Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

Disclaimer:

We put science to work.™

Savannah River National Laboratory™

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

A U.S. DEPARTMENT OF ENERGY NATIONAL LABORATORY • SAVANNAH RIVER SITE • AIKEN, SC

Mobile Plutonium Facility (MPF) Calorimeter Measurement Uncertainty

T. B. Edwards

May 2019

SRNL-TR-2019-00104, Revision 0

SRNL.DOE.GOV

DISCLAIMER

Printed in the United States of America

Prepared for
U.S. Department of Energy

SRNL-TR-2019-00104
Revision 0

Keywords: *random variation, systematic variation*

Retention: *Permanent*

Mobile Plutonium Facility (MPF) Calorimeter Measurement Uncertainty

T. B. Edwards

May 2019

Prepared for the U.S. Department of Energy under contract number DE-AC09-08SR22470.

Savannah River National Laboratory™
OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

EXECUTIVE SUMMARY

The Department of Energy's (DOE) National Nuclear Security Administration (NNSA), specifically the Office of Material Management and Minimization (NA-23), is responsible for removing and/or securing special nuclear materials from around the globe that pose a threat to the U.S. and international community. Part of this responsibility requires developing the means to rapidly de-nuclearize weapons programs in foreign countries.

The Savannah River Site (SRS) has been tasked by NA-23 to support efforts by establishing a Rapid Response Plutonium Team (RRPT) and developing/procuring the necessary equipment to accomplish the goal of removing plutonium from foreign nations. This includes development of a Mobile Plutonium Facility (MPF) with the overall objective of ensuring the operating crew's safety while fulfilling the mission to stabilize, package, and ship special nuclear material in the most expeditious manner possible.

One piece of equipment supporting this mission is a calorimeter that is to be used in the characterization of the nuclear material. This document provides an investigation of measurements conducted utilizing the MPF calorimeter with the purpose of estimating the uncertainty of its measurements.

The evaluations conducted as part of this investigation have identified three sources of variation that are to be integrated into an estimate of the overall uncertainty of measurements provided by the MPF calorimeter. The sources of variation and each of their associated percent relative standard deviations (%RSDs) are base readings with a %RSD of 0.44%, electrical heat standard (EHS) measurements with a %RSD of 1.7157%, and environmental conditions with a %RSD of 0.7984%. Combining these standard deviations in quadrature yields an estimate of the %RSD for overall uncertainty of 1.943%. Note that is a one-sigma expression for the MPF calorimeter measurement uncertainty.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
DMM	Digital Multimeter
DOE	Department of Energy
EHS	Electrical Heat Standard
MPF	Mobile Plutonium Facility
NA-25	Office of Material Management and Minimization (within the NNSA)
NNSA	National Nuclear Security Administration
RRPT	Rapid Response Plutonium Team
RSD	Relative Standard Deviation (usually represented as a percentage)
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
Std Dev	Standard Deviation
Std Error	Standard Error (i.e., the standard deviation of an estimate of a parameter)
Std Err Mean	Standard Error (Deviation) of the Mean
W	watt

1.0 Introduction

The Department of Energy's (DOE) National Nuclear Security Administration (NNSA), specifically the Office of Material Management and Minimization (NA-23), is responsible for removing and/or securing special nuclear materials from around the globe that pose a threat to the U.S. and international community. Part of this responsibility requires developing the means to rapidly de-nuclearize weapons programs in foreign countries.

The Savannah River National Laboratory (SRNL) at the Savannah River Site (SRS) has been tasked by NA-23 to support efforts by establishing a Rapid Response Plutonium Team (RRPT) and developing/procuring the necessary equipment to accomplish the goal of removing plutonium from foreign nations. This includes development of a Mobile Plutonium Facility (MPF) with the overall objective of ensuring the operating crew's safety while fulfilling the mission to stabilize, package, and ship special nuclear material in the most expeditious manner possible.

One piece of equipment supporting this mission is a calorimeter that is to be used in the characterization of the nuclear material. This document provides an investigation of measurements conducted utilizing the MPF calorimeter with the purpose of estimating the uncertainty of its measurements. The approach is to use results from base and standard measurements to estimate instrument uncertainty. In addition, data from environmental testing is used to assess the effect of temperature on standards used in the calibration of the instrument. JMP Pro Version 11.2.1 was used to conduct these evaluations [1].

2.0 Quality Assurance

Requirements for performing reviews of technical reports and the extent of review are established in manual E7 2.60. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2

3.0 Base and Standard Results for the MPF Calorimeter

In the following two sub-sections, base and standard measurements from the MPF calorimeter are reviewed and utilized to estimate two important factors contributing to uncertainty in the performance of the instrument. In the first sub-section, the base results are employed to estimate a random uncertainty component associated with these results. The second sub-section investigates results from the measurement of standards, specifically, electrical heat standards (EHSs), to estimate the impact of variation in their measurements on uncertainty.

The calorimeter's base power reading, the base result, is compared to the calorimeter's power reading with an EHS engaged, and the delta establishes the calorimeter's power measurement for that EHS. Given that the EHS has an established power value, this may be considered as a process to calibrate the calorimeter♠. The calorimeter's software then establishes a bias equal to the ratio of the EHS power level to the calorimeter's measurement of the EHS. The calorimeter's software then applies that bias to samples that are subsequently measured by the calorimeter under the calibration established by the base reading and EHS measurement pair. Any new EHS measurement evaluated against the same base reading re-calibrates (i.e., establishes a new bias value) for use as subsequent samples are measured. The typical protocol for the calorimeter also relies on the measurement of a "closing" EHS using that same base reading with the resulting measurement being assessed against acceptance criteria for quality assurance purposes. If these criteria are met, then all of the samples analyzed against the base reading are deemed acceptable.

♠ The uncertainty of the EHS reference values is considered negligible in these evaluations.

3.1 Random Uncertainty Component Estimated via Variation in Base Values

One of the factors contributing to uncertainty in MPF calorimeter measurements is the variation in base power measurements used in the process to calibrate this instrument. Figure 3-1 provides a graphic display of base power results for runs at various power settings (labeled as watt, W, values in the figure). The power settings cover an interval from 0.25W to 20W. There appear to be two sources contributing to the variation seen in these base power results: variation within the runs at a given power setting and variation in the calorimeter's average power reading between power settings. In addition, the 20W run resulted in a much higher power result, 24.1703, than the interval covering the remaining power values, 23.7802 to 23.9021.

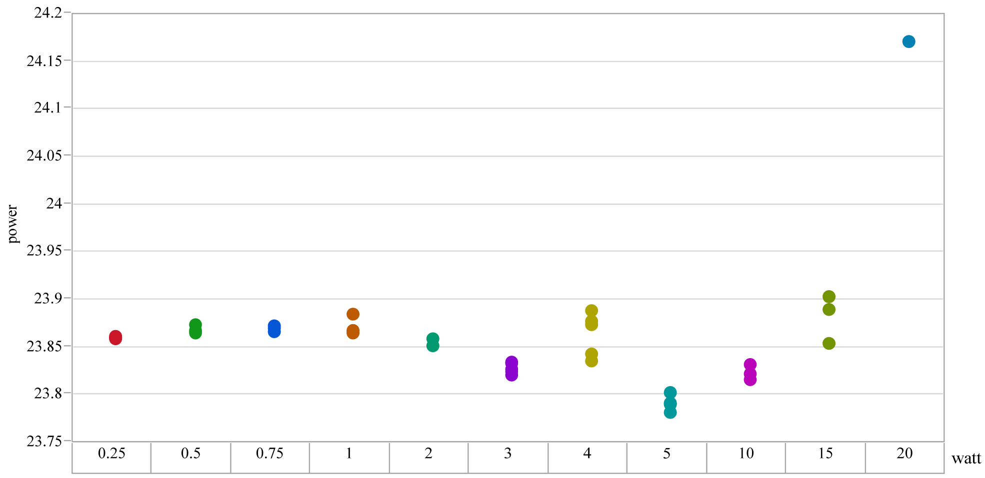


Figure 3-1. Base Power Results for Runs at Various Watt Values.

Exhibit A.1 in Appendix A provides a random effects analysis of variance (ANOVA) evaluation of these results with (provided in Part 1) and without (provided in Part 2) the power result for the 20W setting. The uncertainty of the base results consists of three components: the standard error of mean of these values (provided in the exhibit as the Std Error of the Intercept term), the variance component for the watt (i.e., the calorimeter's power setting), and the residual variance component. Squaring the standard error of the mean to get the variance component for this source of uncertainty facilitates the estimation of the random uncertainty of the base results as the sum of the three variance components. Specifically, the equation for this uncertainty determined using all of the base results is:

$$\text{Uncertainty Variance of the Base Results}_{\text{all data}} = (0.029916)^2 + 0.0097898 + 0.0001541 = 0.010839$$

The result for the estimate of the random variance of the base results with the 20W run excluded is;

$$\text{Uncertainty Variance of the Base Results}_{\text{20W run excluded}} = (0.009001)^2 + 0.0007654 + 0.0001532 = 0.00099962$$

The square root of these estimated variances yields the standard deviation for the random uncertainty of the base results: 0.1041 using all the data and 0.0316 with the 20W run excluded. While the 20W run is a potential outlier, the uncertainty evaluation with this point included (i.e., the estimated standard deviation of 0.1041) is a conservative estimate of this random uncertainty. The smallest value for the base power seen in this study was 23.7802 which implies that the random uncertainty expressed as a relative percentage (i.e., as a percent relative standard deviation, %RSD), would be slightly less than 0.44%.

3.2 Uncertainty Contributions Estimated by Evaluation of EHS Measurements

Another component of the uncertainty in the performance of the MPF calorimeter is explored via a review of results from EHS measurements conducted as part of the calorimetry analytical protocol. As described above, the measured power results of the standards are used to determine a short-term bias for the instrument:

$$\text{bias} = [\text{EHS input watts}]/[\text{measured power for the EHS}]$$

where the measured power for the EHS is the difference between the base power reading and the calorimeter's power reading with the EHS engaged.

Once again, the calorimeter's software applies this bias in the determination of the results for samples that are subsequently analyzed. A closing EHS evaluation is conducted and evaluated against acceptance criteria for quality assurance purposes in monitoring the performance of the MPF calorimeter.

Exhibits A2 through A.7 in Appendix A provide overviews in the form of plots of the data generated by these EHS measurements. In each of these plots, the data are grouped by the watt value for the EHS (i.e., the EHS input power) and measurement runs of the EHS under the corresponding base value (i.e., the Run Group label on the x-axis). The power values displayed in these exhibits are the measured power results while the watt term provides the EHS input power values. In these plots, differences between the input and measured power values are plotted as well as their % difference values. The exhibits also include a plot of the bias values along with additional plots of two other, but mathematically identical, views of these same bias results.

The question to be addressed here: What is the uncertainty of the bias correction developed through this process? A review of the exhibits introduced in this section indicates a sensitivity of the bias values to the EHS input power. Exhibit A.8 in Appendix A provides a display of the % bias from target values for the EHS groupings along with 95% confidence intervals (in the form of green diamonds) for the mean of each group. These results suggest differences in the means for varying EHS input power values, but similar means for the groupings within a fixed EHS input power. Exhibit A.9 in Appendix A provides ANOVA results investigating the Run Groups for each EHS input power level. Statistically significant differences in the Run Group means are seen for only three of the EHS levels: the 0.50W level with a p-value of 0.0338, the 4W level with a p-value of 0.0418, and the 10W level with a p-value of 0.0007.

Two statistical models are utilized to provide more thorough explorations of the groupings for each EHS input power. Exhibit A.10 in Appendix A provides a random effects model of the run groupings for each EHS input power level. Two results are of primary interest for each EHS: the standard error (Std Error) of the intercept term and the estimate of Total Variance. These quantities are combined in quadrature (i.e., the Std Error is squared to obtain its corresponding variance and the two variances are summed to obtain the combined variance). The inputs are provided in Table 3-1 with the last column of the table providing the square root of the combined variance which provides the standard deviation, in this case it is a %RSD since it is being expressed relative to the target value of 1 (which would represent the perfect situation of no bias).

Table 3-1. Estimated Bias Uncertainty (at one sigma) from Random Effects Model.

EHS Watt	Std Error	Total Variance	% Relative Standard Deviation (%RSD)
.25W	0.71638	2.43046	1.7157
.50W	0.41231	0.69944	0.9324
.75W	0.16477	0.15092	0.4220
1W	0.37911	0.65784	0.8953
2W	0.10401	0.07334	0.2901
3W	0.20139	0.23326	0.5233
4W	0.10646	0.05852	0.2643
5W	0.11748	0.05562	0.2635
10W	0.27529	0.17302	0.4988
15W	0.20373	0.46782	0.7137
20W	0.15624	0.04882	0.2706

Exhibit A.11 in Appendix A provides summary statistics for the % bias from target, where once again the target is 1. Included in these results for each EHS power level are a histogram, a table of quantiles, and summary statistics that include the standard deviation and standard error of the mean. Table 3-2 summarizes the uncertainties for each EHS power level by combining the standard error of the mean (Std Err Mean) along with the standard deviation (Std Dev) of the bias variations. These quantities are combined in quadrature (i.e., each is squared to obtain its corresponding variance and the two variances are summed to obtain the total variance). The last column of the table is the square root of the total variance which provides the standard deviation, in this case it is a %RSD since it is being expressed relative to the target value of 1 (which would represent the perfect situation of no bias).

Table 3-2. Estimated Bias Uncertainty (at one sigma) from Summary Statistics.

EHS watt	Std Dev	Std Err Mean	Total Variance	% Relative Standard Deviation (%RSD)
.25W	1.41336	0.44694	2.19736	1.4823
.50W	0.77958	0.24652	0.66851	0.8176
.75W	0.37438	0.11839	0.15418	0.3927
1W	0.77301	0.24445	0.65731	0.8107
2W	0.26530	0.08389	0.07742	0.2782
3W	0.46896	0.14830	0.24191	0.4918
4W	0.23489	0.07428	0.06069	0.2464
5W	0.22286	0.07047	0.05463	0.2337
10W	0.32869	0.10394	0.11884	0.3447
15W	0.67149	0.21234	0.49599	0.7043
20W	0.22096	0.15624	0.07324	0.2706

The larger of the results from Table 3-1 and Table 3-2 may be used selectively to determine this component of uncertainty as the measured values of samples are determined and an appropriate value for the bias correction applied to the sample. In almost all cases the larger of the two %RSDs is provided by Table 3-1. As an alternative, the largest uncertainty value (i.e., 1.7157% from the first row of Table 3-1) may be used to represent a worst case. Note that the effect of the uncertainty in a bias associated with the outcome of an EHS assessment would affect all subsequent samples in the same manner (i.e., it would truly be a short-term bias in the performance of the MPF calorimeter).

4.0 Evaluation of Environmental Effects on the Performance of the Calorimeter

Since the MPF may be utilized under varying environmental conditions, testing was conducted to better understand the potential for such conditions to contribute to the uncertainty in the MPF calorimeter's performance. This contribution to uncertainty is due to the environmental conditions affecting the EHS used for calibrating the calorimeter. Power readings, W in watts, of the EHS (specifically, the EHS readings for both voltage, V, and current, I, with W = V×I) were recorded under various environmental conditions with the purpose of investigating their effect on the performance of the instrument. To provide the data necessary for this evaluation a digital multimeter (DMM) device was setup in a loop with the EHS so as to provide real time data on the voltage and current produced by the EHS♠.

This testing was conducted under five different environmental (temperature) conditions: a 3-day test at room temperature with the voltage of the power supply set to 25 volts (mid-range for temperature), two rate of change test (1 and 2) with the voltage set at 50 volts (varying temperature), a test at 20 volts with the temperature over a 25 to 38 °C interval (high temperature), and a test at 20 volts with the temperature over a 25 to 0 °C interval (low temperature).

Exhibit A.12 in Appendix A provides a plot of the current measurements by the EHS and DMM over time for each of the test conditions. Exhibit A.13 in Appendix A provides similar plots for the voltage measurements for these tests. The current and voltage data were used to determine power values; this was conducted for the EHS and for the DMM. The resulting data were used to calculate a difference of the EHS values relative to the DMM values (i.e., a % relative power [watt] difference). Exhibit A.14 in Appendix A provides a plot of % relative differences for current, voltage, and power over time for each of the test conditions. Exhibit A.15 in Appendix A provides scatterplot displays of the % relative differences for current and voltage between the two devices as well as tables of correlation coefficients for the various tests. The is little correlation seen in these results with correlations ranging from ~ 0.05 to ~ 0.67, with the two 50V tests at varying temperatures having the two highest correlations.

The % relative power [watt] difference have also been plotted in Figure 4-1 with groupings as indicated by information on the x-axis. In most cases, the environmental testing led to a negative bias in the power supplied by the EHS relative to that recorded by the DMM. As seen in Figure 4-1, the extremes of the EHS differences are somewhat sensitive to the conditions under which it is operated.

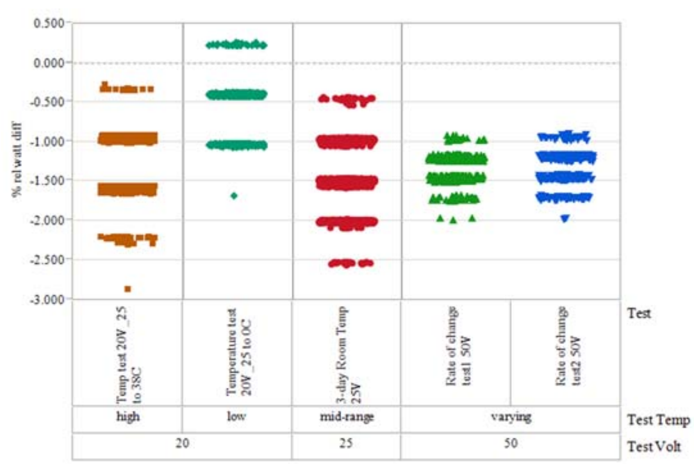


Figure 4-1. % Relative Power Differences for Environmental Tests.

♠ The uncertainty of the DMM values is considered negligible in these evaluations.

The challenge in determining an uncertainty for environmental effects is how to accommodate these test results. Figure 4-2 provides a summary of these results that will be used to facilitate this effort. This figure provides a histogram and summary statistics for the % relative difference values for the power readings. Included in the figure are the standard deviation of the data and a 95% confidence interval for the mean of these difference.

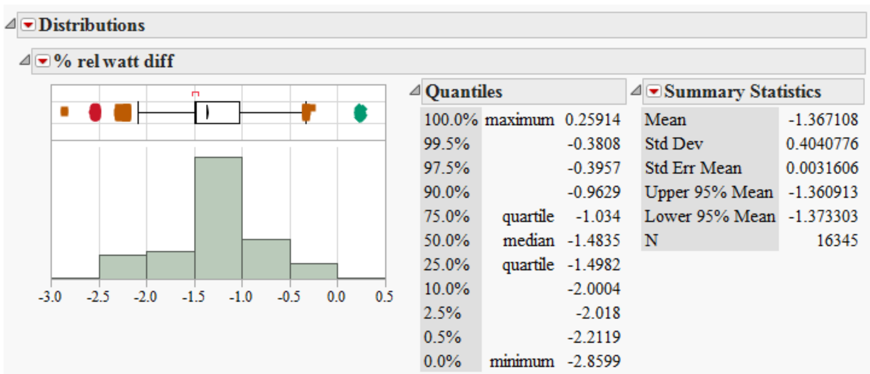


Figure 4-2. Histogram and Summary Statistics for % Relative Power Differences.

The approach is to develop a 95% uncertainty value for these effects by bounding the bias (ignoring its sign in the process) and combining that in quadrature with a 95% bound on the random variation as represented by the standard deviation. For the 95% bound on the bias, the larger of the absolute values of the endpoints of the 95% confidence interval for the mean is determined: 1.373303. Two times the standard deviation (i.e., $2 \times 0.4040776 = 0.8081552$) is used to estimate the random uncertainty to 95% confidence. These two quantities are then combined in quadrature to estimate the square of the total uncertainty at a 95% confidence level:

$$(\text{Uncertainty}_{95\%\ \text{confidence}})^2 = (1.377303)^2 + (0.8081552)^2 = 1.89696 + 0.65311 = 2.55007$$

Taking the square root of this number (i.e., 2.55007) and interpreting the value (i.e., 1.5969) as representing a two-sigma uncertainty lead to a value of 0.7984% as the estimate of the one-sigma, specifically, a %RSD, of the environmental effects on the EHS used to calibrate the MPF calorimeter.

5.0 Conclusions

The NNSA is responsible for removing and/or securing special nuclear materials from around the globe that pose a threat to the U.S. and international community. Part of this responsibility requires developing the means to rapidly de-nuclearize weapons programs in foreign countries. SRS has been tasked by NA-23 to support efforts by establishing a RRPT and developing/procuring the necessary equipment to accomplish the goal of removing plutonium from foreign nations. This includes development of an MPF with the overall objective of ensuring the operating crew's safety while fulfilling the mission to stabilize, package, and ship special nuclear material in the most expeditious manner possible.

One piece of equipment supporting this mission is a calorimeter that is to be used in the characterization of the nuclear material. This document provides an investigation of measurements conducted utilizing the MPF calorimeter with the purpose of estimating the uncertainty of its measurements. The evaluations conducted as part of this investigation have identified three sources of variation that were integrated into an estimate of the overall uncertainty of measurements provided by the MPF calorimeter. The sources of variation and their associated %RSDs are base readings with a %RSD of 0.44%, EHS measurements with a %RSD of 1.7157%, and environmental conditions with a %RSD of 0.7984%. Combining these standard deviations in quadrature yields an estimate of the %RSD for overall uncertainty of 1.943%. Note that is a one-sigma expression for the MPF calorimeter measurement uncertainty.

6.0 References

[1] JMP® Pro Version 11.2.1, SAS Institute, Inc., Cary, NC, 2014.

Appendix A. Supporting Exhibits

Exhibit A.1 Random Effects Analysis of Variance of the Base Power Values

Part 1. Response power Type=Base for all of the results including the 20W run

Whole Model

Summary of Fit

RSquare	0.969291
RSquare Adj	0.969291
Root Mean Square Error	0.012414
Mean of Response	23.85584
Observations (or Sum Wgts)	38

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	23.87939	0.029916	9.836	798.21	<.0001*	23.812582	23.946199

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
watt	63.523446	0.0097898	0.0044394	0.0010888	0.0184908	98.450
Residual		0.0001541	4.2073e-5	9.621e-5	0.0002862	1.550
Total		0.0099439	0.004439	0.0048598	0.0305456	100.000

-2 LogLikelihood = -163.1214544
Note: Total is the sum of the positive variance components.

Total including negative estimates = 0.0099439

Part 2. Response power Type=Base excluding the 20W run result

Whole Model

Summary of Fit

RSquare	0.876898
RSquare Adj	0.876898
Root Mean Square Error	0.012378
Mean of Response	23.84735
Observations (or Sum Wgts)	37

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	23.850477	0.009001	9.144	2649.7	<.0001*	23.830163	23.87079

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
watt	4.995181	0.0007654	0.0003788	2.2849e-5	0.0015079	83.320
Residual		0.0001532	4.1588e-5	9.5884e-5	0.0002833	16.680
Total		0.0009186	0.0003802	0.0004688	0.0025469	100.000

-2 LogLikelihood = -184.0669493
Note: Total is the sum of the positive variance components.

Total including negative estimates = 0.0009186

Exhibit A.2 Calorimeter Power Results (W) for Standards Providing Input Power Values from 0.25W to 20W

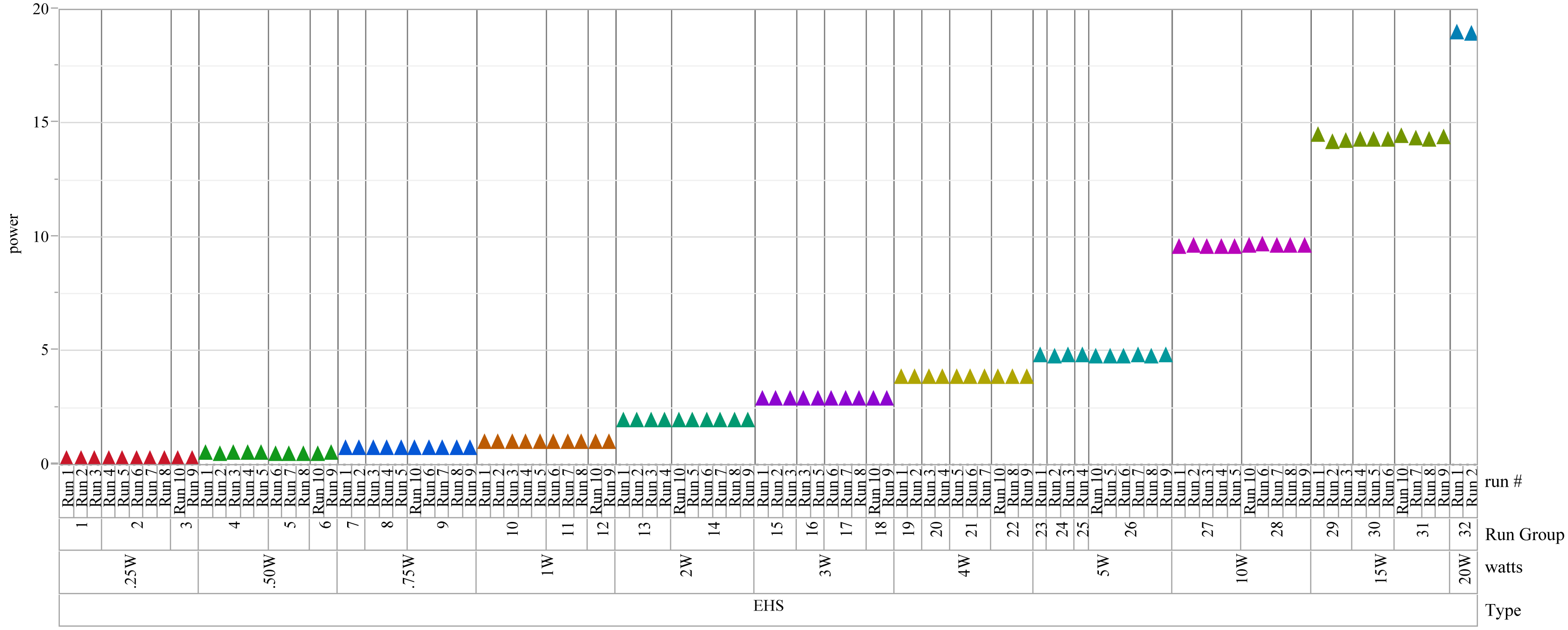


Exhibit A.3 Difference = Measured Power – EHS Watt Results for Standards at Input Power Values from 0.25W to 20W

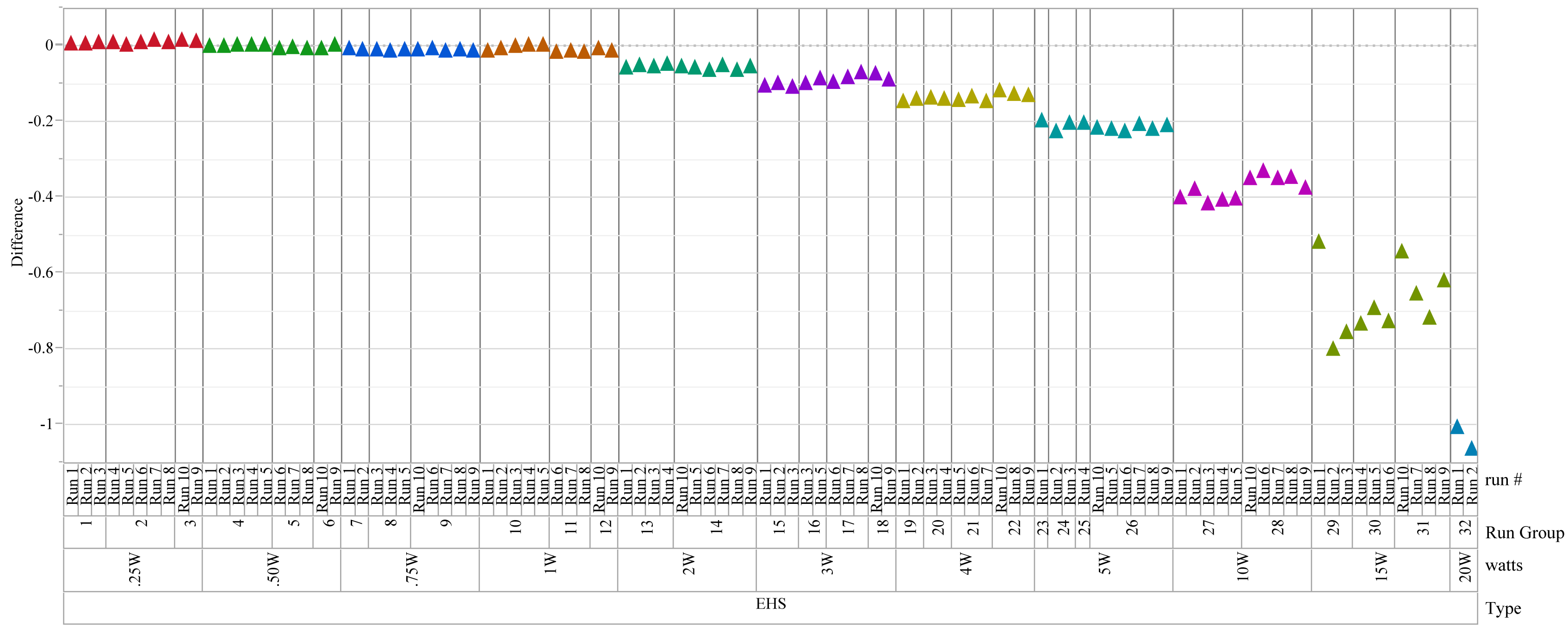


Exhibit A.4 % Difference = 100% ×(Power – Watt)/Watt Results for Standards at Input Power Values from 0.25W to 20W

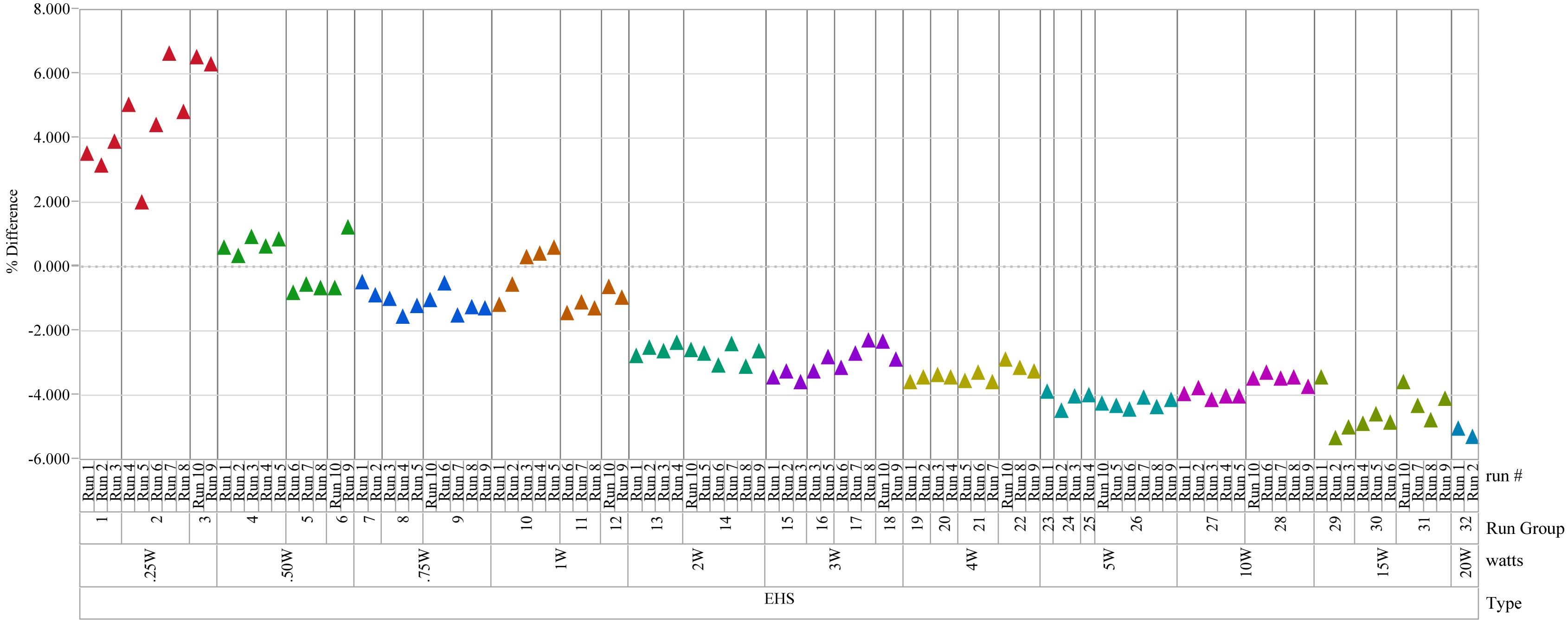


Exhibit A.5 Bias = [Input Watt]/[Measured Power] Results for Standards at Input Power Values from 0.25W to 20W

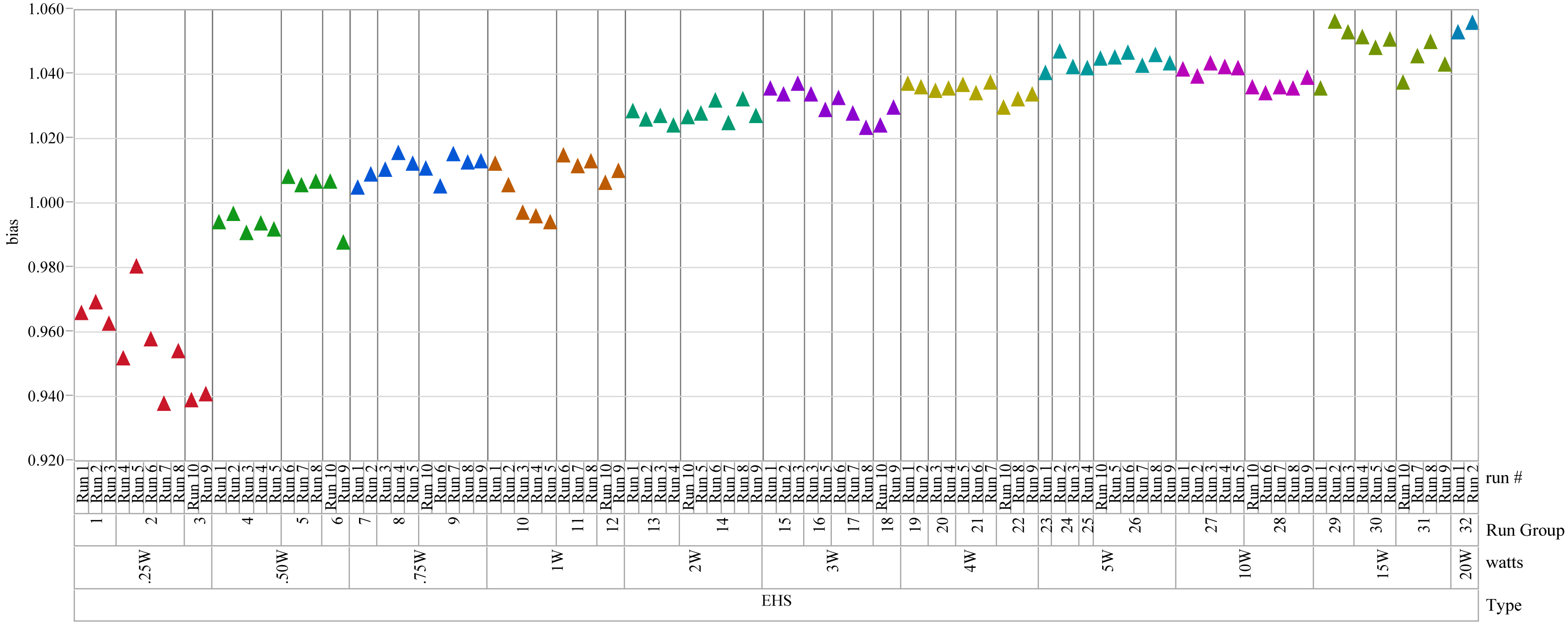


Exhibit A.6 Results for Bias as Deviation from Target = (Watt/Power) – 1 for Standards at Input Power Values from 0.25W to 20W

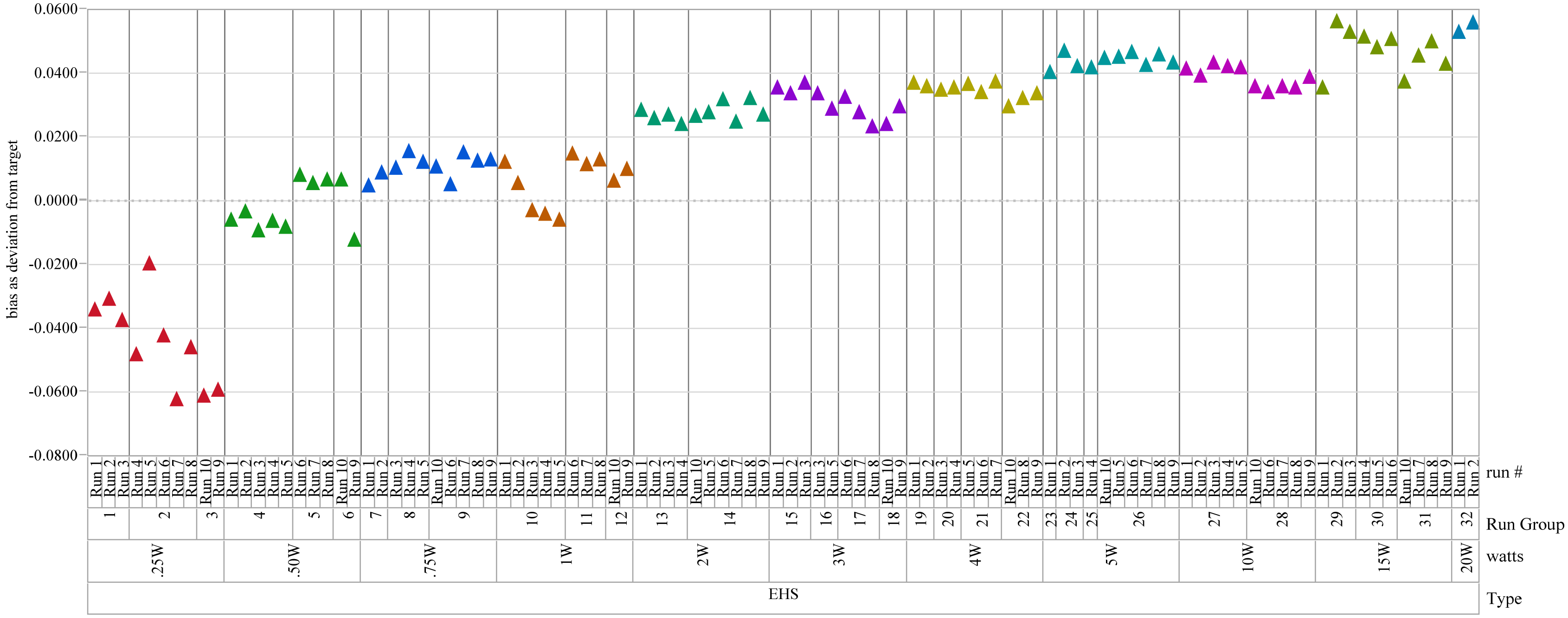


Exhibit A.7 Results for % Bias from Target = 100% × [(Watt/Power) – 1] for Standards at Input Power Values from 0.25W to 20W

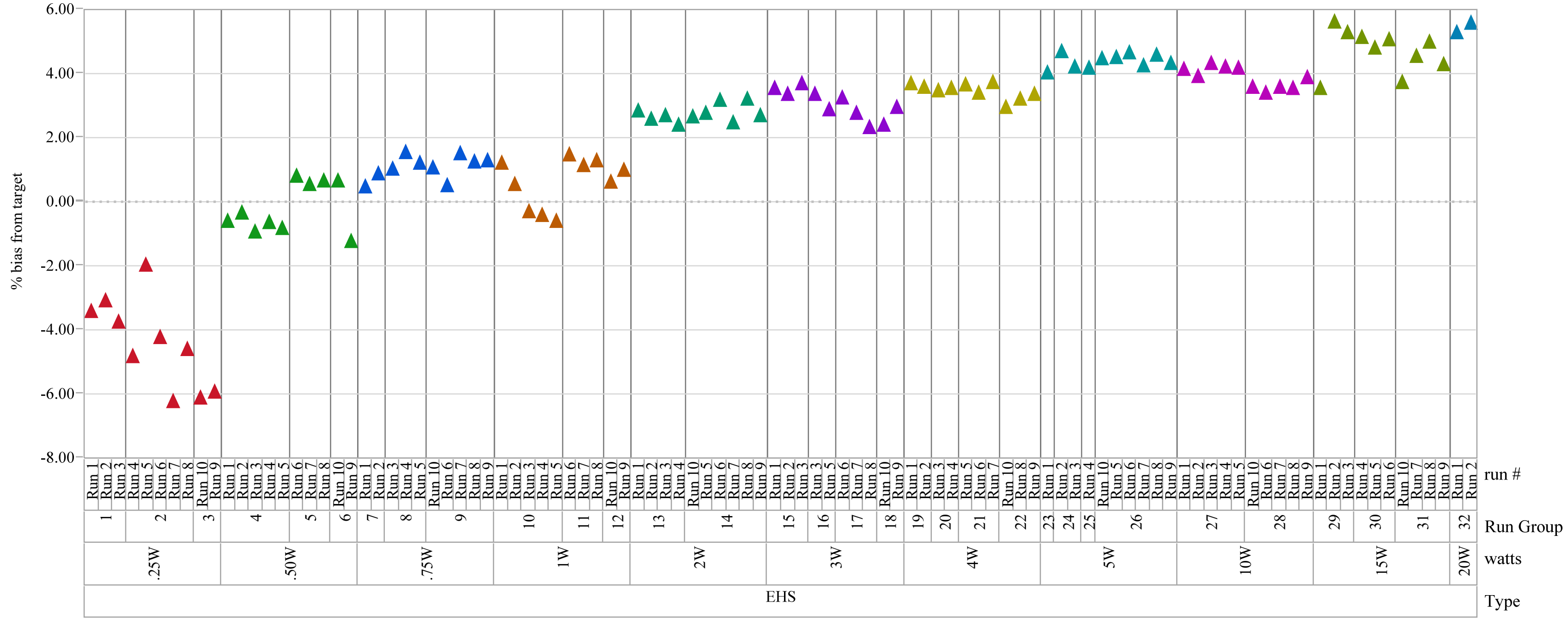


Exhibit A.8 % Bias from Target Values with 95% Confidence Intervals (Green Diamonds) for the Mean of EHS Groupings

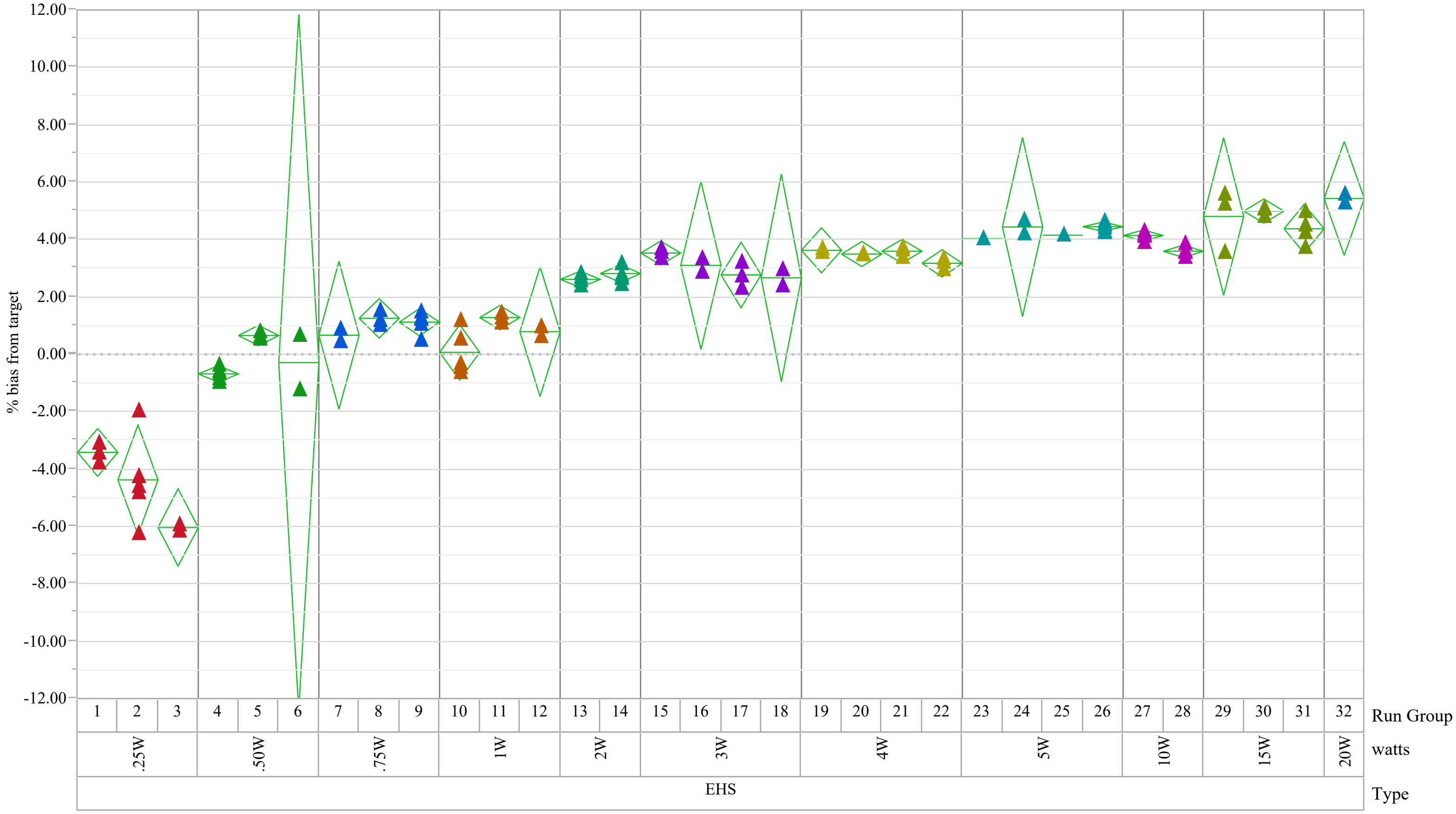
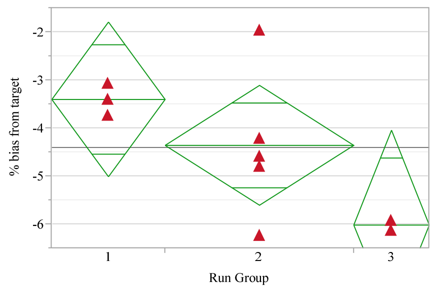


Exhibit A.9 Analysis of Variance for % Bias from Target Values of Groupings within EHS Input Power Levels

Oneway Analysis of % bias from target By Run Group Type=EHS, watts=.25W



Oneway Anova
Summary of Fit

Rsquare	0.457683
Adj Rsquare	0.302735
Root Mean Square Error	1.180193
Mean of Response	-4.40087
Observations (or Sum Wgts)	10

Analysis of Variance

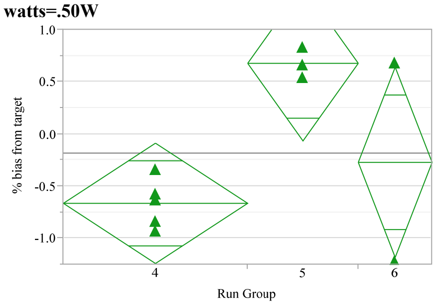
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Run Group	2	8.228392	4.11420	2.9538	0.1175
Error	7	9.749987	1.39286		
C. Total	9	17.978380			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	-3.3995	0.68138	-5.011	-1.788
2	5	-4.3560	0.52780	-5.604	-3.108
3	2	-6.0149	0.83452	-7.988	-4.042

Std Error uses a pooled estimate of error variance

Oneway Analysis of % bias from target By Run Group Type=EHS, watts=.50W



Oneway Anova
Summary of Fit

Rsquare	0.620138
Adj Rsquare	0.511606
Root Mean Square Error	0.544809
Mean of Response	-0.18217
Observations (or Sum Wgts)	10

Analysis of Variance

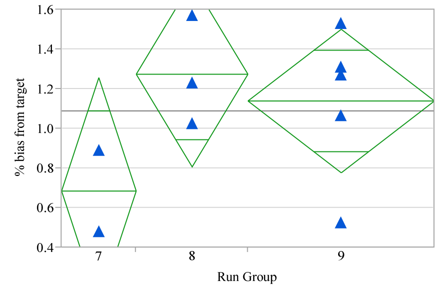
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Run Group	2	3.3919426	1.69597	5.7139	0.0338*
Error	7	2.0777178	0.29682		
C. Total	9	5.4696604			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
4	5	-0.66314	0.24365	-1.239	-0.087
5	3	0.67803	0.31455	-0.066	1.422
6	2	-0.27008	0.38524	-1.181	0.641

Std Error uses a pooled estimate of error variance

Oneway Analysis of % bias from target By Run Group Type=EHS, watts=.75W



Oneway Anova
Summary of Fit

Rsquare	0.350386
Adj Rsquare	0.164782
Root Mean Square Error	0.342146
Mean of Response	1.088953
Observations (or Sum Wgts)	10

Analysis of Variance

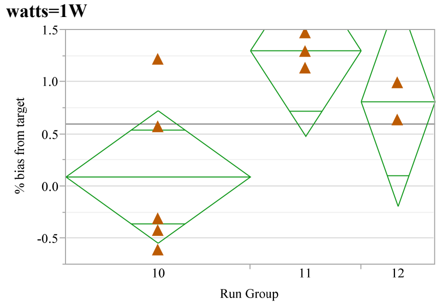
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Run Group	2	0.4419900	0.220995	1.8878	0.2209
Error	7	0.8194460	0.117064		
C. Total	9	1.2614360			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
7	2	0.68506	0.24193	0.11298	1.2571
8	3	1.27430	0.19754	0.80720	1.7414
9	5	1.13930	0.15301	0.77748	1.5011

Std Error uses a pooled estimate of error variance

Oneway Analysis of % bias from target By Run Group Type=EHS, watts=1W



Oneway Anova
Summary of Fit

Rsquare	0.531194
Adj Rsquare	0.397249
Root Mean Square Error	0.600145
Mean of Response	0.597857
Observations (or Sum Wgts)	10

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Run Group	2	2.8567387	1.42837	3.9658	0.0705
Error	7	2.5212182	0.36017		
C. Total	9	5.3779569			

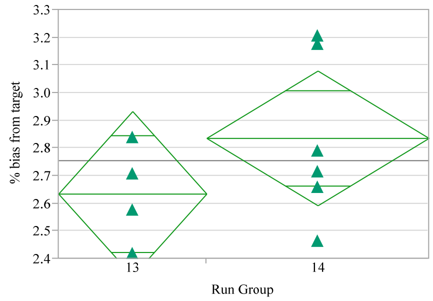
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
10	5	0.09085	0.26839	-0.5438	0.7255
11	3	1.30021	0.34649	0.4809	2.1195
12	2	0.81185	0.42437	-0.1916	1.8153

Std Error uses a pooled estimate of error variance

Exhibit A.9 Analysis of Variance for % Bias from Target Values of Groupings within EHS Input Power Levels (continued)

Oneway Analysis of % bias from target By Run Group Type=EHS, watts=2W



Oneway Anova
Summary of Fit

Rsquare	0.153749
Adj Rsquare	0.047968
Root Mean Square Error	0.258857
Mean of Response	2.754945
Observations (or Sum Wgts)	10

Analysis of Variance

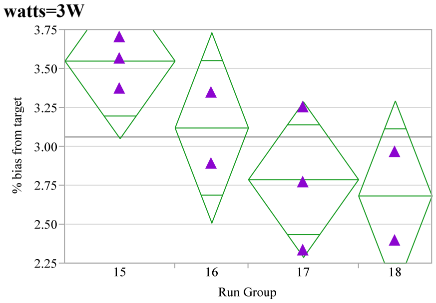
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Run Group	1	0.09739171	0.097392	1.4535	0.2624
Error	8	0.53605432	0.067007		
C. Total	9	0.63344604			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
13	4	2.63408	0.12943	2.3356	2.9325
14	6	2.83552	0.10568	2.5918	3.0792

Std Error uses a pooled estimate of error variance

Oneway Analysis of % bias from target By Run Group Type=EHS, watts=3W



Oneway Anova
Summary of Fit

Rsquare	0.62273
Adj Rsquare	0.434095
Root Mean Square Error	0.352781
Mean of Response	3.063186
Observations (or Sum Wgts)	10

Analysis of Variance

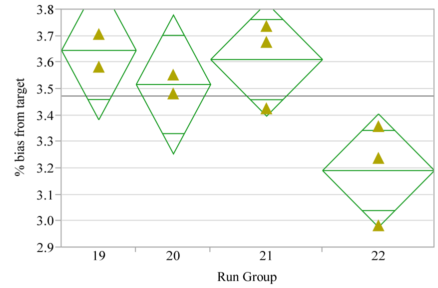
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Run Group	3	1.2325625	0.410854	3.3012	0.0993
Error	6	0.7467265	0.124454		
C. Total	9	1.9792891			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
15	3	3.55082	0.20368	3.0524	4.0492
16	2	3.12165	0.24945	2.5113	3.7320
17	3	2.78921	0.20368	2.2908	3.2876
18	2	2.68425	0.24945	2.0739	3.2946

Std Error uses a pooled estimate of error variance

Oneway Analysis of % bias from target By Run Group Type=EHS, watts=4W



Oneway Anova
Summary of Fit

Rsquare	0.722003
Adj Rsquare	0.583005
Root Mean Square Error	0.151682
Mean of Response	3.473233
Observations (or Sum Wgts)	10

Analysis of Variance

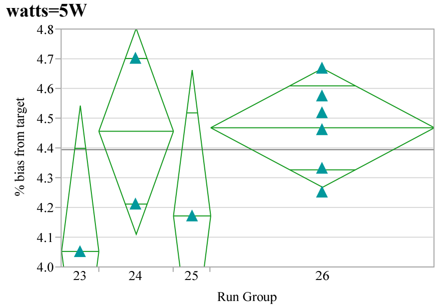
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Run Group	3	0.35852447	0.119508	5.1943	0.0418*
Error	6	0.13804453	0.023007		
C. Total	9	0.49656899			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
19	2	3.64578	0.10726	3.3833	3.9082
20	2	3.51673	0.10726	3.2543	3.7792
21	3	3.61101	0.08757	3.3967	3.8253
22	3	3.19142	0.08757	2.9771	3.4057

Std Error uses a pooled estimate of error variance

Oneway Analysis of % bias from target By Run Group Type=EHS, watts=5W



Oneway Anova
Summary of Fit

Rsquare	0.462189
Adj Rsquare	0.193283
Root Mean Square Error	0.200165
Mean of Response	4.395895
Observations (or Sum Wgts)	10

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Run Group	3	0.20659426	0.068865	1.7188	0.2619
Error	6	0.24039669	0.040066		
C. Total	9	0.44699096			

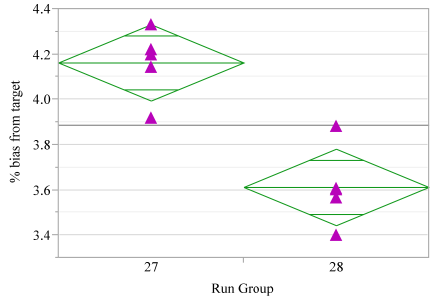
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
23	1	4.05394	0.20017	3.5642	4.5437
24	2	4.45777	0.14154	4.1114	4.8041
25	1	4.17318	0.20017	3.6834	4.6630
26	6	4.46938	0.08172	4.2694	4.6693

Std Error uses a pooled estimate of error variance

Exhibit A.9 Analysis of Variance for % Bias from Target Values of Groupings within EHS Input Power Levels (continued)

Oneway Analysis of % bias from target By Run Group Type=EHS, watts=10W



Oneway Anova
Summary of Fit

Rsquare	0.779378
Adj Rsquare	0.7518
Root Mean Square Error	0.163754
Mean of Response	3.887002
Observations (or Sum Wgts)	10

Analysis of Variance

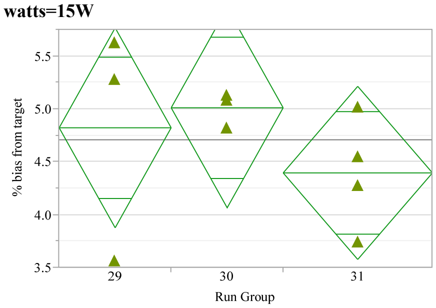
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Run Group	1	0.75783160	0.757832	28.2610	0.0007*
Error	8	0.21452338	0.026815		
C. Total	9	0.97235498			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
27	5	4.16229	0.07323	3.9934	4.3312
28	5	3.61171	0.07323	3.4428	3.7806

Std Error uses a pooled estimate of error variance

Oneway Analysis of % bias from target By Run Group Type=EHS, watts=15W



Oneway Anova
Summary of Fit

Rsquare	0.173483
Adj Rsquare	-0.06266
Root Mean Square Error	0.692213
Mean of Response	4.709937
Observations (or Sum Wgts)	10

Analysis of Variance

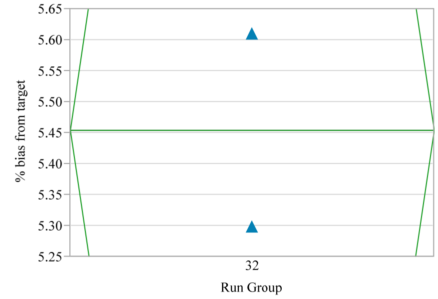
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Run Group	2	0.7040177	0.352009	0.7346	0.5133
Error	7	3.3541092	0.479158		
C. Total	9	4.0581269			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
29	3	4.82351	0.39965	3.8785	5.7685
30	3	5.01278	0.39965	4.0678	5.9578
31	4	4.39762	0.34611	3.5792	5.2160

Std Error uses a pooled estimate of error variance

Oneway Analysis of % bias from target By Run Group Type=EHS, watts=20W



Oneway Anova
Summary of Fit

Rsquare	0
Adj Rsquare	0
Root Mean Square Error	0.220963
Mean of Response	5.454317
Observations (or Sum Wgts)	2

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Run Group	0	0.00000000	.	.	.
Error	1	0.04882454	0.048825		
C. Total	1	0.04882454			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
32	2	5.45432	0.15624	3.4690	7.4396

Std Error uses a pooled estimate of error variance

Exhibit A.10 Random Effects Analysis of Variance for % Bias from Target Values of Groupings within EHS Input Power Levels

Response % bias from target Type=EHS, watts=.25W
Whole Model
Summary of Fit

RSquare	0.392493
RSquare Adj	0.392493
Root Mean Square Error	1.194951
Mean of Response	-4.40087
Observations (or Sum Wgts)	10

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	-4.513021	0.71638	1.587	-6.30	0.0414*

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Run Group	0.7021111	1.0025496	1.6776317	-2.285548	4.2906473	41.249
Residual		1.4279074	0.7855439	0.6124954	6.2584336	58.751
Total		2.430457	1.6625521	0.8943691	18.140466	100.000

-2 LogLikelihood = 33.33070274
Note: Total is the sum of the positive variance components.
Total including negative estimates = 2.430457

Response % bias from target Type=EHS, watts=.50W
Whole Model
Summary of Fit

RSquare	0.602145
RSquare Adj	0.602145
Root Mean Square Error	0.542428
Mean of Response	-0.18217
Observations (or Sum Wgts)	10

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	-0.095891	0.41231	2.094	-0.23	0.8369

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Run Group	1.3771911	0.4052084	0.4912319	-0.557588	1.3680052	57.934
Residual		0.2942282	0.1559379	0.1293374	1.1992217	42.066
Total		0.6994366	0.5040913	0.2474698	6.1386946	100.000

-2 LogLikelihood = 20.114111934
Note: Total is the sum of the positive variance components.
Total including negative estimates = 0.6994366

Response % bias from target Type=EHS, watts=.75W
Whole Model
Summary of Fit

RSquare	0.198034
RSquare Adj	0.198034
Root Mean Square Error	0.35133
Mean of Response	1.088953
Observations (or Sum Wgts)	10

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	1.0697713	0.164769	1.09	6.49	0.0838

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Run Group	0.2227218	0.0274912	0.093869	-0.156489	0.2114711	18.215
Residual		0.1234327	0.0711577	0.0513067	0.5965963	81.785
Total		0.1509239	0.0881296	0.0621862	0.7503511	100.000

-2 LogLikelihood = 10.054278824
Note: Total is the sum of the positive variance components.
Total including negative estimates = 0.1509239

Response % bias from target Type=EHS, watts=1W
Whole Model
Summary of Fit

RSquare	0.502735
RSquare Adj	0.502735
Root Mean Square Error	0.594596
Mean of Response	0.597857
Observations (or Sum Wgts)	10

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	0.7042062	0.379107	2.195	1.86	0.1929

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Run Group	0.8607038	0.3042969	0.3993689	-0.478452	1.0870456	46.257
Residual		0.3535443	0.1858306	0.1562473	1.4188035	53.743
Total		0.6578412	0.4249341	0.2524575	4.1812726	100.000

-2 LogLikelihood = 21.050991239
Note: Total is the sum of the positive variance components.
Total including negative estimates = 0.6578412

Exhibit A.10 Random Effects Analysis of Variance for % Bias from Target Values of Groupings within EHS Input Power Levels (continued)

Response % bias from target Type=EHS, watts=2W
Whole Model
Summary of Fit

RSquare	0.08097
RSquare Adj	0.08097
Root Mean Square Error	0.258857
Mean of Response	2.754945
Observations (or Sum Wgts)	10

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	2.7486606	0.104006	0.927	26.43	0.0302*

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Run Group	0.0944709	0.0063302	0.029531	-0.05155	0.06421	8.632
Residual		0.0670068	0.0335034	0.0305713	0.2459269	91.368
Total		0.073337	0.0390751	0.0321263	0.3019365	100.000

-2 LogLikelihood = 3.8907740257
Note: Total is the sum of the positive variance components.
Total including negative estimates = 0.073337

Response % bias from target Type=EHS, watts=3W
Whole Model
Summary of Fit

RSquare	0.569775
RSquare Adj	0.569775
Root Mean Square Error	0.35022
Mean of Response	3.063186
Observations (or Sum Wgts)	10

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	3.0449198	0.201394	3.15	15.12	0.0005*

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Run Group	0.9017551	0.1106038	0.1298613	-0.14392	0.3651273	47.417
Residual		0.1226539	0.0697908	0.0514369	0.5764003	52.583
Total		0.2332578	0.1358929	0.0962631	1.1537607	100.000

-2 LogLikelihood = 12.450515213
Note: Total is the sum of the positive variance components.
Total including negative estimates = 0.2332578

Response % bias from target Type=EHS, watts=4W
Whole Model
Summary of Fit

RSquare	0.697011
RSquare Adj	0.697011
Root Mean Square Error	0.150706
Mean of Response	3.473233
Observations (or Sum Wgts)	10

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	3.4874731	0.10646	3.142	32.76	<.0001*

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Run Group	1.5764178	0.035804	0.0361971	-0.035141	0.106749	61.186
Residual		0.0227123	0.0129497	0.0095117	0.1071974	38.814
Total		0.0585163	0.0370518	0.0227812	0.3530381	100.000

-2 LogLikelihood = -1.485638812
Note: Total is the sum of the positive variance components.
Total including negative estimates = 0.0585163

Response % bias from target Type=EHS, watts=5W
Whole Model
Summary of Fit

RSquare	0.280273
RSquare Adj	0.280273
Root Mean Square Error	0.202407
Mean of Response	4.395895
Observations (or Sum Wgts)	10

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	4.3511144	0.117478	1.661	37.04	0.0020*

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Run Group	0.3575552	0.0146485	0.0367408	-0.057362	0.0866592	26.338
Residual		0.0409686	0.0242989	0.0167003	0.2109707	73.662
Total		0.0556171	0.033805	0.0222884	0.3032615	100.000

-2 LogLikelihood = 0.5975692865
Note: Total is the sum of the positive variance components.
Total including negative estimates = 0.0556171

Exhibit A.10 Random Effects Analysis of Variance for % Bias from Target Values of Groupings within EHS Input Power Levels (continued)

Response % bias from target Type=EHS, watts=10W
Whole Model
Summary of Fit

RSquare	0.778402
RSquare Adj	0.778402
Root Mean Square Error	0.163754
Mean of Response	3.887002
Observations (or Sum Wgts)	10

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	3.8870023	0.275287	1	14.12	0.0450*

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Run Group	5.4522069	0.1462032	0.2143639	-0.273942	0.5663488	84.501
Residual		0.0268154	0.0134077	0.0122343	0.0984174	15.499
Total		0.1730187	0.2146154	0.0387865	38.503519	100.000

-2 LogLikelihood = -1.38403997
Note: Total is the sum of the positive variance components.
Total including negative estimates = 0.1730187

Response % bias from target Type=EHS, watts=15W
Whole Model
Summary of Fit

RSquare	-0.0832
RSquare Adj	-0.0832
Root Mean Square Error	0.683977
Mean of Response	4.709937
Observations (or Sum Wgts)	10

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	4.7023159	0.203731	2.151	23.08	0.0013*

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Run Group	-0.050017	-0.023399	0.1265443	-0.271422	0.224623	0.000
Residual		0.4678243	0.2447996	0.2073517	1.8618856	100.000
Total		0.4678243	0.2447996	0.2073517	1.8618856	100.000

-2 LogLikelihood = 20.645409239
Note: Total is the sum of the positive variance components.
Total including negative estimates = 0.444425

Response % bias from target Type=EHS, watts=20W
Whole Model
Summary of Fit

RSquare	0
RSquare Adj	0
Root Mean Square Error	0.220963
Mean of Response	5.454317
Observations (or Sum Wgts)	2

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	5.4543168	0.156244	1	34.91	0.0182*

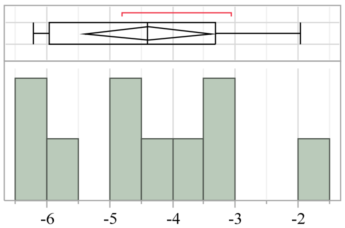
REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Run Group	0	0	0	0	0	0.000
Residual		0.0488245	0.0690483	0.0097185	49.715995	100.000
Total		0.0488245	0.0690483	0.0097185	49.715995	100.000

Not enough data at this EHS for this to be a viable approach.

Exhibit A.11 Summary Statistics for % Bias from Target Values for Each EHS Input Power Level

Distributions watts=.25W
% bias from target



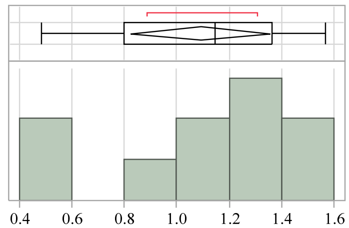
Quantiles

100.0%	maximum	-1.9608
99.5%		-1.9608
97.5%		-1.9608
90.0%		-2.071
75.0%	quartile	-3.316
50.0%	median	-4.3974
25.0%	quartile	-5.9619
10.0%		-6.216
2.5%		-6.2266
0.5%		-6.2266
0.0%	minimum	-6.2266

Summary Statistics

Mean	-4.400865
Std Dev	1.413364
Std Err Mean	0.4469449
Upper 95% Mean	-3.389806
Lower 95% Mean	-5.411925
N	10

Distributions watts=.75W
% bias from target



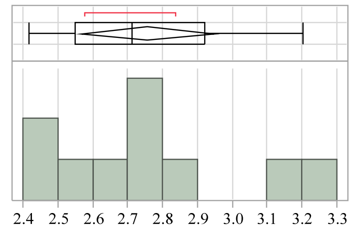
Quantiles

100.0%	maximum	1.57096
99.5%		1.57096
97.5%		1.57096
90.0%		1.56684
75.0%	quartile	1.36514
50.0%	median	1.14639
25.0%	quartile	0.79654
10.0%		0.48636
2.5%		0.48232
0.5%		0.48232
0.0%	minimum	0.48232

Summary Statistics

Mean	1.0889535
Std Dev	0.3743789
Std Err Mean	0.118389
Upper 95% Mean	1.356768
Lower 95% Mean	0.8211389
N	10

Distributions watts=2W
% bias from target



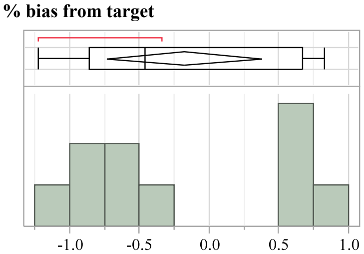
Quantiles

100.0%	maximum	3.2045
99.5%		3.2045
97.5%		3.2045
90.0%		3.20184
75.0%	quartile	2.92322
50.0%	median	2.71159
25.0%	quartile	2.54703
10.0%		2.42176
2.5%		2.41704
0.5%		2.41704
0.0%	minimum	2.41704

Summary Statistics

Mean	2.7549454
Std Dev	0.2652977
Std Err Mean	0.0838945
Upper 95% Mean	2.9447279
Lower 95% Mean	2.5651628
N	10

Distributions watts=.50W
% bias from target



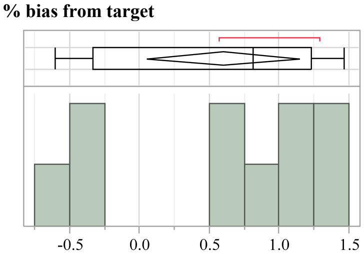
Quantiles

100.0%	maximum	0.82678
99.5%		0.82678
97.5%		0.82678
90.0%		0.81257
75.0%	quartile	0.66945
50.0%	median	-0.4578
25.0%	quartile	-0.8576
10.0%		-1.1955
2.5%		-1.2248
0.5%		-1.2248
0.0%	minimum	-1.2248

Summary Statistics

Mean	-0.182174
Std Dev	0.7795768
Std Err Mean	0.2465238
Upper 95% Mean	0.3755014
Lower 95% Mean	-0.73985
N	10

Distributions watts=1W
% bias from target



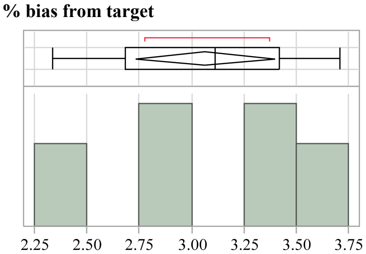
Quantiles

100.0%	maximum	1.47133
99.5%		1.47133
97.5%		1.47133
90.0%		1.45386
75.0%	quartile	1.23508
50.0%	median	0.81185
25.0%	quartile	-0.3363
10.0%		-0.5875
2.5%		-0.6063
0.5%		-0.6063
0.0%	minimum	-0.6063

Summary Statistics

Mean	0.5978566
Std Dev	0.7730141
Std Err Mean	0.2444485
Upper 95% Mean	1.1508375
Lower 95% Mean	0.0448756
N	10

Distributions watts=3W
% bias from target



Quantiles

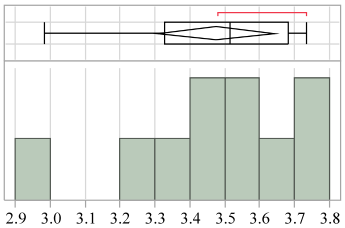
100.0%	maximum	3.70934
99.5%		3.70934
97.5%		3.70934
90.0%		3.69502
75.0%	quartile	3.42427
50.0%	median	3.11247
25.0%	quartile	2.68108
10.0%		2.34298
2.5%		2.33669
0.5%		2.33669
0.0%	minimum	2.33669

Summary Statistics

Mean	3.0631859
Std Dev	0.4689574
Std Err Mean	0.1482973
Upper 95% Mean	3.3986578
Lower 95% Mean	2.727714
N	10

Exhibit A.11 Summary Statistics for % Bias from Target Values for Each EHS Input Power Level (continued)

Distributions watts=4W
% bias from target



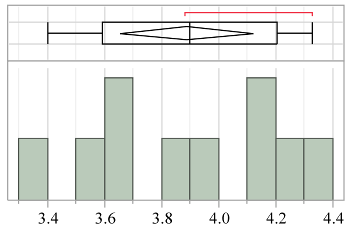
Quantiles

100.0%	maximum	3.73444
99.5%		3.73444
97.5%		3.73444
90.0%		3.73175
75.0%	quartile	3.68335
50.0%	median	3.51673
25.0%	quartile	3.32649
10.0%		3.00682
2.5%		2.98131
0.5%		2.98131
0.0%	minimum	2.98131

Summary Statistics

Mean	3.4732333
Std Dev	0.2348922
Std Err Mean	0.0742794
Upper 95% Mean	3.641265
Lower 95% Mean	3.3052016
N	10

Distributions watts=10W
% bias from target



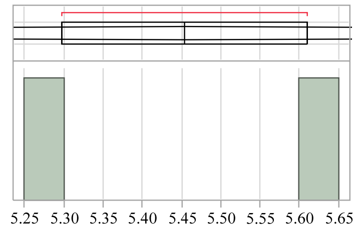
Quantiles

100.0%	maximum	4.32968
99.5%		4.32968
97.5%		4.32968
90.0%		4.31903
75.0%	quartile	4.20439
50.0%	median	3.89988
25.0%	quartile	3.59233
10.0%		3.41638
2.5%		3.39978
0.5%		3.39978
0.0%	minimum	3.39978

Summary Statistics

Mean	3.8870023
Std Dev	0.3286935
Std Err Mean	0.103942
Upper 95% Mean	4.1221354
Lower 95% Mean	3.6518691
N	10

Distributions watts=20W
% bias from target



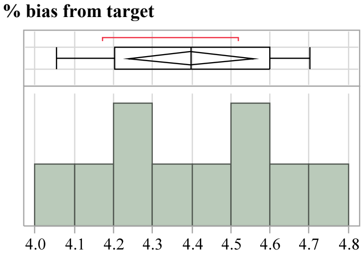
Quantiles

100.0%	maximum	5.61056
99.5%		5.61056
97.5%		5.61056
90.0%		5.61056
75.0%	quartile	5.61056
50.0%	median	5.45432
25.0%	quartile	5.29807
10.0%		5.29807
2.5%		5.29807
0.5%		5.29807
0.0%	minimum	5.29807

Summary Statistics

Mean	5.4543168
Std Dev	0.2209628
Std Err Mean	0.1562443
Upper 95% Mean	7.4395885
Lower 95% Mean	3.4690451
N	2

Distributions watts=5W
% bias from target



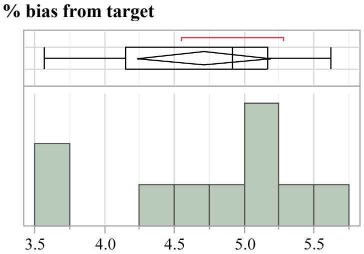
Quantiles

100.0%	maximum	4.70327
99.5%		4.70327
97.5%		4.70327
90.0%		4.69998
75.0%	quartile	4.59979
50.0%	median	4.39834
25.0%	quartile	4.20249
10.0%		4.06587
2.5%		4.05394
0.5%		4.05394
0.0%	minimum	4.05394

Summary Statistics

Mean	4.3958949
Std Dev	0.2228579
Std Err Mean	0.0704739
Upper 95% Mean	4.5553179
Lower 95% Mean	4.236472
N	10

Distributions watts=15W
% bias from target



Quantiles

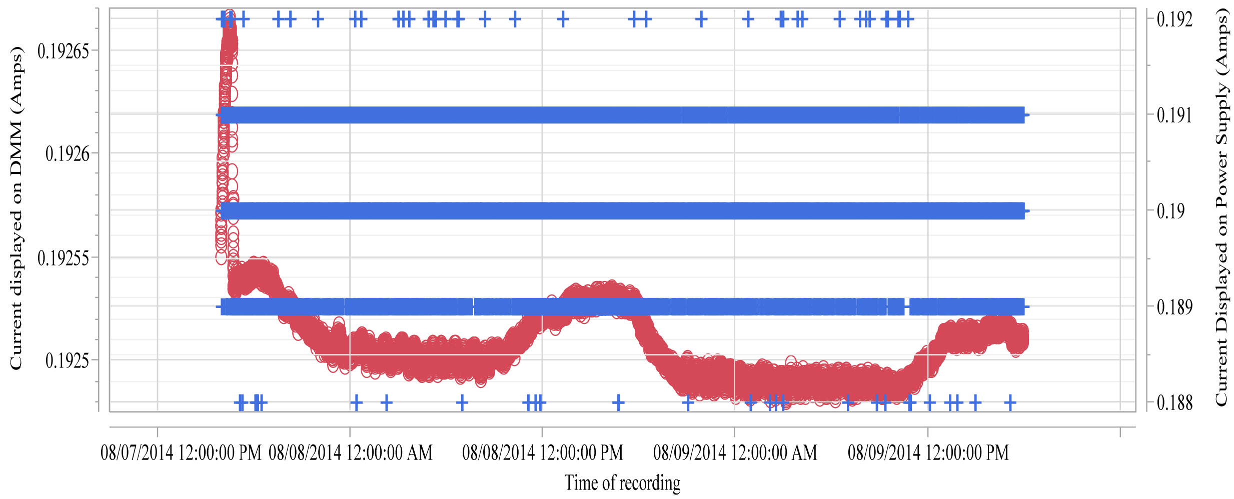
100.0%	maximum	5.62562
99.5%		5.62562
97.5%		5.62562
90.0%		5.5913
75.0%	quartile	5.16947
50.0%	median	4.91868
25.0%	quartile	4.14713
10.0%		3.58039
2.5%		3.56255
0.5%		3.56255
0.0%	minimum	3.56255

Summary Statistics

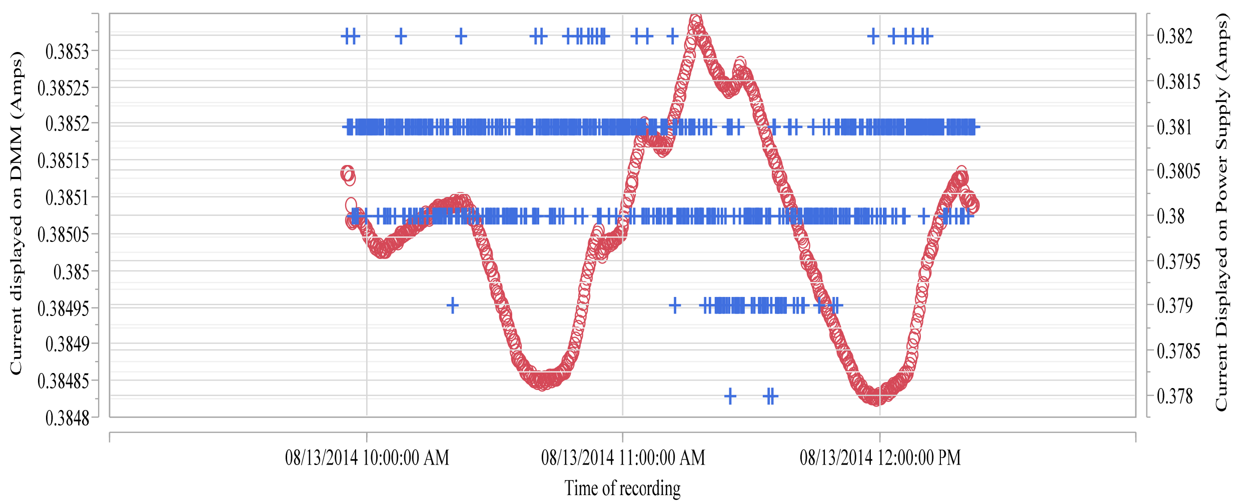
Mean	4.7099367
Std Dev	0.6714931
Std Err Mean	0.2123448
Upper 95% Mean	5.1902939
Lower 95% Mean	4.2295794
N	10

Exhibit A.12 Plots of Current from the EHS Power Supply and the DMM

Test=3-day Room Temp 25V, Test Volt=25, Test Temp=mid-range



Test=Rate of change test1 50V, Test Volt=50, Test Temp=varying

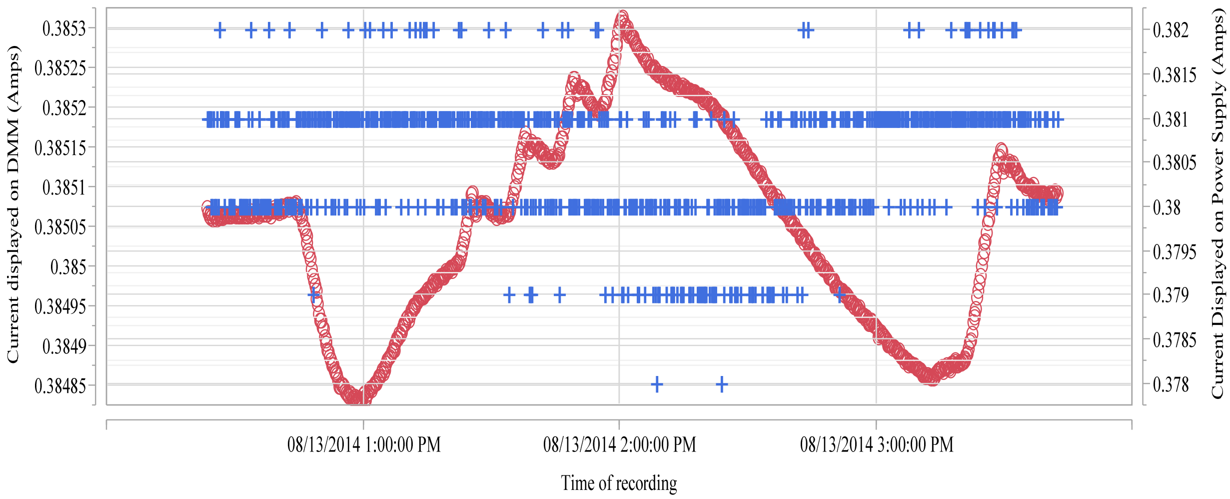


Left Scale: ○ Current displayed on DMM (Amps)

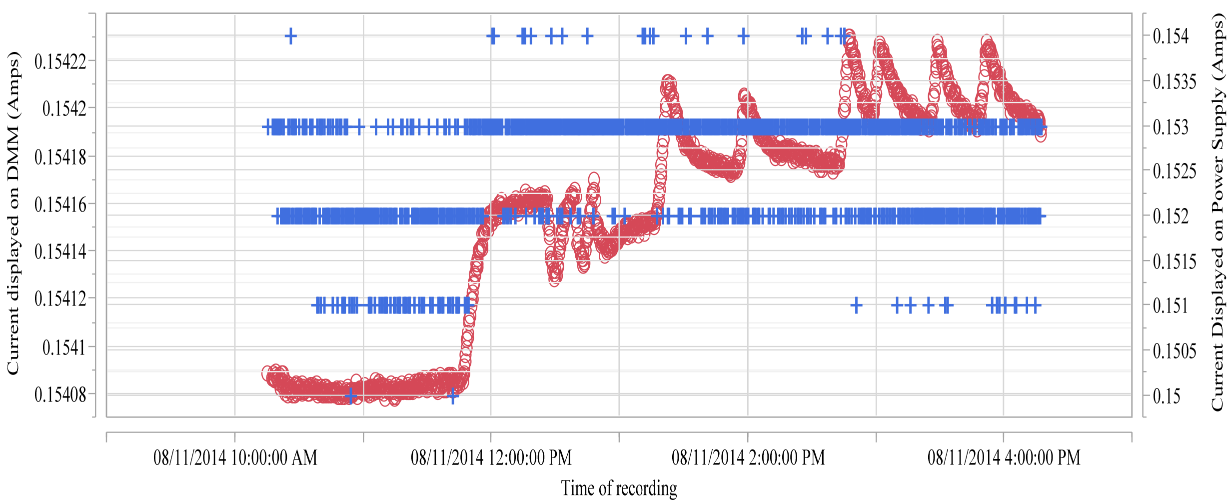
Right Scale: + Current Displayed on Power Supply (Amps)

Exhibit A.12 Plots of Current from the EHS Power Supply and the DMM (continued)

Test=Rate of change test2 50V, Test Volt=50, Test Temp=varying



Test=Temp test 20V_25 to 38C, Test Volt=20, Test Temp=high

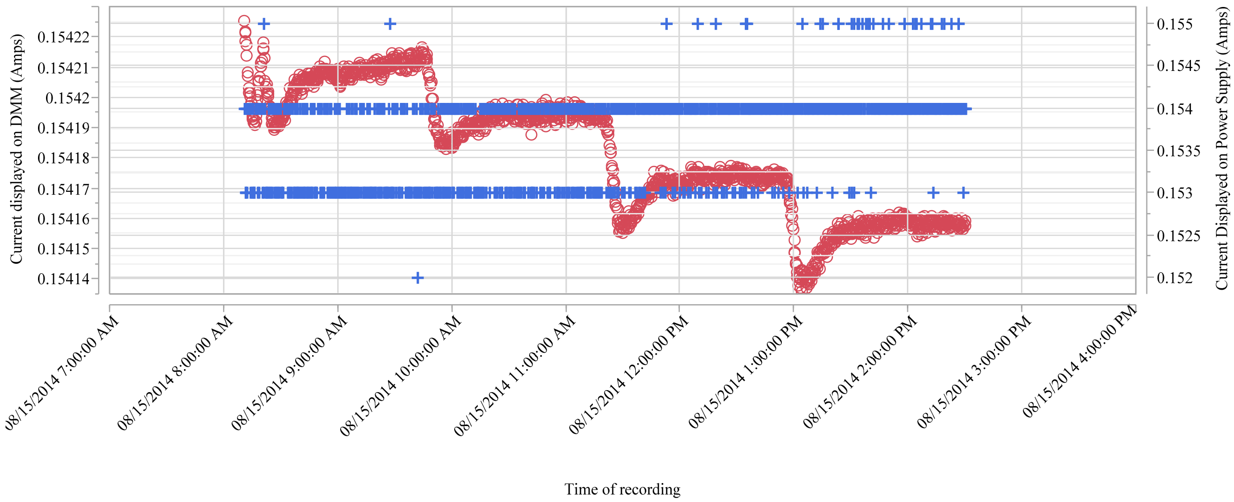


Left Scale: ○ Current displayed on DMM (Amps)

Right Scale: + Current Displayed on Power Supply (Amps)

Exhibit A.12 Plots of Current from the EHS Power Supply and the DMM (continued)

Test=Temperature test 20V_25 to 0C, Test Volt=20, Test Temp=low

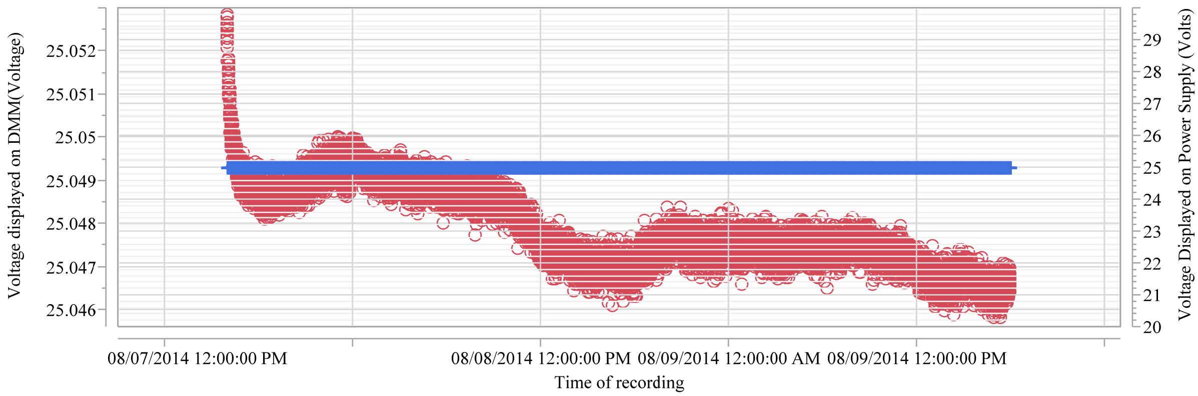


Left Scale: ○ Current displayed on DMM (Amps)

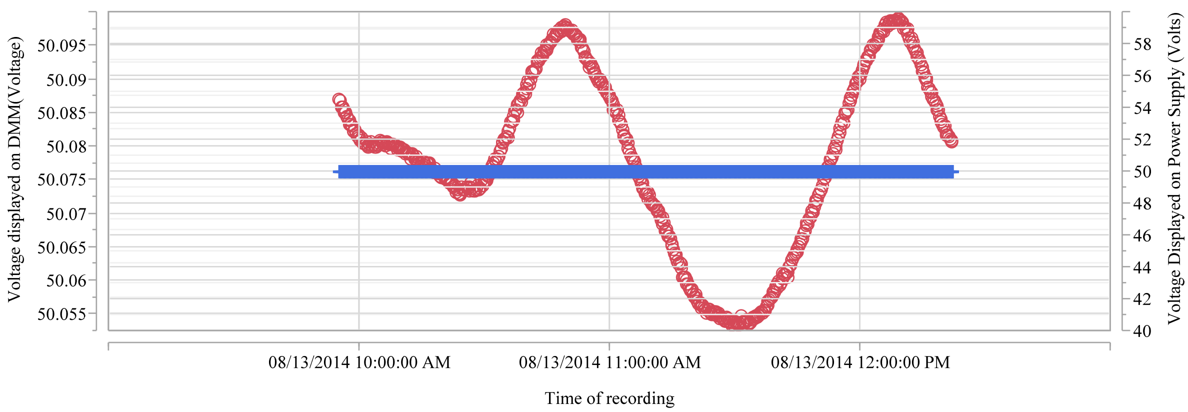
Right Scale: + Current Displayed on Power Supply (Amps)

Exhibit A.13 Plots of Voltage from the EHS Power Supply and the DMM

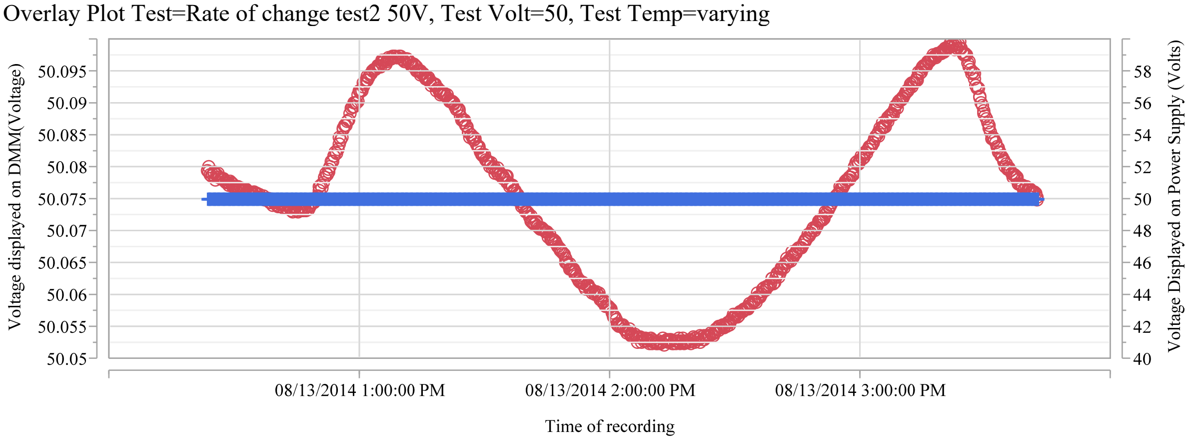
Test=3-day Room Temp 25V, Test Volt=25, Test Temp=mid-range



Test=Rate of change test1 50V, Test Volt=50, Test Temp=varying



Overlay Plot Test=Rate of change test2 50V, Test Volt=50, Test Temp=varying

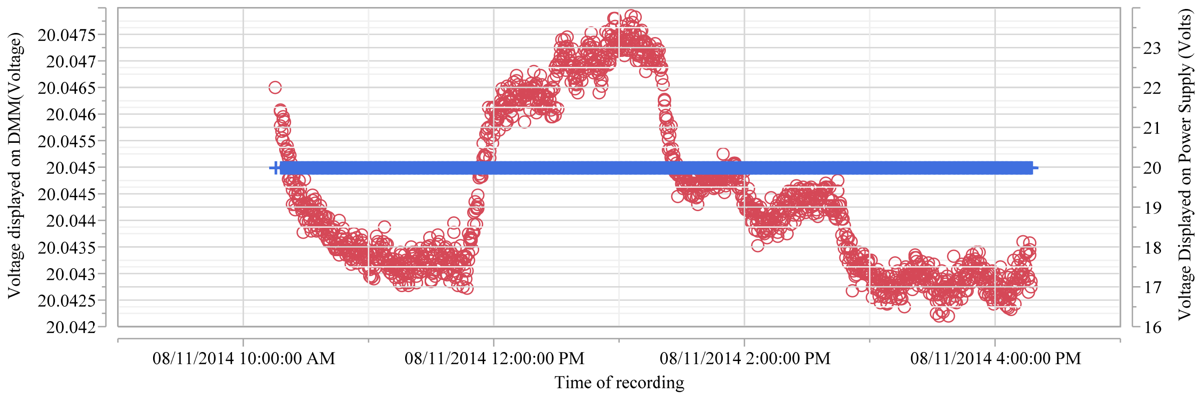


Left Scale: ○ Voltage displayed on DMM(Voltage)

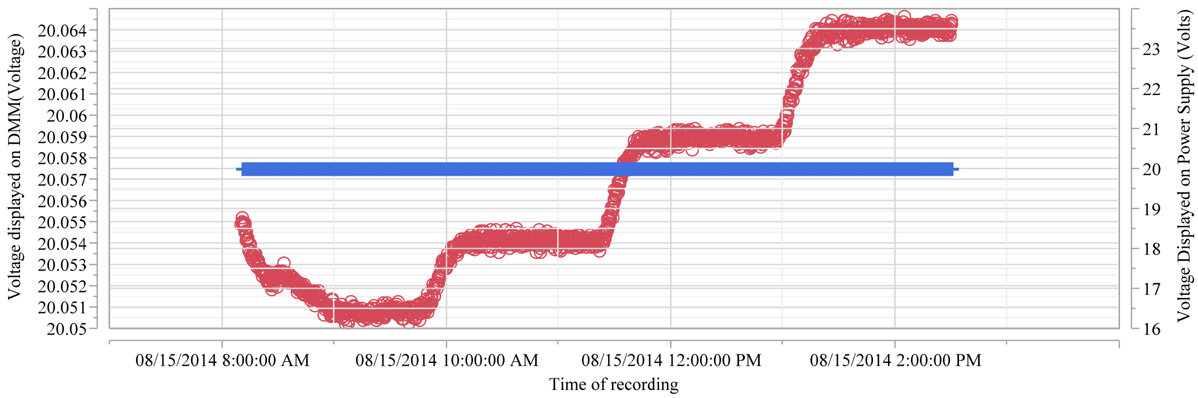
Right Scale: + Voltage Displayed on Power Supply (Volts)

Exhibit A.13 Plots of Voltage from the EHS Power Supply and the DMM (continued)

Test=Temp test 20V_25 to 38C, Test Volt=20, Test Temp=high



Test=Temperature test 20V_25 to 0C, Test Volt=20, Test Temp=low

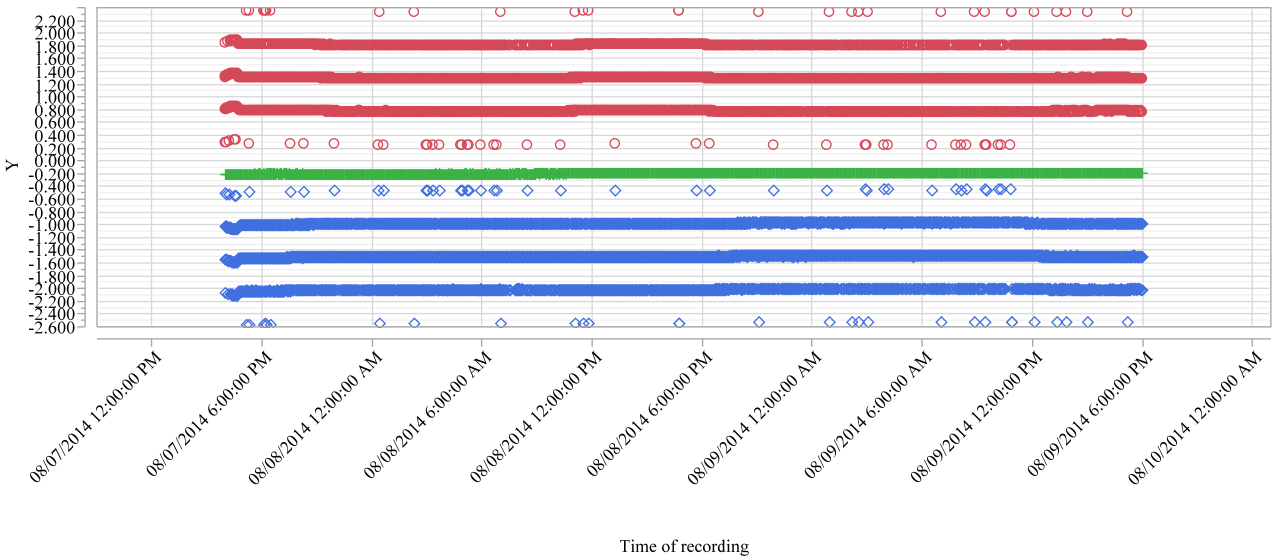


Left Scale: ○ Voltage displayed on DMM(Voltage)

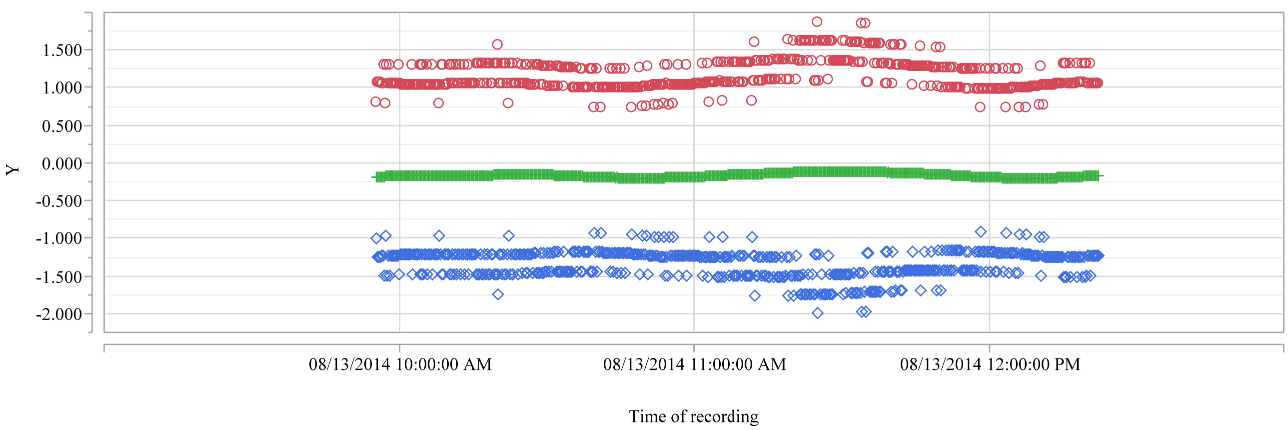
Right Scale: + Voltage Displayed on Power Supply (Volts)

Exhibit A.14 Plots of Percent Relative Differences Between EHS Power Supply and DMM Results

Overlay Plot Test=3-day Room Temp 25V, Test Volt=25, Test Temp=mid-range



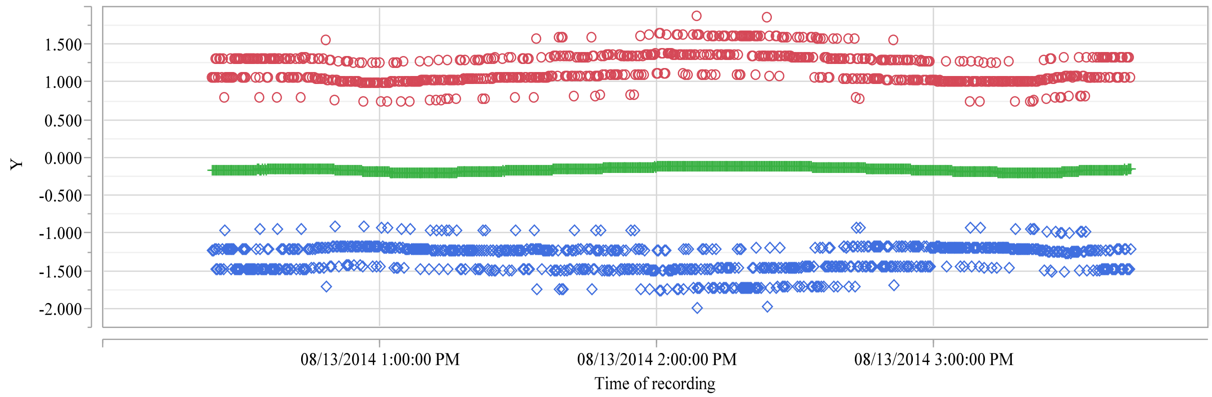
Test=Rate of change test1 50V, Test Volt=50, Test Temp=varying



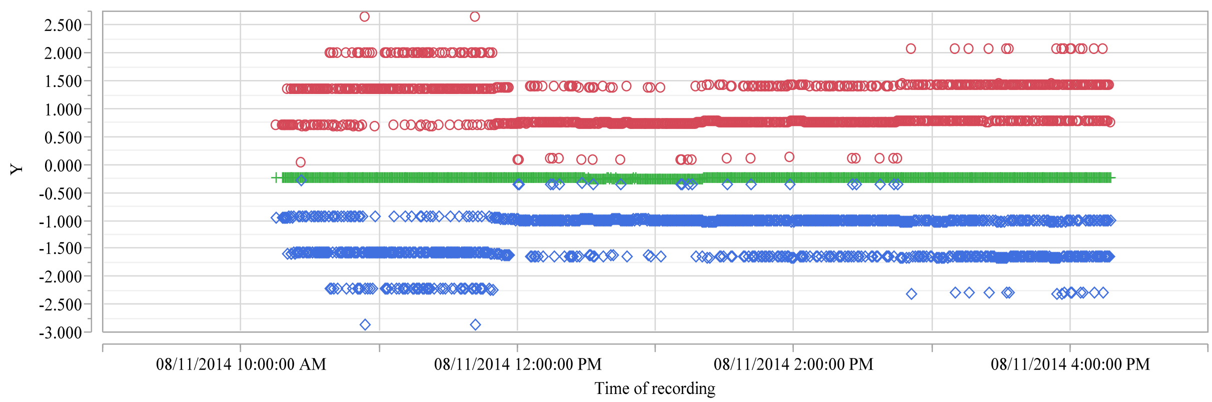
Y ○ % rel amp diff + % rel volt diff ◇ % rel watt diff

Exhibit A.14 Plots of Percent Relative Differences Between EHS Power Supply and DMM Results (continued)

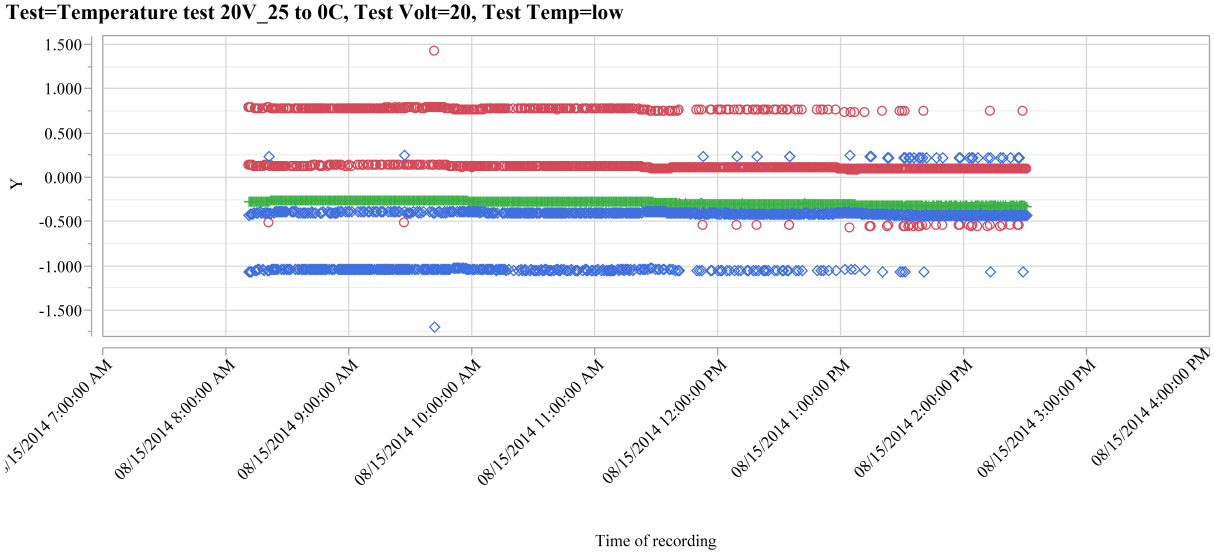
Test=Rate of change test2 50V, Test Volt=50, Test Temp=varying



Test=Temp test 20V_25 to 38C, Test Volt=20, Test Temp=high



Test=Temperature test 20V_25 to 0C, Test Volt=20, Test Temp=low



Y ○ % rel amp diff + % rel volt diff ◇ % rel watt diff

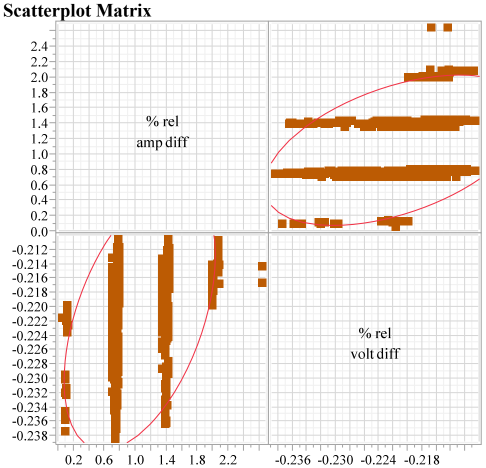
Exhibit A.15 Correlations Between Percent Relative Differences for the EHS Power Supply’s Voltage and Current Results

Multivariate Test Volt=20, Test Temp=high, Test=Temp test 20V_25 to 38C

Correlations

	% rel amp diff	% rel volt diff
% rel amp diff	1.0000	0.4775
% rel volt diff	0.4775	1.0000

Scatterplot Matrix

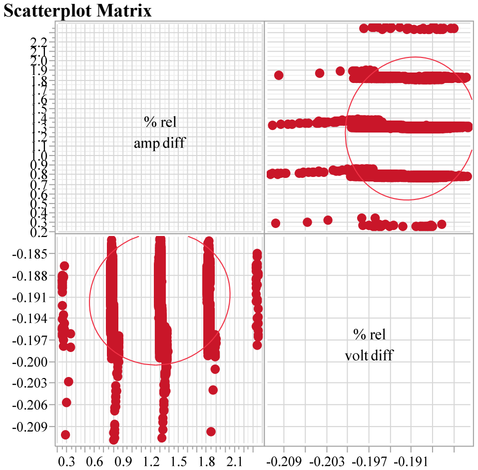


Multivariate Test Volt=25, Test Temp=mid-range, Test=3-day Room Temp 25V

Correlations

	% rel amp diff	% rel volt diff
% rel amp diff	1.0000	0.0572
% rel volt diff	0.0572	1.0000

Scatterplot Matrix

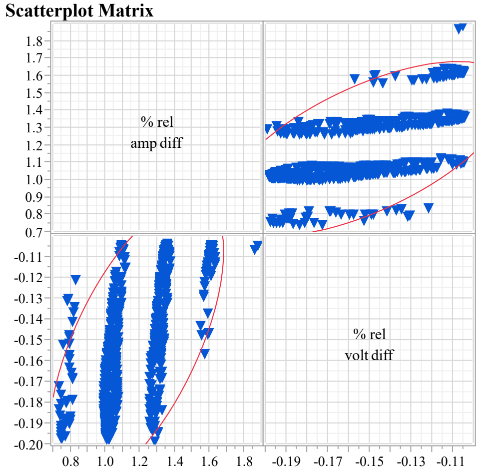


Multivariate Test Volt=50, Test Temp=varying, Test=Rate of change test2 50V

Correlations

	% rel amp diff	% rel volt diff
% rel amp diff	1.0000	0.6344
% rel volt diff	0.6344	1.0000

Scatterplot Matrix

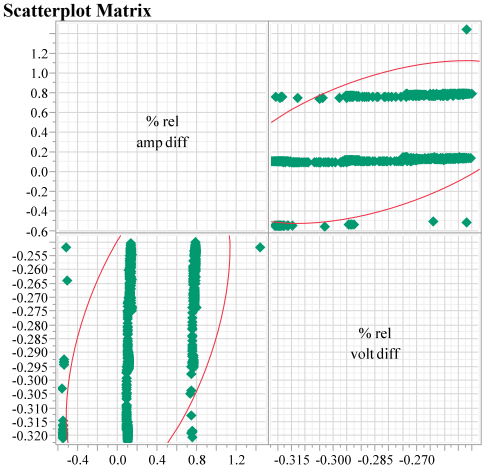


Multivariate Test Volt=20, Test Temp=low, Test=Temperature test 20V_25 to 0C

Correlations

	% rel amp diff	% rel volt diff
% rel amp diff	1.0000	0.5325
% rel volt diff	0.5325	1.0000

Scatterplot Matrix

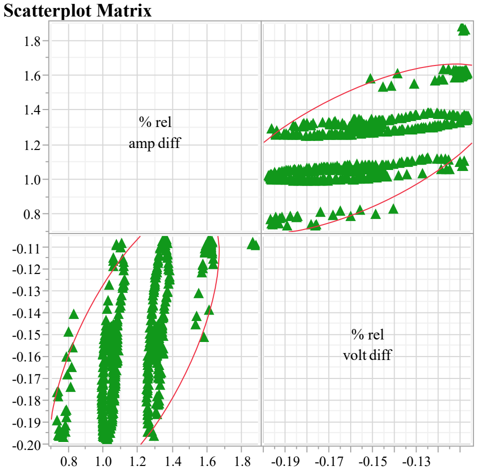


Multivariate Test Volt=50, Test Temp=varying, Test=Rate of change test1 50V

Correlations

	% rel amp diff	% rel volt diff
% rel amp diff	1.0000	0.6741
% rel volt diff	0.6741	1.0000

Scatterplot Matrix



Distribution:

Joseph.Manna@srnl.doe.gov
Matthew.Howard@srnl.doe.gov
timothy.brown@srnl.doe.gov
alex.cozzi@srnl.doe.gov
david.crowley@srnl.doe.gov
a.fellinger@srnl.doe.gov
samuel.fink@srnl.doe.gov
nancy.halverson@srnl.doe.gov
erich.hansen@srnl.doe.gov
connie.herman@srnl.doe.gov
john.mayer@srnl.doe.gov
daniel.mccabe@srnl.doe.gov
Gregg.Morgan@srnl.doe.gov
frank.pennebaker@srnl.doe.gov
Amy.Ramsey@srnl.doe.gov
William.Ramsey@SRNL.DOE.gov
luke.reid@srnl.doe.gov
geoffrey.smoland@srnl.doe.gov
michael.stone@srnl.doe.gov
Boyd.Wiedenman@srnl.doe.gov
bill.wilmarth@srnl.doe.gov
Records Administration (EDWS)