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EVALUATION OF SEGMENTED GAMMA SCANNER MEASUREMENTS ON CANS OF RECOVERABLE SCRAP (U)

by

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EVALUATION OF SEGMENTED GAMMA SCANNER MEASUREMENTS ON CANS OF RECOVERABLE SCRAP

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ABSTRACT

Savannah River Site (SRS) has had a long-standing concern about the inability to measure recoverable scrap. A segmented gamma scanner (SGS) was evaluated for use in measuring cans of scrap materials. Four scrap cans were selected and re-packaged into containers that could be measured using calorimetry and gamma spectrometry. These scrap cans were later used as working standards for the SGS. In addition, replicate measurements were made on all cans of scrap currently stored with estimated values. Before accepting the SGS measurements on the cans, data from the replicate measurements of the standards and a limited number of process cans were analyzed to determine if there was a significant bias between the SGS and the calorimeter-gamma spectrometer measurements, if the random replication error would be acceptable for accountability, to set control limits for the working standards, and to determine acceptable differences between replicate measurements. After completing the measurement of all process scrap cans in the inventory, the final data were analyzed and estimates based on the two sets of data compared. The methodology used to determine the appropriate measurement error model, to estimate the measurement errors, to set control limits, and to determine the significance of the bias will be described as well as a comparison of the error estimates based on the preliminary versus final data.

INTRODUCTION

Adequate quantification of the amount of special nuclear material in recoverable scrap has long been an accountability concern in the nuclear defense industry. Recently, a segmented gamma scanner (SGS) developed by Los Alamos National Laboratory was used at the Savannah River Site (SRS) for measuring cans of scrap materials.[3] Even though the SGS method has existed since the 1970's, its application for measuring scrap material was only begun at SRS in the last two years. Several papers at the 1990 INMM Annual Meeting dealt with this subject and are listed in the references.

With any new measurement technique or new application of an existing method, there is a need for practical statistical information to be developed from the measurement

data. Sometimes the data are only available in limited quantities. The information to be developed includes method bias, error model determination, and estimates of systematic and random variation for use in developing control charts, retest limit determination, and limit of error calculations.

The previous papers on the measurement of scrap material with the SGS did not address the application of statistical techniques which are needed to develop practical information from available measurements. This paper will describe methods for using minimal replicate data to develop this information. Later the paper briefly discusses the utilization of statistical techniques to evaluate additional measurements. Through a discussion of the SGS measurement system, it is hoped that the reader will discover statistical methods that can be utilized in the future for developing similar information for other measurement techniques.

DESCRIPTION OF AVAILABLE MEASUREMENTS

The measurements available for developing statistical information consisted of replicate measurements made on working standards and process cans. Four routine process cans of scrap were chosen for preparation as working standards and reference values were determined using calorimetry-gamma spectrometry. To facilitate measurement with calorimeter-gamma spectrometer, it was necessary to re-package the four process cans.[4] After replicate determinations were made with calorimetry-gamma spectrometry, the working standards were repeatedly measured on the SGS, which provided replicate measurements on each of the standards. Duplicate or triplicate SGS measurements were also available on several process cans.

ANALYSIS OF MEASUREMENTS FOR BIAS

One of the first statistics of interest in a new measurement application is that of possible bias between the new method and some known standard or standard method. For the SGS, the bias was estimated by comparing the average calorimeter-gamma spectrometer measurements for the four working standards to the SGS measurements for the same standards. The absolute and random standard deviation of the differences between the calorimeter average and the SGS measurements were also calculated for each standard. Summary statistics are shown in Table 1 and a graph of the average bias values are shown in Figure 1.

TABLE 1: WORKING STANDARDS SUMMARY STATISTICS

Std.	No. Reps. (n)	Calor. Avg. (g.)	SGS Avg. (g.)	Avg. Bias (g.)	Rel. Bias (%)	Abs.Rnd. Std.Dev. (g.)	Rel.Rnd. Std. Dev.(%)
1	5	351.167	351.2	-0.033	-0.009	8.994	2.534
2	5	374.571	381.2	-6.629	-1.770	9.066	2.378
3	5	113.424	112.2	+1.224	1.079	3.493	3.113
4	9	419.363	418.4	+0.919	+0.219	12.778	3.054

In determining the best estimate of the overall bias, it is intuitive to think that it would be the average bias over all standards. However, before calculating the average bias, a few statistical tests are required, beginning with a check for significant differences in the average bias from standard to standard. If there are differences, then the idea of an average bias for all standards may not be appropriate. An analysis of variance is a good way to test for significant differences in the biases from standard to standard, assuming that the variance of the biases are equal within each standard. To verify this assumption, a check for homogeneity of variances is performed using Bartlett's test. For the SGS, Bartlett's test indicated that the variances were equal for both the absolute and relative errors. Since the variances were not significantly different, the assumption of homogeneity of variances was satisfied and the analysis of variance was performed. No significant difference in bias from standard to standard was indicated by the analysis. Therefore an average bias of -.7885 g., was calculated. This was a relatively small value and a t-test was used to check for significance. The the t-test indicated that the bias was not significantly different from zero. Therefore, the final conclusion was that no statistical significant bias exists between the calorimeter and the SGS measurements of the working standards.

DETERMINATION OF MODEL

It is important to determine the appropriate statistical model for any new measurement method or application. The correct model is fundamental to the proper interpretation of measurements from the measurement method. Without the correct model, inappropriate error estimates, incorrect limit of error calculations, and other invalid statistics will result.

To discuss models, it is necessary to introduce the following notation:

C_i = the average value for the ith standard or process can

B_i = the bias between the calorimeter and SGS on the ith standard

e_{ij} = random error for the jth replicate measure on the ith standard or process can. The random error is assumed to be normally distributed with zero mean

SGS_{ij} = the jth replicate measure for the ith standard or process can

The following three models were considered:

1. Absolute Model: $SGS_{ij} = C_i + B_i + e_{ij}$

2. Relative Model: $SGS_{ij} = C_i(1 + B_i + e_{ij})$

3. A linear combination of the two above (mixed model)

The first step in the analysis was to determine if the measurement data supported the absolute or relative model for the SGS. Later a check of the linear combination was made.

The basic way to verify an absolute or relative model is to observe the error estimates. If the model is absolute, the absolute error should remain constant over different levels of the standards. If the model is relative, the relative error should remain constant over different levels of the standard. It should be pointed out that the absolute and relative bias corrected measurement errors, given in Table 1 for each standard, are identical to the absolute and relative errors of the original SGS measurements. This is true since the bias corrected values were obtained by subtracting a constant calorimeter average value from each SGS measurement for each standard. Therefore, the standard deviations in Table 1 were compared for consistency. They appeared to be more constant for the relative case. However, the previously discussed Bartlett's tests indicated that there were no differences from standard to standard for either the absolute or relative bias errors. As a result, analysis of the standards measurement data was not conclusive as to the appropriate model type.

Since the analysis for model type was not conclusive on the working standard measurements, the same type of analysis was performed on the process can measurements. The summary statistics for these data are shown in Table 2.

TABLE 2: PROCESS CANS SUMMARY STATISTICS

Can #	No. Reps. (n)	SGS Average (grams)	Abs. Rnd. Std. Dev. (grams)	Rel. Rnd. Std. Dev. (%)
1	5	114.980	6.783	5.899
2	7	442.857	12.916	2.916
3	4	61.250	0.947	1.563
4	2	519.500	10.607	2.041
5	2	128.950	3.889	3.016
6	2	111.650	9.066	0.443

Again, study of the standard deviations indicated that the relative random errors were more consistent than the absolute errors, which was confirmed by Bartlett's test. The indication was that an relative model or some linear combination of models was the correct one. The investigation of mixed model was the next step in the process.

The investigation of a mixed model was conducted by performing a least squares regression on the SGS averages of 6 process cans. The SGS absolute average was used as the independent variable and the relative standard deviation was used as the dependent variable. If there is no significant slope in the regression, then the model does not contain any absolute component, and is therefore not mixed. The least squares regression yielded a slope of -.0005 which is shown in Figure 2. This was not significantly different from zero by t-test.

Based on all of the analyses, a relative model was chosen even though this choice was not completely supported by the standards data. This conclusion was strengthened later when additional data were available.

ESTIMATES OF ERROR

Estimates of random and systematic error are other types of statistical information that are desired for new measurement systems. Since we have shown that the appropriate model is a relative one, we will only discuss relative model errors.

Replicate measurements are required to calculate relative random error and were available on both the working standards and some process cans. The individual estimates for each working standard or process can are shown in Tables 1 & 2. As previously stated, there were no significant differences in the relative random error estimates among the working standards or among the process cans. As a result, the estimates for each data set were pooled together

yielding a pooled relative random variance of 8.07 $(\%)^2$ with 20 degree of freedom (df) for the working standards and a pooled relative random variance of 13.03 $(\%)^2$ with 16 df for the process cans. These two estimates were then checked to see if they were significantly different using an F-test. After the F-test indicated no significant difference, the estimates were combined for a final pooled relative random variance estimate of 10.27 $(\%)^2$. This is equivalent to a relative random standard deviation of 3.21 %.

DETERMINATION OF RETEST LIMITS

In the practical application of any measurement method, there is always an interest in how different duplicate or triplicate measurements can be before there is a reason for concern. These are called retest limits and were calculated for the SGS by multiplying the relative random standard deviation by the appropriate factors found in reference 2, page 442. They were calculated for 95% and 99% confidence and were stated as shown below:

> If two replicate measurements are made by the SGS on each scrap can, then these two measurements must agree within 9.06 % of the average value with 95% confidence and within 12.11 % for 99% confidence. If triplicate measurements are made, then the maximum range between any of the values must be within 10.90 % of the average for 95% confidence and 13.85 % for 99% confidence.

If the measurements do not agree within these limits, then there is statistical evidence that one or more of the values are in error. The duplicate or triplicate measurements should be repeated and the original data discarded.

CALCULATION OF SYSTEMATIC ERROR

Information about the systematic error is needed for control limits and any limit of error calculations. Only the relative random systematic error will be discussed. Any fixed systematic error should be detected and corrected by the measurement control system.

The relative random systematic error (RRSE) for the bias was calculated as shown below:

$$RRSE = SQRT\{ \text{Calorimeter Variance} + (\text{SGS Variance})/\underline{n}\}$$

The calorimeter variance used in the formula included the relative random and systematic variance of the calorimeter average and was obtained from an independent study, which was completed at Savannah River by Baylor S.

McClellan. The SGS variance used in the formula was the pooled relative random variance described above and n was the minimum number of values available for any working standard.

DETERMINATION OF CONTROL LIMITS

To insure measurement control, any measurement method should routinely measure one or more standards and compare to the standard value using a control chart.

For the SGS, one or more of the working standards are measured routinely on a control chart. The upper control limit (UCL) and the lower control limit (LCL) for the charts for a particular standard were calculated from the calorimeter average (CA) for the standard, the estimate of the bias error (RRSE) and the SGS relative random error (SGSRRE) as follows:

$$UCL = CA + 3 \times 100 \times \text{Square Root}(RRSE^2 + SGSRRE^2)$$

$$LCL = CA - 3 \times 100 \times \text{Square Root}(RRSE^2 + SGSRRE^2)$$

These are 99.7% confidence limits.

ANALYSIS OF ADDITIONAL DATA

After several months of using the SGS for measuring scrap cans, additional measurement data were available for analysis. These data consisted of additional replicates on standards 3 & 4 and duplicate or triplicate analysis on 17 additional process cans. The additional measurements provided a way to verify the information previously developed. The results were:

. There was still no statistical significant bias between the calorimeter and standard #3, but a bias had developed with standard #4. Since the bias was only on one standard, it was believed that the bias was due to some specific cause for the standard itself and not a general bias between measurement methods. An investigation to determine the cause was initiated.

. The new data supported the original conclusion that the appropriate model is a relative one. Both the new working standard measurements and the new process can measurements supported the conclusion.

. The new measurements gave an estimate of the relative random standard deviation of 4.59%. Like the original measurement data, this standard deviation was a pooled estimate from the working standards and process can replicated data. The 4.59% estimate was with 85 df and is

significantly higher than the estimate from the original data. This new estimate was assumed to more closely approximate the "true" value, since it was estimated with more degrees of freedom. It was necessary to re-calculate all limits such as control limits and retest limits which were derived from this estimate.

CONCLUSION

A report on the new application of the SGS to quantify the amount of special nuclear material in recoverable process waste has been given. The emphasis of the report was the use of statistical techniques to develop timely information when only a minimal amount of measurement data was available. In most cases, the information was reasonably good when compared with analyses of additional measurements which became available at a later time. The timeliness of the information far surpasses the minor corrections which were required when additional measurement data became available.

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3. Simmonds, S. M., Sprinkle, J. K., Hsue, S. T., Kellogg, M. P., "Nondestructive Assay of Plutonium-Bearing Scrap and Waste with Advance Segmented Gamma Scanner," presented at the INMM 31st Annual Meeting, Los Angeles, July 15-18, 1990.

4. Baker, L., MacMurdo, K., Miller, M. C., and Bosler, G. E., "Recent Experiences of Scrap and Waste Assay Using Neutron Coincidence Counting of Materials From F B-Line at the Savannah River Site," presented at the INNM 31st Annual Meeting, Los Angeles, July 15-18, 1990.

Figure 1

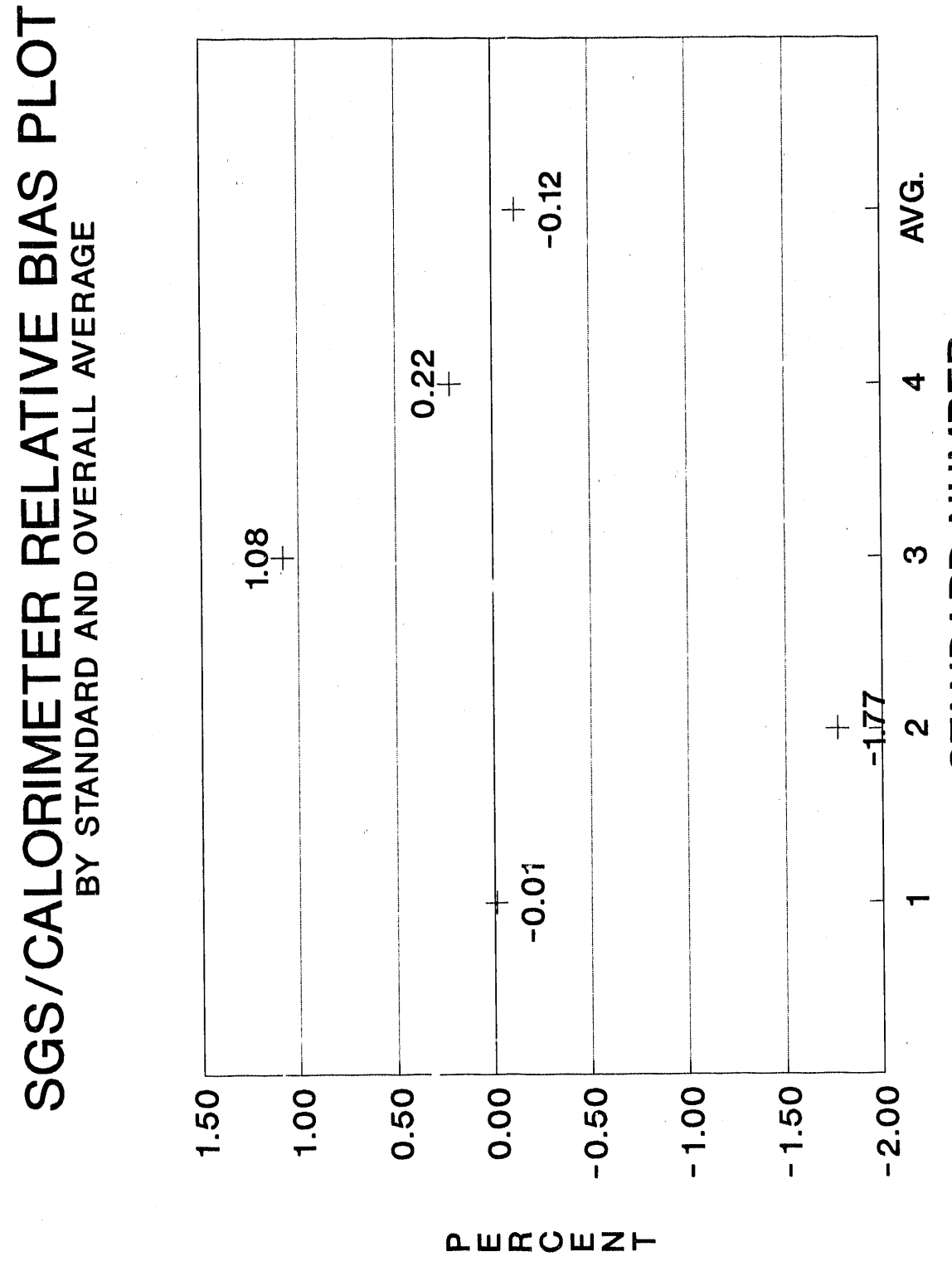
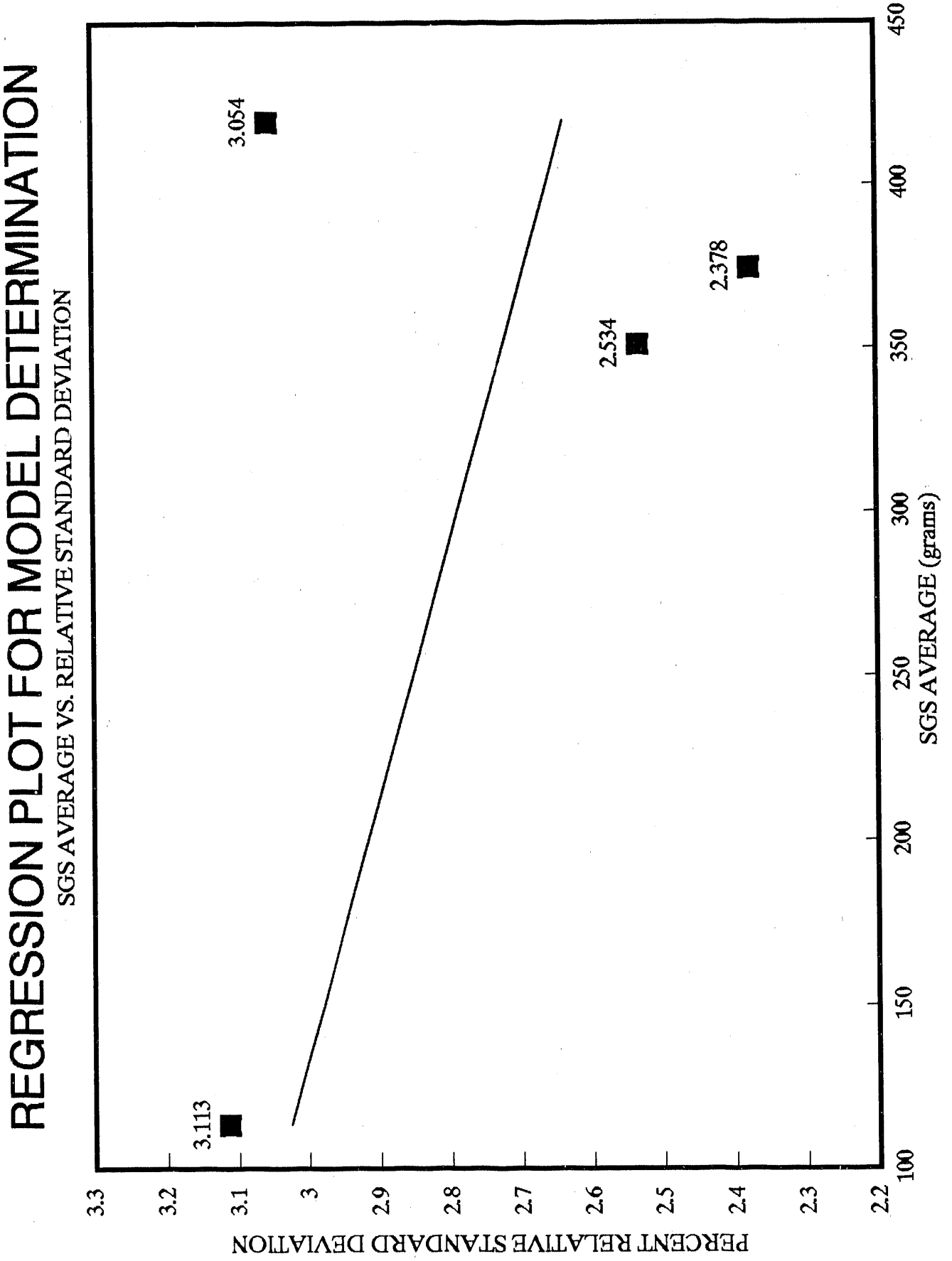

SGS/CALORIMETER RELATIVE BIAS PLOT
BY STANDARD AND OVERALL AVERAGE
1.08
0.22
-0.01
-0.12
-1.77
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
PERCENT
1
2
3
4
AVG.
STANDARD NUMBER

Figure 2


REGRESSION PLOT FOR MODEL DETERMINATION
SGS AVERAGE VS. RELATIVE STANDARD DEVIATION
PERCENT RELATIVE STANDARD DEVIATION
SGS AVERAGE (grams)
3.113
3.054
2.534
2.378
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
100
150
200
250
300
350
400
450

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