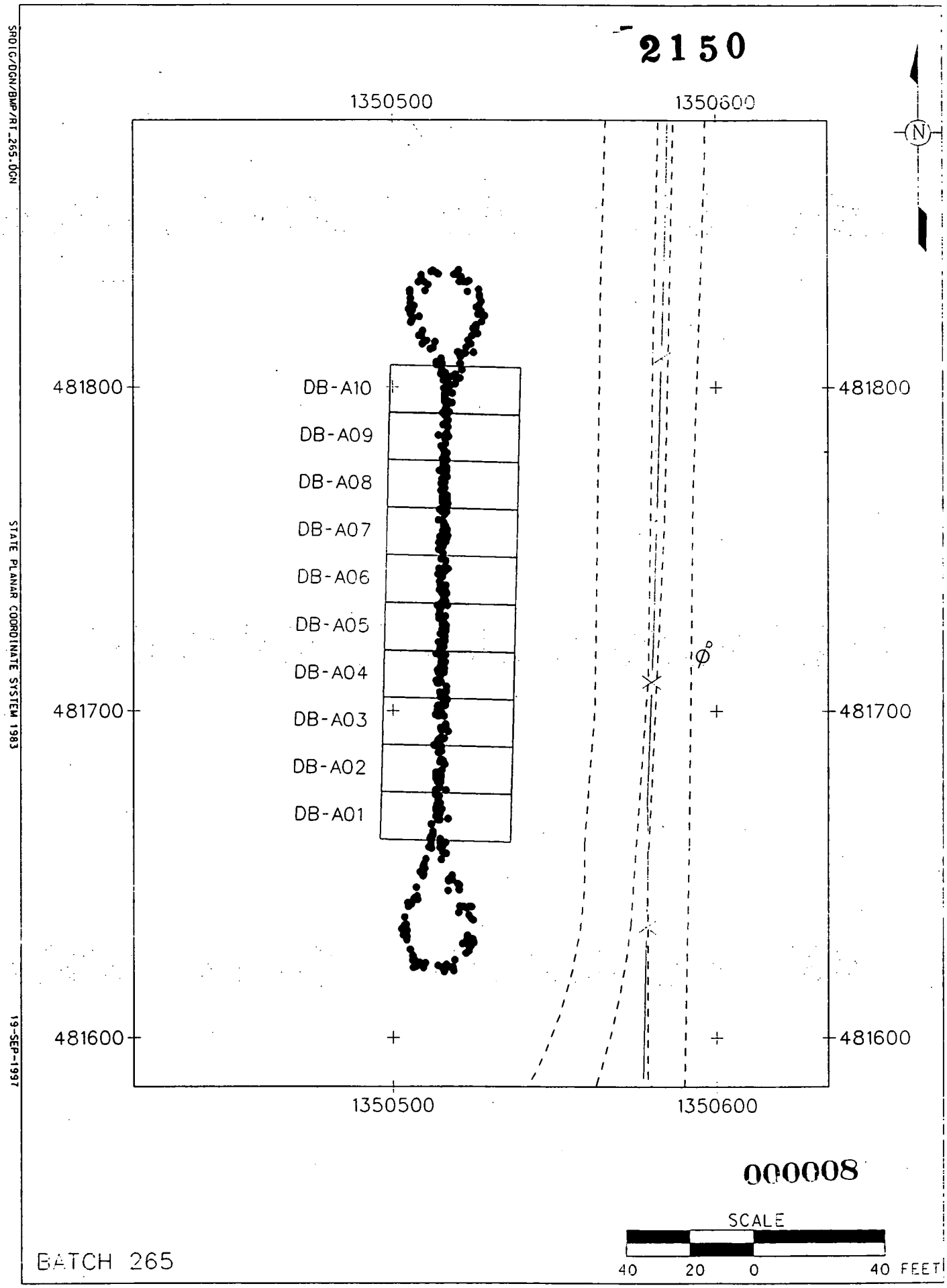
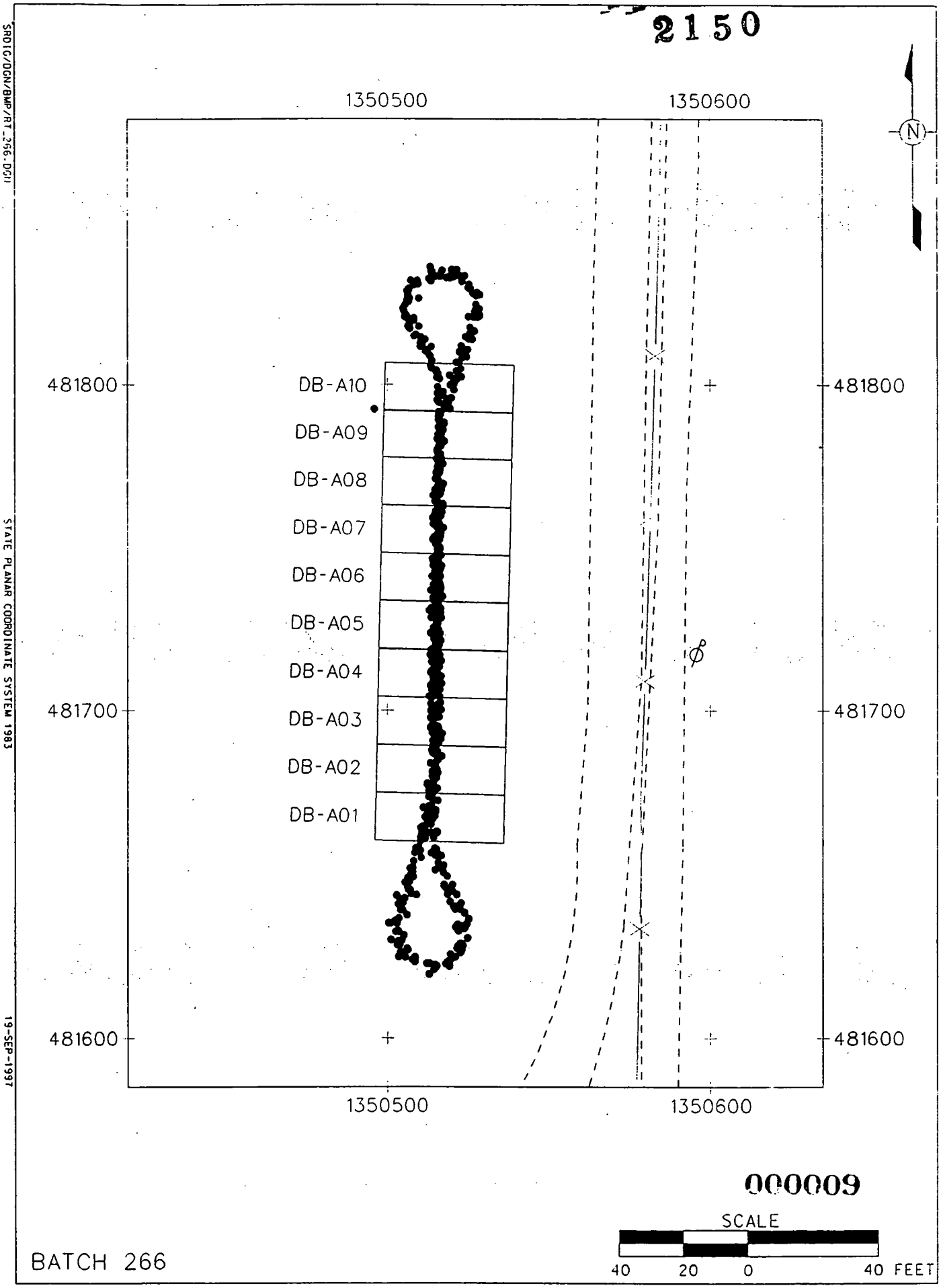



FIGURE 2. CONFIGURATION AND MEASUREMENTS IN PROFILE SEGMENTS FOR DRUM BALING AREA - 0.5 M.P.H./ 8 SEC. ACQUISITION






SR01G/DGN/BMP/RT_266.DGN
STATE PLANAR COORDINATE SYSTEM 1983
19-SEP-1997

FIGURE 3. CONFIGURATION AND MEASUREMENTS IN PROFILE SEGMENTS FOR DRUM BALING AREA - 1 M.P.H./ 4 SEC. ACQUISITION

## CONTRIBUTIONS TO PRECISION

There are three primary factors contributing to the precision of the repeated profile measurements: (1) uncertainties in the measurement technique (also called instrument uncertainty), (2) counting uncertainty associated with counts from the analyte of interest, the background region of interest, and interfering gamma rays, and (3) analyte heterogeneity within the study area. The instrument uncertainties will remain unchanged from those observed for the Uranium in Soils Integrated Demonstration (USID) and South Field studies reported in the July, 1997 RTRAK Applicability Study, but the other two factors are likely to have an impact on the total observed uncertainty of measurements made in the DBA.

As a rule, the counting uncertainty will increase for all analytes of interest as their concentrations increase, because the total number of counts in the detector response peaks of the gamma photon spectrum also increase. However, unless the counts in the background regions of the gamma photon spectrum increase much more rapidly than the peak counts, the percent (of total system uncertainty) of the counting uncertainty will decrease with increasing analyte concentration. This will always be the case for thorium-232 at the FEMP, because there are no significant gamma rays with energies higher than those used to quantify the thorium. The backgrounds for radium-226 will be elevated in the presence of elevated thorium-232. Uranium-238 will be affected by both elevated radium and thorium. Both the thorium-232 and radium-226 contribute to the Compton continuum component of the uranium background and peaks from these two nuclides interfere in regions used to quantify the uranium. Consequently, the uranium-238 measurements in the DBA would be expected to have poorer precision than was observed for either the USID Area of the South Field because of the higher thorium and radium concentrations present in the soils there. The counting uncertainty can be readily calculated from the data collected during RTRAK measurements.

Analyte heterogeneity in the study area is a component of the total uncertainty for uranium-238, thorium-232 and radium-226. However, this uncertainty factor is present as an artifact of the study design and does not contribute to the analytical uncertainty of RTRAK results. For the repeated profile measurements, the heterogeneity contributes to the overall uncertainty because the study design requires that the RTRAK repeatedly traverse the same path. Activity concentrations and standard deviations are calculated on the basis of a series of measurements within a specified segment along that path. During the repeated passes, there is no practical way to control the RTRAK such that all of the

measurements within a segment are collected at exactly the same location. Consequently, each measurement will be at a slightly different location. In areas that are relatively homogeneous, this will have no impact on the observed precision. However, if there is significant heterogeneity in the study area, each measurement may vary because of the variation in the measurement location. During normal operational use, a single location is measured only one time, so the data are not affected by a failure to exactly reproduce the location.

## DATA PRESENTATION AND DISCUSSION

### OVERVIEW OF REPEATED PROFILE DATA

#### Uranium-238

The uranium-238 means, standard deviations, and percent standard deviations (standard deviation as a percentage of the mean) for each of the segments in the DBA are presented in Appendix A, Table A-1, and in Figures A-1 through A-3. The data in Table A-1 are presented as a function of RTRAK operating speed and data acquisition time. These data are summarized in Table 1. The summary results for the USID and South Field areas previously reported in the July 1997 report are included in Table 1 for comparison. Table 1 also lists delta factors for each parameter. These are calculated by dividing the largest positive value of a parameter for any segment by the smallest positive value. The delta factors represent the range of the data. The uranium concentrations within the DBA segments are significantly higher than for the other locations; by factors of approximately 20 and 12 for the South Field and the USID areas, respectively. Both the segment means and the associated standard deviations vary significantly, with delta factors for the means of approximately 5 and as high as approximately 7 for the standard deviations. Mean concentrations exceed 300 pCi/g for some segments. The highest uranium-238 concentrations are in segments DB-A01, DB-A02, DB-A04 and DB-A05.

The maximum standard deviations for the individual segments were 200, 175, and 179 pCi/g , respectively, for the 2, 4, and 8 sec acquisition times (Table A-1). Average standard deviations (Table 1) for the segments are 90.14, 87.83 and 69.83 for the 2, 4, and 8 second acquisition times, respectively. These are higher than those observed for the USID and South Field areas, but this is partly reflective of 1) the higher concentrations of analytes present which result in a higher counting uncertainty and 2) heterogeneity within the DBA. However, the percent standard deviations are significantly smaller in the DBA than those observed for the USID and South Field areas (Table 1); this reflects the fact that the instrument error remains relatively constant regardless of the analyte

# TABLE 1

## SUMMARY OF URANIUM-238 INFORMATION FOR USID, SOUTH FIELD, AND DRUM BALING AREAS

| Operating Conditions | Area | Isotope | Avg. Segment Means (pCi/g) | Delta Factor for Segment Means | Avg. Segment Sds (pCi/g) | Delta Factor for Segment SDs | Avg. Segment % SDs | Delta Factor for Segment % SDs |
|---|---|---|---|---|---|---|---|---|
| 2 mph/2 sec | USID | U-238 | 16.73 | 3.38 | 25.82 | 1.35 | 171.11 | 3.08 |
| 0.5 mph/2 sec | USID | U-238 | 14.38 | 3.88 | 26.66 | 1.38 | 217.22 | 3.84 |
| 0.5 mph/8 sec | USID | U-238 | 17.16 | 2.59 | 14.10 | 1.28 | 87.65 | 2.69 |
| 2 mph/2 sec | SF | U-238 | 9.88 | 25.90 | 27.28 | 2.32 | 474.14 | 18.96 |
| 1 mph/4 sec | SF | U-238 | 10.57 | 11.23 | 20.19 | 2.78 | 277.88 | 26.37 |
| 0.5 mph/8 sec | SF | U-238 | 9.71 | 14.23 | 14.29 | 3.84 | 285.78 | 131.70 |
| 2 mph/2 sec | DBA | U-238 | 203.33 | 5.08 | 90.14 | 3.95 | 52.88 | 2.80 |
| 1 mph/4 sec | DBA | U-238 | 206.12 | 5.03 | 87.83 | 4.82 | 47.08 | 3.08 |
| 0.5 mph/8 sec | DBA | U-238 | 209.04 | 5.08 | 69.83 | 6.85 | 38.28 | 5.65 |

concentration, and the relative counting uncertainty decreases with increased concentration. The heterogeneity of the uranium-238 in the soil is greater for the DBA than the other two areas and this contributes to the overall uncertainty, but this contribution is smaller than the increase in the uranium-238 concentration. The uncertainties associated with the uranium-238 results are discussed quantitatively below.

Thorium-232

The thorium-232 means, standard deviations, and percent standard deviations for the DBA are presented in Appendix A, Table A-2 and Figures A-4 through A-6. The data in Table A-2 are presented as a function of RTRAK operating speed and data acquisition time. These data are summarized in Table 2. The summary results for the USID and South Field areas previously reported in the July 1997 report are included here also for comparison. Included in Table 2 are delta factors for each parameter. These are calculated by dividing the largest positive value of a parameter for any segment by the smallest positive value. The delta factors represent the range of the data.

The average segment mean thorium-232 concentration (approximately 3.8 pCi/g) across the DBA profile is approximately a factor of four higher than those observed for the other two study areas (Table 2). For the individual segments, the highest observed concentrations in the DBA are 6.35, 7.98, and 6.83 pCi/g, respectively, for the 2, 4, and 8 sec acquisition times. These maxima were observed for segment DB-A09. Segment DB-A10 had comparable concentrations of approximately 6 pCi/g for all acquisition times. Across the segments, the concentrations varied significantly, with delta factors of approximately 3.

The thorium-232 standard deviations for the DBA measurements are higher than those for the other two study areas, and the percent standard deviations are smaller than those observed for the other two areas. As was the case for the uranium-238, the larger standard deviations reflect the higher analyte concentrations and the heterogeneity of the thorium in the soil. Across the DBA, the average segment standard deviations are 1.10, 1.14, and 0.78 pCi/g for the 2, 4, and 8 sec acquisition times, respectively, and the corresponding delta factors 4.38, 6.11, and 3.93. The percent standard deviations are approximately 29, 28, and 21 percent for 2, 4, and 8 sec acquisition times, respectively, with delta factors of 2.1, 2.1, and 2.7. The thorium-232 uncertainties are discussed quantitatively below.

## TABLE 2

## SUMMARY OF THORIUM-232 INFORMATION FOR USID, SOUTH FIELD, AND DRUM BALING AREAS

| Operating Conditions | Area | Isotope | Avg. Segment Means (pCi/g) | Delta Factor for Segment Means | Avg. Segment SDs (pCi/g) | Delta Factor for Segment SDs | Avg. Segment % SDs | Delta Factor for Segment % SDs |
|---|---|---|---|---|---|---|---|---|
| 2 mph/2 sec | USID | TH-232 | 0.75 | 2.48 | 0.35 | 1.31 | 48.88 | 2.32 |
| 0.5 mph/2 sec | USID | TH-232 | 0.74 | 1.91 | 0.36 | 1.29 | 49.58 | 1.97 |
| 0.5 mph/8 sec | USID | TH-232 | 0.75 | 1.58 | 0.19 | 1.56 | 25.95 | 2.23 |
| 2 mph/2 sec | SF | TH-232 | 0.82 | 5.62 | 0.39 | 3.62 | 49.54 | 2.40 |
| 1 mph/4 sec | SF | TH-232 | 0.86 | 8.54 | 0.30 | 6.42 | 37.58 | 4.27 |
| 0.5 mph/8 sec | SF | TH-232 | 0.83 | 5.31 | 0.22 | 5.55 | 26.13 | 3.16 |
| 2 mph/2 sec | DBA | TH-232 | 3.76 | 3.25 | 1.10 | 4.38 | 29.38 | 2.08 |
| 1 mph/4 sec | DBA | TH-232 | 3.89 | 3.61 | 1.14 | 6.11 | 28.33 | 2.11 |
| 0.5 mph/8 sec | DBA | TH-232 | 3.83 | 2.82 | 0.78 | 3.93 | 20.55 | 2.72 |

Radium-226

The radium-226 means, standard deviations, and percent standard deviations are presented in Table A-3 and Figures A-7 through A-9. The data in Table A-3 are presented as a function of RTRAK operating speed and data acquisition time. These data are summarized in Table 3. The summary results for the USID and South Field areas previously presented in the July 1997 RTRAK report are included here also for comparison. Included in Table 3 are delta factors for each parameter. These are calculated by dividing the largest positive value of a parameter for any segment by the smallest positive value. The delta factors represent the range of the data.

The average segment mean concentrations for radium-226 across the full DBA profile are greater by a factor of 10 than those for the USID area and more than a factor of 6 than those for the South Field. The average DBA segment means are 8.68, 8.38, and 8.46 pCi/g with large delta factors of 8.3, 7.1, and 8.9, respectively, for the 2, 4, and 8 sec acquisition times. For the individual segments, the highest segment means are near 17 pCi/g for segments DB-A01 and DB-A04, although DB-A02 and DB-A05 are also elevated, with concentrations exceeding 10 pCi/g. These are the same segments that have the highest uranium-238 concentrations. The lowest segment means are about 2 pCi/g for DB-A09; this is comparable to some of the segments in the South Field. DB-A09 is one of the segments, however, that has the highest thorium-232 concentrations.

The radium-226 standard deviations for the DBA measurements are much larger than those observed for the other two study areas, although the percent standard deviations are lower. As was the case for uranium-238 and thorium-232, the elevated standard deviation for radium-226 reflects both the heterogeneity of the radium-226 in the DBA and higher radium-226 concentrations. The average profile standard deviations are 3.21, 2.68. And 2.44 pCi/g with delta factors of 4.6, 4.8, and 6.7, respectively, for 2, 4, and 8 sec acquisition times. The percent standard deviations are approximately 49, 38, and 35 percent with delta factors of 4.7, 3.1, and 4.4, respectively, for the 2, 4, and 8 sec acquisition times. The radium-226 uncertainties are discussed quantitatively below.

Gross Counts

The means, standard deviations, and percent standard deviations for the DBA gross count RTRAK data are presented in Table A-4 and Figures A-10 through A-12. The data in Table A-3 are presented as a function of RTRAK operating speed and data acquisition time. These data are summarized in Table 4.

## TABLE 3
## SUMMARY OF RADIUM-226 INFORMATION
## FOR USID, SOUTH FIELD, AND DRUM BALING AREAS

| Operating Conditions | Area | Isotope | Avg. Segment Means (pCi/g) | Delta Factor for Segment Means | Avg. Segment SDs (pCi/g) | Delta Factor for Segment SDs | Avg. Segment % SDs | Delta Factor for Segment % SDs |
|---|---|---|---|---|---|---|---|---|
| 2 mph/2 sec | USID | RA-232 | 0.77 | 1.57 | 0.77 | 1.40 | 100.43 | 1.24 |
| 0.5 mph/2 sec | USID | RA-232 | 0.79 | 1.52 | 0.80 | 1.37 | 101.65 | 1.35 |
| 0.5 mph/8 sec | USID | RA-232 | 0.81 | 1.24 | 0.40 | 1.33 | 50.16 | 1.60 |
| 2 mph/2 sec | SF | RA-232 | 1.36 | 9.43 | 0.91 | 2.75 | 82.08 | 6.63 |
| 1 mph/4 sec | SF | RA-232 | 1.39 | 8.40 | 0.67 | 5.54 | 57.39 | 11.04 |
| 0.5 mph/8 sec | SF | RA-232 | 1.38 | 13.79 | 0.47 | 7.17 | 40.84 | 14.20 |
| 2 mph/2 sec | DBA | RA-232 | 8.68 | 8.32 | 3.21 | 4.62 | 49.44 | 4.66 |
| 1 mph/4 sec | DBA | RA-232 | 8.38 | 7.06 | 2.68 | 4.77 | 38.28 | 3.13 |
| 0.5 mph/8 sec | DBA | RA-232 | 8.46 | 8.89 | 2.44 | 6.70 | 35.31 | 4.39 |

## TABLE 4

## SUMMARY OF GROSS INFORMATION FOR USID, SOUTH FIELD, AND DRUM BALING AREAS

| Operating Conditions | Area | Isotope | Avg. Segment Means (cps) | Delta Factor for Segment Means | Avg. Segment SDs (cps) | Delta Factor for Segment SDs | Avg. Segment % SDs | Delta Factor for Segment % SDs |
|---|---|---|---|---|---|---|---|---|
| 2 mph/2 sec | USID | Gross Counts | 2937 | 1.53 | 142 | 7.73 | 5.30 | 10.91 |
| 0.5 mph/2 sec | USID | Gross Counts | 2924 | 1.15 | 152 | 8.16 | 5.78 | 11.98 |
| 0.5 mph/8 sec | USID | Gross Counts | 2456 | 1.39 | 176 | 10.75 | 6.36 | 13.84 |
| 2 mph/2 sec | SF | Gross Counts | 2849 | 2.95 | 198 | 23.52 | 6.29 | 14.36 |
| 1 mph/4 sec | SF | Gross Counts | 2893 | 3.07 | 194 | 37.57 | 5.90 | 22.60 |
| 0.5 mph/8 sec | SF | Gross Counts | 2883 | 2.93 | 180 | 45.13 | 5.34 | 21.78 |
| 2 mph/2 sec | DBA | Gross Counts | 15666 | 2.60 | 2147 | 9.41 | 13.31 | 4.97 |
| 1 mph/4 sec | DBA | Gross Counts | 15796 | 2.59 | 2420 | 8.88 | 15.02 | 4.97 |
| 0.5 mph/8 sec | DBA | Gross Counts | 15703 | 2.47 | 2298 | 11.83 | 14.48 | 6.47 |

The summary results for the USID and South Field areas previously presented in the July 1997 report are included here also for comparison. Included in Table 4 are delta factors for each parameter. These are calculated by dividing the largest positive value of a parameter for any segment by the smallest positive value. The delta factors represent the range of the data.

The average gross counts per second for the segment means across the full DBA profile are more than a factor of 5 larger than those for the other study areas. This is consistent with the higher concentrations observed for the uranium-238, thorium-232, and radium-226. The average segment means are 15666, 15796, and 15703 cps with delta factors of 2.6. 2.6, and 2.5, respectively, for 2, 4, and 8 sec acquisition times. Four of the individual segments have gross counts results approximately a factor of two higher than the others: DB-A01, DB-A02, DB-A04, and DB-A05. These are the same segments that have elevated concentrations of uranium-238 and radium-226. The segment with the lowest gross counts is DB-A07; this segment has the lowest concentrations of uranium-238 and thorium-232 and a lower than average radium-226 concentration. The gross counts results are consistent with the analyte-specific data previously discussed in this report.

The average segment standard deviations and percent standard deviations for the DBA are larger than those observed for the USID and South Field areas. This is not the pattern seen for the analyte-specific data where the DBA standard deviations are larger than those for the other two study areas, but the percent standard deviations are smaller. This difference is likely a consequence of the large analyte heterogeneity in the DBA. Because the counting uncertainties for the gross counts data are only a few percent of the mean, even for analyte concentrations near background, significant increases in gross counts do not result in a decrease in a percentage decrease in the counting uncertainty that compensates for the increased uncertainty due to increased analyte heterogeneity in the DBA. Consequently, the heterogeneity greatly dominates the observed uncertainty for the gross counts repeated profile data. The average segment standard deviations are 2147, 2420, and 2298, with delta factors of 9.4, 8.9, and 11.8, respectively for the 2, 4, and 8 sec acquisition times. The percent standard deviations are 13.3, 15.0, and 14.5 percent with delta factors of 5.0, 5.0, and 6.5.

## UNCERTAINTY OF REPEATED PROFILE MEASUREMENTS

The observed standard deviations of the repeated profile measurements, a measure of the precision (or uncertainty) of the data, are higher than were predicted in Tables 4-12 through 4-14 of the July 1997

RTRAK Applicability Study report. The expected measurement precision or standard deviation for RTRAK measurements can be described by the relationship:

$$\sigma^2_{estimated} = \sigma^2_{counting} + \sigma^2_{instrument}$$

where:

$\sigma^2_{estimated}$ = The variance of a single measurement or the standard deviation squared of a set of RTRAK measurements.

$\sigma^2_{counting}$ = The squared counting uncertainty. This is obtained by applying standard propagation of error relationships to the uncertainties associated with the raw counting data.

$\sigma^2_{instrument}$ = The squared standard deviation or variance associated with instrument parameters. These were calculated from the data reported in the July 1997 RTRAK Applicability Study Report.

Using this relationship, the expected standard deviation of the repeated profile measurements can be calculated. The results of such calculations for are presented in Tables 5 through 7. The column labeled $\sigma_{observed}$ is the standard deviation for the observed (measured) results of the repeated profiles runs in the DBA. The column labeled $\sigma_{estimated}$ is the standard deviation calculated using the relationship given above. As is clear from the tables, the onserved (measured) standard deviations are all higher than those estimated using the above relationship. This indicates the presence of is an additional significant contributor to the observed standard deviation. As discussed above, this additional factor relates to the heterogeneity of the analyte in the soil of the DBA as well as to the study design which involves making repeated measurements in the same approximate location.

A comparison of data for single passes of the RTRAK along the profile reveals that the analyte concentrations within a segment can vary greatly between multiple passes. This occurs because throughout much of the DBA, the analyte concentrations are highly heterogeneous over distances much smaller than the dimensions of the profile segments. While the RTRAK data was being collected, the field crew observed that dose rate values as measured using portable survey instruments would change significantly with changes in the instrument location of only a few feet. It is not practical to exactly duplicate the position of the RTRAK for each of the profile passes, so the measured results exhibit the effects of the heterogeneity and the inexact placement. Heterogeneity, then, is not a true contributor to the precision of RTRAK measurements are collected during normal field use, but rather is seen in these data as an artifact of the repeated profile design. During normal use of the RTRAK, only single

measurements are collected for given location and the measurements are used individually or aggregated to cover an extended area. The values in the $\sigma_{estimated}$ columns of Tables 5 through 7 represent the precision that would have been measured in normal use.

The counting uncertainty for a specific isotope measurement is a function of both the number of counts that are related to unscattered gamma rays detected and to the number of counts that contribute to the gamma photon spectrum background and interferences. Thus, the counting uncertainty for any specific isotope is dependent upon the concentrations of the isotope in question along with the concentrations of any other gamma emitting isotopes that are present. In practice, this means that it is not possible to make a highly accurate a priori estimate of the counting uncertainty for an analyte at a given concentration. The counting uncertainty can only be determined a posteriori or it can be estimated by making assumptions of the concentrations at which other interfering analytes are present, as is done below.

Table 8 presents estimated counting uncertainties and total uncertainties (standard deviations) for analyte concentrations near the FRL, hot spot criteria, and WAC (uranium-238 only) for 2, 4, and 8 sec acquisition times. These uncertainties are calculated using the relationship given above and the $\sigma_{instrument}$ values presented in Tables 5 through 7; for convenience, these values are repeated in Table 8. The following assumptions are made:

1. Gamma photon spectrum background at the FRL and at hot spot limits that is unrelated to the presence of other gamma emitting nuclides is constant and is taken from the spectrum backgrounds measured in the USID area.

2. Instrument-related uncertainties ($\sigma_{instrument}$) were obtained from the repeated profile measurements reported in the July 1997 RTRAK Applicability Study report.

3. For measurements near the FRLs, it is assumed that the concentrations of analytes that interfere with other analytes (i.e., thorium-232 and radium-226 interfering with uranium-238) or contribute to their background are equal in concentration to their corresponding FRL.

4. For measurements near the hot spot criterion (3xFRL) it is assumed that the concentrations of analytes that interfere with other analytes or contribute to their background, are equal in concentration to their corresponding FRL.

**TABLE 5**
**SUMMARY OF UNCERTAINTY CONTRIBUTORS - 2 SEC ACQUISITION TIME**

| | URANIUM-238 (pCi/g) | | | | | THORIUM-232 (pCi/g) | | | | | RADIUM-226 (pCi/g) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | $\sigma_{OBSERVED}$ | $\sigma_{INSTRUMENT}$ | $\sigma_{COUNTING}$ | $\sigma_{ESTIMATED}$ | Average | $\sigma_{OBSERVED}$ | $\sigma_{INSTRUMENT}$ | $\sigma_{COUNTING}$ | $\sigma_{ESTIMATED}$ | Average | $\sigma_{OBSERVED}$ | $\sigma_{INSTRUMENT}$ | $\sigma_{COUNTING}$ | $\sigma_{ESTIMATED}$ |
| DB-A01 | 373.99 | 103.33 | 13.86 | 73.88 | 75.17 | 3.21 | 0.99 | 0.27 | 0.59 | 0.64 | 17.15 | 4.02 | 0.37 | 2.68 | 2.71 |
| DB-A02 | 328.24 | 200.19 | 13.86 | 62.39 | 63.91 | 2.99 | 1.04 | 0.27 | 0.53 | 0.59 | 13.45 | 7.20 | 0.37 | 2.20 | 2.23 |
| DB-A03 | 158.73 | 88.17 | 13.86 | 50.11 | 51.99 | 2.81 | 0.82 | 0.27 | 0.45 | 0.53 | 8.70 | 3.54 | 0.37 | 1.81 | 1.84 |
| DB-A04 | 321.44 | 83.19 | 13.86 | 65.39 | 66.84 | 3.98 | 0.86 | 0.27 | 0.58 | 0.63 | 16.72 | 3.69 | 0.37 | 2.42 | 2.45 |
| DB-A05 | 351.19 | 95.90 | 13.86 | 65.13 | 66.59 | 3.79 | 1.07 | 0.27 | 0.57 | 0.63 | 14.58 | 3.96 | 0.37 | 2.33 | 2.36 |
| DB-A06 | 119.72 | 68.41 | 13.86 | 43.08 | 45.26 | 2.31 | 0.73 | 0.27 | 0.41 | 0.49 | 5.05 | 2.24 | 0.37 | 1.44 | 1.49 |
| DB-A07 | 73.67 | 50.69 | 13.86 | 37.56 | 40.04 | 2.10 | 0.60 | 0.27 | 0.39 | 0.47 | 3.10 | 1.56 | 0.37 | 1.19 | 1.25 |
| DB-A08 | 85.37 | 57.00 | 13.86 | 42.29 | 44.50 | 3.82 | 1.22 | 0.27 | 0.52 | 0.58 | 2.44 | 1.79 | 0.37 | 1.30 | 1.35 |
| DB-A09 | 131.65 | 95.51 | 13.86 | 50.14 | 52.02 | 6.83 | 2.63 | 0.27 | 0.65 | 0.70 | 2.06 | 2.12 | 0.37 | 1.52 | 1.57 |
| DB-A10 | 89.30 | 58.96 | 13.86 | 47.93 | 49.89 | 5.77 | 1.07 | 0.27 | 0.63 | 0.68 | 3.57 | 2.02 | 0.37 | 1.54 | 1.59 |
| Average | 203.33 | 90.14 | 13.86 | 53.79 | 55.62 | 3.76 | 1.10 | 0.27 | 0.53 | 0.60 | 8.68 | 3.21 | 0.37 | 1.84 | 1.88 |



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**TABLE 6**
**SUMMARY OF UNCERTAINTY CONTRIBUTORS - 4 SEC ACQUISITION TIME**

| | URANIUM-238 (pCi/g) | | | | | THORIUM-232 (pCi/g) | | | | | RADIUM-226 (pCi/g) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | $\sigma_{OBSERVED}$ | $\sigma_{INSTRUMENT}$ | $\sigma_{COUNTING}$ | $\sigma_{ESTIMATED}$ | Average | $\sigma_{OBSERVED}$ | $\sigma_{INSTRUMENT}$ | $\sigma_{COUNTING}$ | $\sigma_{ESTIMATED}$ | Average | $\sigma_{OBSERVED}$ | $\sigma_{INSTRUMENT}$ | $\sigma_{COUNTING}$ | $\sigma_{ESTIMATED}$ |
| DB-A01 | 383.07 | 111.31 | 12.00 | 51.88 | 53.25 | 3.02 | 1.16 | 0.25 | 0.41 | 0.48 | 16.23 | 3.22 | 0.39 | 1.85 | 1.85 |
| DB-A02 | 293.82 | 175.44 | 12.00 | 42.55 | 44.21 | 2.99 | 1.06 | 0.25 | 0.36 | 0.44 | 11.45 | 5.10 | 0.39 | 1.50 | 1.51 |
| DB-A03 | 174.35 | 76.65 | 12.00 | 36.01 | 37.96 | 2.76 | 0.73 | 0.25 | 0.32 | 0.40 | 9.19 | 3.36 | 0.39 | 1.30 | 1.30 |
| DB-A04 | 310.24 | 77.56 | 12.00 | 46.39 | 47.92 | 3.69 | 0.71 | 0.25 | 0.41 | 0.48 | 15.91 | 3.20 | 0.39 | 1.71 | 1.72 |
| DB-A05 | 317.46 | 92.71 | 12.00 | 45.82 | 47.36 | 3.85 | 0.79 | 0.25 | 0.41 | 0.47 | 14.08 | 4.09 | 0.39 | 1.66 | 1.67 |
| DB-A06 | 152.15 | 86.60 | 12.00 | 31.39 | 33.60 | 2.35 | 0.60 | 0.25 | 0.29 | 0.38 | 5.67 | 2.69 | 0.39 | 1.05 | 1.06 |
| DB-A07 | 76.12 | 36.41 | 12.00 | 26.32 | 28.93 | 2.21 | 0.53 | 0.25 | 0.27 | 0.37 | 3.19 | 1.07 | 0.39 | 0.85 | 0.86 |
| DB-A08 | 101.67 | 45.17 | 12.00 | 30.47 | 32.75 | 4.15 | 1.19 | 0.25 | 0.36 | 0.44 | 2.77 | 1.16 | 0.39 | 0.94 | 0.94 |
| DB-A09 | 160.74 | 123.63 | 12.00 | 37.35 | 39.23 | 7.98 | 3.24 | 0.25 | 0.50 | 0.55 | 2.30 | 1.43 | 0.39 | 1.12 | 1.12 |
| DB-A10 | 91.55 | 52.85 | 12.00 | 34.31 | 36.35 | 5.85 | 1.43 | 0.25 | 0.44 | 0.51 | 3.00 | 1.43 | 0.39 | 1.09 | 1.10 |
| Average | 206.12 | 87.83 | 12.00 | 38.25 | 40.16 | 3.89 | 1.14 | 0.25 | 0.38 | 0.45 | 8.38 | 2.68 | 0.39 | 1.31 | 1.31 |

**TABLE 7**
**SUMMARY OF UNCERTAINTY CONTRIBUTORS - 8 SEC ACQUISITION TIME**

| | URANIUM-238 (pCi/g) | | | | | THORIUM-232 (pCi/g) | | | | | RADIUM-226 (pCi/g) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | $\sigma_{OBSERVED}$ | $\sigma_{INSTRUMENT}$ | $\sigma_{COUNTING}$ | $\sigma_{ESTIMATED}$ | Average | $\sigma_{OBSERVED}$ | $\sigma_{INSTRUMENT}$ | $\sigma_{COUNTING}$ | $\sigma_{ESTIMATED}$ | Average | $\sigma_{OBSERVED}$ | $\sigma_{INSTRUMENT}$ | $\sigma_{COUNTING}$ | $\sigma_{ESTIMATED}$ |
| DB-A01 | 422.24 | 85.07 | 8.66 | 36.46 | 37.48 | 3.45 | 0.57 | 0.19 | 0.29 | 0.35 | 17.16 | 2.43 | 0.24 | 1.31 | 1.33 |
| DB-A02 | 314.50 | 179.01 | 8.66 | 30.53 | 31.73 | 2.95 | 0.59 | 0.19 | 0.26 | 0.32 | 12.05 | 5.24 | 0.24 | 1.08 | 1.10 |
| DB-A03 | 177.56 | 58.16 | 8.66 | 26.12 | 27.52 | 2.87 | 0.62 | 0.19 | 0.24 | 0.30 | 9.55 | 3.41 | 0.24 | 0.94 | 0.97 |
| DB-A04 | 338.09 | 39.47 | 8.66 | 32.62 | 33.75 | 3.69 | 0.40 | 0.19 | 0.29 | 0.35 | 15.81 | 2.59 | 0.24 | 1.20 | 1.23 |
| DB-A05 | 322.13 | 97.24 | 8.66 | 31.66 | 32.82 | 3.87 | 0.65 | 0.19 | 0.28 | 0.34 | 14.24 | 4.22 | 0.24 | 1.14 | 1.17 |
| DB-A06 | 126.78 | 61.42 | 8.66 | 21.45 | 23.13 | 2.26 | 0.62 | 0.19 | 0.21 | 0.28 | 5.04 | 2.28 | 0.24 | 0.71 | 0.75 |
| DB-A07 | 86.15 | 26.12 | 8.66 | 18.96 | 20.84 | 2.25 | 0.49 | 0.19 | 0.20 | 0.27 | 3.68 | 0.85 | 0.24 | 0.61 | 0.66 |
| DB-A08 | 101.99 | 36.04 | 8.66 | 21.32 | 23.01 | 4.31 | 1.27 | 0.19 | 0.26 | 0.32 | 2.54 | 0.78 | 0.24 | 0.66 | 0.70 |
| DB-A09 | 112.75 | 57.54 | 8.66 | 24.43 | 25.92 | 6.35 | 1.57 | 0.19 | 0.32 | 0.37 | 1.93 | 1.20 | 0.24 | 0.75 | 0.79 |
| DB-A10 | 88.24 | 58.22 | 8.66 | 24.53 | 26.01 | 6.26 | 1.02 | 0.19 | 0.32 | 0.37 | 2.59 | 1.36 | 0.24 | 0.78 | 0.82 |
| Average | 209.04 | 69.83 | 8.66 | 26.81 | 28.22 | 3.83 | 0.78 | 0.19 | 0.27 | 0.33 | 8.46 | 2.44 | 0.24 | 0.92 | 0.95 |

5. At WAC concentrations of uranium-238, it is assumed that the uranium-238 counting uncertainty is equivalent to the average percent counting uncertainty observed for measurements within the DBA that are at or greater than the WAC. This takes into consideration elevated radium and thorium concentrations that may be present.

Comparison of the estimated standard deviations in Table 8 with those in Tables 4-12 through 4-14 in the July 1997 RTRAK report indicates that no changes have occurred in estimated standard deviations for uranium-238, thorium-232 and radium-226 at their FRL and hot spot concentrations. However, the estimated standard deviations for uranium-238 at WAC concentrations are approximately twice those in the July 1997 report. This reflects the fact that measured data for the DBA allow a more accurate assessment of contributions of interferences from thorium-232 and radium-226 in the standard deviation of uranium at WAC levels.

## ACCURACY

As a check of the accuracy of the RTRAK system at higher analyte concentrations than were reported in the July 1997 RTRAK Applicability Study Report, HPGe measurements and static RTRAK measurements were made at the same location. Two locations were selected during the study planning phase. At each location, both static RTRAK and HPGe measurements were made. Several sets of RTRAK measurements were collected. The acquisition times of the individual RTRAK measurements were either 2 or 8 seconds. For each set of RTRAK measurements, the total acquisition period was 300 seconds. HPGe measurements were 900 seconds and were taken at a 1.0 meter detector height. The results of these measurements are summarized in Table 9.

The July 1997 HPGe comparability report proposed criteria for determining the comparability of sets of data using different analytical techniques. Relative deviations of less than 20% are defined as being very similar, relative deviations greater than 20 % but less than 35% are defined as having acceptable similarity. For the measurement locations reported in Table 6, the relative deviations between the RTRAK and HPGe results are less than 20% (most are 10% or less) for uranium-238 and radium-226 at both locations and for thorium-232 at one of the locations (RBS 3-2); this is defined as very similar results. At the other location (RBS 3-1), the RTRAK thorium-232 result is approximately 33% lower than the HPGe result: this deviation is defined as acceptable. Although all results are defined as having acceptable similarity, the larger deviation for location RBS 3-1 is puzzling in light of the excellent agreement observed for the other results. However, this probably results from the fact that at 1.0 m

# TABLE 8
# ESTIMATED CONTRIBUTORS TO ANALYTE STANDARD DEVIATIONS

| Acq. Time | Limit Type | Uranium-238 (ppm) | | | | Thorium-232 (pCi/g) | | | | Radium-226 (pCi/g) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Limit | $\sigma_{instrument}$ | $\sigma_{counting}$ | $\sigma_{total}$ | Limit (pCi/g) | $\sigma_{instrument}$ | $\sigma_{counting}$ | $\sigma_{total}$ | Limit (pCi/g) | $\sigma_{instrument}$ | $\sigma_{counting}$ | $\sigma_{total}$ |
| 2 sec | FRL | 82 | 42 | 69 | 81 | 1.50 | 0.27 | 0.28 | 0.39 | 1.70 | 0.37 | 0.74 | 0.83 |
| 2 sec | Hot Spot | 246 | 42 | 75 | 86 | 4.50 | 0.27 | 0.42 | 0.50 | 5.10 | 0.37 | 0.93 | 1.00 |
| 2 sec | WAC | 1030 | 42 | 199 | 203 | na | na | na | na | na | na | na | na |
| 4 sec | FRL | 82 | 36 | 51 | 62 | 1.50 | 0.25 | 0.20 | 0.33 | 1.70 | 0.39 | 0.53 | 0.65 |
| 4 sec | Hot Spot | 246 | 36 | 54 | 65 | 4.50 | 0.25 | 0.30 | 0.40 | 5.10 | 0.39 | 0.67 | 0.77 |
| 4 sec | WAC | 1030 | 36 | 143 | 147 | na | na | na | na | na | na | na | na |
| 8 sec | FRL | 82 | 27 | 36 | 45 | 1.50 | 0.19 | 0.19 | 0.30 | 1.70 | 0.24 | 0.38 | 0.53 |
| 8 sec | Hot Spot | 246 | 27 | 39 | 47 | 4.50 | 0.19 | 0.19 | 0.34 | 5.10 | 0.24 | 0.47 | 0.60 |
| 8 sec | WAC | 1030 | 27 | 100 | 104 | na | na | na | na | na | na | na | na |

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**TABLE 9**
**COMPARISON OF CO-LOCATED STATIC RTRAK AND HPGe MEASUREMENTS**

| Data Point | RTRAK Acquisition Time | Uranium-238 (pCi/g) | | | | Thorium-232 (pCi/g) | | | | Radium-226 (pCi/g) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | HPGe | HPGe SD | RTRAK Mean | RTRAK SD of Mean | HPGe | HPGe SD | RTRAK Mean | RTRAK SD of Mean | HPGe | HPGe SD | RTRAK Mean | RTRAK SD of Mean |
| RBS 3-1 | 2 sec | 77.8 | 0.9 | 76.31 | 3.04 | 4.9 | 0.7 | 3.06 | 0.039 | 3.04 | 0.96 | 2.49 | 0.11 |
| RBS 3-1 | 8 sec | 77.8 | 0.55 | 74.05 | 3.31 | 4.9 | 0.7 | 3.13 | 0.038 | 3.04 | 0.96 | 2.77 | 0.12 |
| RBS 3-1 | 2 sec | 111 | 0.69 | 123 | 2.43 | 2.05 | 1.3 | 2.21 | 0.034 | 5.92 | 0.55 | 6.40 | 0.08 |
| RBS 3-1 | 8 sec | 111 | 0.69 | 123 | 3.83 | 2.05 | 1.3 | 2.20 | 0.055 | 5.92 | 0.55 | 6.32 | 0.10 |

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detector height, HPGe has a larger viewing area than the RTRAK, and is thus picking up gamma photons from thorium-232 in higher concentration areas that are not "seen" by the RTRAK. These data provide support for the validity of RTRAK measurements at analyte concentrations higher than those reported in the July 1997 report and indicate that the existing calibration is adequate at these elevated concentrations.

## RTRAK APPLICATIONS AND TRIGGER LEVELS

RTRAK applications were discussed generically in some detail in the July 1997 RTRAK Applicability Study report. The following discussion is more limited and only addresses the concept of "trigger levels" that may be used to identify locations potentially exceeding exceed FRLs, hot spot criteria, or WAC. In use, it is practical to establish "trigger levels." A "trigger level" can be defined as an analyte concentration that, if exceeded by an RTRAK measurement, would require further action. Because every RTRAK measurement will have some corresponding uncertainty, in order to have confidence that a regulatory or operational limit will not be exceeded, trigger levels are typically set below the actual limiting criteria. The acceptable difference between the limiting criterion and the trigger level is a function of the precision of the actual measurement and the confidence level that is chosen for that measurement. Because the precision of a measurement is analyte specific, the trigger level will also be analyte specific. The trigger level can be calculated as:

$$\text{Trigger} = L - k\sigma_{limit}$$

where:

$L$ = the limiting criterion such as the FRL, hot spot criterion, or WAC

$\sigma_{limit}$ = the standard deviation expected for the RTRAK measurement at that limit

$k$ = a statistical factor related to the acceptable confidence level of the measurement. k is equal to 1.96 for a 95% confidence level.

The trigger level must also be greater than both the background concentration of an analyte and its detection limit. For RTRAK measurements, the standard deviations for individual measurements are high (on a relative basis) for concentrations near the FRL and hot spot criteria under current operating conditions. Consequently, it is necessary to aggregate measurements in order to obtain a concentration value that has a standard deviation small enough to allow a reasonable trigger level to be established.

In this case, one practical approach to setting the trigger level is to arbitrarily set a minimum acceptable trigger level as a percentage of the applicable limit. This percentage can be set at any convenient value that is above the detection limit and the analyte background but still maintains acceptable spatial resolution for the measurements. The closer the trigger is to the limit, the greater the number of measurements that must be aggregated and consequently the poorer the spatial resolution of the measurements.

For the purposes of this discussion, the minimum acceptable trigger level is set at 80% of the applicable limit. This is not based on a rigorous, statistical evaluation, but was chosen as a "reasonable" and practical level. Using the uncertainties estimated for individual RTRAK measurements, taken from Table 8, the number of measurements that must be aggregated to achieve the minimum acceptable trigger level were calculated. The number of measurements that must be aggregated were calculated using the following relationship and solving for the number of measurements being aggregated (n):

$$\text{Minimum Acceptable Trigger} = \text{Limit} - k\sigma_{limit}/(n)^{1/2}$$

where:

- $k$ = 1.96 for a 95% confidence level
- $\sigma_{limit}$ = the total standard deviation for an individual measurement at a concentration equal to the applicable limit
- $n$ = the number of measurements that are aggregated

The trigger levels and the number of measurements that must be aggregated to achieve that level are presented in Tables 10 through 12.

## CONCLUSIONS

The data collected in the DBA extends the applicability study to analyte concentrations significantly exceeding those encountered in the USID area and the South Field. Throughout the study area, uranium-238 concentrations exceed the FRL and in numerous locations they exceed WAC. There are segments within the profile for which thorium-232 concentrations are more than 4 times the FRL and for which radium-226 concentrations are greater than 10 times the FRL. While the study was designed with the intent to directly measure the precision of data at the higher analyte concentrations, the high analyte heterogeneity of the soils presented complications. Nonetheless, the data allow the following conclusions to be drawn:

1. The RTRAK system can be used to monitor uranium-238, thorium-232, and radium-226 in soils in areas of elevated analyte concentrations.

2. Analyte heterogeneity should not impact the reliability of RTRAK measurements.

3. The precision of the RTRAK uranium measurements at concentrations near the FRL is not sufficient to allow single measurements to be used for that purpose.

4. The existing RTRAK calibration is adequate to provide results that are in acceptable agreement with HPGe results at analyte concentrations well above the FRL.

5. RTRAK measurement precision can be estimated at concentrations ranging from FRL to WAC levels (for uranium-238).

6. Trigger levels can be set for uranium-238, thorium-232, and radium-226 for FRLs, hot spots, and WAC attainments.

# TABLE 10
# URANIUM-238 RTRAK TRIGGER LEVELS (ppm)

| Application | Limit (ppm) | Min. Acceptable Trigger | 2 Sec Acquisition Time | | 4 Sec Acquisition Time | | 8 Sec Acquisition Time | |
|---|---|---|---|---|---|---|---|---|
| | | | Single Measurement Trigger | No. Aggregated Measurements (Trigger) | Single Measurement Trigger | No. Aggregated Measurements (Trigger) | Single Measurement Trigger | No. Aggregated Measurements (Trigger) |
| FRL | 82 | 65.6 | -76 unacceptable | 94 (65.7) | -40 unacceptable | 56 (65.6) | -6 unacceptable | 29 (65.6) |
| Hot Spot | 246 | 196.8 | 78 unacceptable | 12 (197.4) | 119 unacceptable | 7 (197.9) | 153 unacceptable | 4 (199.5) |
| WAC | 1030 | 824 | 631 unacceptable | 4 (830.7 | 741 unacceptable | 2 (825.6) | 827 unacceptable | 1 (827) |

# TABLE 11
# THORIUM-232 RTRAK TRIGGER LEVELS (pCi/g)

| Application | Limit (ppm) | Min. Acceptable Trigger | 2 Sec/2 Mph | | 4 Sec/2 Mph | | 8 Sec Acquisition Time | |
|---|---|---|---|---|---|---|---|---|
| | | | Single Measurement Trigger | No. Aggregated Measurements (Trigger) | Single Measurement Trigger | No. Aggregated Measurements (Trigger) | Single Measurement Trigger | No. Aggregated Measurements (Trigger) |
| FRL | 1.5 | 1.2 | 0.7 unacceptable | 7 (1.2) | 0.8 unacceptable | 5 (1.2) | 0.9 unacceptable | 4 (1.2) |
| Hot Spot | 4.5 | 3.6 | 3.5 unacceptable | 2 (3.8) | 3.7 unacceptable | 1 (3.7) | 3.8 unacceptable | 1 (3.8) |
| WAC | na | na | na | na | na | na | na | na |

# TABLE 12
# RADIUM-226 RTRAK TRIGGER LEVELS (pCi/g)

| Application | Limit (ppm) | Min. Acceptable Trigger | 2 Sec/2 Mph | | 4 Sec/2 Mph | | 8 Sec Acquisition Time | |
|---|---|---|---|---|---|---|---|---|
| | | | Single Measurement Trigger | No. Aggregated Measurements (Trigger) | Single Measurement Trigger | No. Aggregated Measurements (Trigger) | Single Measurement Trigger | No. Aggregated Measurements (Trigger) |
| FRL | 1.7 | 1.4 | 0.1 unacceptable | 23 (1.4) | 0.4 unacceptable | 14 (1.4) | 0.7 unacceptable | 10 (1.4) |
| Hot Spot | 5.1 | 4.1 | 3.1 unacceptable | 4 (4.1) | 3.6 unacceptable | 3 (4.2) | 3.9 unacceptable | 2 (4.3) |
| WAC | na | na | na | na | na | na | na | na |

# APPENDIX A

**TABLE A-1**
**URANIUM-238 REPEATED PROFILE RUNS IN DRUM BAILING AREA**

| | 2 sec - 2 mph | | | | 4 sec - 1 mph | | | | 8 sec - 0.5 mph | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AREA | No. Measurements | MEAN | STD DEV | % STD DEV | No. Measurements | MEAN | STD DEV | % STD DEV | No. Measurements | MEAN | STD DEV | % STD DEV |
| DB-A01 | 40 | 373.99 | 103.33 | 27.63 | 45 | 383.07 | 111.31 | 29.06 | 27 | 422.24 | 85.07 | 20.15 |
| DB-A02 | 42 | 328.24 | 200.19 | 60.99 | 43 | 293.82 | 175.44 | 59.71 | 27 | 314.50 | 179.01 | 56.92 |
| DB-A03 | 40 | 158.73 | 88.17 | 55.55 | 35 | 174.35 | 76.65 | 43.96 | 29 | 177.56 | 58.16 | 32.76 |
| DB-A04 | 40 | 321.44 | 83.19 | 25.88 | 43 | 310.24 | 77.56 | 25.00 | 27 | 338.09 | 39.47 | 11.67 |
| DB-A05 | 41 | 351.19 | 95.9 | 27.31 | 38 | 317.46 | 92.71 | 29.20 | 29 | 322.13 | 97.24 | 30.19 |
| DB-A06 | 41 | 119.72 | 68.41 | 57.14 | 45 | 152.15 | 86.6 | 56.92 | 28 | 126.78 | 61.42 | 48.45 |
| DB-A07 | 42 | 73.67 | 50.69 | 68.81 | 38 | 76.12 | 36.41 | 47.83 | 28 | 86.15 | 26.12 | 30.32 |
| DB-A08 | 40 | 85.37 | 57 | 66.77 | 44 | 101.67 | 45.17 | 44.43 | 28 | 101.99 | 36.04 | 35.34 |
| DB-A09 | 48 | 131.65 | 95.51 | 72.55 | 39 | 160.74 | 123.63 | 76.91 | 28 | 112.75 | 57.54 | 51.03 |
| DB-A10 | 32 | 89.30 | 58.96 | 66.03 | 39 | 91.55 | 52.85 | 57.73 | 29 | 88.24 | 58.22 | 65.98 |
| Averages | | 203.33 | 90.14 | 52.86 | | 206.12 | 87.83 | 47.08 | | 209.04 | 69.83 | 38.28 |

## TABLE A-2
## THORIUM-232 REPEATED PROFILE RUNS IN DRUM BALING AREA

| | 2 sec - 2 mph | | | | 4 sec - 1 mph | | | | 8 sec - 0.5 mph | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AREA | No. Measurements | MEAN | STD DEV | % STD DEV | No. Measurements | MEAN | STD DEV | % STD DEV | No. Measurements | MEAN | STD DEV | % STD DEV |
| DB-A01 | 40 | 3.21 | 0.99 | 30.84 | 45 | 3.02 | 1.16 | 38.41 | 27 | 3.45 | 0.57 | 16.52 |
| DB-A02 | 42 | 2.99 | 1.04 | 34.78 | 43 | 2.99 | 1.06 | 35.45 | 27 | 2.95 | 0.59 | 20.00 |
| DB-A03 | 40 | 2.81 | 0.82 | 29.18 | 35 | 2.76 | 0.73 | 26.45 | 29 | 2.87 | 0.62 | 21.60 |
| DB-A04 | 40 | 3.98 | 0.86 | 21.61 | 43 | 3.69 | 0.71 | 19.24 | 27 | 3.69 | 0.4 | 10.84 |
| DB-A05 | 41 | 3.79 | 1.07 | 28.23 | 38 | 3.85 | 0.79 | 20.52 | 29 | 3.87 | 0.65 | 16.80 |
| DB-A06 | 41 | 2.31 | 0.73 | 31.60 | 45 | 2.35 | 0.6 | 25.53 | 28 | 2.26 | 0.62 | 27.43 |
| DB-A07 | 42 | 2.10 | 0.6 | 28.57 | 38 | 2.21 | 0.53 | 23.98 | 28 | 2.25 | 0.49 | 21.78 |
| DB-A08 | 40 | 3.82 | 1.22 | 31.94 | 44 | 4.15 | 1.19 | 28.67 | 28 | 4.31 | 1.27 | 29.47 |
| DB-A09 | 48 | 6.83 | 2.63 | 38.51 | 39 | 7.98 | 3.24 | 40.60 | 28 | 6.35 | 1.57 | 24.72 |
| DB-A10 | 32 | 5.77 | 1.07 | 18.54 | 39 | 5.85 | 1.43 | 24.44 | 29 | 6.26 | 1.02 | 16.29 |
| Averages | | 3.76 | 1.10 | 29.38 | | 3.89 | 1.14 | 28.33 | | 3.83 | 0.78 | 20.55 |

## TABLE A-3

### RADIUM-226 REPEATED PROFILE RUNS IN DRUM BALING AREA

| | 2 sec - 2 mph | | | | 4 sec - 1 mph | | | | 8 sec - 0.5 mph | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AREA | No. Measurements | MEAN | STD DEV | % STD DEV | No. Measurements | MEAN | STD DEV | % STD DEV | No. Measurements | MEAN | STD DEV | % STD DEV |
| DB-A01 | 40 | 17.15 | 4.02 | 23.44 | 45 | 16.23 | 3.22 | 19.84 | 27 | 17.16 | 2.43 | 14.16 |
| DB-A02 | 42 | 13.45 | 7.2 | 53.53 | 43 | 11.45 | 5.1 | 44.54 | 27 | 12.05 | 5.24 | 43.49 |
| DB-A03 | 40 | 8.70 | 3.54 | 40.69 | 35 | 9.19 | 3.36 | 36.56 | 29 | 9.55 | 3.41 | 35.71 |
| DB-A04 | 40 | 16.72 | 3.69 | 22.07 | 43 | 15.91 | 3.2 | 20.11 | 27 | 15.81 | 2.59 | 16.38 |
| DB-A05 | 41 | 14.58 | 3.96 | 27.16 | 38 | 14.08 | 4.09 | 29.05 | 29 | 14.24 | 4.22 | 29.63 |
| DB-A06 | 41 | 5.05 | 2.24 | 44.36 | 45 | 5.67 | 2.69 | 47.44 | 28 | 5.04 | 2.28 | 45.24 |
| DB-A07 | 42 | 3.10 | 1.56 | 50.32 | 38 | 3.19 | 1.07 | 33.54 | 28 | 3.68 | 0.85 | 23.10 |
| DB-A08 | 40 | 2.44 | 1.79 | 73.36 | 44 | 2.77 | 1.16 | 41.88 | 28 | 2.54 | 0.78 | 30.71 |
| DB-A09 | 48 | 2.06 | 2.12 | 102.91 | 39 | 2.30 | 1.43 | 62.17 | 28 | 1.93 | 1.2 | 62.18 |
| DB-A10 | 32 | 3.57 | 2.02 | 56.58 | 39 | 3.00 | 1.43 | 47.67 | 29 | 2.59 | 1.36 | 52.51 |
| Averages | | 8.68 | 3.21 | 49.44 | | 8.38 | 2.68 | 38.28 | | 8.46 | 2.44 | 35.31 |

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**TABLE A-4**

**GROSSCOUNTS/SEC - REPEATED PROFILE RUNS IN DRUM BALING AREA**

| AREA | 2 sec - 2 mph | | | | 4 sec - 1 mph | | | | 8 sec - 0.5 mph | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. Measurements | MEAN (CPS) | STD DEV | % STD DEV | No. Measurements | MEAN (CPS) | STD DEV | % STD DEV | No. Measurements | MEAN (CPS) | STD DEV | % STD DEV |
| DB-A01 | 40 | 24548.21 | 2550.22 | 10.39 | 45 | 24495.21 | 2953.34 | 12.06 | 27 | 24433.30 | 2020.16 | 8.27 |
| DB-A02 | 42 | 19840.57 | 5893.34 | 29.70 | 43 | 19010.63 | 5825.21 | 30.64 | 27 | 19477.18 | 6422.73 | 32.98 |
| DB-A03 | 40 | 14610.55 | 2729.11 | 18.68 | 35 | 14961.60 | 2311.94 | 15.45 | 29 | 15485.49 | 2363.50 | 15.26 |
| DB-A04 | 40 | 20707.99 | 1532.91 | 7.40 | 43 | 20913.29 | 1496.68 | 7.16 | 27 | 20820.33 | 1259.25 | 6.05 |
| DB-A05 | 41 | 20531.66 | 2336.67 | 11.38 | 38 | 20359.53 | 3152.36 | 15.48 | 29 | 19905.35 | 3356.46 | 16.86 |
| DB-A06 | 41 | 11892.34 | 2153.04 | 18.10 | 45 | 12502.35 | 3059.79 | 24.47 | 28 | 11741.16 | 3035.52 | 25.85 |
| DB-A07 | 42 | 9443.32 | 800.80 | 8.48 | 38 | 9458.07 | 815.47 | 8.62 | 28 | 9901.23 | 1061.36 | 10.72 |
| DB-A08 | 40 | 10484.69 | 626.36 | 5.97 | 44 | 10662.81 | 656.33 | 6.16 | 28 | 10652.36 | 542.83 | 5.10 |
| DB-A09 | 48 | 12572.71 | 1936.28 | 15.40 | 39 | 13374.39 | 2896.54 | 21.66 | 28 | 12287.36 | 1490.64 | 12.13 |
| DB-A10 | 32 | 12029.48 | 908.24 | 7.55 | 39 | 12222.88 | 1037.56 | 8.49 | 29 | 12335.19 | 1430.15 | 11.59 |
| Averages | | 15666.15 | 2146.70 | 13.31 | | 15796.08 | 2420.52 | 15.02 | | 15703.89 | 2298.26 | 14.48 |

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FIG A-1

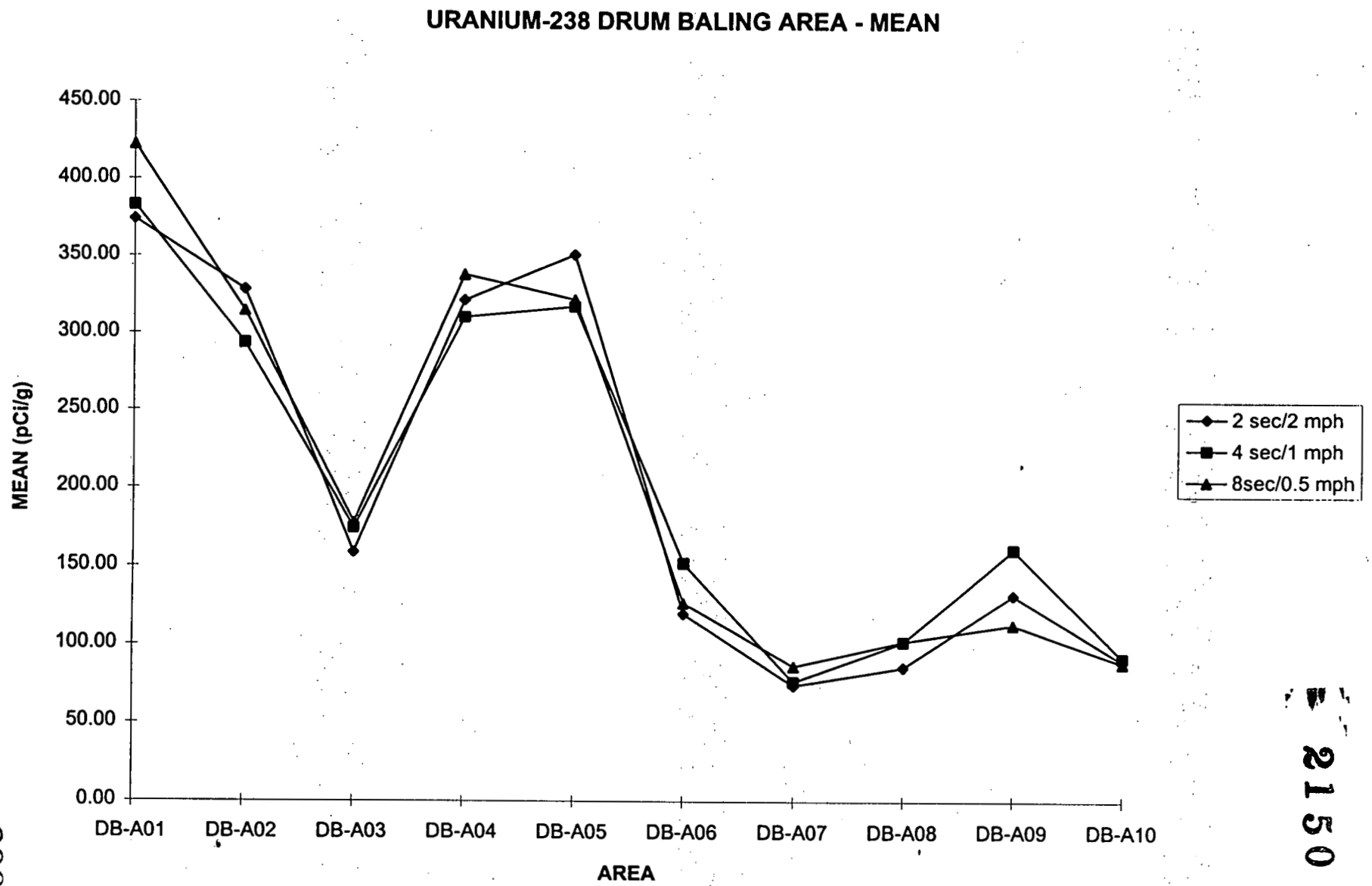
URANIUM-238 DRUM BALING AREA - MEAN
MEAN (pCi/g)
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
DB-A01
DB-A02
DB-A03
DB-A04
DB-A05
DB-A06
DB-A07
DB-A08
DB-A09
DB-A10
AREA
2 sec/2 mph
4 sec/1 mph
8sec/0.5 mph

FIG A-2

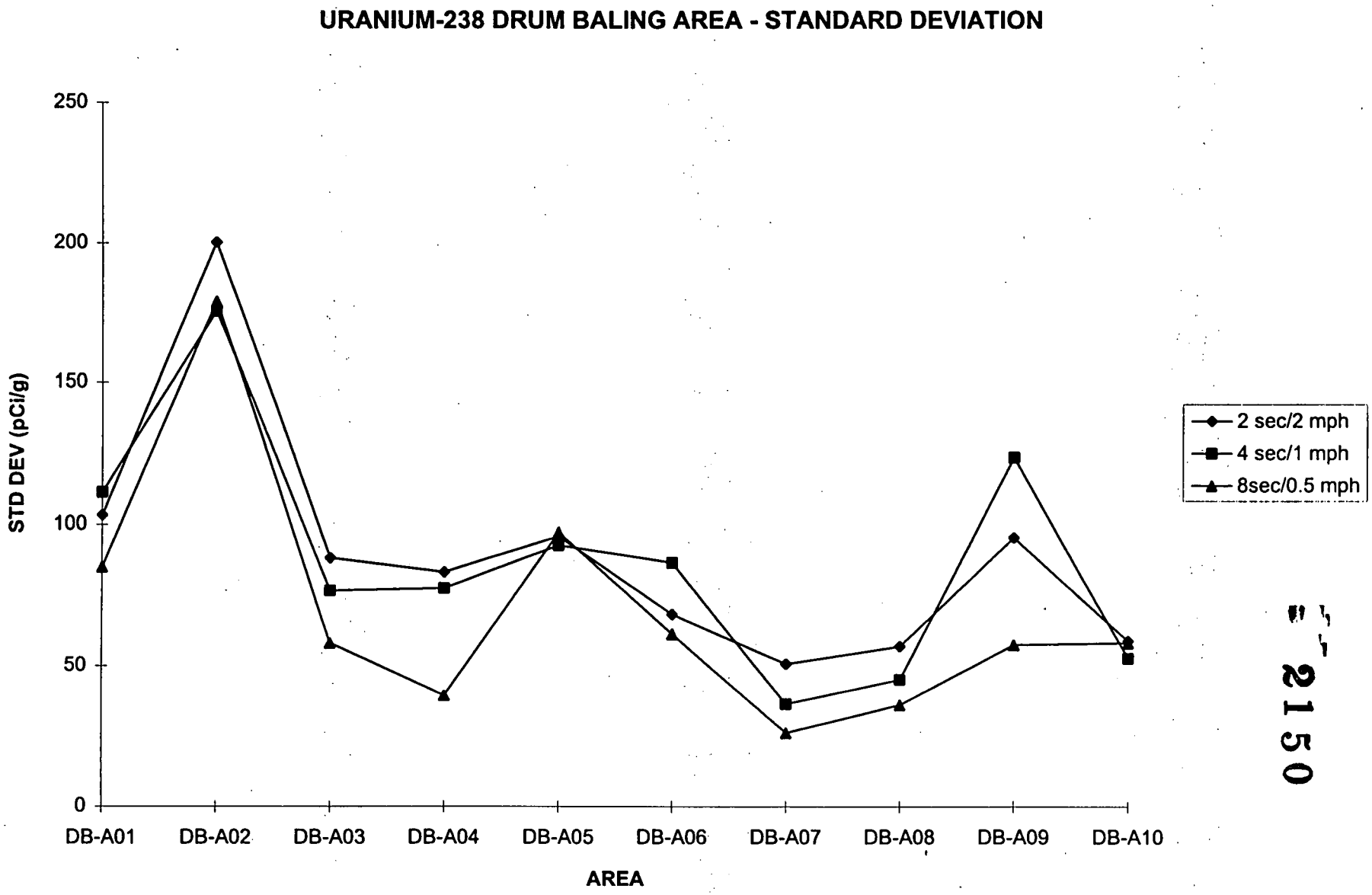
URANIUM-238 DRUM BALING AREA - STANDARD DEVIATION
STD DEV (pCi/g)
250
200
150
100
50
0
DB-A01
DB-A02
DB-A03
DB-A04
DB-A05
DB-A06
DB-A07
DB-A08
DB-A09
DB-A10
AREA
2 sec/2 mph
4 sec/1 mph
8sec/0.5 mph

FIG A-3

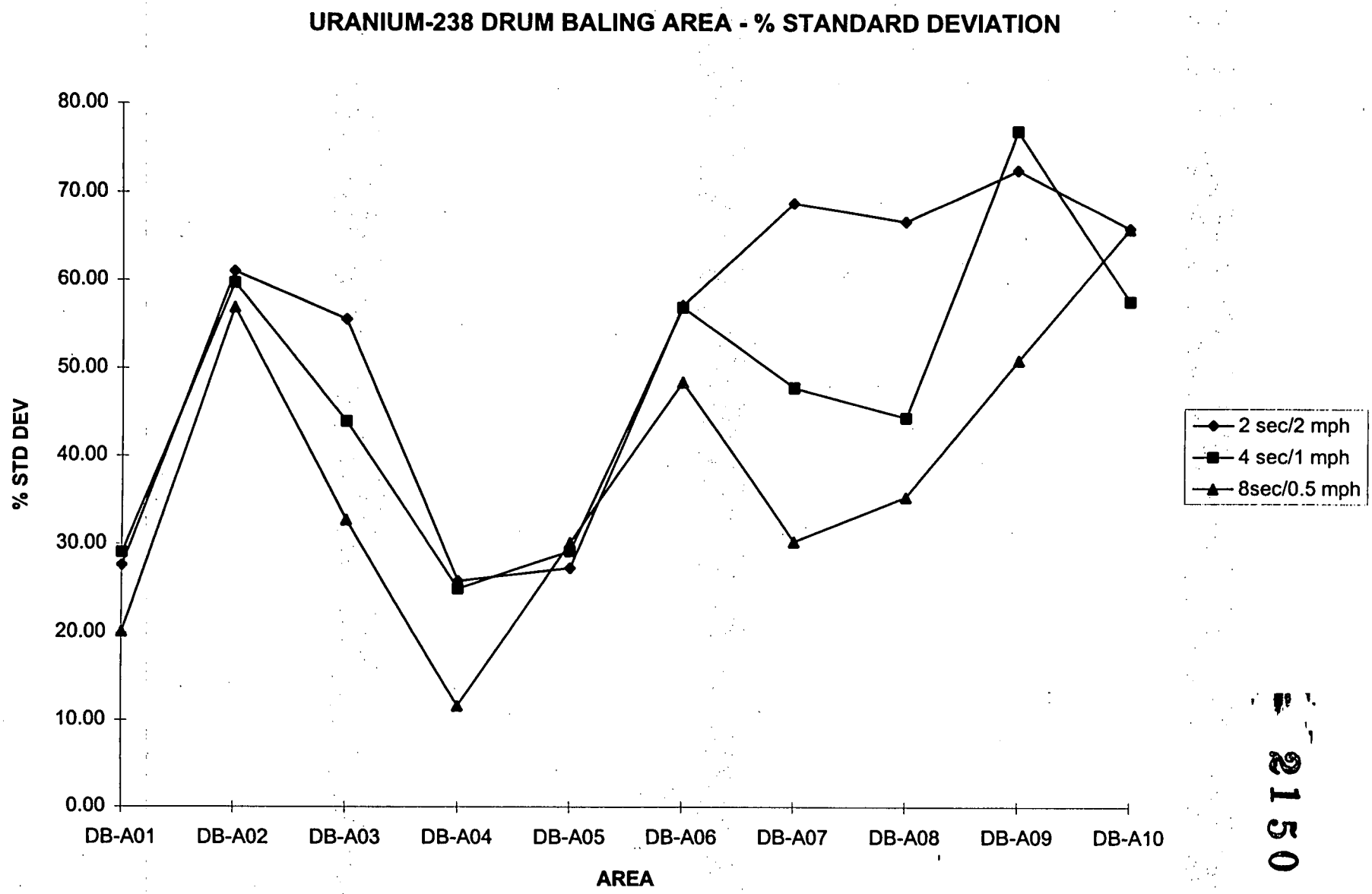
URANIUM-238 DRUM BALING AREA - % STANDARD DEVIATION
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% STD DEV
DB-A01
DB-A02
DB-A03
DB-A04
DB-A05
DB-A06
DB-A07
DB-A08
DB-A09
DB-A10
AREA
2 sec/2 mph
4 sec/1 mph
8sec/0.5 mph

FIG A-4

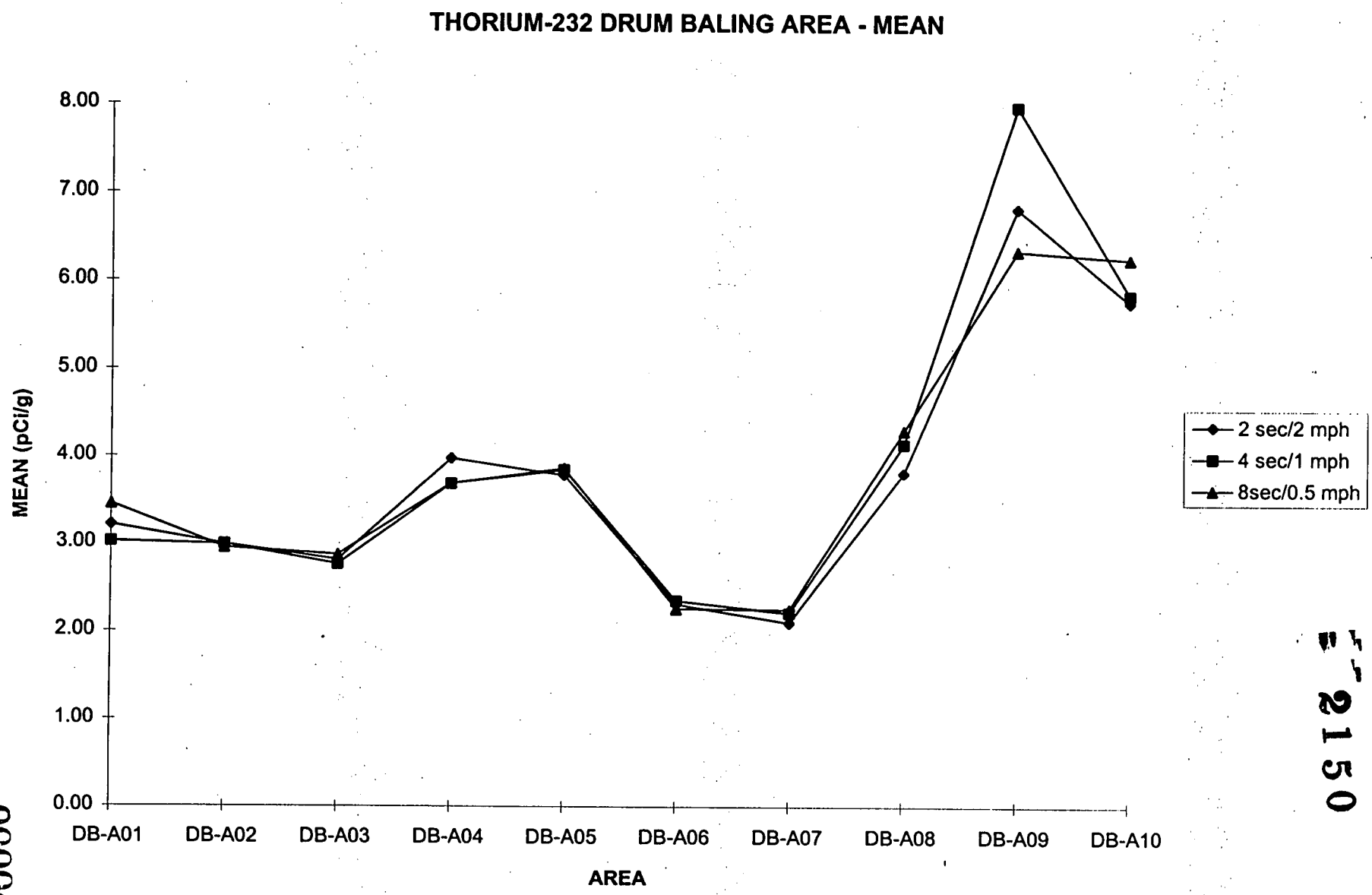
THORIUM-232 DRUM BALING AREA - MEAN
MEAN (pCi/g)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
DB-A01
DB-A02
DB-A03
DB-A04
DB-A05
DB-A06
DB-A07
DB-A08
DB-A09
DB-A10
AREA
2 sec/2 mph
4 sec/1 mph
8sec/0.5 mph

FIG A-5

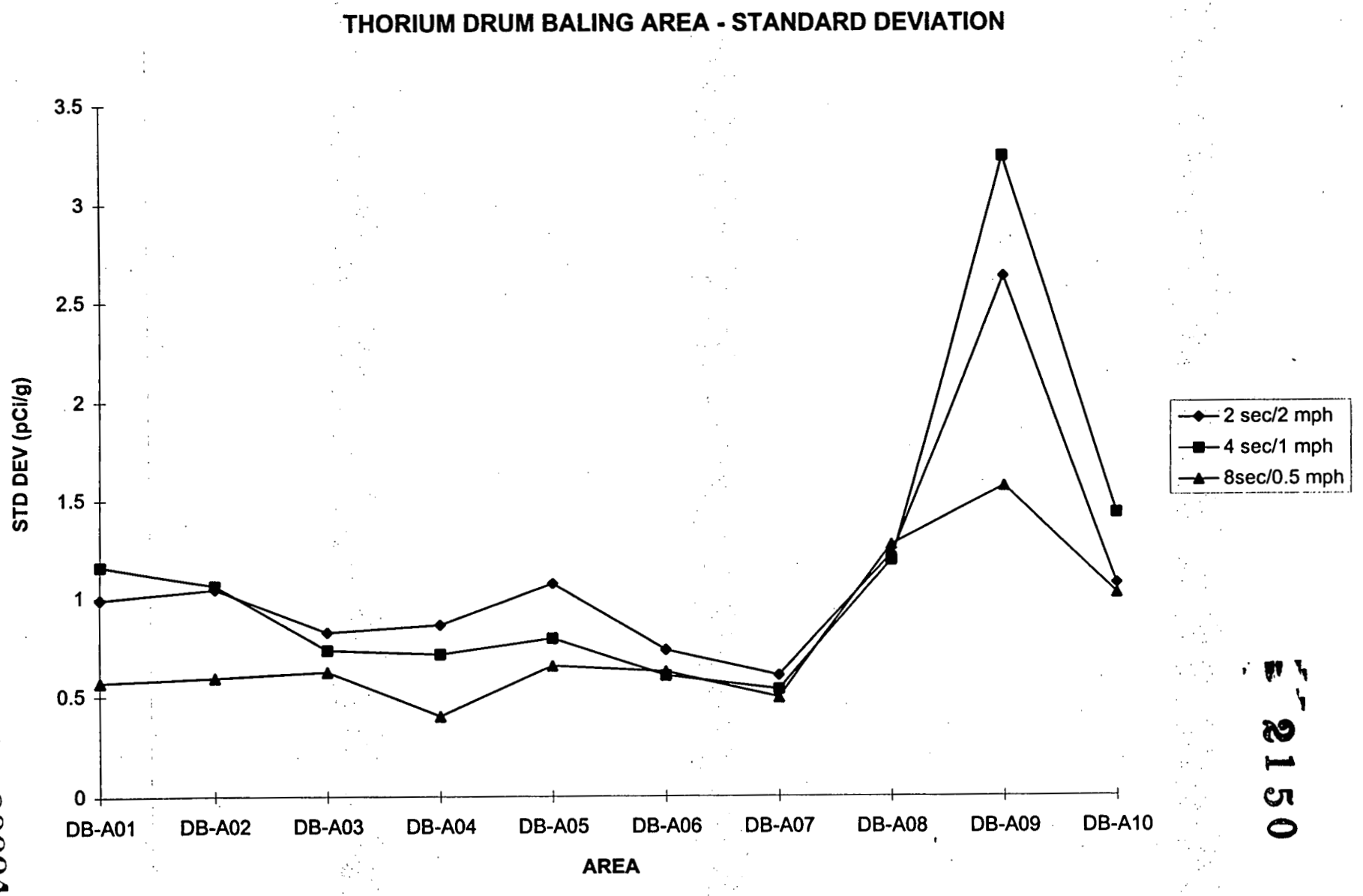
THORIUM DRUM BALING AREA - STANDARD DEVIATION
STD DEV (pCi/g)
3.5
3
2.5
2
1.5
1
0.5
0
DB-A01
DB-A02
DB-A03
DB-A04
DB-A05
DB-A06
DB-A07
DB-A08
DB-A09
DB-A10
AREA
2 sec/2 mph
4 sec/1 mph
8sec/0.5 mph

FIG A-6

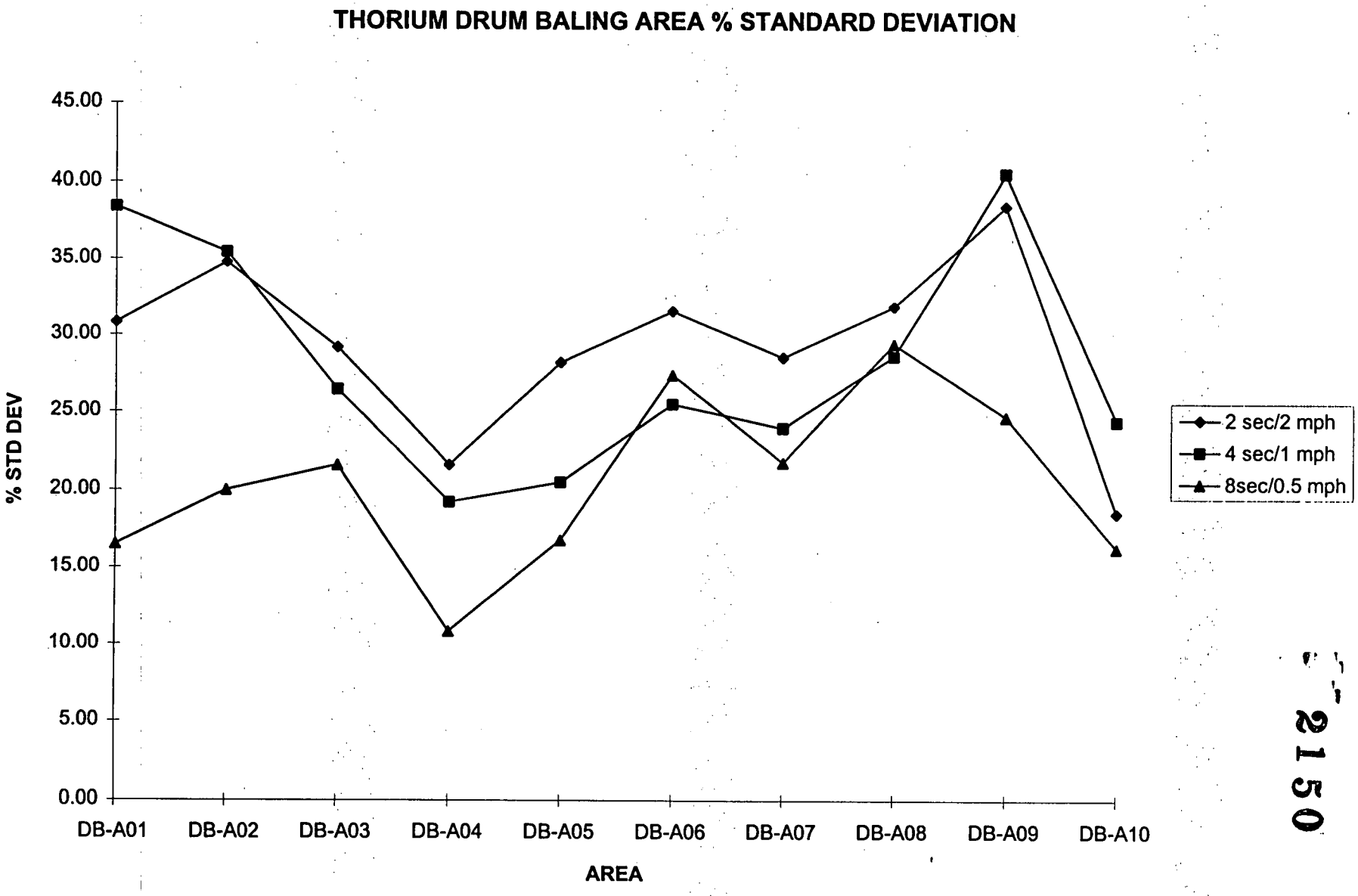


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FIG A-7

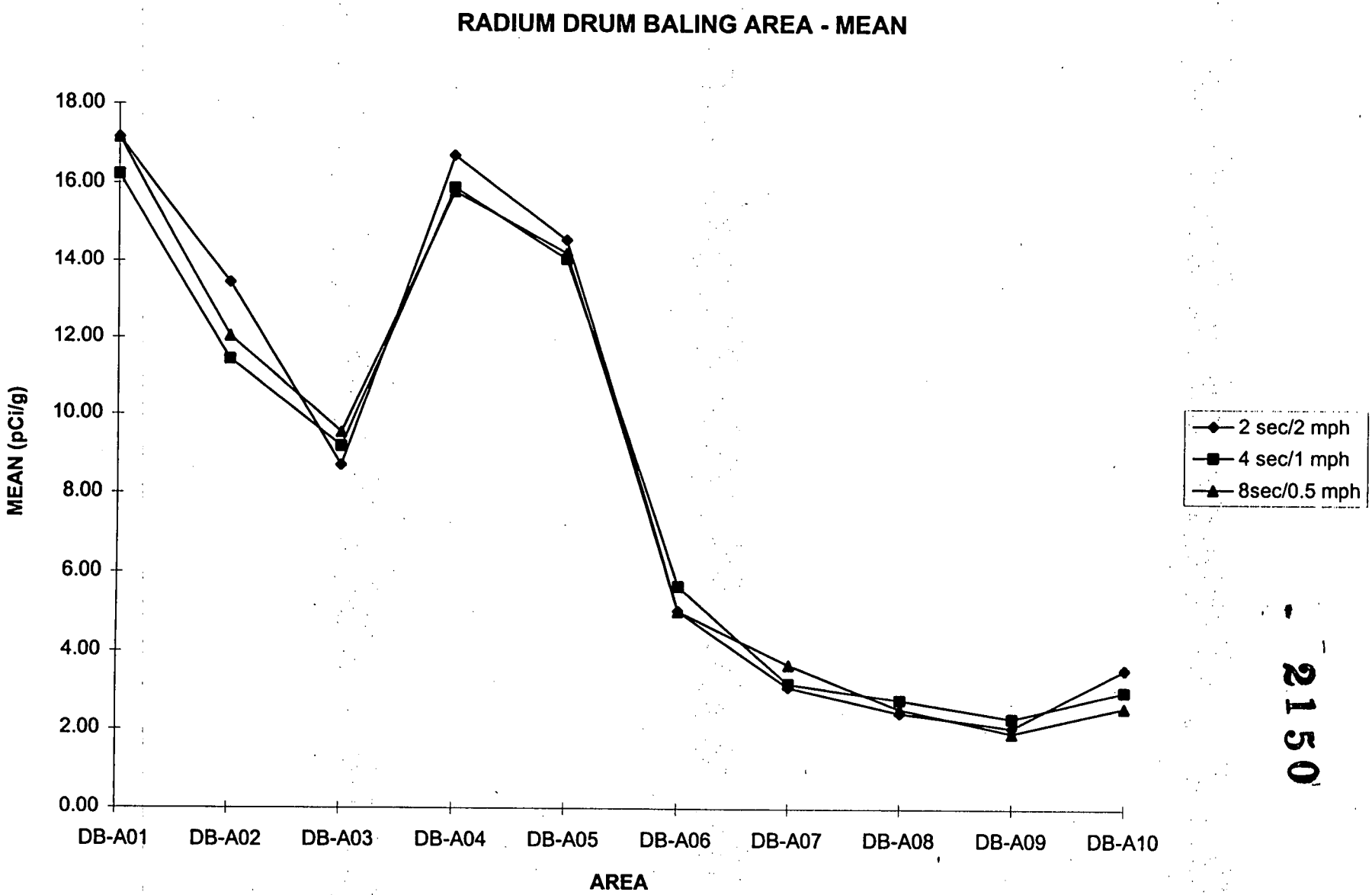


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FIG A-8

## RADIUM DRUM BALING AREA - STANDARD DEVIATION

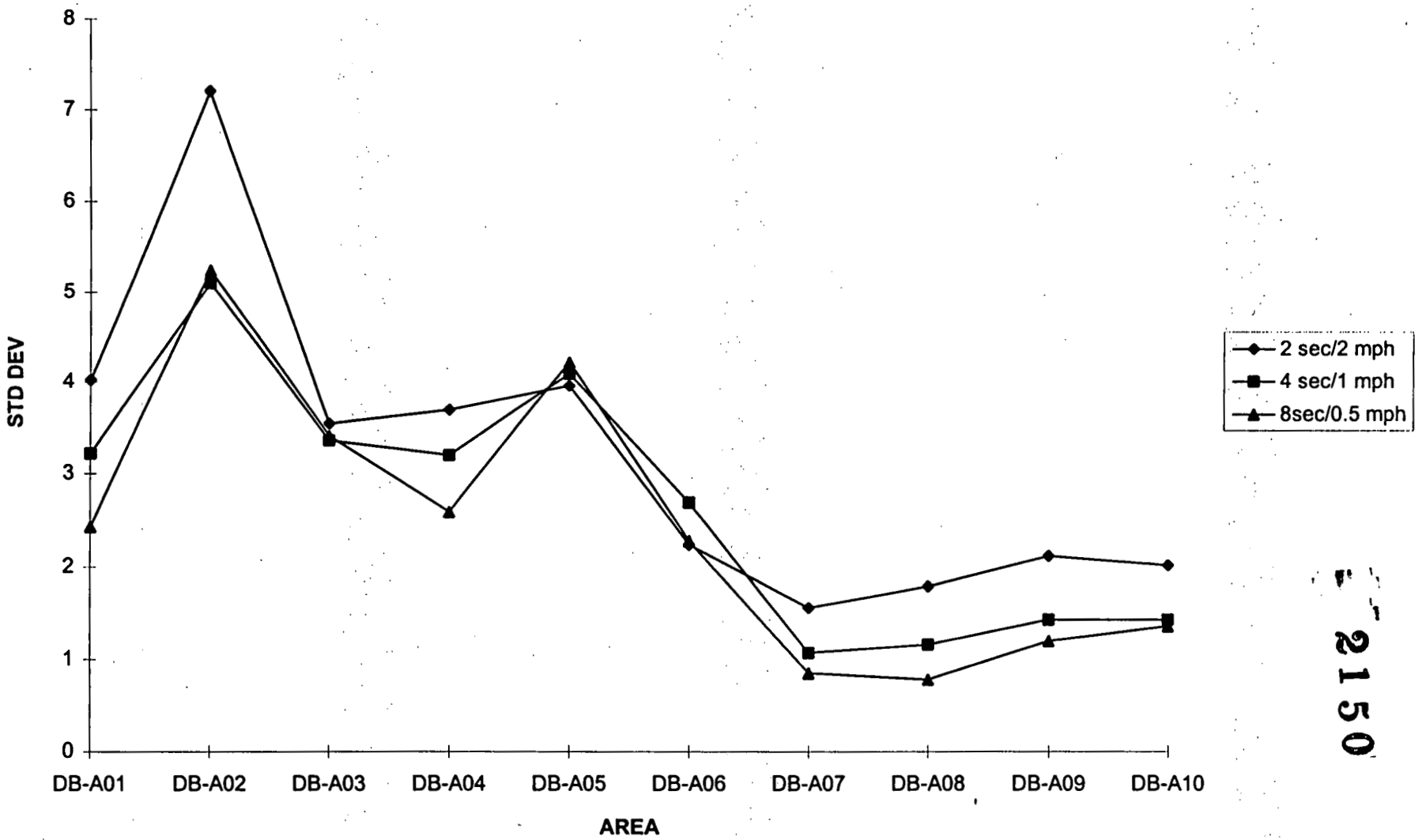

FIG A-9

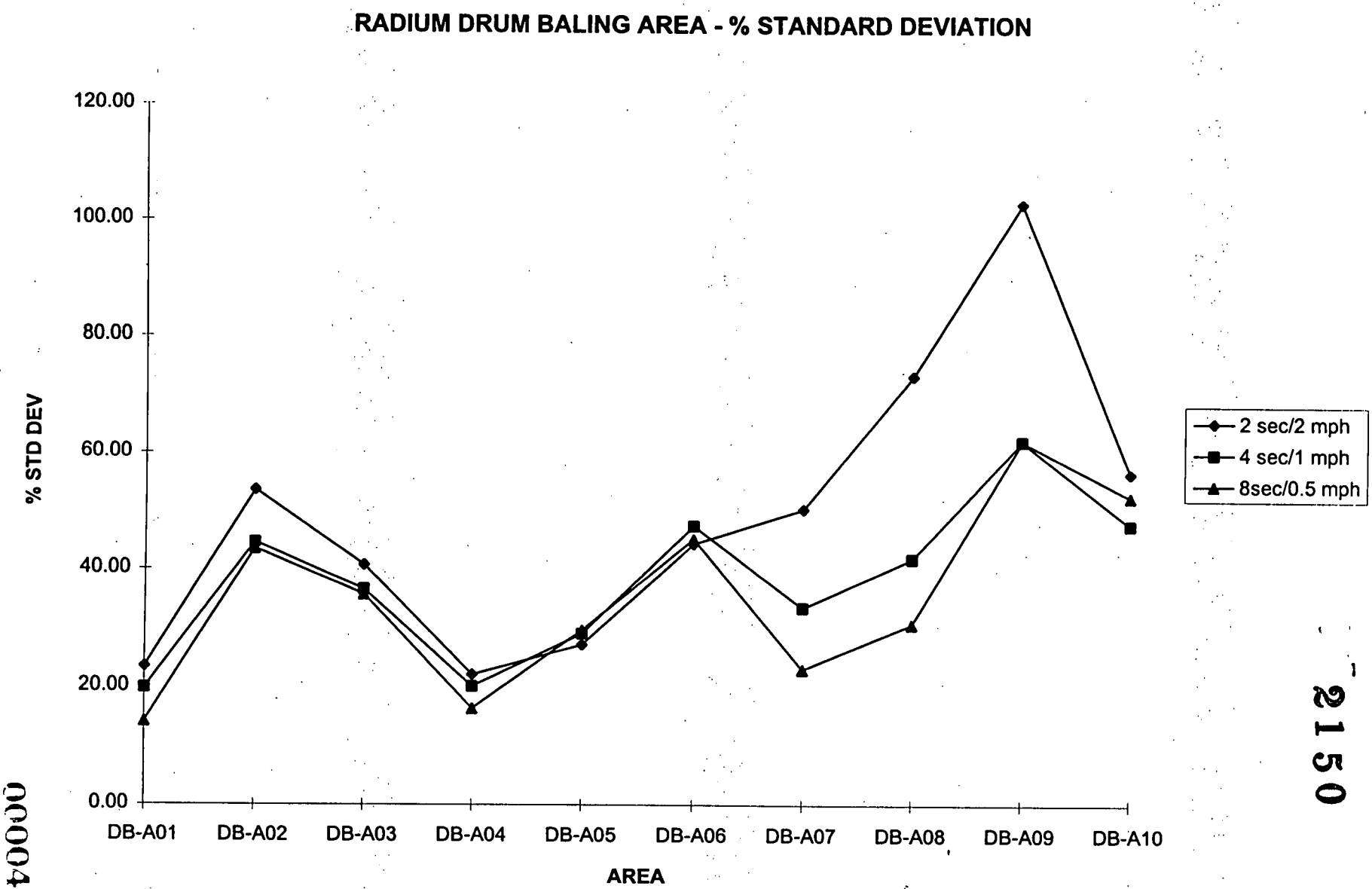
RADIUM DRUM BALING AREA - % STANDARD DEVIATION
120.00
100.00
80.00
60.00
40.00
20.00
0.00
% STD DEV
DB-A01
DB-A02
DB-A03
DB-A04
DB-A05
DB-A06
DB-A07
DB-A08
DB-A09
DB-A10
AREA
2 sec/2 mph
4 sec/1 mph
8sec/0.5 mph

FIG A-10

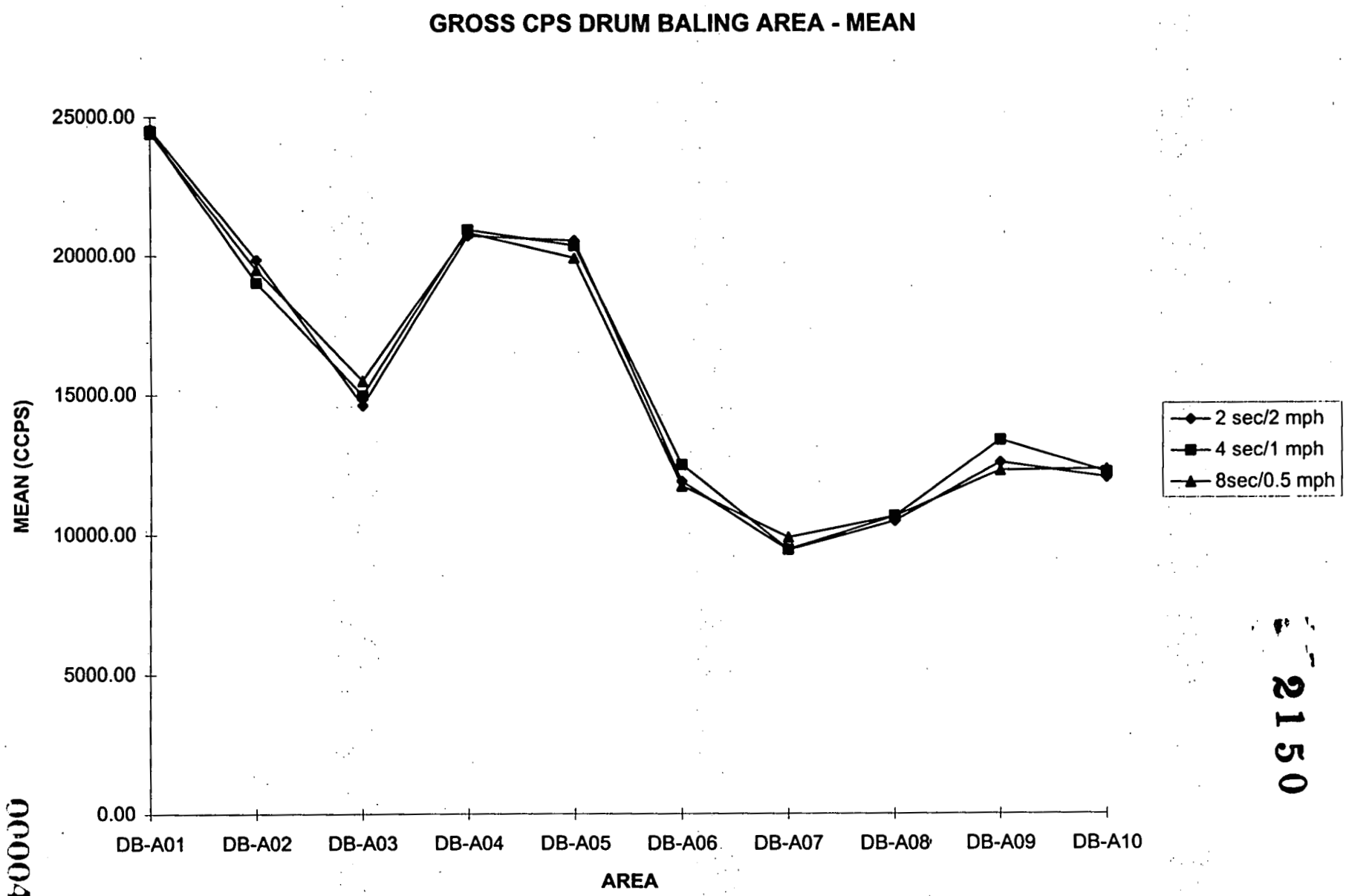


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FIG A-11

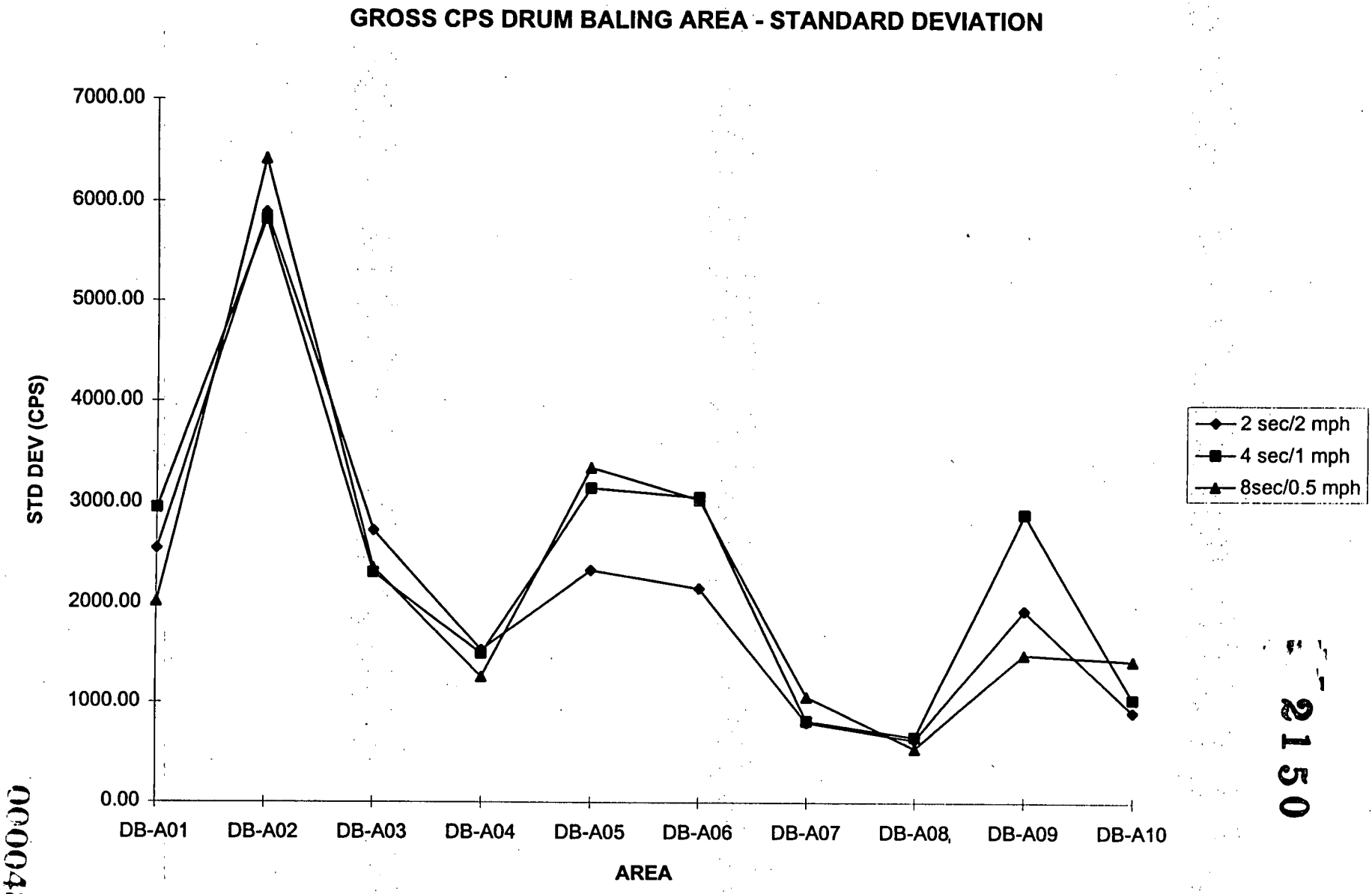
GROSS CPS DRUM BALING AREA - STANDARD DEVIATION
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
STD DEV (CPS)
DB-A01
DB-A02
DB-A03
DB-A04
DB-A05
DB-A06
DB-A07
DB-A08
DB-A09
DB-A10
AREA
2 sec/2 mph
4 sec/1 mph
8sec/0.5 mph

FIG A-11

## GROSS CPS DRUM BALING AREA - STANDARD DEVIATION

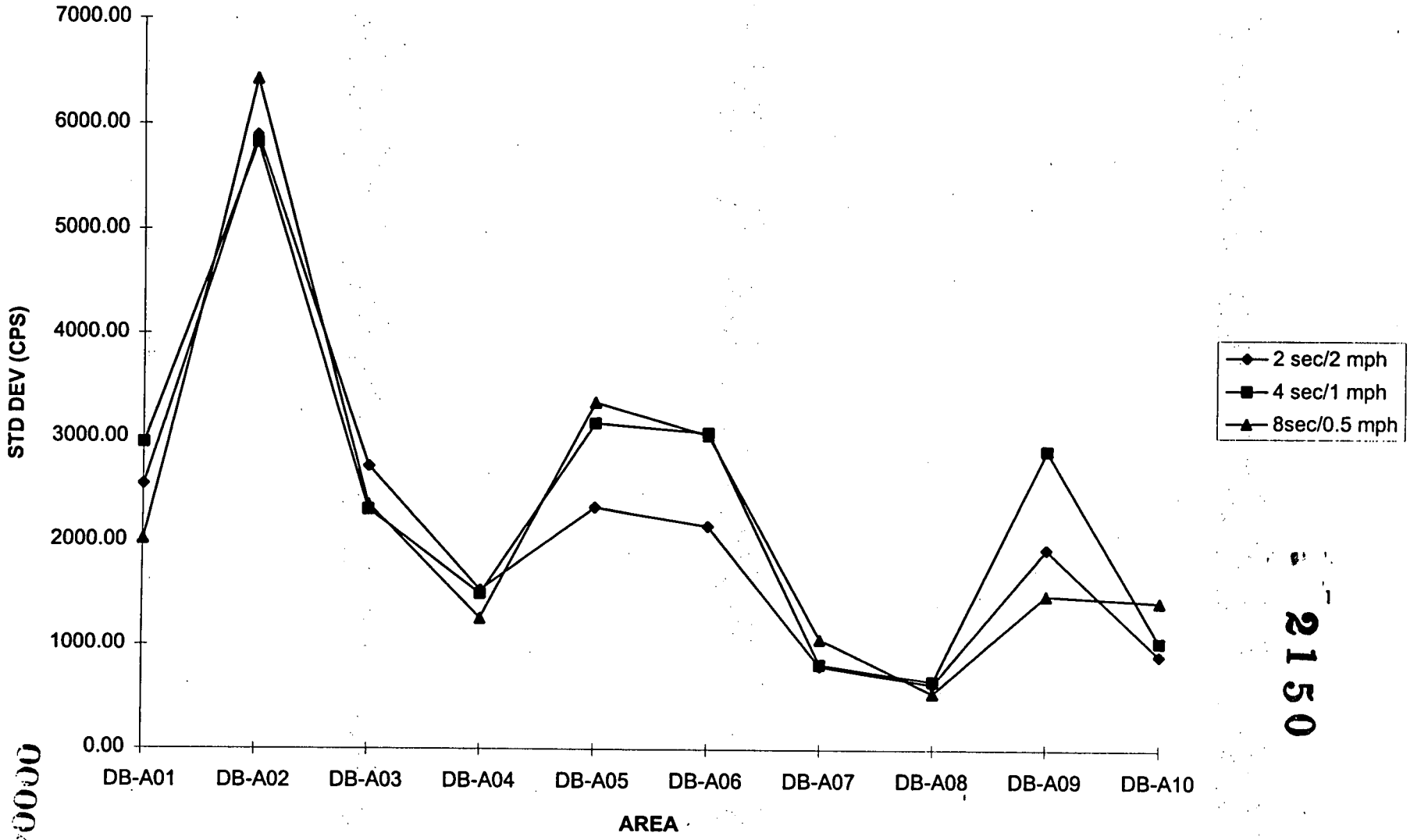




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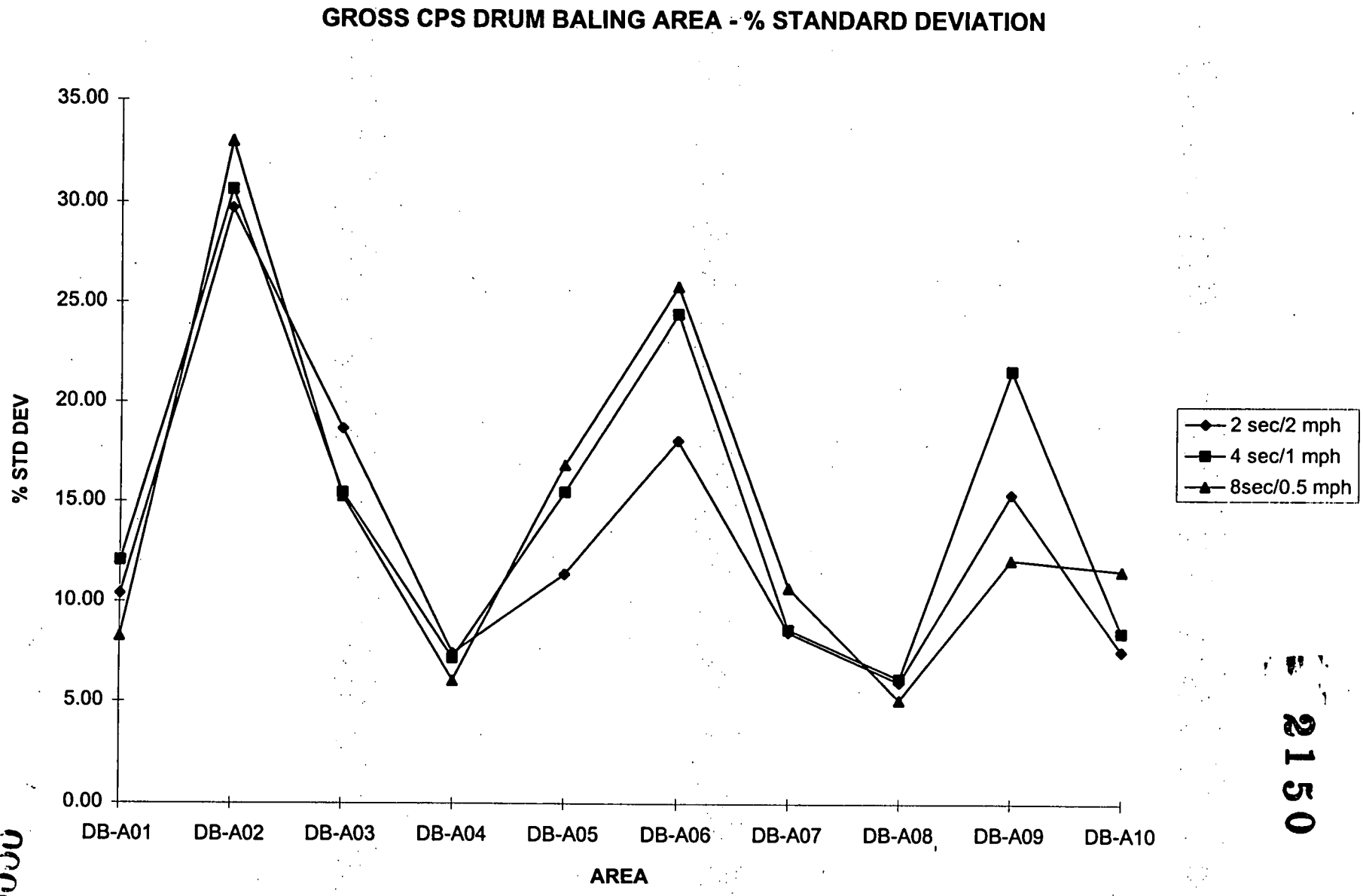
FIG A-12

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