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Performance Benchmarking of Coating Systems Evaluated in Cyclic Corrosion Tests

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Performance Benchmarking of Coating Systems Evaluated in Cyclic Corrosion Tests

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Foreword

The study described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the High-Performance Materials and Systems (HPM&S) Research Program. The work was performed under Work Unit 33109, "High-Performance Paint Systems, Phase I," for which Mr. Alfred D. Beitelman, U.S. Army Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL), was the Principal Investigator. Messrs. Andy Wu and M.K. Lee, HQUSACE, were the HPM&S Program Monitors.

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During the preparation of this edition of the report, Mr. Mark W. Slaughter was Chief, CF-M, and Mr. L. Michael Golish was Chief, CF. The CERL Technical Director for this work unit was Dr. Paul A. Howdyshell, CV-ZT, and the Director of CERL was Dr. Alan W. Moore.

Dr. Tony C. Liu was the HPM&S Coordinator at the Directorate of Research and Development, HQUSACE. Mr. James E. McDonald, ERDC Geotechnical and Structures Laboratory (GSL), was the HPM&S Program Manager. Dr. Mary Ellen Hynes, GSL, was the Laboratory Manager for the HPM&S Program.

At the time of publication, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

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Executive Summary

The trend in the coatings industry today is away from composition specifications and toward performance specifications. Standardized levels of coating performance could be promulgated as industry-wide reference points through the establishment of benchmarks. The term *benchmark* may be defined simply as a widely recognized measure of performance. An established government or industry standard (such as MIL-P-24441 for an epoxy system or SSPC Paint 25/TT-E-489 for an oil-based system) could serve as a benchmark, as could a brand-name paint that is well known and accepted industry-wide for its level of performance in its intended application.

To write performance specifications and establish benchmarks for coating systems, reliable and reproducible test methods must be used to determine pass/fail criteria. Undercutting at the scribe is a common mode of deterioration in coating systems applied to structural steel. A method for testing coatings for this type of damage is prescribed by ASTM D 5894.

The objective of this research was to establish as benchmarks a number of well-known coating systems whose performance is widely accepted by users throughout the industry. Performance levels of the selected benchmark coatings were tested using ASTM D 5894, and two alternative methods of assessing the damage were evaluated for reliability and reproducibility.

A standard method of assessing and quantifying the extent of scribe undercutting should possess the following properties:

- The method should be straightforward and easy to use without the need for sophisticated tools such as electronic scanners;
- The method should be accurate and minimize subjective judgments of the evaluator;
- The method should have enough sensitivity to differentiate among coating systems with different levels of performance;
- The method should be reproducible;
- Computations should be able to be performed on any commercial statistics software package or even on a hand-held calculator.

Nine different well-known painting systems representing a variety of generic types were exposed in an accelerated cyclic laboratory test described by ASTM D 5894. Six or seven replicate panels for each system were prepared and scribed prior to exposure.

This project investigated two general methods for assessing scribe undercutting. In Method 1 (overall means), one determines the mean (average) undercutting from measurements taken at a large number of pre-selected positions along the scribe. In Method 2 (average maximum), one measures the maximum undercutting value along the entire scribe, or a designated portion of the scribe, and computes the average of these maxima.

Within each method there are variations of the specific procedure. For Method 1, one must select the number and spacing of the location to measure. For Method 2, one can determine the maximum of the entire scribe or of selected increments along the scribe (e.g., along 10-mm intervals). Several such variations were investigated for Method 2. In addition, alternative statistical methods may be used to analyze the data. In this project, the methods used were analysis of means, analysis of variance, and Weibull distribution.

Either method may be used to establish a benchmark based on statistical principles. Method 2 will compute scribe-undercutting levels that are higher than those from Method 1 because one is measuring a maximum undercutting rather than the undercutting at specific intervals. The ratio of these two quantities depends on the number of measurements taken and the type of distribution of scribe undercutting. In these experiments, the average maximum was about 20 to 30% higher than the overall mean.

For this experiment, Method 1 involved measuring the undercutting to the left and to the right of the centerline at 5-mm intervals along the length of the scribe. For a 60-mm long scribe, 12 measurements were made to the left and 12 to the right for a total of 24 measurements per scribe. Since each panel had two scribes, there were 48 measurements per panel. Six panels in a set gave 288 data points for each set. The 288 data points from Method 1 closely followed a normal distribution. The method treats all the data (288 measurements) from the 12 scribes as a single population. Using a calculator, compute the mean and the standard deviation. Multiply the standard deviation by two and add this to the mean. The resulting figure, rounded to the nearest millimeter, is the scribe parameter or benchmark.

For the initial analysis with Method 2, 12 measurements, the maximum undercutting at each scribe, were taken. The mean plus two standard deviations computed from these 12 measurements constituted the Method 2 benchmark. The maximum undercutting at the scribe on a similar panel would have more than a 95% probability of being less than this benchmark.

A Weibull analysis was also done on the 12 data points representing maximum undercutting of the 12 scribes. The 95% probability target is very close to the benchmark computed with statistics based on analysis of mean.

Analysis of Reduced Data Sets

It is useful to determine the validity of the method for experimenting with fewer than 12 replicate scribes. Method 2 data was analyzed using reduced data sets, two panels with two scribes each (4 scribes compared to 12 in the full set). The analysis yielded benchmarks comparable to those derived from larger numbers of replicates. In this case, the benchmark was derived from two replicate panels (four scribes) in which each scribe was divided into three equal portions with the maximum undercutting on each portion considered a separate data point. **Note:** It is recognized that under rigorous statistical methodology these points would not be considered independent measurements.

Analysis of CERL Test Panels

The analysis showed that either method was satisfactory to produce a statistically valid undercutting benchmark for the data in these experiments. The test panels furnished by CERL included a relatively large number (six) of replicate panels. With 2 scribes on each panel, there was a total of 12 scribes. This resulted in 288 individual data points for Method 1 and 12 maxima for Method 2. Because Method 2 is easier to use and because it has a close linear relationship with Method 1, it is recommended as the preferred industry practice.

For these experiments, Method 2 was also considered suitable for data sets with fewer replicates. For this situation, one divides the scribes into equal lengths and measures the maximum undercutting within each segment. Each segment is then treated as an independent measurement. This approach may require additional verification for practical and statistical validity.

Use of Benchmark Criteria

Specifiers seek a means to determine if a candidate coating meets the performance levels of a known proven coating system. The results of this project indicate that scribe undercutting can provide a suitable benchmark for performance of high technology coatings in an accelerated cyclic corrosion cabinet test (ASTM D 5894).

The coating systems examined in this project represent the range of generic systems most commonly used in industry. The test systems also have a history of good performance in industrial applications. For example, the Method 2 benchmark was 13-mm for System 2, a zinc-rich epoxy primer/epoxy topcoat system. A performance specification for this type of coating system could require scribe undercutting after 3360 hours (20 weeks) exposure in ASTM D 5894 to be less than 15 mm as measured by Method 2. If the test coating met this requirement, there would be a high likelihood of having atmospheric performance at least as good as the zinc-rich epoxy system examined in this study. The target of 15 mm instead of 13 mm would allow for fluctuations in the panel preparation and other testing conditions. As more coatings are tested according to this criterion, the target could be adjusted up or down to accommodate experience and the state of the technology.

There was good reproducibility when the same observer remeasured the scribes and there was good agreement among three different observers in computing benchmarks by any of the methods. System 1 had data for three different exposure times, ten weeks, 16 weeks, and 20 weeks. Because of an apparent data reversal, the System 1 data suggest a variation between separate runs on the order of 10 to 20%.

Based on these data, general procedures are proposed for:

- Deriving a benchmark for scribe undercutting
- Evaluating a candidate system against the benchmark

Proposed Method for Deriving a Benchmark for Scribe Undercutting

1. Prepare replicate test specimens of the coating system to be benchmarked.
2. Scribe each of the panels in accordance with standard procedures.
3. Identify 12 separate scribes or scribe segments of at least 20 mm in length. (The replicates must provide a minimum of four scribed areas of at least 60 mm each.)
4. Expose the test specimens for which a benchmark performance is sought in a cabinet or environment conforming to ASTM D 5894. A minimum duration is five cycles (10 weeks or 1680 hours).
5. Measure the maximum undercutting at each of the scribes or scribe segments.
6. Compute the mean and standard deviation for each coating system. The benchmark is the mean plus two standard deviations.

Proposed Method for Evaluating a Candidate System Against the Benchmark

1. Prepare replicate test specimens of the candidate coating system.
2. Scribe each of the panels in accordance with standard procedures. A minimum of two test specimens and four scribed areas of at least 60 mm each is required.
3. Expose the replicate specimens in the test cabinets for the prescribed time and test parameters.
4. Measure scribe in accordance with procedure above.
5. Compute the average and standard deviation of the maximum undercutting of the scribe segments. These parameters must be comparable to previously established benchmarks.

Note: Additional criteria can be established for an alternate number of measurements.

There is no reason that these methods of evaluating scribe undercutting could not be used for panels on a test fence. The benchmarks would have to be determined for each generic coating system for different atmospheric exposure conditions, such as heavy industrial, light industrial, or marine. The variability of the data and the number of replicates needed would have to be ascertained. This is a project for future work.

1 Introduction

Background

The revised Federal Acquisition Regulation (FAR) requires that government agencies procure commercial services and products to the greatest extent practicable. FAR also states that procurement of commercial products should be based on performance, and industry criteria documents are preferred over Government specifications. The Construction Engineering Research Laboratory (CERL), an element of the U.S. Army Engineer Research and Development Center (ERDC), is working with The Society for Protective Coatings (SSPC) to standardize a format for performance-based paint specifications. Accelerated laboratory testing is the logical and rapid way to specify coating performance. However, this approach is hampered by a lack of readily accessible performance data. Furthermore, the interpretation of rust undercutting data is poorly understood and must be elucidated if pass/fail performance criteria based on coating reliability are to be implemented. Benchmarks for performance are needed as a reference point prior to the development of performance-based paint specifications.

Objectives

The objectives of this research are to:

1. Develop a rigorous method for evaluating and interpreting rust undercutting data from test specimens.
2. Report on performance "benchmarking" experiments conducted on these coating systems.

Approach

Test panels coated with one of nine different well-known painting systems representing a variety of generic types were exposed for up to 20 weeks in an accelerated cyclic laboratory test described by ASTM D 5894. The extent of rust undercutting at the scribes was measured using two alternative well-defined procedures. The results of these procedures were compared.

Scope

This project measured undercutting for selected two- and three-coat systems. Benchmarking for single coat systems or for generic types not tested here will have to be the object of another investigation. The method of measuring and characterizing the scribe can be applied to any coating system.

Mode of Technology Transfer

This method of scribe undercutting measurement will be incorporated into future drafts of SSPC paint performance specifications and may also be adopted as a test method by ASTM. As SSPC members review this method, further refinements will be made.

2 Testing Procedures

Panel Preparation

The coating systems used in this study are listed in Table 1.

Table 1. Coating systems.

System Code	Recommended DFT (mils)
1. Epoxy-Polyamide Coating system	
Primer: MIL-P-24441, Type IV, Formula 150	2.8
Topcoat: MIL-P-24441, Type IV, Formula 152	2.8
2. Zinc-Rich Epoxy Primer / Epoxy Topcoat System	
Primer: Amercoat 68HS Zinc 3.0	3.0
Topcoat: Amercoat 385 Multipurpose	4.0 to 6.0
3. Aluminum filled Epoxy Coating System	
Primer: Carbomastic 90 Aluminum	5.0
Topcoat: Carbomastic 90 Aluminum	5.0
4. Alkyd Paint System	
Primer: SSPC-Paint 25	2.0
2nd:T-T-E-489	2.5
Topcoat: T-T-E-489	2.5
5. Moisture Cure Polyurethane System	
Primer: Wasser MC-Zinc	3.0
2nd Wasser MC-Ferrox B	3.0
Topcoat: Wasser MC-Ferrox A	3.0
6. State of Georgia Waterborne Bridge Paint System VI	
Primer: Amercoat 148 (brown)	3.0
2nd:Amercoat 220 (white)	3.0
Topcoat: Amercoat 220 (green)	3.0
7. 3329 Corps of Engineers Vinyl System 5-E-Z	
Primer: VZ-108d	2.0
2nd:V-766e (white)	2.0
Topcoat V-766e (gray)	2.0
8. 3330 Corps of Engineers Vinyl System 4	
Primer: V-766e (white)	2.0
2nd:V-766e (gray)	2.0
Topcoat: V-766e (gray)	2.0
9. 3331 Corps of Engineers Vinyl System 3-A-Z	
Primer: VZ-108d	2.0
2nd:V-766e (white)	2.0
Topcoat: V-102e Aluminum	2.0

Mild hot rolled steel panels were blast cleaned to SSPC-SP 5, White Metal Blast Cleaning, with #24 aluminum oxide abrasive. The blast profile was measured using Testex Tape (ASTM D 4417, Method C; NACE RP0287-95) to be between 1.5 and 2.5 mils. Panel sizes, given in Table 2, were typically 3 x 6 x 1/8 inch (76 x 152 x 3 mm). Note that Systems 7, 8, and 9 had slightly larger panels, 3 x 9 x 1/8 inch (76 x 229 x 3 mm), than the other systems. All coatings were spray applied using conventional equipment. Two parallel scribes, each about 60 mm (2.5 inch) long, were scored at an angle across the face of each test panel. The scribes were 8 to 10 cm (3 to 4 inches) apart. The dry film thicknesses (DFTs) of the panels are given in Table 3.

The test systems had similar, but not exactly the same, test parameters. Systems 1 to 6 had six replicate panels, and each panel had two 60+ mm long scribes. Systems 7,8, and 9 had seven replicate panels in each set, and each panel had two scribes, but some of the scribes were less than 60 mm. The shorter scribes had from two to six fewer data points. System 1 had sets of six panels at 1680 hours (10 weeks), 2688 hours (16 weeks), and 3360 hours (20 weeks) for a total of 18 panels. System 6 had sets of 6 panels at 1680 hours and 3360 hours for a total of 12 panels. The other systems had panel sets only at 3360 hours. The panel sets and individual panel IDs are given in Table 2.

Table 2. Sets of test panels.

System	Panel ID	Number of Panels	Panel Size	Exposure Time
System 1	1A-F	6 panels	3” x 6” x 1/8	1680 h (10 weeks)
	1G-L	6 panels	3” x 6” x 1/8	2688 h (16 weeks)
	1 M-R	6 panels	3” x 6” x 1/8	3360 h (20 weeks)
System 2	2A-F	6 panels	3” x 6” x 1/8	3360 h
System 3	3A-F	6 panels	3” x 6” x 1/8	3360 h
System 4	4A-F	6 panels	3” x 6” x 1/8	3360 h
System 5	5A-F	6 panels	3” x 6” x 1/8	3360 h
System 6	6A-F	6 panels	3” x 6” x 1/8	1680 h (10 weeks)
	6G-L	6 panels	3” x 6” x 1/8	3360 h
System 7	7A-G	7 panels	3” x 9” x 1/8	3360 h
System 8	8A-G	7 panels	3” x 9” x 1/8	3360 h
System 9	9A-G	7 panels	3” x 9” x 1/8	3360 h

Table 3. Total dry film thickness of individual panels.

Panel	Exposure Time (h)	DFT		Panel	Exposure Time (h)	DFT	
		mils	micrometers			mils	micrometers
1A	1680	6.7	170	5A	3360	8.9	226
1B		5.0	127	5B		9.6	244
1C		6.1	155	5C		9.0	229
1D		5.4	137	5D		9.5	241
1E		5.8	147	5E		8.8	224
1F		6.0	152	5F		9.2	234
1G	2688	7.0	178	6A	1680	6.0	152
1H		5.4	137	6B		7.3	185
1I		6.7	170	6C		7.3	185
1J		5.0	127	6D		7.0	178
1K		5.5	140	6E		8.0	203
1L		7.3	185	6F		7.9	201
1M	3360	6.4	163	6G	3360	7.0	178
1N		6.0	152	6H		7.6	193
1O		5.0	127	6I		7.7	196
1P		4.8	122	6J		6.6	168
1Q		5.5	140	6K		7.5	191
1R		5.5	140	6L		8.0	203
2A	3360	8.5	216	7A	3360	7.7	196
2B		9.7	246	7B		7.6	193
2C		8.5	216	7C		8.0	203
2D		9.0	229	7D		7.7	196
2E		7.3	185	7E		7.8	198
2F		11.9	302	7F		7.5	191
				7G		7.3	
3A	3360	13.0	330	8A	3360	8.0	203
3B		12.0	305	8B		8.0	203
3C		16.0	406	8C		7.7	196
3D		14.5	368	8D		6.8	173
3E		12.0	305	8E		6.9	175
3F		13.0	330	8F		7.2	183
				8G		6.8	
4A	3360	6.0	152	9A	3360	8.9	226
4B		6.5	165	9B		8.3	211
4C		5.9	150	9C		8.5	216
4D		6.0	152	9D		8.0	203
4E		6.3	160	9E		8.7	221
4F		6.1	155	9F		8.9	226
				9G		8.2	

Exposure Conditions

The panels were exposed for the stated number of hours in accordance with ASTM D 5894, Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal, (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet). Specifically, a 2- week test cycle started with 168 hours (1 week) in a UV/condensation cabinet followed by 168 hours in a cyclic salt fog cabinet (also known as a prohesion cabinet). The UV/condensation cycle consisted of 4 hours of ultraviolet exposure (UVA 340 lamps) at 60°C alternating with 4 hours of condensation at 50°C. The cyclic salt fog cycle was 1 hour of fog (Timmons' solution) at 24°C alternating with one hour of drying at 35°C.

Post-Exposure Scribe Preparation

Prior to measurement of undercutting on systems 1 to 6, the scribes were scraped according to the procedure described in Section 7.2 of ASTM D 1654, Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments. This method removes all coating near the scribe that is not tightly adhered. The three vinyl systems (7, 8, and 9) were prepared according to Section 7.1 of ASTM D 1654 and were not scraped.

Scribe Measurement Methods

Two methods were used for evaluating scribe undercutting: Method 1, where measurements were made at 5-mm intervals along the scribe; and Method 2, where only the maximum undercutting for each scribe was determined.

Method 1: Measuring Scribe Undercutting at 5-mm Intervals

This method involved measuring the undercutting to the left and to the right of the centerline at 5-mm intervals along the length of the scribe. For a 60-mm long scribe, 12 measurements were made to the left and 12 to the right for a total of 24 measurements per scribe. Since each panel had 2 scribes, there were 48 measurements per panel. Six panels in a set gave 288 data points for each set.

Some of the panels in Systems 7, 8, and 9 had scribes that were less than 60 mm. Since the 5-mm spacing was maintained, only 18, 20, or 22 measurements were taken for these short scribes. These three systems also had seven replicates instead of six. This method can easily be adapted to different scribe lengths or different numbers of replicate panels. The number of data points ranged from 294 for System 7 to 334 for System 9.

In order to make the method as objective as possible, a template, shown in Figure 1, was made that could be taped over the scribe. A rectangular hole approximately 60 mm x 25 mm was cut into an index card. Twelve hash marks were made 5 mm apart down each side of the hole. It was often helpful to locate the center of the scribe and mark the centerline with a utility knife. The template was then centered over the scribe and taped to the panel. A ruler was aligned with the corresponding hash marks and the extent of the undercutting from the centerline was measured and recorded. A different size template could be used for scribes of different length or with greater undercutting.

Method 2: Maximum Undercutting

The other method to characterize a scribe is to measure the maximum undercutting from the center of the scribe at any point along the scribe. One simply scans the scribe visually to locate the possible points where the scribe appears to be a maximum, measures those points, and records the maximum value.

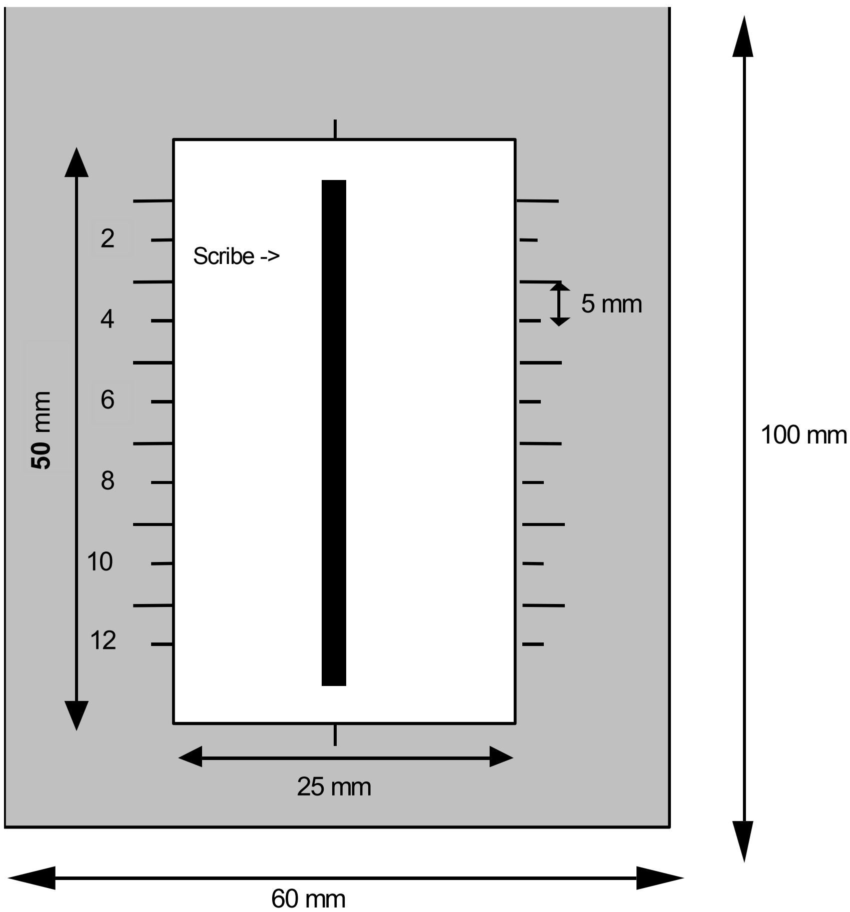


Figure 1. Template used in measuring scribe undercutting.

Performance Evaluation Procedures

ASTM D 1654 stipulates recording of the mean, the maximum, and the minimum undercutting but does not give a precise method for determining the mean. If the maximum is an isolated spot it should be stated as such. The minimum scribe gives information about the range of undercutting but does not really say how good the coating is. There is no single number that adequately describes the scribe. One of the objectives of this project is to establish a method to quantify scribe undercutting.

Statistical Evaluation of Data From Method 1

A series of scribe undercutting measurements can be described in several ways. The most complete picture of the scribe would be to look at all 288 data points. Statistical methods are used to describe the scribe with fewer numbers. Common statistical measurements of central tendency are mean, median, and mode. The mean is the arithmetic average value: add up the measurements and divide by the number of measurements. The median is the measurement in the middle: half the measurements are greater than the median and half are less than the median. The mode is the measurement that occurs most frequently. In an ideal normal distribution, these three numbers are the same. For the systems tested in this project, the mean, the median, and the mode were very similar.

The mean is proportional to the total area of undercutting, but it does not describe the distribution of the data or the shape of the undercutting. This measure of dispersion is given by the range, the variance, or the standard deviation. The range is simply the difference between the maximum and the minimum measurements. The range is likely to increase as more measurements are taken and it does not describe the shape of the distribution. Variance is a measure of the variation among measurements that is due to the measurement process variables. Measurements with a small variance are close together and those with a large variance are spread out. The standard deviation for a normal distribution has a quantitative meaning. For example, if the mean scribe undercutting is 6 mm and the standard deviation is 1 mm, there is a 68% probability that a measurement taken at random will be between 5 and 7 mm, there is a 95% probability that the measurement will fall between 4 and 8 mm, and there is a 99% probability that the measurement will fall between 3 and 9 mm. The larger the standard deviation, the more spread out are the data. An advantage of using standard deviation is that it describes the data distribution. Whether 100 data points or 600 data points are used, the standard deviation of each set should be about the same.

When evaluating a coating system, is the most critical parameter the maximum undercutting or the total area (mean) of undercutting? The method developed in this project considers both factors. Suppose two scribes have the same maximum undercutting. Scribe A has an isolated spot where the undercutting is 6 mm, and everywhere else the undercutting is less than 2 mm. Scribe B has nearly uniform undercutting of 5 to 6 mm everywhere. Clearly, Scribe A is better than Scribe B. Conversely, suppose two scribes have the same average undercutting. Scribe C has scribe undercutting between 5 and 7 mm with an average of 6 mm. Scribe D has undercutting from 2 to 10 mm with an average of 6 mm. Scribe C would be better than Scribe D. Because of the way standard deviation is computed, scribes that deviate farthest from the mean contribute a disproportionate share to the standard deviation. Thus, the parameter used to characterize scribe undercutting is the mean plus two standard deviations. The mean is proportional to the total area of undercutting and the standard deviation takes into account the very large undercutting measurements.

The proposed method (Method 1) is to: (1) treat all the data (288 measurements) from the 12 scribes as a single population; (2) use a calculator to compute the mean and the standard deviation; (3) multiply the standard deviation by 2 and add this to the mean. The resulting figure, rounded to the nearest millimeter, is the scribe parameter. If a similar panel were chosen and a random spot were picked along the scribe, there would be more than a 95% probability that the undercutting would be less than this number.

Treating Maximum Undercutting Data From Method 2

When the maximum undercutting data are used, each set of 6 panels yields 12 data points (14 data points for sets of 7 panels). The scribe can be characterized by the average of these 12 maximum readings or by the average plus one or two standard deviations. If these 12 data points are used to compute an average and a standard deviation, the average plus two standard deviations would give an upper limit for scribe undercutting, a benchmark. Assuming that the maximum undercutting measurements are normally distributed, the next scribe measured would have greater than a 95% probability of having a maximum undercutting less than the computed benchmark. If fewer replicates were used, similar computations could be performed, but the standard deviation would most likely be higher. Also, using one-fourth the number of replicates would double the uncertainty of the mean.

Another alternative method of data treatment is to perform a Weibull analysis of the 12 (or 14) maximum undercutting values. In this report, this is referred to as Method 2W. There are not enough data in the current set of panels to show that the undercutting follows a Weibull distribution. However, a Weibull distribution could be assumed and then the computations performed. Once the Weibull computation is set up in a spreadsheet, whole number target values are entered until one is found to give a Weibull probability greater than 95%. A Weibull calculation can be used to determine the probability that the scribe undercutting will be less than any other target value.

3 Test Results

The raw data for Method 1 taken at 5-mm intervals along the scribe are given in Table 4 for System 3 and in Appendix A for the other data sets. The test panels are identified by the coating system and the panel within the set. For example, 2C is System 2, panel C. For ease of logging the data onto the computer while the measurements were being taken, the tables include a “left” and a “right” column for the data on the appropriate side of the centerline. Each panel has two scribes. Data from the top scribe are numbered 1 to 12 and the data from the bottom scribe are numbered 13 to 24. Thus, there are 48 data points for each panel. For the analysis, all the data for a given set (288 measurements) are lumped together.

The maximum undercutting measured from the center of the scribe at any point along the scribe, Method 2 data, are given in Table 5.

Table 4. Scribe undercutting (mm) at 5-mm intervals for System 3.

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
3A-1	7	8	3C-1	6	4	3E-1	10	10
3A-2	10	10	3C-2	5	5	3E-2	10	7
3A-3	10	9	3C-3	6	5	3E-3	7	4
3A-4	10	9	3C-4	5	7	3E-4	15	2
3A-5	10	6	3C-5	2	9	3E-5	6	7
3A-6	8	8	3C-6	7	10	3E-6	7	5
3A-7	7	4	3C-7	3	8	3E-7	9	9
3A-8	7	6	3C-8	5	9	3E-8	5	9
3A-9	6	7	3C-9	4	9	3E-9	4	9
3A-10	6	8	3C-10	5	7	3E-10	9	7
3A-11	10	11	3C-11	8	5	3E-11	13	6
3A-12	11	13	3C-12	6	9	3E-12	12	5
3A-13	11	8	3C-13	11	7	3E-13	7	5
3A-14	4	2	3C-14	7	5	3E-14	7	8
3A-15	2	6	3C-15	8	7	3E-15	5	8
3A-16	7	3	3C-16	9	11	3E-16	7	11
3A-17	14	4	3C-17	8	9	3E-17	5	11
3A-18	14	8	3C-18	8	8	3E-18	9	8
3A-19	10	7	3C-19	9	6	3E-19	9	8
3A-20	11	3	3C-20	9	8	3E-20	8	5
3A-21	3	10	3C-21	10	6	3E-21	9	6
3A-22	5	6	3C-22	13	8	3E-22	11	5
3A-23	10	11	3C-23	12	8	3E-23	12	7
3A-24	8	12	3C-24	7	5	3E-24	7	9
3B-1	4	10	3D-1	4	7	3F-1	5	4
3B-2	6	4	3D-2	6	7	3F-2	4	4
3B-3	6	3	3D-3	5	6	3F-3	7	6
3B-4	2	4	3D-4	3	5	3F-4	5	13
3B-5	4	4	3D-5	6	6	3F-5	6	14
3B-6	5	3	3D-6	10	5	3F-6	14	12
3B-7	5	2	3D-7	10	4	3F-7	12	7
3B-8	5	3	3D-8	6	4	3F-8	14	9
3B-9	5	5	3D-9	6	11	3F-9	10	6
3B-10	6	5	3D-10	8	13	3F-10	12	6
3B-11	5	5	3D-11	11	12	3F-11	5	7
3B-12	5	4	3D-12	7	5	3F-12	10	2
3B-13	5	8	3D-13	5	3	3F-13	3	7
3B-14	4	4	3D-14	8	6	3F-14	7	7
3B-15	5	1	3D-15	5	7	3F-15	12	5
3B-16	8	1	3D-16	8	9	3F-16	5	8
3B-17	8	1	3D-17	6	9	3F-17	9	8
3B-18	3	6	3D-18	6	12	3F-18	9	8
3B-19	1	7	3D-19	13	9	3F-19	8	7
3B-20	2	6	3D-20	11	9	3F-20	12	4
3B-21	3	5	3D-21	9	7	3F-21	9	5
3B-22	6	8	3D-22	7	7	3F-22	5	4
3B-23	9	5	3D-23	8	5	3F-23	8	7
3B-24	8	3	3D-24	8	9	3F-24	5	7

Table 5. Maximum undercutting at each scribe, Method 2.

Panel	Exposure Time (h)	Maximum Undercutting (mm)		Panel	Exposure Time (h)	Maximum Undercutting (mm)	
		Top Scribe	Bottom Scribe			Top Scribe	Bottom Scribe
1A	1680	10	10	5A	3360	3	3
1B		6	9	5B		4	3
1C		16	11	5C		4	5
1D		5	11	5D		4	4
1E		8	7	5E		3	5
1F		8	12	5F		5	3
1G	2688	10	11	6A	1680	8	6
1H		10	11	6B		10	7
1I		16	12	6C		8	8
1J		8	10	6D		12	7
1K		9	6	6E		6	6
1L		11	12	6F		6	6
1M	3360	9	10	6G	3360	9	9
1N		9	8	6H		9	9
1O		9	12	6I		8	7
1P		10	9	6J		7	7
1Q		12	8	6K		13	9
1R		12	8	6L		12	14
2A	3360	7	8	7A	3360	2	2
2B		11	12	7B		2	2
2C		8	10	7C		3	2
2D		8	11	7D		4	3
2E		10	7	7E		3	2
2F		10	10	7F		4	3
				7G		3	4
3A	3360	14	14	8A	3360	6	9
3B		8	9	8B		5	6
3C		9	16	8C		5	5
3D		13	13	8D		5	4
3E		15	11	8E		5	5
3F		15	12	8F		6	5
						7	7
4A	3360	8	8	9A	3360	5	5
4B		8	10	9B		5	4
4C		5	11	9C		5	5
4D		9	7	9D		5	5
4E		9	6	9E		4	4
4F		5	6	9F		5	5
				9G		3	4

4 Data Analysis

Results of Method 1

This section will describe the analysis of System 3 and show some appropriate tables and charts. The corresponding tables and charts for the other panel sets are similar. Additional tables and charts for System 3 and statistical parameters for the other systems are given in Appendix B.

The first step in the analysis was to make a frequency plot and to determine the nature of the distribution. Figure 2, which shows a histogram of the data with a normal distribution superimposed, indicates that when all 288 scribe measurements are lumped together to form a single population, the data closely resemble a normal distribution. Further indication that the data are normally distributed is given in Figure 3, which shows a comparison of the actual quantiles with those expected from a normal distribution.

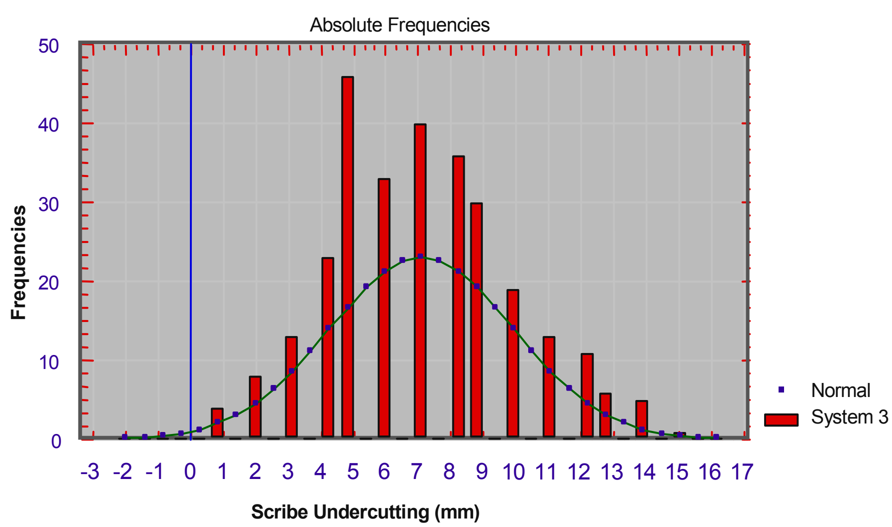


Figure 2. Histogram of System 3 versus normal distribution.

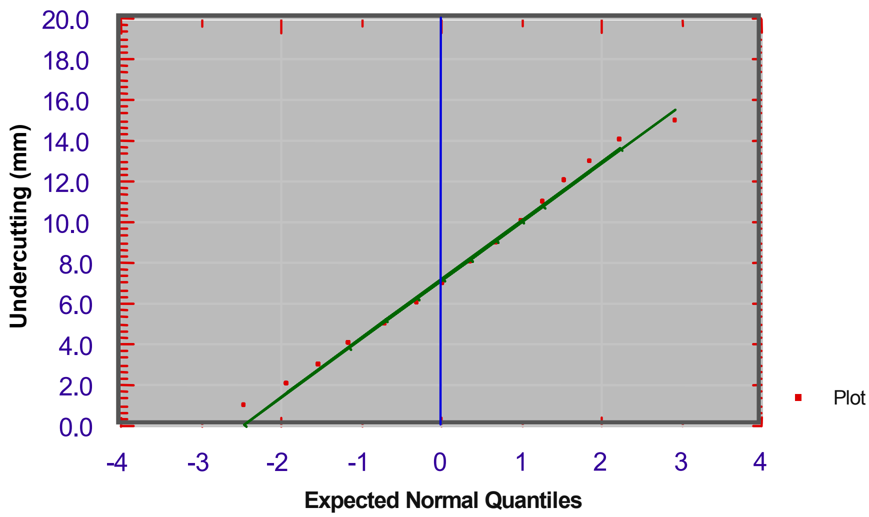


Figure 3. Normal probability plot of System 3.

Many different statistical parameters were computed from the data collected using Method 1. These parameters along with the associated tables and charts for System 3 are given in Appendix B. For example, Table B2 can be used to find the probability that the undercutting at a random point will be less than a given number; or conversely, below what number will 95% of the measurements fall. Table B3 lists statistical parameters for all of the data sets. The "benchmark" derived from this data is the mean plus two standard deviations. These benchmarks are listed in Table 6.

Table 6. Benchmarks (scribe undercutting, mm) for 12 data sets sorted by Method 1.

System	Time (h)	Generic Type	Method 1	Method 2	Method 2W
7	3360	3329 Corps of Engineers Vinyl System 5-E-Z	3	4	5
9	3360	3331 Corps of Engineers Vinyl System 3-A-Z	4	6	8
5	3360	Moisture cure polyurethane (3 coat)	4	6	6
8	3360	3330 Corps of Engineers Vinyl System 4	6	8	9
4	3360	Alkyd (3 coat)	7	12	12
6	1680	State of Georgia waterborne (3 coat)	8	11	11
2	3360	Zinc-rich epoxy/epoxy (2 coat)	9	13	13
1	3360	Epoxy polyamide (2 coat)	10	13	13
6	3360	State of Georgia waterborne (3 coat)	10	14	14
1	1680	Epoxy polyamide (2 coat)	10	15	15
1	2688	Epoxy polyamide (2 coat)	11	15	16
3	3360	Aluminum filled epoxy (2 coat)	13	18	18

Method 1: Mean + two standard deviations, 288 (or more) data points.
Method 2: Mean + two standard deviations of maximums; 12 (or 14) data points.
Method 2W: Target value such that the Weibull probability of the maximum exceeds 95%; 12 (or 14) data points.

Analysis of Maximum Undercutting Data Using Method 2

Normal Probability Analysis

The raw data of maximum undercutting, sorted in descending order, are given in Table 7. From this data, grouping all measurements for a set together, the mean or average of the maxima and the standard deviation were calculated. Table 8 lists these values for each of the 12 data sets as well as the mean plus one or two standard deviations and the absolute maximum measurement.

Weibull Analysis

A Weibull analysis was also performed on the maximum undercut data. The Weibull analysis gives the probability that the maximum undercutting will be less than any target value. Since scribe measurements are only made to the nearest millimeter, whole number target values were chosen. The target values, 6, 12, and 25 mm, were chosen to correspond approximately to 1/4, 1/2, and 1 inch. The Weibull probabilities for these target values are given in Table 9 for each data set.

Another approach is to find the target value that will give a Weibull probability more than 95%. This means that there is a 95 % probability that an identical panel will have a scribe undercutting less than this target value. Whole number target values were substituted into the Weibull function until the 95% limit was exceeded. These 95% targets are also listed in Table 7. Details of the Weibull computations are given in Appendix C.

Normal Probability Analysis Using Fewer Replicates

A variation of Method 2 is to use fewer replicates to generate 12 data points. Four scribes (two test panels) are divided into thirds and then each third is treated as a separate scribe. The benchmarks computed with fewer replicates are close to the benchmark computed using all 12 scribes; however, they are slightly smaller and there is more variability. This approach is examined in Appendix D.

Table 8. Maximum undercutting (mm) at each scribe, sorted by Method 2.

System ->	1	1	1	2	3	4	5	6	6	7	8	9
Hours ->	1680	2688	3360	3360	3360	3360	3360	1680	3360	3360	3360	3360
Maximum	16	16	12	12	16	11	5	12	14	4	9	5
	12	12	12	11	15	10	5	10	13	4	7	5
	11	12	12	11	15	9	5	8	12	4	7	5
	11	11	10	10	14	9	4	8	9	3	6	5
	10	11	10	10	14	8	4	8	9	3	6	5
	10	11	9	10	13	8	4	7	9	3	6	5
	9	10	9	10	13	8	4	7	9	3	5	5
	8	10	9	8	12	7	3	6	9	3	5	5
	8	10	9	8	11	6	3	6	8	2	5	5
	7	9	8	8	9	6	3	6	7	2	5	4
	6	8	8	7	9	5	3	6	7	2	5	4
	5	6	8	7	8	5	3	6	7	2	5	4
										2	5	4
Minimum										2	4	3

Table 7. Summary statistics based on maximum undercutting at each scribe.

System ->	1	1	1	2	3	4	5	6	6	7	8	9
Hours ->	1680	2688	3360	3360	3360	3360	3360	1680	3360	3360	3360	3360
Average Max, x'	9.4	10.5	9.7	9.3	12.4	7.7	3.8	7.5	9.4	2.8	5.7	4.6
Std. Dev. s	3.0	2.4	1.6	1.7	2.6	1.9	0.8	1.9	2.4	0.8	1.3	0.6
x' + s	12.4	12.9	11.2	11.0	15.1	9.6	4.7	9.4	11.8	3.6	7.0	5.2
x' + 2s	15.4	15.4	12.8	12.7	17.7	11.5	5.5	11.3	14.1	4.4	8.2	5.9
Absolute Max	16	16	12	12	16	11	5	12	14	4	9	5

Weibull Probabilities

Target (mm)												
6	0.081	0.024	0.004	0.011	0.008	0.094	0.986	0.039	0.017	1.000	0.239	0.559
12	0.741	0.579	0.811	0.869	0.321	0.988	1.000	0.999	0.757	1.000	1.000	1.000
25	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Maximum Scribe Undercutting (rounded up to the nearest mm) with at Least 95% Weibull Probability

Undercutting (mm)	15	16	13	13	18	12	6	11	14	5	9	8
Weibull Prob.	0.960	0.975	0.965	0.975	0.972	0.988	0.986	0.973	0.975	0.992	0.994	0.991

Comparison of Methods of Evaluating Scribe Undercutting

In the search for a number that can be used as a benchmark to describe scribe undercutting, the three primary candidates are as follows.

Method 1

Take many measurements (e.g., 288) and use the mean plus two standard deviations.

Advantages of Method 1 are:

- Straightforward and easy to take measurements
- Computations are elementary and can be done on a hand held calculator or with any computer statistics package
- Consideration is given to the shape of the scribe undercutting; total area of undercutting as well as rogue peaks contribute to the final number.

Disadvantages of Method 1 are:

- Time consuming to make and record 288 measurements
- Easy to miss narrow peaks
- Some subjective judgments must be made, especially for non-uniform scribes.

Method 2

Measure only the maximum undercutting on each scribe (12 measurements) and use the mean plus two standard deviations.

Advantages of Method 2 are:

- Straightforward and easy to take measurements
- Short time required to make and record 12 measurements
- Very objective, little judgment required
- Computations are elementary and can be done on a hand held calculator or with any computer statistics package
- The maximum undercutting is definitely measured.

Disadvantages of Method 2 are:

- No consideration is given to the total area of the scribe undercutting; a rogue peak exerts a disproportionate weight on the computation
- Small data set increases statistical uncertainty.

Method 2W

Measure only the maximum undercutting on each scribe (12 measurements) and use Weibull analysis to compute the target undercutting at 95% confidence.

Advantages of Method 2W are:

- Straightforward and easy to take measurements
- Short time required to make and record 12 measurements
- Very objective, little judgment required
- The maximum undercutting is definitely measured.

Disadvantages of Method 2W are:

- No consideration is given to the total area of the scribe undercutting; a rogue peak exerts a disproportionate weight on the computation
- Computations are more complicated and are not supported by all statistics software
- Small data set increases statistical uncertainty.

The possible benchmarks using the 3 methods discussed above are listed in Table 8 for each of the 12 data sets.

The benchmarks computed by Methods 1 and 2 have a close linear relationship, as can be seen in Figure 4. The Method 2 benchmarks are higher than those of Method 1 because they are based on the absolute maximum undercutting for each scribe rather than undercutting at a random position.

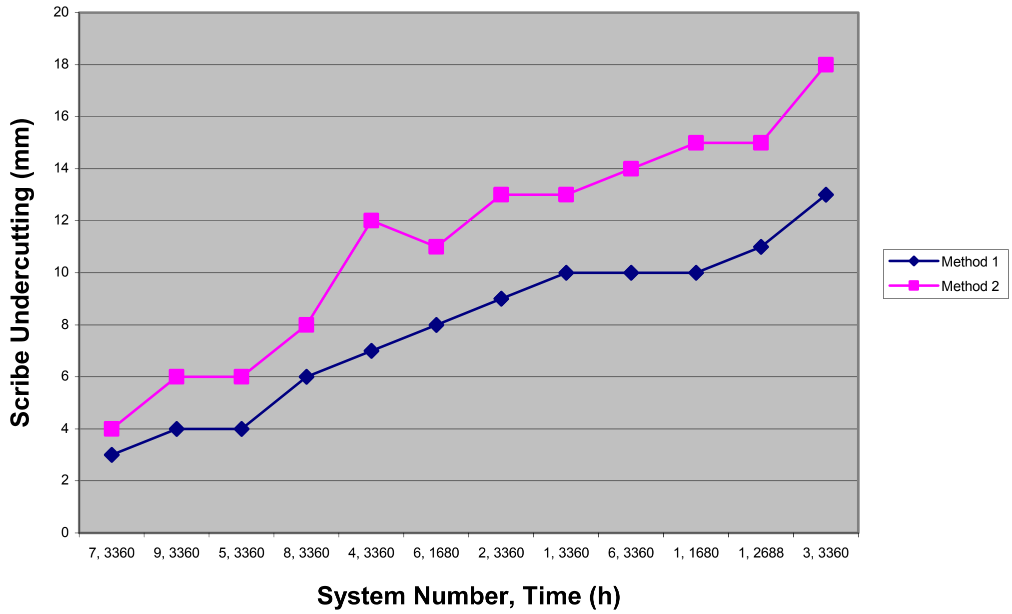


Figure 4. Comparison of Methods 1 and 2 for benchmarking.

There is almost identical agreement between Methods 2 and 2W (Figure 5). Of the 12 data sets, 9 were identical (rounded to the nearest millimeter), 2 differed by 1 mm, and only system 9 differed by 2 mm. The benchmark calculated by Method 2 is simply the average maximum plus two standard deviations. The computation could be performed very easily on a hand held calculator, as only 12 (or 14) data entries are required. This is in contrast to the more complicated Weibull analysis, Method 2W.

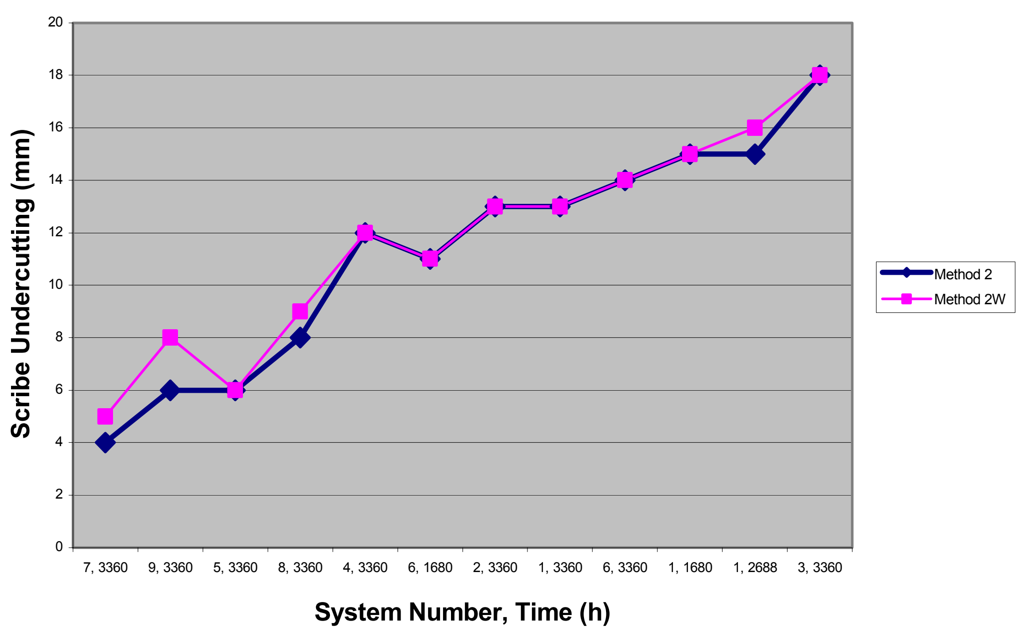


Figure 5. Comparison of Methods 2 and 2W for benchmarking.

Looking at the benchmarks for System 1 it becomes apparent that there was a reversal of the data from what would normally be expected. It is impossible for the scribes to be worse at shorter exposure times than at longer times. If the identical panels, rather than replicate sets, were measured at different times, this reversal in undercutting would not occur. Two possible explanations are: (1) this discrepancy may be due to variations in the panel preparations, position within the test cabinet, or some other experimental factor or (2) the variation is within the range of precision of the measurement technique and that the rate of undercutting was greatest during the first 1680 hours of exposure. As discussed in a later section, DFT variations are not responsible for the reversal.

Reproducibility of Results

In order to test the intralaboratory reproducibility of the scribe evaluation methods, Systems 2 and 3 were measured by two other observers in the same laboratory. They were also remeasured by the principal observer. The raw data for Method 1 are given in Appendix A and for Method 2 in Table 9. System 3 was chosen because most of the discussion in the report focuses on System 3. System 2 was chosen because the scribe undercutting is not as uniformly smooth as that for System 3. There are more isolated blisters along most of the System 2 scribes.

The statistical computations or descriptive estimates based on each set of 288 measurements (Method 1) are listed in Table 10. Each set of measurements very closely fits a normal distribution. The mean undercutting for these four measurements differs by less than a mil (25 micrometers) and the other statistics are also very similar to each other. When the template is taped to the panel prior to taking the measurements, it is randomly positioned along the scribe as long as 24 measurements can be taken. It is unlikely that the template would be in exactly the same position for two different data sets. Nonetheless, the method is sufficient to achieve uniform results among different observers.

The benchmarks computed from the data of the different observers for Method 1, Method 2, and Method 2W are compared in Table 11. The data clearly show that the benchmarks are consistent among different observers. Weibull statistics (Method 2W) gives benchmarks that are a little higher than those computed assuming a normal distribution (Method 2).

Table 9. Reproducibility of maximum scribe undercutting (Systems 2 and 3).

			Maximum Undercutting (mm)			
System	Panel		Observer 1		Observer 2	Observer 3
			Initial Measurement	Remeasurement		
2	2A	top scribe	7	7	6	8
	2B		11	11	11	11
	2C		8	8	8	10
	2D		8	8	7	12
	2E		10	10	10	7
	2F		10	11	11	10
	2A	bottom scribe	8	8	8	7
	2B		12	11	11	11
	2C		10	10	10	8
	2D		11	11	12	8
	2E		7	8	8	10
	2F		10	13	11	11
3	3A	top scribe	14	14	14	14
	3B		8	8	7	7
	3C		9	11	11	11
	3D		13	13	13	13
	3E		15	16	13	13
	3F		15	15	16	15
	3A	bottom scribe	14	14	14	14
	3B		9	9	10	9
	3C		16	16	11	16
	3D		13	13	11	11
	3E		11	11	12	12
	3F		12	13	12	12

Table 10. Selected statistical parameters for Method 1 data taken by different observers for Systems 2 and 3.

System ->	2				3			
Observer ->	1	1*	2	3	1	1*	2	3
Statistic								
# of data points	288	288	288	288	288	288	288	288
Minimum	1	1	0	0	1	1	1	1
Maximum	11	11	11	11	15	15	15	15
Range	10	10	11	11	14	14	14	14
Median	6	6	6	6	7	8	7	7
90th percentile	8	8	8	8	11	12	10	11
95th percentile	9	9	9	9	12	13	12	13
Mean	5.6	6.0	5.3	5.7	7.1	7.9	6.9	7.3
Upper 95% C.I.	5.8	6.2	5.6	5.9	7.4	8.3	7.2	7.6
Upper 99% C.I.	5.9	6.2	5.7	6.0	7.5	8.4	7.3	7.7
Variance	3.7	3.2	5.3	3.8	8.0	7.3	7.2	7.3
Standard deviation	1.9	1.8	2.3	2.0	2.8	2.7	2.7	2.7
Coef. of variation	0.3	0.3	0.4	0.3	0.4	0.3	0.4	0.4
Standard error	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
t-value (mean=0)	49.312	56.865	38.957	49.293	42.493	49.820	43.655	45.957
Mean abs. dev.	1.5	1.4	1.9	1.5	2.3	2.1	2.1	2.1
Skewness	-0.0198	-0.0101	-0.3665	-0.1577	0.3236	0.1831	0.4261	0.3007
Kurtosis	0.1267	-0.1405	-0.3091	0.2826	-0.2100	-0.0820	0.3228	-0.0728

* Remeasured by Observer 1.

Table 11. Comparison of scribe undercutting benchmarks (mm) determined by different observers.

	System 2				System 3			
Observer ->	1	1*	2	3	1	1*	2	3
Method 1 (288 data points)	9	10	10	10	13	13	12	13
Method 2 (12 data points)	13	13	13	13	18	18	17	17
Method 2W (12 data points)	13	14	14	13	18	19	19	18

* Remeasured by Observer 1.

ANOVA for Panels of System 3

Method 1 involved taking 24 measurements on each scribe or 48 measurements per panel and then lumping them all together into a single population of 288 data points. This section examines the panel-to-panel variation within System 3. The raw data for the six panels of System 3 are given in Table 4. The two scribes on a panel form one data set. Statistical computations were run for each panel and are summarized in Table 12. Except for panel 3B, data from the individual panels agree with each other and with the overall computations. ANOVA confirms what appears obvious from the raw data that panel 3B is different from the others. Table 13 is the t-Test pairwise comparisons. Figure 6 is a plot of means and intervals of the six panels from System 3 and clearly shows panel 3B to be an outlier. Both of these analyses indicate Panel 3B is statistically different from the other five panels.

Table 12. Descriptive estimates of scribe undercutting for System 3 panels.

Panel # ->	3A	3B	3C	3D	3E	3F	ALL
STATISTIC							
# of data points	48	48	48	48	48	48	288
Minimum	2	1	2	3	2	2	1
Maximum	14	10	13	13	15	14	15
Range	12	9	11	10	13	12	14
Median	8	5	7	7	7.5	7	7
90th percentile	11	8	10	11	11	12	11
95th percentile	14	9	12	13	13	14	12
Mean, x’	7.9	4.7	7.3	7.4	7.8	7.6	7.1
Upper 95% C.I.	8.8	5.4	7.9	8.1	8.5	8.5	7.4
Upper 99% C.I.	9.1	5.6	8.1	8.3	8.8	8.8	7.5
Variance	9.1	4.6	5.3	6.5	6.7	9.7	8.0
Standard deviation, s	3.0	2.1	2.3	2.6	2.6	3.1	2.8
Coef. of variation	0.382	0.453	0.318	0.348	0.332	0.411	0.399
Standard error	0.436	0.309	0.332	0.369	0.373	0.449	0.167
t-value (mean=0)	18.1	15.3	21.8	19.9	20.9	16.9	42.5
Mean abs. dev.	2.4	1.6	1.8	2.1	2.0	2.5	2.3
Skewness	-0.11	0.27	0.16	0.50	0.40	0.59	0.32
Kurtosis	-0.49	-0.08	0.02	-0.38	0.34	-0.45	-0.21
x’ + 2s	14	9	12	12	13	14	13

Taking 1 measurement of maximum per scribe							
Max (top scribe)	14	8	9	13	15	15	
Max (bottom scribe)	14	9	16	13	11	12	
Absolute max	14	9	16	13	15	15	16

Maximum Scribe Undercutting (rounded up to the nearest millimeter) with at Least 95% Weibull Probability	18

Table 13. T-test correlated groups (pairwise comparisons) for System 3 panels.

	3A	3B	3C	3D	3E	3F
3A	0	6.323012††	1.142113	0.978312	0.216614	0.529586
3B	6.323012††	0	5.354732††	5.379113††	5.876001††	4.816532††
3C	1.142113	5.354732††	0	0.219413	1.18432	0.554585
3D	0.978312	5.379113††	0.219413	0	0.91319	0.36931
3E	0.216614	5.876001††	1.18432	0.91319	0	0.362731
3F	0.529586	4.816532††	0.554585	0.36931	0.362731	0

†† $p<0.01$; † $p<0.05$

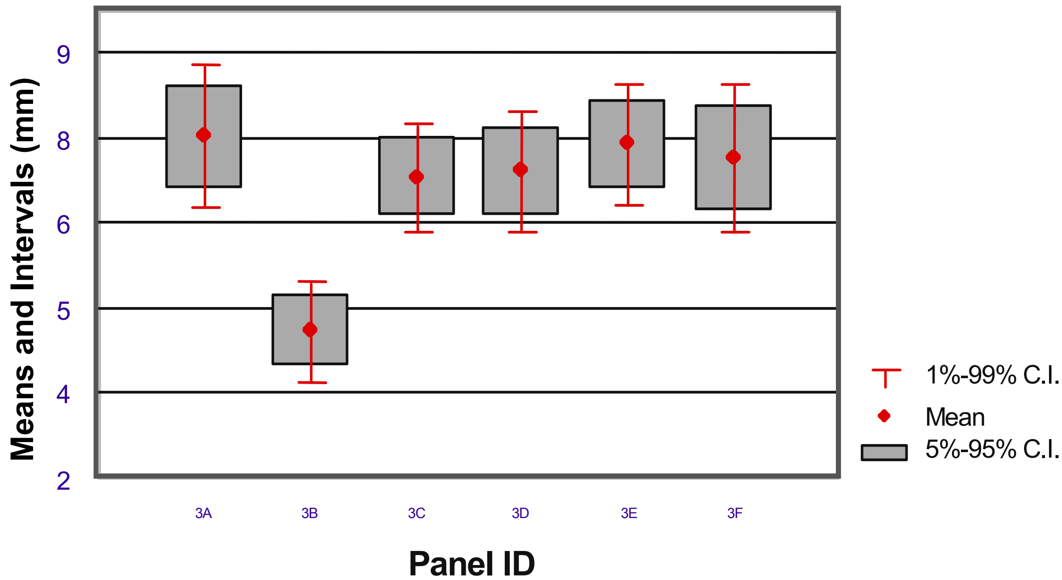


Figure 6. Correlated t-test comparisons for System 3.

Effect of Dry Film Thickness

Table 14 lists the DFT for each panel of System 3 as well as several different measurements of scribe undercutting. For ease of comparison, the data are sorted according to increasing DFT. It is clear from Table 14 that none of the parameters correlate with DFT. Running a correlation program confirms this observation.

Table 14. Comparison of DFT with scribe measurements (mm) for individual panels of System 3 (sorted by DFT).

Panel	DFT	Absolute max undercutting	Mean x'	Std. Dev. (s)	95th percentile	Benchmark Method 1
3B	12.0	9	5	2.1	9	9
3E	12.0	15	8	2.6	13	13
3A	13.0	14	8	3.0	14	14
3F	13.0	15	8	3.1	14	14
3D	14.5	13	7	2.6	13	12
3C	16.0	16	7	2.3	12	12

It can be reasonably assumed that, for the panels investigated in this study of scribe undercutting, variations in the dry film thickness do not have a statistically significant effect on any of the parameters used to measure scribe undercutting. The DFT data for all of the panels for each coating system are given in Table 3.

The reversal in performance as a function of time for System 1 cannot be explained with DFT variations. Table 15 gives average DFT for the three batches of System 1 panels which were exposed for 1680, 2688, or 3360 hours. The panels exposed for the longest time had the smallest undercutting. The undercutting of the 3360 h panels is less than that for the 1680 h panels even though their DFTs are about the same. Based on DFT alone, one might expect the thickest panels (2688 h) to have the least undercutting, but the opposite is true. Clearly, factors other than DFT are the cause of the unexpected behavior of System 1.

Table 15. DFT vs scribe undercutting (mm) for System 1 for three exposure times.

Exposure Time (hours)	Average DFT (mils)	Mean, x' (mm)	Absolute max	Benchmark Method 1	Benchmark Method 2	Benchmark Method 2W
1680	5.8	4.6	16	10	15	15
2688	6.2	5.1	16	11	15	16
3360	5.5	5.0	12	10	13	13

5 Conclusions

The trend today in the coating industry is to write performance specifications instead of composition specifications. The cyclic salt fog/UV condensation test, ASTM D 5894, has become the most highly regarded accelerated laboratory test to evaluate coating systems. Scribe undercutting is the primary mode of degradation in this test. The problem was to quantify the scribe undercutting and to establish a pass/fail benchmark.

This project had two main objectives: (1) develop a rigorous method for evaluating and interpreting rust undercutting data and (2) report on performance "benchmarking" experiments conducted on these coating systems.

Measuring Scribe Undercutting

In order to achieve the first objective it was necessary to develop a standard method of measuring the extent of scribe undercutting. Ideally, the method should possess the following properties:

- The method should be straightforward and easy to use without the need for sophisticated tools such as electronic scanners.
- The method should be accurate and minimize subjective judgments of the evaluator.
- The method should have enough sensitivity to differentiate among coating systems with different levels of performance.
- The method should be reproducible.
- Computations should be able to be performed on any commercial statistics software package or even on a hand held calculator.

Two methods of measuring scribes, each possessing the properties mentioned above, were examined. Method 1 involved measuring the undercutting on both sides of the scribe at 5-mm intervals along the scribe. For panel sets with 12 scribes, this resulted in 288 data points for each coating system exposed for a given time. Method 2 involved only 12 measurements, the maximum undercutting for each of the 12 scribes.

In order to achieve the second objective it was necessary to describe the scribe undercutting with a number, a benchmark. One approach, using the 288 data points acquired with Method 1, was to describe the scribe by the average undercutting or other measure of central tendency. The average undercutting is proportional to the total undercut area near the scribe. However, if the coating does not undercut uniformly along the length of the scribe, the average will not be a good measure of the ability of the coating to protect at the scribe. In this case the maximum undercutting may be a more appropriate measurement. On the other hand, a coating that has only one point with a large undercutting will have the same maximum undercutting as a coating with a uniform scribe with that same large undercutting. Thus, a method incorporating both of these two measures is probably more indicative of a coating's performance at the scribe. A benchmark that incorporates both of these tendencies is the mean plus two standard deviations. The mean is a measure of the average undercutting and any extraordinarily large point of undercutting will cause an increase in the standard deviation. If a similar panel were chosen and a random spot were picked along the scribe, there would be more than a 95% probability that the undercutting would be less than this Method 1 benchmark.

The second objective was also achieved by computing a benchmark from the 12 data points measured using Method 2. The benchmark is the average plus two standard deviations of these 12 maximum readings. There would be more than a 95% probability that the next scribe would have a maximum undercutting less than this Method 2 benchmark.

Scribe Measurement Methods

Two acceptable methods for measuring scribes have been defined. Scribe undercutting can be quantitatively measured with reasonable precision by either measuring undercutting at 5-mm intervals along the scribe, Method 1, or by measuring the maximum undercutting wherever it occurs on the scribe, Method 2.

- Method 1: Undercutting was measured on both sides of the scribe at 5-mm intervals along the scribe. A spacing of 5 mm was adequate to describe the undercutting. The method was tedious in that 288 or more measurements were made. The mean plus two standard deviations provided a benchmark to evaluate the coating system. Using six panels with two scribes per panel provided adequate replication to compensate for a rogue panel.
- Method 2: The maximum undercutting on each scribe was measured. With 2 scribes per panel and 6 replicates, there were 12 data points. The average plus two standard deviations provided a benchmark. There is a greater than

95% probability that the maximum undercutting of the next scribe will fall below this benchmark.

- Method 2W: This method uses the same 12 data points as Method 2 except the 95% target or benchmark is computed using Weibull analysis. The benchmark computed with Method 2W was nearly the same as the benchmark computed with Method 2 for the panel sets used in this project. The 2W benchmark was about 5% higher.

Method 1 has some advantages and some disadvantages. The biggest advantage is that it is an objective method and is easy to use. However, there are situations where judgment must be used. If the hash mark lines up with the edge of a bubble, a slight change in the alignment can easily lead to a difference of 2 mm in that particular scribe undercutting measurement. Another disadvantage of the method is that the hash marks may not line up with the maximum undercutting. Because so many measurements are made (288), it is probable that at least some of the measurements will approximate the maximum. If there are only a few places along the scribe with substantial undercutting, and if these areas are not very wide, the method may lose some of its validity. This method would not be applicable to filiform corrosion.

Some of these drawbacks could be overcome by taking measurements at smaller intervals, such as every 2 mm. However, doing this would dramatically increase the number of data points and the effort involved in characterizing the scribe. For the paint systems examined in this study, a 5-mm interval seemed to be a reasonable choice.

Method 2, measuring the maximum undercutting from the center of the scribe at any point along the scribe, is the simplest and most objective method to characterize a scribe. One simply scans the scribe visually to locate the possible points where the scribe appears to be a maximum, measures those points, and records the maximum value. The biggest disadvantage of this method is that it does not describe the distribution of the undercutting. For example, a scribe with no appreciable undercutting except for a single spot of 8 mm will have the same maximum undercutting value as a scribe that is undercut 6 to 8 mm along its entire length. This situation did not occur for the test panels of this study.

There was a strong linear correlation between the benchmarks computed by Method 1 and those computed by Method 2. Thus, if one of the benchmarks were known, the other corresponding benchmark could be easily found from the regression equation. Taking 288 measurements according to Method 1 provided essentially the same information as taking only 12 measurements according to Method 2.

Preferred Benchmark Method

When all factors are considered, the recommended method for computing a benchmark for evaluating scribe undercutting is Method 2. Taking measurements was easy, reproducible, and objective. The statistical computations were straightforward and could be done on a hand held calculator. For the variety of systems tested, there were no isolated points with unusually large undercutting that would tend to skew the measurement of an absolute maximum undercutting. The strong linear correlation between the Method 2 benchmark and the Method 1 benchmark means that no needed information is gained by collecting scribe data with the more tedious Method 1. The Method 2 benchmark is understandably higher than the Method 1 benchmark since the Method 2 data include only the maximum undercutting.

Replication

The six individual System 3 panels were analyzed separately and then compared with each other in Chapter 4. The fact that one panel can be so different from the others supports the need for more than two or three replicates. Statistical analyses can be performed on any data set, but enough replicates are needed to guard against the effect of rogue panels such as panel 3B. Since the mean of panel 3B is more than three standard deviations from the mean of the others (outside the 99% confidence interval), an argument can be made for ignoring the panel 3B data. If only two or three replicates were used, it would be difficult to identify panel 3B as the rogue panel.

6 Recommendations and Future Work

Prescribed Procedures

Based on the various methods used to gather and analyze data in this project, general procedures are proposed for:

- deriving a benchmark for scribe undercutting
- evaluating a candidate system against the benchmark.

The procedures described below are starting points that will probably require some modification after they are put into practice.

Proposed Method for Deriving a Benchmark for Scribe Undercutting

1. Prepare replicate test specimens of the coating system to be benchmarked.
2. Scribe each of the panels in accordance with standard procedures.
3. Identify 12 separate scribes or scribe segments of at least 20 mm in length. The replicates must provide a minimum of four scribed areas of at least 60 mm each.
4. Expose the test specimens for which a performance benchmark is sought in a cabinet or environment conforming to ASTM D 5894. A minimum duration is five cycles (10 weeks or 1680 hours).
5. Measure the maximum undercutting at each of the scribes or scribe segments.
6. Compute the mean and standard deviation for each coating system. The benchmark is the mean plus two standard deviations.

Proposed Method for Evaluating a Candidate System Against the Benchmark

1. Prepare replicate test specimens of the candidate coating system.
2. Scribe each of the panels in accordance with standard procedures. A minimum of two test specimens and four scribed areas of at least 60 mm each is required.
3. Expose the replicate specimens in the test cabinets for the prescribed time and test parameters.
4. Measure scribe in accordance with procedure above.

5. Compute the average and standard deviation of the maximum undercutting of the scribe segments. These parameters must be comparable to previously established benchmarks.

Note: Additional criteria can be established for an alternate number of measurements.

This project has defined adequate methods to measure scribe undercutting and has defined viable methods to compute benchmarks. There is still a need to determine the variability of the exposure test (ASTM D 5894) including variability caused by panel preparation, consistency of coating formulations, and so on. After the level of variability inherent in panel preparation and exposure is determined, pass/fail targets based on the benchmarks for each coating type can be more accurately established.

Use of Benchmarks in Coating Specifications

Accelerated Laboratory Tests

A problem in writing performance specifications for coatings is to determine pass/fail criteria. The number chosen should be based on experimental data rather than a "gut feeling" for an acceptable benchmark. The coating systems examined in this project represent the range of generic systems most commonly used in industry. The test systems also have a history of good performance in industrial applications. For System 2, zinc-rich epoxy primer/epoxy topcoat, the Method 1 benchmark was 10 mm and the Method 2 benchmark was 13 mm. For example, a performance specification for this type of coating system could require scribe undercutting after 3360 hours (20 weeks) exposure in ASTM D 5894 to be less than 15 mm as measured by Method 2. If the test coating met this requirement, there would be a high likelihood of having performance at least as good as the zinc-rich epoxy system examined in this study. The target of 15 mm instead of 13 mm would allow for fluctuations in the panel preparation and other testing conditions. The System 1 data suggest a variation between separate but similar data sets on the order of 10 to 20%. As more coatings are tested according to this criterion, the target could be adjusted up or down to accommodate experience and the state of the technology.

Field Tests

There is no reason these methods of evaluating scribe undercutting could not be used for panels on a test fence in order to evaluate coating performance in atmospheric exposures typically affecting infrastructure such as service bridges, light poles, cranes, etc. For each generic coating system, benchmarks would have to be determined for different atmospheric exposure conditions such as heavy industrial, light industrial, or marine.

Miscellaneous Recommendations

It is the authors' opinion that scraping does not make it easier to determine the extent of scribe undercutting. In fact, when panel 2F was re-measured, the maximum undercutting was found to be 13 mm compared to 10 mm for the initial measurement made weeks earlier. The reason for this 3 mm discrepancy was that all the blistered paint was not removed during the scraping. This was not noticed the first time. If no scraping had been done, the observer would have been more alert to this undercutting.

Another disadvantage to scraping that became apparent during the scribe measurement was that the scraping made it difficult to determine the extent of undercutting when intact paint was removed. Ideally, intact paint should not have been removed, but it was.

Future Work

There are other promising methods of generating scribe data that have not been examined in this project but may prove to be viable. The data may then be interpreted in several different manners.

Additional Statistical Analysis of Current Panels

Additional methods to be evaluated include the following:

- Measure maxima and average at additional increments (e.g., every 10 mm) to determine the sensitivity of the analysis to the number of data points.
- Determine the influence of shape and size (e.g., number of measurements on the precision of the test method). This would help to confirm the validity of the proposed method for establishing a benchmark.

Determine Interlaboratory Reproducibility of the Test Procedures

The reproducibility of the entire process needs to be determined with a 'round-robin' type of testing program. This would entail preparing test panels and exposing them in cyclic cabinets in various labs e.g., from testing organizations or paint manufacturers. Those would be administered from ASTM-SSPC protocols. Identical sets of panels have been coated with industrial maintenance coatings and are waiting for distribution to various laboratories by ASTM Committee D01.27.31.

The precision of the method must be known to avoid setting the target too low (thereby eliminating good coatings) or too high (passing inferior coatings). For example, the benchmarks for System 2 were 10 mm for Method 1 and 13 mm for Method 2. How much leeway should be given for experimental error? Should the target for Method 2 be set at 13, 15, or 20 mm? This project has determined the scale or magnitude of undercutting to be expected, it has determined the precision of the measurement method, but it has not determined the precision of the accelerated test method.

Analyze History of SSPC and Other Files

Historical data in the archives of SSPC, CERL, and others could be examined to better define the benchmarks for these coating systems, both for exterior atmospheric exposures and for exposures in test cabinets. The testing conditions under which the panels were exposed would need to be closely scrutinized. In general, the SSPC data would not have the same degree of replication that this study provided. However, one SSPC test used 30 replicates at Kure Beach and in various immersion and fog tests with panels coated with two or three coats of MIL-P-24441 epoxy (System 1 in this project). This was reported in SSPC Publication 90-02, *Performance Testing of Marine Coatings: New Test and Evaluation Procedures*. SSPC has field exposure data for the same generic coating systems (different coating manufacturers) as examined in this project. These data, however, would only include the maximum undercutting at each scribe.

Panels from the APEC and ACTS programs are still on exposure at the coke works test site and at the 25-m lot at Kure Beach, NC. Some panels with 10 years exposure at Kure Beach and 6 years on the Mellon Institute roof are in storage at SSPC and could be evaluated using Method 1 or Method 2. These panels include six different aluminum filled epoxy systems exposed outdoors as well as in the cyclic salt fog cabinet. Some of these data are from CERL Project DACW88-90-M-1363.

Determine Validity of Benchmarking for Other Systems and Exposures

This project examined two- and three-coat systems. Benchmarks will need to be determined for single-coat systems. These would be useful in the development of paint specifications as opposed to coating system specifications.

For use in coating performance specifications, it will be useful to determine scribe-undercutting benchmarks for atmospheric exposure tests.

APPENDIX A: Raw Data, Method 1

Appendix A contains the raw data for Method 1 where scribe undercutting was measured at five millimeter intervals along the scribe. The IDs in the Panel/Scribe column can be interpreted as follows:

2A-7 means System 2, Panel A, the 7th step of 5 mm, i.e., 30 mm from the top of the scribe.

Since there are two scribes per panel, 2A-1 to 2A-12 are measurements made on the top scribe while 2A-13 to 2A-24 are measurements made on the bottom scribe. Thus,

4C-15 means System 4, Panel C, the 3rd step (15 - 12) of 5 mm, i.e., 10 mm from the top of the lower scribe.

A further example:

5F-1 means System 5, Panel F, top of the upper scribe
5F-2 means System 5, Panel F, 5 mm from the top measurement of the upper scribe
5F-3 means System 5, Panel F, 10 mm from the top measurement of the upper scribe
…
5F-12 means System 5, Panel F, 55 mm from the top measurement of the upper scribe (the last measurement taken on the upper scribe). The template was centered so that no measurements were taken at the very ends of the scribe.

5F-13 means System 5, Panel F, top measurement of the lower scribe
5F-14 means System 5, Panel F, 5 mm from the top measurement of the lower scribe
5F-15 means System 5, Panel F, 10 mm from the top measurement of the lower scribe

5F-24 means System 5, Panel F, 55 mm from the top measurement of the lower scribe (the last measurement taken on the lower scribe).

Some of the scribes for Systems 7, 8, and 9 were not long enough for 12 measurements 5 mm apart.

System 1 - 1680 Hours

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
1A-1	3	3	1C-1	1	1	1E-1	2	5
1A-2	3	2	1C-2	4	6	1E-2	7	8
1A-3	2	2	1C-3	6	5	1E-3	6	7
1A-4	3	2	1C-4	6	3	1E-4	6	4
1A-5	4	5	1C-5	11	12	1E-5	6	6
1A-6	5	7	1C-6	10	15	1E-6	4	3
1A-7	4	7	1C-7	6	13	1E-7	7	3
1A-8	1	3	1C-8	11	4	1E-8	8	2
1A-9	2	3	1C-9	8	8	1E-9	4	4
1A-10	2	9	1C-10	3	3	1E-10	3	5
1A-11	2	9	1C-11	6	6	1E-11	4	3
1A-12	7	2	1C-12	6	4	1E-12	4	4
1A-13	3	5	1C-13	4	6	1E-13	6	3
1A-14	1	5	1C-14	4	6	1E-14	6	4
1A-15	10	6	1C-15	4	5	1E-15	4	4
1A-16	7	7	1C-16	3	4	1E-16	1	6
1A-17	3	4	1C-17	4	4	1E-17	2	6
1A-18	2	3	1C-18	4	5	1E-18	3	5
1A-19	2	4	1C-19	5	5	1E-19	2	3
1A-20	2	5	1C-20	4	5	1E-20	3	3
1A-21	2	8	1C-21	5	6	1E-21	5	3
1A-22	2	2	1C-22	5	6	1E-22	5	4
1A-23	1	4	1C-23	11	2	1E-23	3	5
1A-24	5	3	1C-24	10	7	1E-24	5	6
1B-1	1	2	1D-1	3	2	1F-1	4	4
1B-2	4	3	1D-2	4	2	1F-2	5	5
1B-3	6	4	1D-3	2	3	1F-3	7	5
1B-4	2	2	1D-4	2	2	1F-4	7	4
1B-5	3	1	1D-5	2	3	1F-5	5	6
1B-6	3	4	1D-6	1	2	1F-6	5	6
1B-7	4	3	1D-7	2	2	1F-7	3	4
1B-8	3	4	1D-8	2	1	1F-8	3	7
1B-9	6	5	1D-9	1	2	1F-9	6	5
1B-10	1	5	1D-10	4	5	1F-10	6	5
1B-11	5	4	1D-11	4	4	1F-11	3	3
1B-12	6	3	1D-12	3	3	1F-12	3	3
1B-13	5	6	1D-13	6	4	1F-13	10	6
1B-14	2	2	1D-14	1	4	1F-14	12	6
1B-15	5	4	1D-15	8	10	1F-15	5	4
1B-16	7	10	1D-16	6	11	1F-16	7	3
1B-17	8	4	1D-17	3	8	1F-17	7	9
1B-18	8	8	1D-18	5	7	1F-18	1	11
1B-19	1	1	1D-19	5	2	1F-19	2	11
1B-20	6	7	1D-20	6	5	1F-20	1	7
1B-21	5	2	1D-21	5	6	1F-21	2	3
1B-22	5	7	1D-22	3	5	1F-22	5	8
1B-23	5	5	1D-23	5	5	1F-23	6	10
1B-24	5	6	1D-24	4	4	1F-24	5	3

System 1 - 2688 Hours

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
1G-1	10	9	1I-1	10	4	1K-1	6	3
1G-2	10	5	1I-2	10	1	1K-2	3	2
1G-3	2	3	1I-3	3	2	1K-3	3	4
1G-4	6	7	1I-4	8	5	1K-4	1	5
1G-5	3	8	1I-5	8	14	1K-5	4	6
1G-6	4	6	1I-6	14	14	1K-6	4	2
1G-7	5	4	1I-7	10	10	1K-7	6	1
1G-8	2	2	1I-8	7	3	1K-8	1	3
1G-9	5	2	1I-9	10	3	1K-9	4	5
1G-10	5	2	1I-10	12	2	1K-10	3	5
1G-11	5	4	1I-11	12	3	1K-11	1	5
1G-12	4	3	1I-12	5	5	1K-12	9	2
1G-13	2	5	1I-13	4	4	1K-13	6	3
1G-14	2	2	1I-14	4	4	1K-14	2	6
1G-15	6	9	1I-15	5	8	1K-15	1	4
1G-16	6	9	1I-16	5	12	1K-16	6	6
1G-17	7	7	1I-17	4	9	1K-17	1	2
1G-18	9	6	1I-18	2	4	1K-18	1	1
1G-19	6	7	1I-19	9	3	1K-19	2	2
1G-20	7	3	1I-20	9	3	1K-20	2	3
1G-21	7	5	1I-21	6	3	1K-21	1	4
1G-22	8	6	1I-22	6	7	1K-22	2	4
1G-23	6	2	1I-23	6	8	1K-23	5	5
1G-24	3	2	1I-24	3	3	1K-24	5	2
1H-1	8	5	1J-1	4	6	1L-1	6	3
1H-2	9	6	1J-2	2	5	1L-2	0.5	6
1H-3	2	8	1J-3	6	4	1L-3	5	9
1H-4	2	5	1J-4	6	6	1L-4	0.5	7
1H-5	2	2	1J-5	5	6	1L-5	9	8
1H-6	2	2	1J-6	1	5	1L-6	7	7
1H-7	7	1	1J-7	2	4	1L-7	5	7
1H-8	9	4	1J-8	8	6	1L-8	9	12
1H-9	2	7	1J-9	5	6	1L-9	6	8
1H-10	2	10	1J-10	3	4	1L-10	9	12
1H-11	3	10	1J-11	5	5	1L-11	11	9
1H-12	4	6	1J-12	6	4	1L-12	7	9
1H-13	9	2	1J-13	7	2	1L-13	10	4
1H-14	9	8	1J-14	6	8	1L-14	8	7
1H-15	8	2	1J-15	1	8	1L-15	8	8
1H-16	5	4	1J-16	6	4	1L-16	8	10
1H-17	4	2	1J-17	0.5	1	1L-17	8	6
1H-18	4	7	1J-18	6	0.5	1L-18	3	3
1H-19	5	6	1J-19	5	2	1L-19	1	3
1H-20	1	9	1J-20	6	6	1L-20	3	2
1H-21	2	8	1J-21	4	5	1L-21	2	7
1H-22	7	4	1J-22	2	1	1L-22	3	7
1H-23	6	8	1J-23	1	7	1L-23	0.5	3
1H-24	6	9	1J-24	2	9	1L-24	1	1

System 1 - 3360 Hours

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
1M-1	9	7	1O-1	2	2	1Q-1	8	0.5
1M-2	8	3	1O-2	5	5	1Q-2	6	12
1M-3	3	2	1O-3	5	5	1Q-3	4	11
1M-4	6	4	1O-4	6	9	1Q-4	11	5
1M-5	3	2	1O-5	6	9	1Q-5	11	0.5
1M-6	5	7	1O-6	3	8	1Q-6	3	5
1M-7	9	7	1O-7	6	5	1Q-7	7	4
1M-8	6	4	1O-8	3	3	1Q-8	4	7
1M-9	5	9	1O-9	4	4	1Q-9	4	2
1M-10	7	8	1O-10	3	4	1Q-10	4	4
1M-11	7	5	1O-11	8	3	1Q-11	2	3
1M-12	3	1	1O-12	8	3	1Q-12	4	5
1M-13	10	6	1O-13	3	4	1Q-13	5	3
1M-14	8	10	1O-14	2	3	1Q-14	4	4
1M-15	5	9	1O-15	1	10	1Q-15	3	3
1M-16	5	1	1O-16	0.5	12	1Q-16	3	4
1M-17	8	1	1O-17	3	5	1Q-17	5	4
1M-18	7	7	1O-18	2	3	1Q-18	6	4
1M-19	5	8	1O-19	5	4	1Q-19	4	5
1M-20	5	5	1O-20	10	4	1Q-20	4	6
1M-21	6	3	1O-21	12	7	1Q-21	6	5
1M-22	6	6	1O-22	11	5	1Q-22	7	6
1M-23	6	4	1O-23	4	6	1Q-23	5	6
1M-24	5	3	1O-24	4	7	1Q-24	3	4
1N-1	8	5	1P-1	4	7	1R-1	7	7
1N-2	9	0.5	1P-2	4	9	1R-2	4	7
1N-3	5	2	1P-3	6	8	1R-3	4	4
1N-4	7	2	1P-4	5	7	1R-4	5	4
1N-5	6	6	1P-5	6	6	1R-5	8	5
1N-6	5	3	1P-6	4	7	1R-6	7	5
1N-7	1	2	1P-7	6	5	1R-7	8	5
1N-8	7	1	1P-8	3	5	1R-8	7	3
1N-9	7	4	1P-9	4	6	1R-9	1	7
1N-10	1	0.5	1P-10	5	5	1R-10	6	3
1N-11	5	5	1P-11	5	5	1R-11	1	4
1N-12	6	4	1P-12	7	4	1R-12	10	5
1N-13	3	5	1P-13	3	8	1R-13	5	5
1N-14	4	6	1P-14	5	3	1R-14	4	5
1N-15	8	5	1P-15	2	10	1R-15	7	5
1N-16	5	3	1P-16	5	5	1R-16	5	6
1N-17	1	5	1P-17	3	5	1R-17	8	4
1N-18	6	3	1P-18	4	6	1R-18	6	7
1N-19	1	3	1P-19	4	4	1R-19	4	6
1N-20	1	3	1P-20	3	2	1R-20	2	3
1N-21	1	3	1P-21	7	4	1R-21	5	5
1N-22	6	6	1P-22	7	5	1R-22	6	6
1N-23	2	5	1P-23	7	4	1R-23	3	4
1N-24	1	1	1P-24	6	4	1R-24	2	5

System 2 - 3360 Hours

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
2A-1	2	5	2C-1	3	3	2E-1	3	5
2A-2	1	6	2C-2	4	5	2E-2	5	4
2A-3	5	5	2C-3	2	7	2E-3	8	4
2A-4	4	7	2C-4	4	6	2E-4	10	4
2A-5	3	6	2C-5	6	7	2E-5	7	6
2A-6	2	5	2C-6	7	3	2E-6	5	7
2A-7	4	4	2C-7	5	5	2E-7	4	6
2A-8	3	5	2C-8	6	5	2E-8	6	3
2A-9	4	4	2C-9	3	7	2E-9	4	5
2A-10	3	3	2C-10	5	5	2E-10	3	6
2A-11	3	3	2C-11	6	4	2E-11	3	6
2A-12	3	4	2C-12	5	4	2E-12	2	5
2A-13	7	5	2C-13	7	10	2E-13	1	3
2A-14	7	5	2C-14	7	5	2E-14	1	5
2A-15	5	5	2C-15	5	7	2E-15	4	6
2A-16	5	7	2C-16	8	7	2E-16	4	6
2A-17	6	4	2C-17	7	9	2E-17	3	3
2A-18	4	1	2C-18	5	8	2E-18	4	7
2A-19	6	8	2C-19	8	8	2E-19	4	7
2A-20	2	5	2C-20	7	5	2E-20	5	6
2A-21	1	4	2C-21	5	6	2E-21	3	6
2A-22	6	6	2C-22	4	8	2E-22	5	6
2A-23	1	1	2C-23	4	7	2E-23	5	3
2A-24	2	4	2C-24	4	5	2E-24	5	6
2B-1	5	6	2D-1	6	4	2F-1	6	5
2B-2	7	5	2D-2	3	6	2F-2	8	9
2B-3	5	7	2D-3	5	6	2F-3	8	4
2B-4	5	6	2D-4	7	7	2F-4	7	5
2B-5	4	8	2D-5	6	7	2F-5	5	6
2B-6	5	7	2D-6	6	8	2F-6	8	6
2B-7	5	2	2D-7	4	7	2F-7	6	4
2B-8	5	6	2D-8	6	5	2F-8	8	6
2B-9	1	6	2D-9	6	6	2F-9	5	7
2B-10	5	5	2D-10	7	6	2F-10	7	6
2B-11	11	5	2D-11	5	5	2F-11	7	9
2B-12	4	4	2D-12	7	3	2F-12	10	8
2B-13	7	8	2D-13	5	6	2F-13	6	3
2B-14	8	5	2D-14	6	5	2F-14	7	7
2B-15	8	5	2D-15	5	5	2F-15	9	8
2B-16	8	5	2D-16	6	5	2F-16	8	9
2B-17	5	6	2D-17	8	7	2F-17	10	6
2B-18	4	5	2D-18	9	4	2F-18	7	8
2B-19	11	8	2D-19	11	8	2F-19	8	7
2B-20	7	4	2D-20	7	8	2F-20	9	7
2B-21	6	7	2D-21	6	7	2F-21	8	9
2B-22	7	7	2D-22	7	7	2F-22	6	8
2B-23	7	7	2D-23	8	9	2F-23	6	5
2B-24	5	5	2D-24	5	7	2F-24	6	7

System 3 - 3360 Hours

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
3A-1	7	8	3C-1	6	4	3E-1	10	10
3A-2	10	10	3C-2	5	5	3E-2	10	7
3A-3	10	9	3C-3	6	5	3E-3	7	4
3A-4	10	9	3C-4	5	7	3E-4	15	2
3A-5	10	6	3C-5	2	9	3E-5	6	7
3A-6	8	8	3C-6	7	10	3E-6	7	5
3A-7	7	4	3C-7	3	8	3E-7	9	9
3A-8	7	6	3C-8	5	9	3E-8	5	9
3A-9	6	7	3C-9	4	9	3E-9	4	9
3A-10	6	8	3C-10	5	7	3E-10	9	7
3A-11	10	11	3C-11	8	5	3E-11	13	6
3A-12	11	13	3C-12	6	9	3E-12	12	5
3A-13	11	8	3C-13	11	7	3E-13	7	5
3A-14	4	2	3C-14	7	5	3E-14	7	8
3A-15	2	6	3C-15	8	7	3E-15	5	8
3A-16	7	3	3C-16	9	11	3E-16	7	11
3A-17	14	4	3C-17	8	9	3E-17	5	11
3A-18	14	8	3C-18	8	8	3E-18	9	8
3A-19	10	7	3C-19	9	6	3E-19	9	8
3A-20	11	3	3C-20	9	8	3E-20	8	5
3A-21	3	10	3C-21	10	6	3E-21	9	6
3A-22	5	6	3C-22	13	8	3E-22	11	5
3A-23	10	11	3C-23	12	8	3E-23	12	7
3A-24	8	12	3C-24	7	5	3E-24	7	9
3B-1	4	10	3D-1	4	7	3F-1	5	4
3B-2	6	4	3D-2	6	7	3F-2	4	4
3B-3	6	3	3D-3	5	6	3F-3	7	6
3B-4	2	4	3D-4	3	5	3F-4	5	13
3B-5	4	4	3D-5	6	6	3F-5	6	14
3B-6	5	3	3D-6	10	5	3F-6	14	12
3B-7	5	2	3D-7	10	4	3F-7	12	7
3B-8	5	3	3D-8	6	4	3F-8	14	9
3B-9	5	5	3D-9	6	11	3F-9	10	6
3B-10	6	5	3D-10	8	13	3F-10	12	6
3B-11	5	5	3D-11	11	12	3F-11	5	7
3B-12	5	4	3D-12	7	5	3F-12	10	2
3B-13	5	8	3D-13	5	3	3F-13	3	7
3B-14	4	4	3D-14	8	6	3F-14	7	7
3B-15	5	1	3D-15	5	7	3F-15	12	5
3B-16	8	1	3D-16	8	9	3F-16	5	8
3B-17	8	1	3D-17	6	9	3F-17	9	8
3B-18	3	6	3D-18	6	12	3F-18	9	8
3B-19	1	7	3D-19	13	9	3F-19	8	7
3B-20	2	6	3D-20	11	9	3F-20	12	4
3B-21	3	5	3D-21	9	7	3F-21	9	5
3B-22	6	8	3D-22	7	7	3F-22	5	4
3B-23	9	5	3D-23	8	5	3F-23	8	7
3B-24	8	3	3D-24	8	9	3F-24	5	7

System 4 - 3360 Hours

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
4A-1	4	4	4C-1	5	2	4E-1	3	6
4A-2	6	5	4C-2	3	1	4E-2	2	4
4A-3	5	7	4C-3	2	2	4E-3	4	6
4A-4	5	6	4C-4	2	1	4E-4	3	4
4A-5	4	4	4C-5	3	1	4E-5	2	3
4A-6	5	4	4C-6	3	2	4E-6	2	3
4A-7	4	5	4C-7	1	1	4E-7	1	3
4A-8	5	5	4C-8	3	2	4E-8	4	6
4A-9	8	2	4C-9	1	2	4E-9	3	7
4A-10	3	3	4C-10	1	1	4E-10	3	5
4A-11	4	5	4C-11	1	2	4E-11	2	5
4A-12	3	4	4C-12	3	2	4E-12	3	3
4A-13	3	4	4C-13	2	5	4E-13	3	3
4A-14	5	4	4C-14	2	4	4E-14	2	4
4A-15	4	3	4C-15	4	3	4E-15	2	2
4A-16	5	7	4C-16	7	3	4E-16	4	3
4A-17	4	4	4C-17	2	5	4E-17	3	3
4A-18	4	3	4C-18	3	4	4E-18	2	4
4A-19	5	2	4C-19	3	4	4E-19	3	2
4A-20	5	3	4C-20	1	3	4E-20	4	2
4A-21	2	5	4C-21	1	3	4E-21	3	5
4A-22	4	2	4C-22	4	5	4E-22	3	2
4A-23	4	4	4C-23	2	2	4E-23	4	4
4A-24	4	6	4C-24	4	2	4E-24	4	6
4B-1	4	3	4D-1	3	2	4F-1	2	2
4B-2	6	4	4D-2	1	3	4F-2	4	2
4B-3	3	6	4D-3	3	2	4F-3	3	5
4B-4	4	6	4D-4	3	3	4F-4	1	5
4B-5	4	5	4D-5	3	2	4F-5	1	4
4B-6	3	4	4D-6	4	5	4F-6	4	4
4B-7	4	5	4D-7	2	5	4F-7	4	2
4B-8	3	5	4D-8	3	5	4F-8	4	2
4B-9	8	9	4D-9	2	9	4F-9	4	5
4B-10	6	6	4D-10	2	6	4F-10	3	5
4B-11	5	4	4D-11	4	3	4F-11	2	3
4B-12	5	3	4D-12	2	6	4F-12	2	2
4B-13	3	2	4D-13	10	5	4F-13	4	3
4B-14	4	3	4D-14	4	8	4F-14	2	3
4B-15	4	4	4D-15	3	3	4F-15	3	3
4B-16	6	9	4D-16	5	3	4F-16	3	5
4B-17	6	5	4D-17	3	6	4F-17	4	4
4B-18	5	4	4D-18	3	7	4F-18	4	3
4B-19	5	6	4D-19	1	6	4F-19	4	7
4B-20	5	4	4D-20	2	4	4F-20	3	4
4B-21	4	5	4D-21	2	3	4F-21	3	4
4B-22	8	6	4D-22	3	2	4F-22	3	2
4B-23	3	5	4D-23	3	3	4F-23	3	3
4B-24	3	4	4D-24	2	4	4F-24	6	4

System 5 - 3360 Hours

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
5A-1	0.5	0.5	5C-1	2	1	5E-1	0.5	0.5
5A-2	1	1	5C-2	2	2	5E-2	0.5	1
5A-3	1	2	5C-3	2	4	5E-3	2	2
5A-4	0.5	0.5	5C-4	3	2	5E-4	1	1
5A-5	0.5	0.5	5C-5	2	2	5E-5	2	0.5
5A-6	1	0.5	5C-6	2	5	5E-6	2	1
5A-7	0.5	0.5	5C-7	3	4	5E-7	1	0.5
5A-8	0.5	0.5	5C-8	2	6	5E-8	1	1
5A-9	0.5	0.5	5C-9	3	5	5E-9	2	1
5A-10	0.5	1	5C-10	5	4	5E-10	2	1
5A-11	0.5	2	5C-11	3	5	5E-11	1	2
5A-12	1	2	5C-12	5	5	5E-12	1	2
5A-13	1	2	5C-13	5	3	5E-13	2	1
5A-14	0.5	3	5C-14	3	3	5E-14	2	2
5A-15	2	2	5C-15	3	3	5E-15	1	2
5A-16	1	2	5C-16	3	3	5E-16	1	2
5A-17	0.5	2	5C-17	3	3	5E-17	1	3
5A-18	2	1	5C-18	2	4	5E-18	1	3
5A-19	1	0.5	5C-19	3	3	5E-19	2	3
5A-20	0.5	0.5	5C-20	2	2	5E-20	2	1
5A-21	0.5	0.5	5C-21	1	2	5E-21	2	1
5A-22	2	3	5C-22	1	2	5E-22	3	2
5A-23	1	1	5C-23	1	1	5E-23	3	5
5A-24	1	1	5C-24	2	2	5E-24	3	2
5B-1	0.5	3	5D-1	4	3	5F-1	3	2
5B-2	3	0.5	5D-2	3	3	5F-2	1	1
5B-3	0.5	0.5	5D-3	3	3	5F-3	3	3
5B-4	0.5	0.5	5D-4	3	3	5F-4	2	2
5B-5	2	0.5	5D-5	3	3	5F-5	3	1
5B-6	0.5	0.5	5D-6	3	3	5F-6	2	2
5B-7	0.5	2	5D-7	3	3	5F-7	2	1
5B-8	0.5	0.5	5D-8	2	3	5F-8	1	3
5B-9	2	1	5D-9	3	3	5F-9	3	3
5B-10	0.5	0.5	5D-10	3	2	5F-10	3	2
5B-11	0.5	0.5	5D-11	3	3	5F-11	1	2
5B-12	0.5	2	5D-12	3	3	5F-12	2	4
5B-13	1	2	5D-13	3	3	5F-13	2	2
5B-14	2	2	5D-14	2	3	5F-14	3	1
5B-15	0.5	0.5	5D-15	2	3	5F-15	1	4
5B-16	0.5	1	5D-16	3	2	5F-16	1	1
5B-17	0.5	3	5D-17	3	4	5F-17	2	1
5B-18	0.5	2	5D-18	3	3	5F-18	1	1
5B-19	0.5	1	5D-19	3	3	5F-19	0.5	1
5B-20	0.5	2	5D-20	2	2	5F-20	1	1
5B-21	2	1	5D-21	3	3	5F-21	1	2
5B-22	1	2	5D-22	4	4	5F-22	1	2
5B-23	0.5	2	5D-23	3	3	5F-23	1	2
5B-24	1	1	5D-24	2	3	5F-24	1	1

System 6 - 1680 Hours

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
6A-1	3	2	6C-1	4	5	6E-1	4	4
6A-2	3	3	6C-2	4	5	6E-2	3	3
6A-3	3	3	6C-3	6	7	6E-3	1	3
6A-4	2	3	6C-4	6	6	6E-4	2	4
6A-5	5	5	6C-5	3	5	6E-5	3	2
6A-6	7	8	6C-6	4	4	6E-6	2	4
6A-7	4	5	6C-7	2	6	6E-7	4	4
6A-8	4	5	6C-8	7	4	6E-8	1	3
6A-9	3	8	6C-9	7	10	6E-9	5	4
6A-10	4	5	6C-10	5	7	6E-10	2	3
6A-11	3	5	6C-11	7	6	6E-11	1	1
6A-12	4	5	6C-12	5	4	6E-12	2	2
6A-13	2	2	6C-13	7	6	6E-13	5	5
6A-14	1	4	6C-14	5	5	6E-14	3	4
6A-15	2	2	6C-15	6	5	6E-15	4	5
6A-16	2	3	6C-16	5	5	6E-16	3	4
6A-17	4	3	6C-17	2	5	6E-17	3	4
6A-18	5	4	6C-18	5	8	6E-18	2	3
6A-19	3	4	6C-19	4	5	6E-19	2	6
6A-20	1	2	6C-20	4	4	6E-20	2	4
6A-21	5	4	6C-21	3	3	6E-21	4	4
6A-22	4	3	6C-22	4	6	6E-22	3	3
6A-23	2	4	6C-23	5	5	6E-23	2	2
6A-24	3	5	6C-24	5	3	6E-24	3	4
6B-1	4	6	6D-1	7	5	6F-1	2	3
6B-2	4	5	6D-2	9	10	6F-2	5	3
6B-3	10	8	6D-3	3	11	6F-3	3	2
6B-4	5	8	6D-4	5	6	6F-4	2	3
6B-5	5	7	6D-5	4	5	6F-5	3	3
6B-6	9	6	6D-6	3	7	6F-6	3	3
6B-7	2	7	6D-7	5	5	6F-7	3	4
6B-8	7	7	6D-8	5	5	6F-8	2	3
6B-9	6	5	6D-9	4	3	6F-9	2	3
6B-10	4	6	6D-10	5	7	6F-10	4	4
6B-11	4	4	6D-11	7	5	6F-11	4	4
6B-12	3	2	6D-12	7	5	6F-12	4	3
6B-13	3	5	6D-13	6	8	6F-13	4	3
6B-14	4	2	6D-14	6	11	6F-14	3	4
6B-15	5	5	6D-15	4	7	6F-15	3	3
6B-16	4	6	6D-16	5	7	6F-16	2	2
6B-17	5	5	6D-17	4	6	6F-17	2	5
6B-18	4	4	6D-18	5	5	6F-18	5	4
6B-19	4	5	6D-19	4	6	6F-19	3	4
6B-20	3	5	6D-20	6	5	6F-20	4	6
6B-21	5	3	6D-21	5	4	6F-21	5	6
6B-22	7	6	6D-22	3	3	6F-22	5	5
6B-23	2	4	6D-23	5	3	6F-23	5	5
6B-24	4	5	6D-24	5	6	6F-24	5	5

System 6 - 3360 Hours

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
6G-1	5	4	6I-1	3	2	6K-1	2	4
6G-2	8	6	6I-2	1	7	6K-2	2	3
6G-3	7	6	6I-3	2	3	6K-3	4	3
6G-4	7	8	6I-4	4	3	6K-4	5	3
6G-5	6	9	6I-5	2	3	6K-5	4	5
6G-6	6	4	6I-6	2	3	6K-6	4	7
6G-7	7	5	6I-7	2	2	6K-7	3	3
6G-8	6	5	6I-8	2	2	6K-8	3	3
6G-9	7	4	6I-9	2	2	6K-9	3	4
6G-10	8	7	6I-10	3	5	6K-10	13	9
6G-11	8	8	6I-11	3	3	6K-11	12	11
6G-12	7	5	6I-12	7	2	6K-12	11	6
6G-13	4	4	6I-13	4	4	6K-13	8	5
6G-14	5	4	6I-14	2	2	6K-14	3	3
6G-15	4	3	6I-15	3	2	6K-15	4	2
6G-16	3	6	6I-16	3	3	6K-16	7	4
6G-17	3	3	6I-17	2	3	6K-17	7	5
6G-18	5	6	6I-18	4	2	6K-18	7	3
6G-19	7	4	6I-19	2	6	6K-19	8	6
6G-20	5	4	6I-20	2	2	6K-20	5	3
6G-21	4	6	6I-21	2	3	6K-21	3	2
6G-22	5	9	6I-22	2	2	6K-22	4	3
6G-23	5	5	6I-23	2	2	6K-23	3	4
6G-24	9	7	6I-24	3	7	6K-24	4	3
6H-1	4	4	6J-1	3	2	6L-1	4	5
6H-2	3	5	6J-2	5	3	6L-2	8	6
6H-3	4	3	6J-3	4	5	6L-3	8	9
6H-4	3	7	6J-4	4	4	6L-4	7	11
6H-5	4	3	6J-5	5	4	6L-5	6	8
6H-6	2	5	6J-6	2	7	6L-6	11	5
6H-7	2	8	6J-7	3	4	6L-7	5	6
6H-8	3	3	6J-8	4	3	6L-8	9	8
6H-9	5	4	6J-9	3	2	6L-9	7	11
6H-10	5	8	6J-10	2	4	6L-10	8	12
6H-11	4	8	6J-11	2	4	6L-11	11	4
6H-12	3	3	6J-12	3	2	6L-12	7	9
6H-13	4	9	6J-13	5	5	6L-13	4	10
6H-14	6	5	6J-14	1	2	6L-14	6	3
6H-15	4	6	6J-15	1	3	6L-15	6	4
6H-16	4	7	6J-16	2	1	6L-16	4	3
6H-17	7	7	6J-17	3	2	6L-17	4	4
6H-18	6	7	6J-18	4	2	6L-18	4	5
6H-19	5	5	6J-19	3	5	6L-19	8	6
6H-20	5	4	6J-20	3	3	6L-20	10	6
6H-21	5	5	6J-21	4	4	6L-21	9	7
6H-22	5	5	6J-22	3	4	6L-22	8	8
6H-23	6	7	6J-23	3	3	6L-23	4	8
6H-24	8	7	6J-24	3	3	6L-24	14	8

System 7 - 3360 Hours

PANEL/ SCRIBE	LEFT	RIGHT	PANEL/ SCRIBE	LEFT	RIGHT	PANEL /SCRIBE	LEFT	RIGHT	PANEL/ SCRIBE	LEFT	RIGHT
7A-1	0.5	0.5	7C-1	1	1	7E-1	2	1	7G-1	1	1
7A-2	1	1	7C-2	2	1	7E-2	1	1	7G-2	1	1
7A-3	1	1	7C-3	2	1	7E-3	1	2	7G-3	1	2
7A-4	1	1	7C-4	3	1	7E-4	2	3	7G-4	2	2
7A-5	1	1	7C-5	1	1	7E-5	2	2	7G-5	2	2
7A-6	1	1	7C-6	2	1	7E-6	2	2	7G-6	1	2
7A-7	1	2	7C-7	2	1	7E-7	2	1	7G-7	2	2
7A-8	1	1	7C-8	1	1	7E-8	1	2	7G-8	2	2
7A-9	1	1	7C-9	2	1	7E-9	1	2	7G-9	2	2
7A-10	0.5	0.5	7C-10	1	1	7E-10	2	1	7G-10	2	2
7A-11	0.5	1	7C-11	2	1	7E-11	1	1	7G-11	1	2
7A-12	1	1	7C-12	2	1	7E-12	1	2	7G-12	1	1
7A-13	1	1	7C-13	1	2	7E-13	1	1	7G-13	1	1
7A-14	1	2	7C-14	1	1	7E-14	1	2	7G-14	1	1
7A-15	1	1	7C-15	1	1	7E-15	2	1	7G-15	1	2
7A-16	1	1	7C-16	1	1	7E-16	1	1	7G-16	1	2
7A-17	1	2	7C-17	1	1	7E-17	1	1	7G-17	1	1
7A-18	1	1	7C-18	1	1	7E-18	1	1	7G-18	1	1
7A-19	1	1	7C-19	1	2	7E-19	1	4	7G-19	1	1
7A-20	1	1	7C-20	1	1	7E-20	2	1	7G-20	1	2
7B-1	2	1	7D-1	1	1	7F-1	3	2	7G-21	1	2
7B-2	1	1	7D-2	1	2	7F-2	1	1	7G-22	1	4
7B-3	1	1	7D-3	2	2	7F-3	2	1	7G-23	1	2
7B-4	1	1	7D-4	2	2	7F-4	1	2	7G-24	1	1
7B-5	1	1	7D-5	1	1	7F-5	1	2			
7B-6	1	1	7D-6	1	1	7F-6	1	2			
7B-7	1	2	7D-7	1	2	7F-7	1	2			
7B-8	1	1	7D-8	1	2	7F-8	1	2			
7B-9	1	1	7D-9	3	1	7F-9	4	4			
7B-10	2	2	7D-10	1	2	7F-10	1	2			
7B-11	1	1	7D-11	1	2	7F-11	1	3			
7B-12	2	2	7D-12	1	1	7F-12	2	1			
7B-13	1	1	7D-13	1	1	7F-13	2	1			
7B-14	1	1	7D-14	3	1	7F-14	2	1			
7B-15	1	1	7D-15	1	1	7F-15	2	1			
7B-16	1	1	7D-16	1	1	7F-16	2	1			
7B-17	1	2	7D-17	1	1	7F-17	2	2			
7B-18	1	1	7D-18	2	1	7F-18	2	1			
7B-19	1	1	7D-19	2	2	7F-19	2	2			
			7D-20	1	2	7F-20	2	1			
			7D-21	1	2	7F-21	2	2			
			7D-22	1	2	7F-22	1	2			

System 8 - 3360 Hours

PANEL/ SCRIBE	LEFT	RIGHT	PANEL/ SCRIBE	LEFT	RIGHT	PANEL/ SCRIBE	LEFT	RIGHT	PANEL/ SCRIBE	LEFT	RIGHT
8A-1	2	1	8C-1	2	2	8E-1	1	4	8G-1	4	4
8A-2	4	2	8C-2	1	5	8E-2	2	2	8G-2	1	5
8A-3	3	2	8C-3	2	2	8E-3	2	4	8G-3	3	5
8A-4	2	1	8C-4	3	3	8E-4	3	3	8G-4	4	5
8A-5	4	5	8C-5	5	1	8E-5	1	5	8G-5	3	1
8A-6	4	4	8C-6	1	1	8E-6	1	4	8G-6	6	4
8A-7	6	2	8C-7	2	2	8E-7	1	3	8G-7	3	4
8A-8	2	4	8C-8	2	1	8E-8	1	4	8G-8	3	1
8A-9	5	3	8C-9	1	3	8E-9	1	3	8G-9	5	3
8A-10	5	2	8C-10	4	4	8E-10	1	2	8G-10	6	6
8A-11	4	4	8C-11	2	4	8E-11	1	1	8G-11	3	4
8A-12	2	3	8C-12	1	2	8E-12	2	2	8G-12	2	2
8A-13	2	2	8C-13	1	3	8E-13	3	4	8G-13	1	2
8A-14	4	5	8C-14	4	4	8E-14	2	5	8G-14	2	4
8A-15	3	2	8C-15	1	1	8E-15	3	4	8G-15	4	2
8A-16	5	4	8C-16	3	4	8E-16	4	4	8G-16	3	1
8A-17	5	4	8C-17	4	4	8E-17	4	6	8G-17	1	1
8A-18	5	5	8C-18	3	3	8E-18	4	5	8G-18	3	4
8A-19	7	4	8C-19	3	3	8E-19	4	2	8G-19	4	4
8A-20	5	8	8C-20	3	3	8E-20	2	3	8G-20	3	6
8A-21	7	4	8C-21	4	3	8E-21	2	4	8G-21	4	5
8A-22	7	5	8C-22	3	2	8E-22	4	3	8G-22	2	3
8A-23	7	5	8C-23	3	2	8E-23	3	4	8G-23	3	2
8A-24	5	8	8C-24	1	2	8F-1	3	1	8G-24	3	1
8B-1	4	3	8D-1	2	4	8F-2	1	4			
8B-2	5	4	8D-2	1	2	8F-3	3	4			
8B-3	3	4	8D-3	1	3	8F-4	3	4			
8B-4	5	4	8D-4	1	5	8F-5	2	2			
8B-5	4	4	8D-5	4	3	8F-6	2	5			
8B-6	4	5	8D-6	3	1	8F-7	2	4			
8B-7	3	1	8D-7	4	1	8F-8	2	3			
8B-8	5	2	8D-8	3	3	8F-9	1	4			
8B-9	5	4	8D-9	3	2	8F-10	1	3			
8B-10	4	4	8D-10	4	2	8F-11	1	5			
8B-11	4	3	8D-11	1	1	8F-12	4	2			
8B-12	4	3	8D-12	5	1	8F-13	5	5			
8B-13	1	1	8D-13	1	2	8F-14	5	1			
8B-14	2	3	8D-14	2	2	8F-15	3	4			
8B-15	2	2	8D-15	3	4	8F-16	5	1			
8B-16	3	2	8D-16	3	2	8F-17	5	3			
8B-17	4	5	8D-17	3	1	8F-18	3	4			
8B-18	5	6	8D-18	4	2	8F-19	4	4			
8B-19	4	4	8D-19	4	3	8F-20	1	4			
8B-20	3	3	8D-20	2	3	8F-21	2	2			
8B-21	5	4	8D-21	3	4	8F-22	3	5			
8B-22	2	2	8D-22	3	3						
8B-23	3	2	8D-23	2	3						
8B-24	5	4	8D-24	2	2						

System 9 - 3360 Hours

PANEL/ SCRIBE	LEFT	RIGHT	PANEL/ SCRIBE	LEFT	RIGHT	PANEL/ SCRIBE	LEFT	RIGHT	PANEL/ SCRIBE	LEFT	RIGHT
9A-1	3	2	9C-1	3	4	9E-1	1	2	9G-1	1	3
9A-2	3	3	9C-2	2	1	9E-2	2	1	9G-2	1	1
9A-3	1	3	9C-3	1	2	9E-3	1	4	9G-3	2	1
9A-4	1	4	9C-4	2	3	9E-4	1	1	9G-4	1	1
9A-5	2	2	9C-5	3	1	9E-5	2	3	9G-5	1	1
9A-6	2	2	9C-6	1	1	9E-6	1	2	9G-6	1	1
9A-7	4	1	9C-7	1	1	9E-7	3	1	9G-7	1	1
9A-8	2	1	9C-8	2	1	9E-8	1	4	9G-8	1	1
9A-9	2	2	9C-9	2	4	9E-9	3	3	9G-9	1	1
9A-10	2	2	9C-10	2	3	9E-10	2	1	9G-10	1	1
9A-11	4	2	9C-11	4	1	9E-11	3	2	9G-11	1	1
9A-12	1	2	9C-12	4	1	9E-12	1	1	9G-12	2	2
9A-13	2	2	9C-13	2	4	9E-13	2	1	9G-13	1	1
9A-14	2	1	9C-14	4	4	9E-14	2	1	9G-14	1	2
9A-15	1	2	9C-15	3	3	9E-15	1	4	9G-15	2	2
9A-16	1	2	9C-16	2	2	9E-16	3	4	9G-16	1	3
9A-17	4	4	9C-17	2	3	9E-17	3	3	9G-17	1	1
9A-18	4	4	9C-18	2	4	9E-18	3	2	9G-18	1	1
9A-19	1	2	9C-19	3	3	9E-19	3	2	9G-19	1	2
9A-20	3	2	9C-20	2	3	9E-20	1	2	9G-20	1	1
9A-21	2	2	9C-21	2	3	9E-21	1	1	9G-21	2	3
9A-22	3	3	9C-22	2	3	9E-22	1	1	9G-22	2	3
9A-23	1	1	9C-23	3	4	9E-23	3	4	9G-23	2	4
9B-1	3	3	9C-24	3	1	9E-24	2	1	9G-24	2	1
9B-2	1	4	9D-1	4	2	9F-1	2	3			
9B-3	3	2	9D-2	1	3	9F-2	2	4			
9B-4	1	2	9D-3	2	3	9F-3	3	3			
9B-5	2	3	9D-4	2	4	9F-4	3	1			
9B-6	3	3	9D-5	3	3	9F-5	1	2			
9B-7	3	3	9D-6	2	2	9F-6	4	4			
9B-8	2	1	9D-7	2	1	9F-7	4	5			
9B-9	3	2	9D-8	3	3	9F-8	1	3			
9B-10	1	1	9D-9	4	3	9F-9	1	4			
9B-11	3	2	9D-10	1	2	9F-10	3	4			
9B-12	2	3	9D-11	1	3	9F-11	1	2			
9B-13	2	2	9D-12	2	4	9F-12	1	1			
9B-14	2	1	9D-13	1	2	9F-13	1	1			
9B-15	1	1	9D-14	1	2	9F-14	1	4			
9B-16	2	2	9D-15	3	3	9F-15	2	1			
9B-17	1	3	9D-16	3	4	9F-16	1	3			
9B-18	1	1	9D-17	3	3	9F-17	2	3			
9B-19	2	2	9D-18	2	3	9F-18	3	2			
9B-20	1	3	9D-19	1	2	9F-19	1	1			
9B-21	1	3	9D-20	3	2	9F-20	3	3			
9B-22	2	2	9D-21	2	1	9F-21	2	4			
9B-23	1	1	9D-22	2	2	9F-22	3	2			
9B-24	3	2	9D-23	3	2	9F-23	3	4			
			9D-24	3	4	9F-24	1	2			

System 2 - 3360 Hours - Remeasured by Observer 1

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
2A-1	3	4	2C-1	3	3	2E-1	3	5
2A-2	4	6	2C-2	3	7	2E-2	6	5
2A-3	6	6	2C-3	6	8	2E-3	9	4
2A-4	3	7	2C-4	6	7	2E-4	9	4
2A-5	3	5	2C-5	6	7	2E-5	6	7
2A-6	3	5	2C-6	6	6	2E-6	6	7
2A-7	4	4	2C-7	4	5	2E-7	6	7
2A-8	3	5	2C-8	4	5	2E-8	6	3
2A-9	4	5	2C-9	6	5	2E-9	4	6
2A-10	2	2	2C-10	4	7	2E-10	3	6
2A-11	4	5	2C-11	6	5	2E-11	4	5
2A-12	5	5	2C-12	5	6	2E-12	2	5
2A-13	8	6	2C-13	5	10	2E-13	2	6
2A-14	8	5	2C-14	7	10	2E-14	3	5
2A-15	6	2	2C-15	4	6	2E-15	3	6
2A-16	6	7	2C-16	8	6	2E-16	4	6
2A-17	6	4	2C-17	7	7	2E-17	5	6
2A-18	5	1	2C-18	6	9	2E-18	5	7
2A-19	6	8	2C-19	4	8	2E-19	4	5
2A-20	7	5	2C-20	6	6	2E-20	6	4
2A-21	5	4	2C-21	6	6	2E-21	5	4
2A-22	7	6	2C-22	3	6	2E-22	4	6
2A-23	3	5	2C-23	4	8	2E-23	4	6
2A-24	3	5	2C-24	4	3	2E-24	5	6
2B-1	7	4	2D-1	6	6	2F-1	7	5
2B-2	7	6	2D-2	5	7	2F-2	8	4
2B-3	4	7	2D-3	6	6	2F-3	8	4
2B-4	5	7	2D-4	5	8	2F-4	7	5
2B-5	5	8	2D-5	6	8	2F-5	7	7
2B-6	4	4	2D-6	7	8	2F-6	8	6
2B-7	6	2	2D-7	7	5	2F-7	7	5
2B-8	5	7	2D-8	7	6	2F-8	8	5
2B-9	6	10	2D-9	7	4	2F-9	6	8
2B-10	11	6	2D-10	6	6	2F-10	8	6
2B-11	9	7	2D-11	5	7	2F-11	7	9
2B-12	3	6	2D-12	8	4	2F-12	10	8
2B-13	8	7	2D-13	5	6	2F-13	4	4
2B-14	8	7	2D-14	6	5	2F-14	8	7
2B-15	5	6	2D-15	5	5	2F-15	8	8
2B-16	8	6	2D-16	6	5	2F-16	9	9
2B-17	5	7	2D-17	8	7	2F-17	10	7
2B-18	4	5	2D-18	10	6	2F-18	8	7
2B-19	8	8	2D-19	10	8	2F-19	8	8
2B-20	9	6	2D-20	7	7	2F-20	8	8
2B-21	7	7	2D-21	6	7	2F-21	8	9
2B-22	7	7	2D-22	7	7	2F-22	7	7
2B-23	7	7	2D-23	8	9	2F-23	6	8
2B-24	6	7	2D-24	5	7	2F-24	5	6

System 2 - 3360 Hours - Observer 2

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
2A-1	2	1	2C-1	1	1	2E-1	4	6
2A-2	5	5	2C-2	1	2	2E-2	5	4
2A-3	6	6	2C-3	1	6	2E-3	7	4
2A-4	1	6	2C-4	4	1	2E-4	10	4
2A-5	5	3	2C-5	5	7	2E-5	7	6
2A-6	4	2	2C-6	7	0	2E-6	5	8
2A-7	4	3	2C-7	6	1	2E-7	5	6
2A-8	4	1	2C-8	5	3	2E-8	7	2
2A-9	3	4	2C-9	4	3	2E-9	4	2
2A-10	1	1	2C-10	4	6	2E-10	3	5
2A-11	3	2	2C-11	7	4	2E-11	3	5
2A-12	2	2	2C-12	5	4	2E-12	3	5
2A-13	7	6	2C-13	2	9	2E-13	0	2
2A-14	7	6	2C-14	7	8	2E-14	0	5
2A-15	7	5	2C-15	5	6	2E-15	4	6
2A-16	4	7	2C-16	8	3	2E-16	4	6
2A-17	6	5	2C-17	7	8	2E-17	3	5
2A-18	5	2	2C-18	6	9	2E-18	5	6
2A-19	3	7	2C-19	6	8	2E-19	4	7
2A-20	7	5	2C-20	6	5	2E-20	6	6
2A-21	1	4	2C-21	6	6	2E-21	3	6
2A-22	1	1	2C-22	2	7	2E-22	5	6
2A-23	1	5	2C-23	5	7	2E-23	4	6
2A-24	3	1	2C-24	6	2	2E-24	5	6
2B-1	2	1	2D-1	6	5	2F-1	6	5
2B-2	1	4	2D-2	2	7	2F-2	8	4
2B-3	0	7	2D-3	5	7	2F-3	8	5
2B-4	1	6	2D-4	6	8	2F-4	8	5
2B-5	0	8	2D-5	6	7	2F-5	7	7
2B-6	4	1	2D-6	7	7	2F-6	8	6
2B-7	5	1	2D-7	6	6	2F-7	8	1
2B-8	6	5	2D-8	7	5	2F-8	8	6
2B-9	2	6	2D-9	6	5	2F-9	7	7
2B-10	11	6	2D-10	6	6	2F-10	7	6
2B-11	10	3	2D-11	5	6	2F-11	7	9
2B-12	4	4	2D-12	6	4	2F-12	10	7
2B-13	8	7	2D-13	6	6	2F-13	5	4
2B-14	8	6	2D-14	7	4	2F-14	5	4
2B-15	7	5	2D-15	6	4	2F-15	9	7
2B-16	9	5	2D-16	7	4	2F-16	9	8
2B-17	5	7	2D-17	9	6	2F-17	9	6
2B-18	2	5	2D-18	9	5	2F-18	8	8
2B-19	10	8	2D-19	11	7	2F-19	7	7
2B-20	8	5	2D-20	8	7	2F-20	8	9
2B-21	6	8	2D-21	6	6	2F-21	7	8
2B-22	7	7	2D-22	8	7	2F-22	6	8
2B-23	7	7	2D-23	7	5	2F-23	6	4
2B-24	6	7	2D-24	7	8	2F-24	7	6

System 2 - 3360 Hours - Observer 3

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
2A-1	2	3	2C-1	3	6	2E-1	6	5
2A-2	6	1	2C-2	7	4	2E-2	1	3
2A-3	3	6	2C-3	6	3	2E-3	6	6
2A-4	5	6	2C-4	6	6	2E-4	4	3
2A-5	7	8	2C-5	8	7	2E-5	5	6
2A-6	7	5	2C-6	8	5	2E-6	5	4
2A-7	4	6	2C-7	9	6	2E-7	6	5
2A-8	6	7	2C-8	7	6	2E-8	5	2
2A-9	7	5	2C-9	6	8	2E-9	6	4
2A-10	5	7	2C-10	6	5	2E-10	6	4
2A-11	5	7	2C-11	9	6	2E-11	5	0
2A-12	6	7	2C-12	9	4	2E-12	3	0
2A-13	4	7	2C-13	3	5	2E-13	5	3
2A-14	5	4	2C-14	4	6	2E-14	5	4
2A-15	2	2	2C-15	6	4	2E-15	6	2
2A-16	5	4	2C-16	5	6	2E-16	5	3
2A-17	6	3	2C-17	5	4	2E-17	1	5
2A-18	4	5	2C-18	4	5	2E-18	6	5
2A-19	5	3	2C-19	5	7	2E-19	6	5
2A-20	6	2	2C-20	7	6	2E-20	4	7
2A-21	7	4	2C-21	5	6	2E-21	1	7
2A-22	5	6	2C-22	1	4	2E-22	4	8
2A-23	6	4	2C-23	6	3	2E-23	4	6
2A-24	3	4	2C-24	3	2	2E-24	4	2
2B-1	6	5	2D-1	8	5	2F-1	6	6
2B-2	7	7	2D-2	8	7	2F-2	7	4
2B-3	6	7	2D-3	7	8	2F-3	7	6
2B-4	7	7	2D-4	7	6	2F-4	8	9
2B-5	4	11	2D-5	8	7	2F-5	7	9
2B-6	9	7	2D-6	8	11	2F-6	7	8
2B-7	5	4	2D-7	4	9	2F-7	6	8
2B-8	7	5	2D-8	8	7	2F-8	6	10
2B-9	5	9	2D-9	5	6	2F-9	9	8
2B-10	6	5	2D-10	6	5	2F-10	8	8
2B-11	5	7	2D-11	5	6	2F-11	7	7
2B-12	8	8	2D-12	6	6	2F-12	4	5
2B-13	4	3	2D-13	3	7	2F-13	8	10
2B-14	3	10	2D-14	6	6	2F-14	9	7
2B-15	5	11	2D-15	6	6	2F-15	6	7
2B-16	9	6	2D-16	6	6	2F-16	7	6
2B-17	6	5	2D-17	5	7	2F-17	5	8
2B-18	2	6	2D-18	7	6	2F-18	8	7
2B-19	3	3	2D-19	8	6	2F-19	6	8
2B-20	8	3	2D-20	7	6	2F-20	7	5
2B-21	7	4	2D-21	8	6	2F-21	5	7
2B-22	6	5	2D-22	6	5	2F-22	4	9
2B-23	5	8	2D-23	7	2	2F-23	4	8
2B-24	4	6	2D-24	5	5	2F-24	5	6

System 3 - 3360 Hours - Remeasured by Observer 1

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
3A-1	8	9	3C-1	9	5	3E-1	10	10
3A-2	9	10	3C-2	8	5	3E-2	12	7
3A-3	11	10	3C-3	7	5	3E-3	7	5
3A-4	10	8	3C-4	4	10	3E-4	15	6
3A-5	13	7	3C-5	6	11	3E-5	6	7
3A-6	12	7	3C-6	7	11	3E-6	7	7
3A-7	5	8	3C-7	8	7	3E-7	9	9
3A-8	7	8	3C-8	3	7	3E-8	5	10
3A-9	7	7	3C-9	3	10	3E-9	5	9
3A-10	11	10	3C-10	4	8	3E-10	10	6
3A-11	9	10	3C-11	8	7	3E-11	14	6
3A-12	13	14	3C-12	6	8	3E-12	12	5
3A-13	8	8	3C-13	11	7	3E-13	7	6
3A-14	7	8	3C-14	7	8	3E-14	7	7
3A-15	5	11	3C-15	9	9	3E-15	5	10
3A-16	7	8	3C-16	9	10	3E-16	7	10
3A-17	14	6	3C-17	9	11	3E-17	9	8
3A-18	14	7	3C-18	8	10	3E-18	7	11
3A-19	10	7	3C-19	9	10	3E-19	9	8
3A-20	10	14	3C-20	8	8	3E-20	8	11
3A-21	5	10	3C-21	7	7	3E-21	9	7
3A-22	6	7	3C-22	7	11	3E-22	11	5
3A-23	9	8	3C-23	3	8	3E-23	12	7
3A-24	8	11	3C-24	6	7	3E-24	8	9
3B-1	4	10	3D-1	5	8	3F-1	8	4
3B-2	6	5	3D-2	6	8	3F-2	8	4
3B-3	6	4	3D-3	10	6	3F-3	7	7
3B-4	3	5	3D-4	5	5	3F-4	9	13
3B-5	5	7	3D-5	7	8	3F-5	10	13
3B-6	6	6	3D-6	10	10	3F-6	13	13
3B-7	5	6	3D-7	11	9	3F-7	13	8
3B-8	5	5	3D-8	9	5	3F-8	14	9
3B-9	5	5	3D-9	7	13	3F-9	12	7
3B-10	7	4	3D-10	8	13	3F-10	10	6
3B-11	8	2	3D-11	13	12	3F-11	10	8
3B-12	4	4	3D-12	7	5	3F-12	12	7
3B-13	4	6	3D-13	5	4	3F-13	7	9
3B-14	3	7	3D-14	10	7	3F-14	8	9
3B-15	6	2	3D-15	11	9	3F-15	11	9
3B-16	7	2	3D-16	12	8	3F-16	9	8
3B-17	8	1	3D-17	6	12	3F-17	8	9
3B-18	6	5	3D-18	12	12	3F-18	10	8
3B-19	1	6	3D-19	14	9	3F-19	11	4
3B-20	1	6	3D-20	12	7	3F-20	13	6
3B-21	5	6	3D-21	8	7	3F-21	13	7
3B-22	5	8	3D-22	8	7	3F-22	9	8
3B-23	8	6	3D-23	9	7	3F-23	7	8
3B-24	9	5	3D-24	7	8	3F-24	5	11

System 3 - 3360 Hours - Observer 2

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
3A-1	8	8	3C-1	6	5	3E-1	9	8
3A-2	8	10	3C-2	7	6	3E-2	7	8
3A-3	11	9	3C-3	5	5	3E-3	6	3
3A-4	8	7	3C-4	3	7	3E-4	5	3
3A-5	13	7	3C-5	5	8	3E-5	6	7
3A-6	8	7	3C-6	9	6	3E-6	7	4
3A-7	6	7	3C-7	3	7	3E-7	9	9
3A-8	7	5	3C-8	4	9	3E-8	6	6
3A-9	5	7	3C-9	5	8	3E-9	5	8
3A-10	5	6	3C-10	8	5	3E-10	6	8
3A-11	8	10	3C-11	8	5	3E-11	13	6
3A-12	14	13	3C-12	7	9	3E-12	12	6
3A-13	5	7	3C-13	4	6	3E-13	7	5
3A-14	4	7	3C-14	4	8	3E-14	1	8
3A-15	6	5	3C-15	4	8	3E-15	5	8
3A-16	7	7	3C-16	3	10	3E-16	3	8
3A-17	14	4	3C-17	7	10	3E-17	8	10
3A-18	11	5	3C-18	7	6	3E-18	6	12
3A-19	10	5	3C-19	7	5	3E-19	9	8
3A-20	10	14	3C-20	9	7	3E-20	6	7
3A-21	6	10	3C-21	8	6	3E-21	10	6
3A-22	5	7	3C-22	7	7	3E-22	12	6
3A-23	10	12	3C-23	4	9	3E-23	11	7
3A-24	8	8	3C-24	5	4	3E-24	8	9
3B-1	1	3	3D-1	6	8	3F-1	6	4
3B-2	7	2	3D-2	6	6	3F-2	5	4
3B-3	3	3	3D-3	7	4	3F-3	7	6
3B-4	4	3	3D-4	6	4	3F-4	5	13
3B-5	3	6	3D-5	8	9	3F-5	13	15
3B-6	6	4	3D-6	10	6	3F-6	12	15
3B-7	6	4	3D-7	9	5	3F-7	11	8
3B-8	6	4	3D-8	9	10	3F-8	12	8
3B-9	4	5	3D-9	8	10	3F-9	10	11
3B-10	6	4	3D-10	11	13	3F-10	10	8
3B-11	6	2	3D-11	11	10	3F-11	5	7
3B-12	6	2	3D-12	7	6	3F-12	5	5
3B-13	4	6	3D-13	5	4	3F-13	7	7
3B-14	6	7	3D-14	9	6	3F-14	7	7
3B-15	7	2	3D-15	8	8	3F-15	8	5
3B-16	8	1	3D-16	6	5	3F-16	5	8
3B-17	8	1	3D-17	6	8	3F-17	9	7
3B-18	7	4	3D-18	7	7	3F-18	9	5
3B-19	2	4	3D-19	10	7	3F-19	8	8
3B-20	1	5	3D-20	2	9	3F-20	12	4
3B-21	4	6	3D-21	8	6	3F-21	12	4
3B-22	2	4	3D-22	7	7	3F-22	9	6
3B-23	7	5	3D-23	9	5	3F-23	10	7
3B-24	10	5	3D-24	7	9	3F-24	6	10

System 3 - 3360 Hours - Observer 3

PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT	PANEL/SCRIBE	LEFT	RIGHT
3A-1	8	8	3C-1	5	5	3E-1	9	3
3A-2	9	10	3C-2	6	4	3E-2	11	8
3A-3	11	9	3C-3	6	5	3E-3	6	4
3A-4	11	8	3C-4	3	6	3E-4	4	4
3A-5	12	6	3C-5	3	11	3E-5	8	8
3A-6	12	9	3C-6	6	10	3E-6	7	5
3A-7	9	7	3C-7	7	6	3E-7	8	9
3A-8	7	5	3C-8	3	6	3E-8	5	9
3A-9	7	6	3C-9	3	10	3E-9	5	9
3A-10	7	9	3C-10	4	8	3E-10	9	8
3A-11	9	11	3C-11	8	4	3E-11	12	7
3A-12	13	14	3C-12	6	7	3E-12	13	5
3A-13	6	3	3C-13	11	6	3E-13	7	4
3A-14	11	7	3C-14	6	8	3E-14	5	8
3A-15	5	1	3C-15	5	9	3E-15	5	8
3A-16	6	8	3C-16	4	10	3E-16	7	11
3A-17	8	5	3C-17	9	11	3E-17	9	9
3A-18	14	4	3C-18	8	9	3E-18	7	11
3A-19	13	9	3C-19	9	9	3E-19	9	8
3A-20	13	7	3C-20	8	8	3E-20	6	6
3A-21	11	6	3C-21	9	5	3E-21	9	7
3A-22	9	13	3C-22	7	7	3E-22	11	6
3A-23	5	8	3C-23	8	8	3E-23	11	6
3A-24	8	13	3C-24	7	8	3E-24	8	9
3B-1	2	3	3D-1	5	7	3F-1	5	4
3B-2	6	3	3D-2	6	7	3F-2	5	3
3B-3	6	3	3D-3	6	7	3F-3	6	6
3B-4	2	4	3D-4	7	8	3F-4	9	13
3B-5	5	7	3D-5	7	9	3F-5	7	13
3B-6	5	4	3D-6	11	9	3F-6	13	15
3B-7	3	5	3D-7	11	9	3F-7	13	8
3B-8	5	4	3D-8	8	6	3F-8	13	7
3B-9	5	5	3D-9	7	13	3F-9	10	8
3B-10	6	4	3D-10	8	13	3F-10	8	7
3B-11	7	2	3D-11	11	12	3F-11	9	7
3B-12	5	3	3D-12	7	5	3F-12	9	4
3B-13	4	6	3D-13	4	4	3F-13	6	8
3B-14	4	6	3D-14	8	6	3F-14	6	9
3B-15	6	1	3D-15	5	8	3F-15	6	8
3B-16	7	2	3D-16	8	9	3F-16	10	9
3B-17	9	2	3D-17	6	9	3F-17	7	9
3B-18	5	6	3D-18	6	7	3F-18	8	9
3B-19	3	6	3D-19	11	7	3F-19	10	7
3B-20	4	7	3D-20	9	10	3F-20	10	5
3B-21	4	7	3D-21	8	6	3F-21	12	7
3B-22	2	8	3D-22	8	7	3F-22	12	7
3B-23	7	7	3D-23	8	5	3F-23	6	6
3B-24	8	6	3D-24	7	9	3F-24	7	8

Appendix B: Statistics Tables and Charts, Method 1

B1. Supplementary Statistical Tables and Charts for System 3

Appendix B contains tables and charts that are meant to supplement the discussion in the main body of the report. Figure B1 compares cumulative frequencies with a normal distribution. Figure B2 is similar to Figure B1 except that the cumulative frequencies are plotted as per cent.

Figure B1: Histogram vs. Normal of System 3

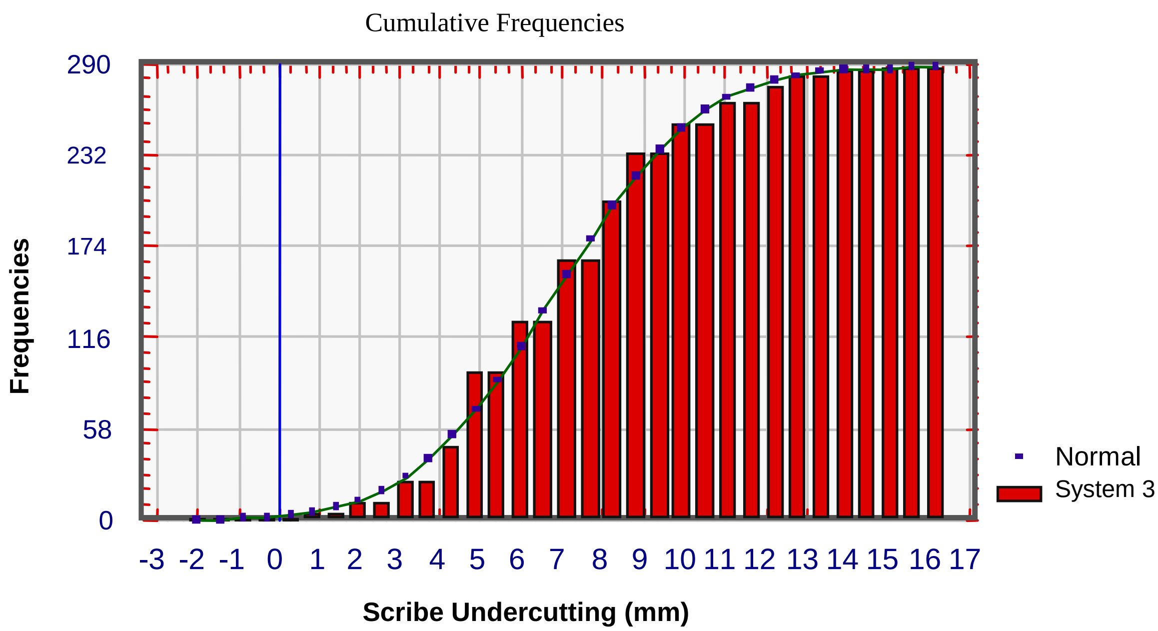
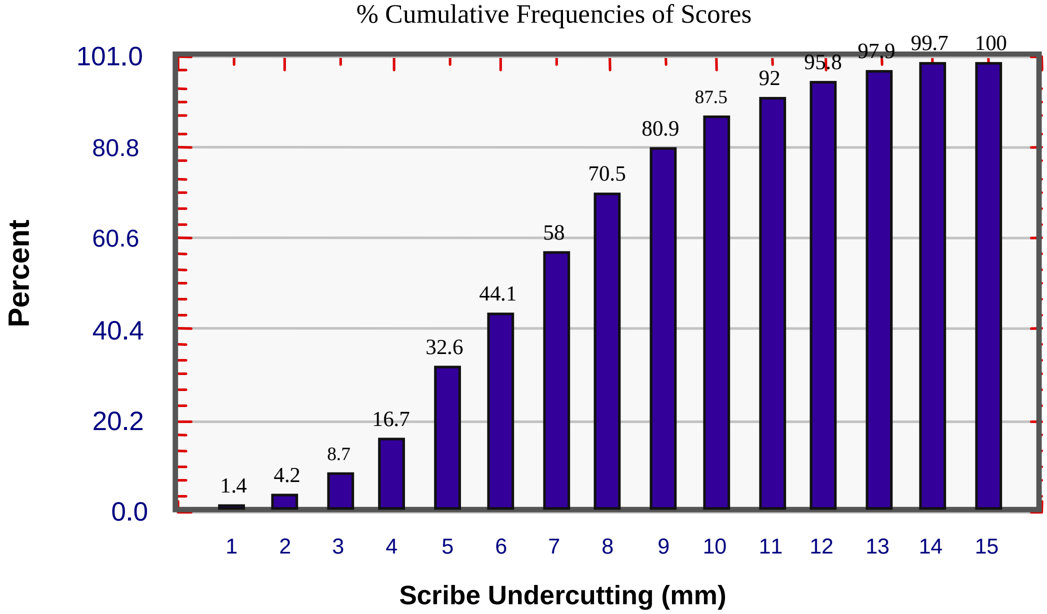


Figure B2: Simple Count Chart of System 3



The statistics software computes descriptive estimates such as that shown in Table B1 for System 3. Different software will not necessarily display the statistics in the same format, but these computations are fairly standard. Figure B3, the percentile score chart for System 3, displays a few common percentiles. Referring to Table B1, there is a 90% probability that the undercutting at a random point will be less than or equal to 11 mm. There is a 95% probability that it will be less than 12 mm.

Figure B3: Percentile Score Chart - System 3

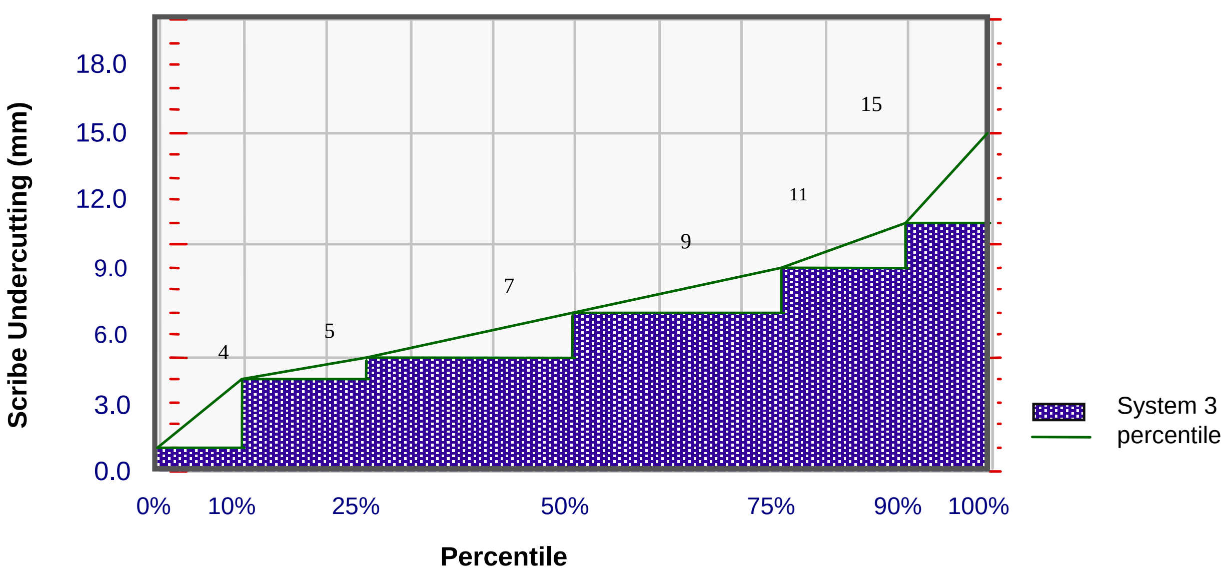


Table B1: Descriptive Estimates for System 3

Sample Size:	288	Minimum:	1
		Maximum:	15
Sum:	2045	Range:	14
Sum of Squares:	16829	Semi-Inner Qt. Range:	2
Mean:	7.1007	Median:	7
Lower 99% C.I.:	6.6703	5th Percentile:	3
Lower 95% C.I.:	6.7732	10th Percentile:	4
Upper 95% C.I.:	7.4282	25th Percentile:	5
Upper 99% C.I.:	7.5311	75th Percentile:	9
Adj. Sum Squares:	2308.0799	90th Percentile:	11
Harmonic Mean:	5.6234	95th Percentile:	12
Variance:	8.0421	Standard Error:	0.1671
Standard Deviation:	2.8359	t-Value (Mean=0):	42.4925
Coef. of Variation:	0.3994	Mean Abs. Dev:	2.2696
Skewness:	0.3236	Kurtosis:	-0.21

If the concern is the probability that a scribe measurement taken at random will be less than a particular value, one can refer to Table B2 that gives the cumulative frequency distribution of System 3 or to Figure B4 which is a plot of this data. For example, there is a 44.1% probability that scribe undercutting at a random point on a panel coated with System 3 will be less than or equal to 6 mm. There is a 87.5% probability that the undercutting will be less than or equal to 10 mm. Thus, for a particular value of scribe undercutting, the corresponding probability can be determined.

Figure B4: Cumulative Percent Distribution Polygon of System 3

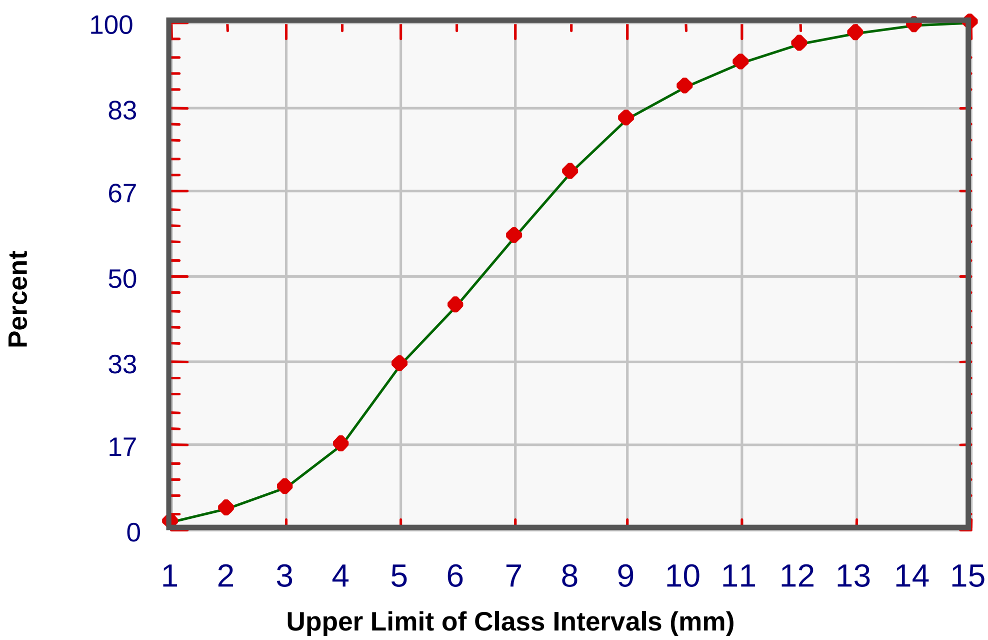


Table B2: Cumulative Frequency Distribution of System 3

Scribe Undercutting (mm)	Frequency	Cumulative Frequency	Cumulative %
1	4	4	1.39
2	8	12	4.17
3	13	25	8.68
4	23	48	16.67
5	46	94	32.64
6	33	127	44.10
7	40	167	57.99
8	36	203	70.49
9	30	233	80.90
10	19	252	87.50
11	13	265	92.01
12	11	276	95.83
13	6	282	97.92
14	5	287	99.65
15	1	288	100.00
>16	0	288	100.00

B2. Comparison of Statistical Calculations from All Data Sets

Each set of 288 (or more) data points was analyzed using a statistics software computer application. The results are summarized in Table B3 which lists selected statistical parameters for all of the data sets. Most of the data sets conform closely to a normal distribution. Kurtosis is a measure of how much the distribution differs from normal. An ideal normally distributed data set will have a kurtosis of zero. Kurtosis is positive if there is excess density in the tails. Figures B5 to B10 show distributions for the data sets with the largest kurtosis, System 1 at 1680 hours and System 7 at 3360 hours. Figures B11 to B16 show the distributions for the data sets with kurtosis closest to zero, Systems 5 and 8 at 3360 hours.

Table B3: Selected Statistical Parameters for Method 1 Data

SYSTEM ->	1	1	1	2	3	4	5	6	6	7	8	9
HOURS ->	1680	2688	3360	3360	3360	3360	3360	1680	3360	3360	3360	3360
STATISTIC												
# of data points	288	288	288	288	288	288	288	288	288	294	330	334
Minimum	1	0.5	0.5	1	1	1	0.5	1	1	0.5	1	1
Maximum	15	14	12	11	15	10	6	11	14	4	8	5
Range	14	13.5	11.5	10	14	9	5.5	10	13	3.5	7	4
Median	4	5	5	6	7	4	2	4	4	1	3	2
90th percentile	8	9	8	8	11	6	3	7	8	2	5	4
95th percentile	10	10	9	9	12	7	4	7	9	2	5	4
Mean	4.6	5.1	5.0	5.6	7.1	3.7	1.9	4.3	4.8	1.4	3.1	2.1
Upper 95% C. I.	4.9	5.5	5.3	5.8	7.4	3.9	2.0	4.5	5.1	1.5	3.3	2.3
Upper 99% C. I.	5.0	5.6	5.3	5.9	7.5	3.9	2.1	4.6	5.2	1.5	3.3	2.3
Variance	6.0	8.4	5.4	3.7	8.0	2.6	1.3	3.1	5.8	0.4	2.1	1.0
Standard deviation	2.5	2.9	2.3	1.9	2.8	1.6	1.2	1.8	2.4	0.6	1.5	1.0
Coef. of variation	0.5	0.6	0.5	0.3	0.4	0.4	0.6	0.4	0.5	0.4	0.5	0.5
Standard error	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.0	0.1	0.1
t-value (mean=0)	32.032	29.918	36.255	49.312	42.493	38.658	28.073	41.533	33.645	38.834	39.136	38.374
Mean abs. dev.	1.9	2.4	1.8	1.5	2.3	1.3	0.9	1.4	1.9	0.5	1.2	0.9
Skewness	1.0279	0.5217	0.4830	-0.0198	0.3236	0.8265	0.6671	0.8298	0.9962	1.5789	0.3715	0.4240
Kurtosis	1.4660	-0.1887	0.3381	0.1267	-0.2100	1.1315	0.0990	1.3311	0.8245	3.2150	-0.0764	-0.9082

Figure B5: Histogram vs. Normal of System 1 (1680 h)

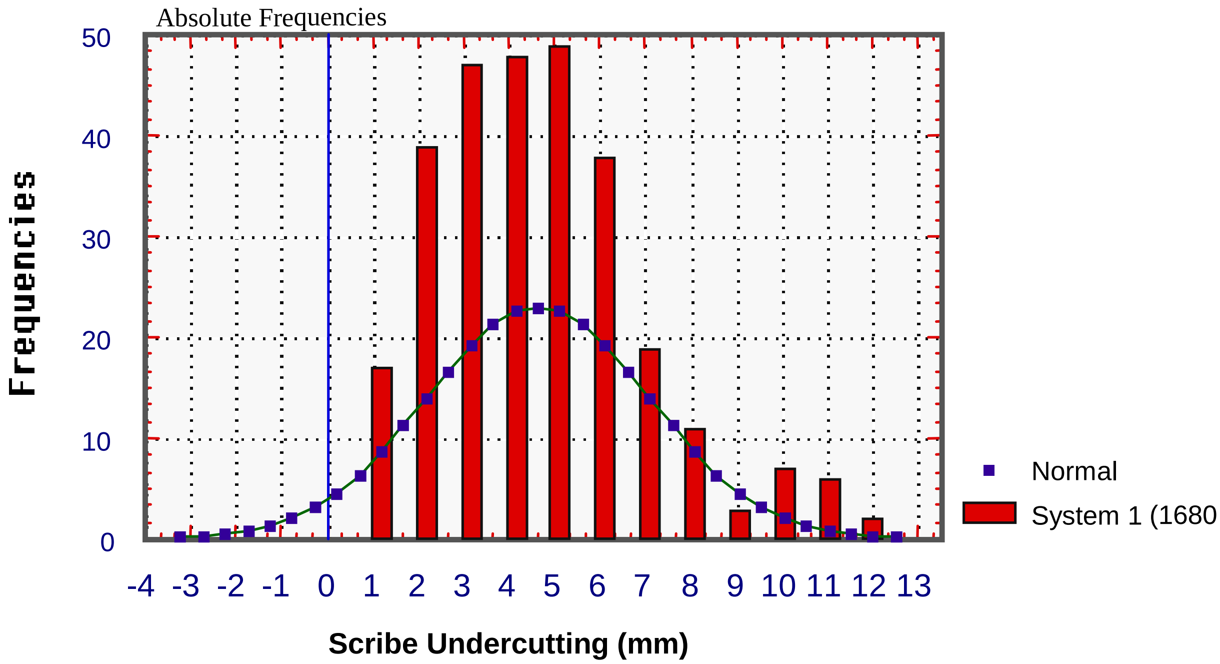


Figure B6: Normal Probability Plot of System 1 (1680 h)

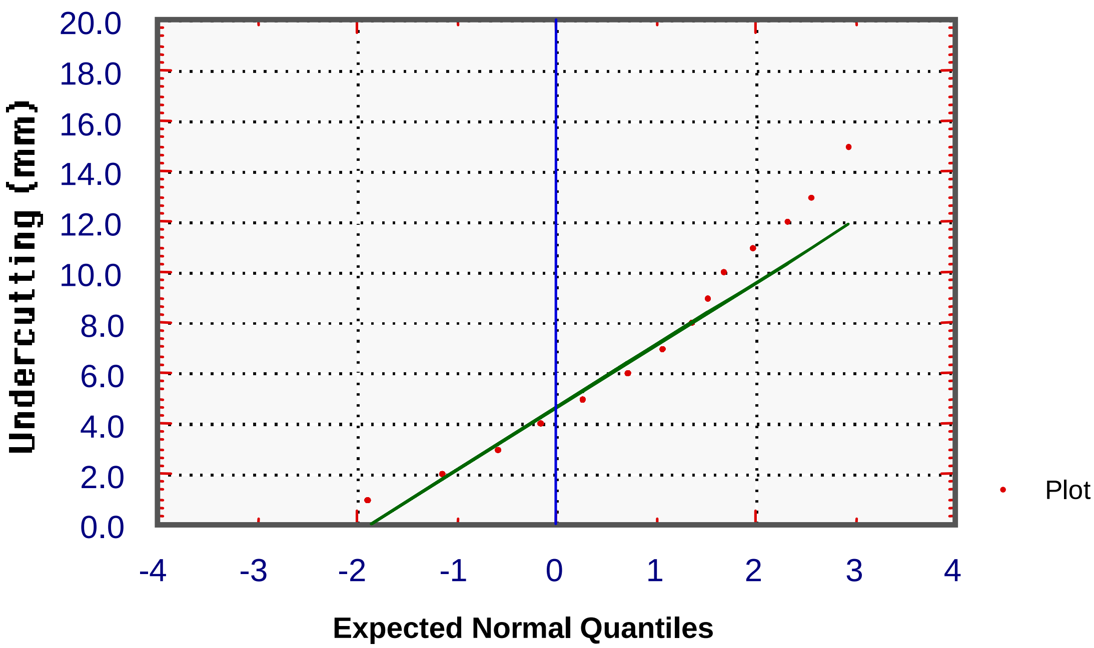


Figure B7: Histogram vs. Normal of System 1 (1680 h)

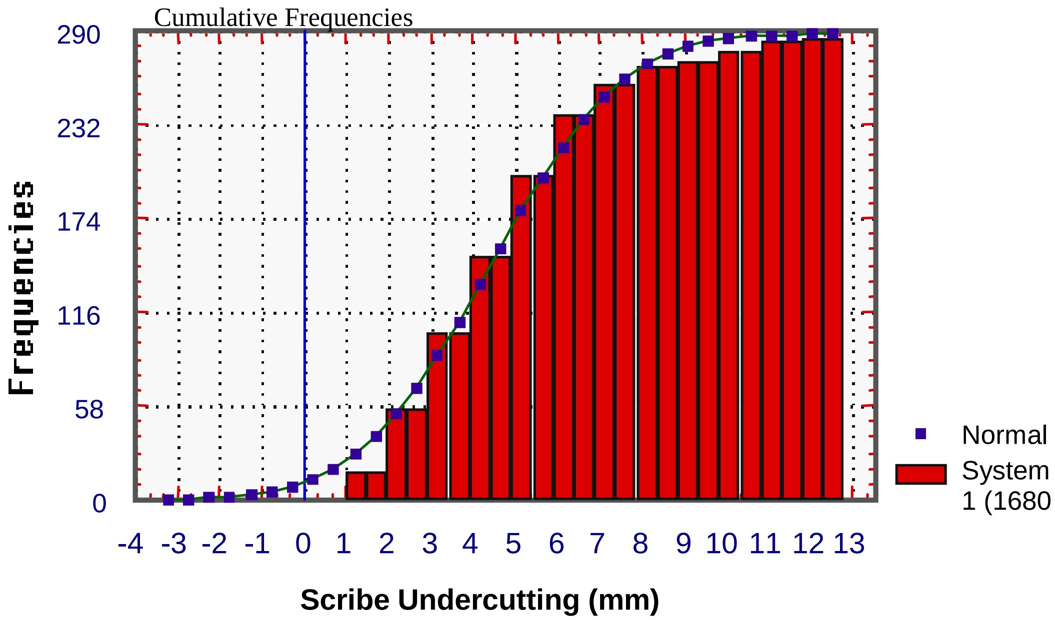


Figure B8: Histogram vs. Normal of System 7

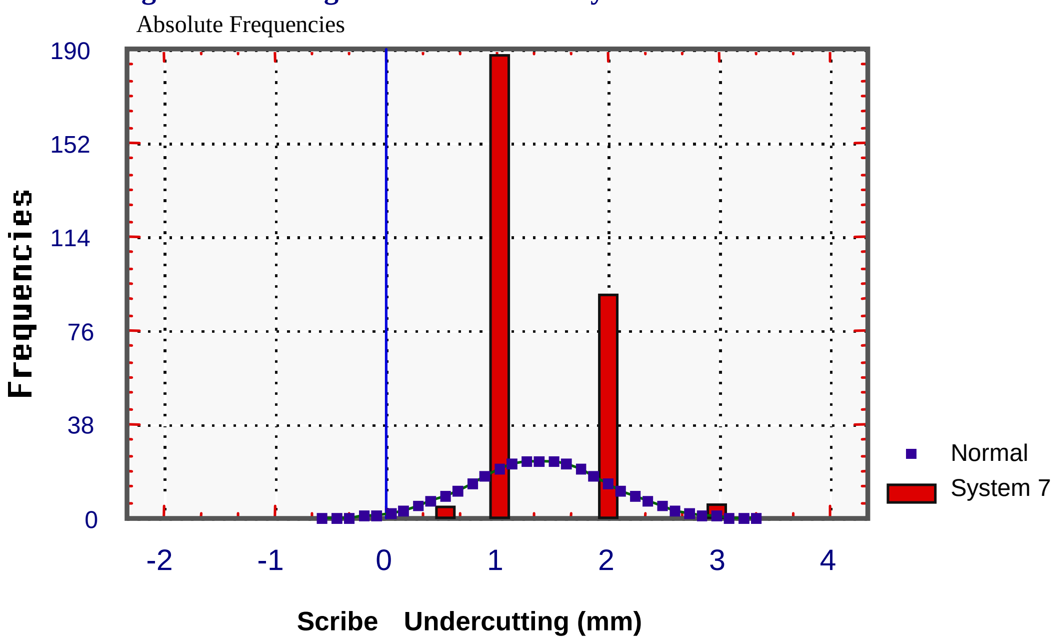


Figure B9: Normal Probability Plot of System 7

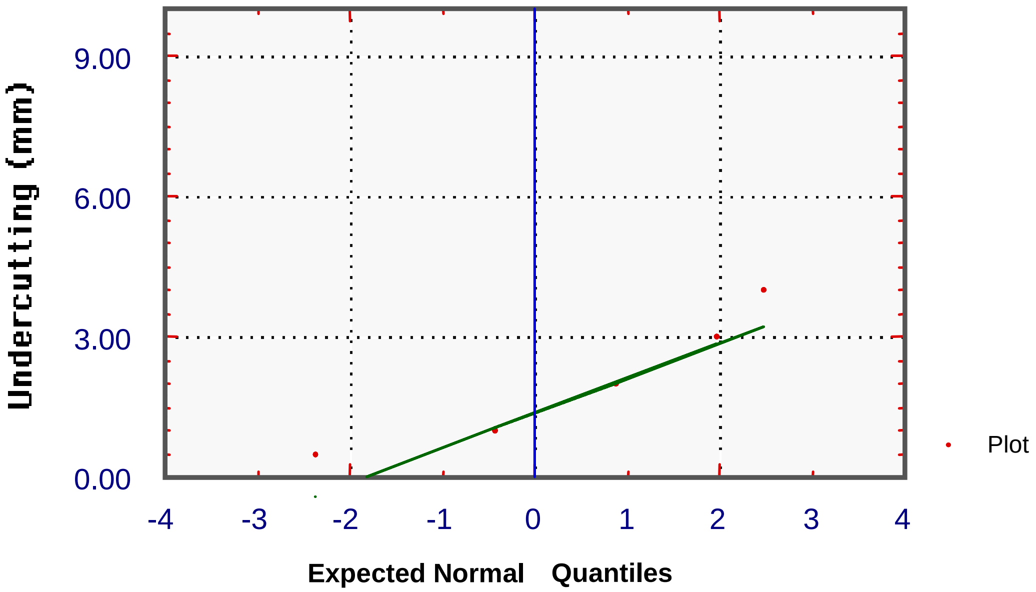


Figure B10: Histogram vs. Normal of System 7

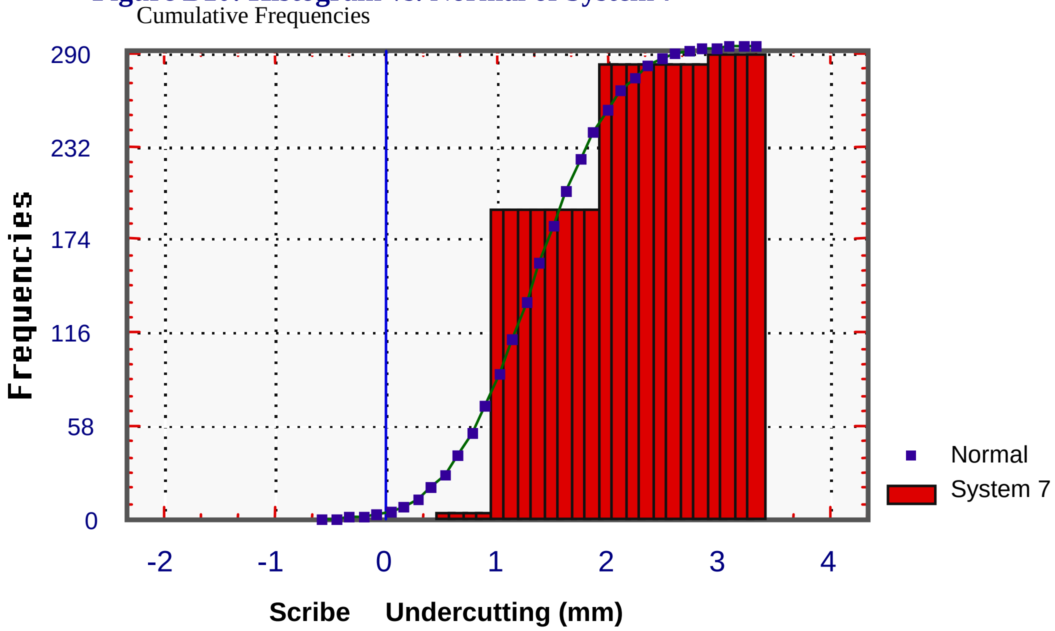


Figure B11: Histogram vs. Normal of System 5

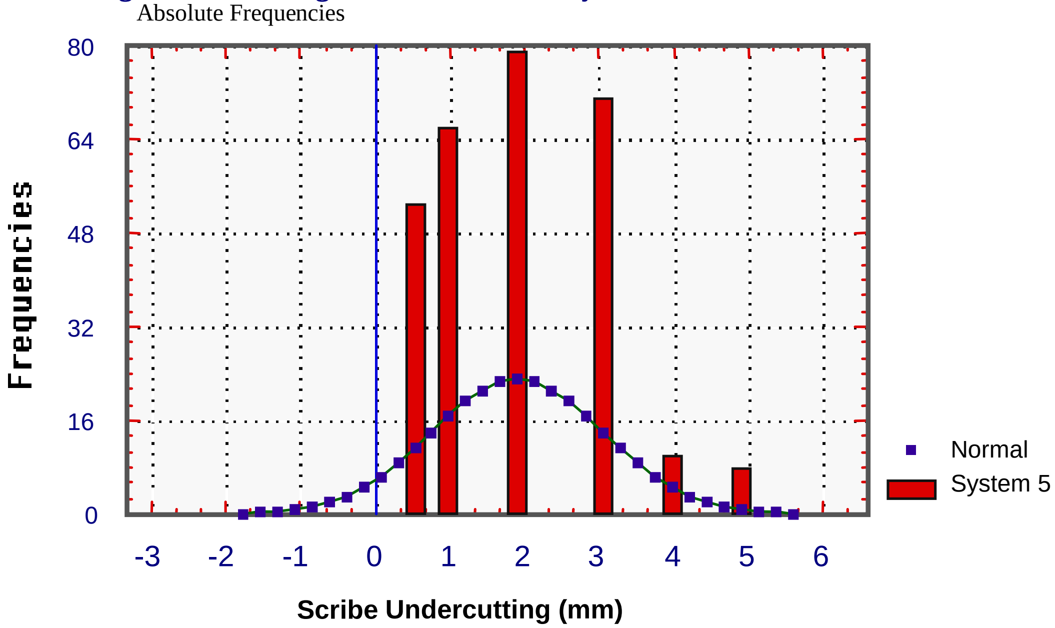


Figure B12: Normal Probability Plot of System 5

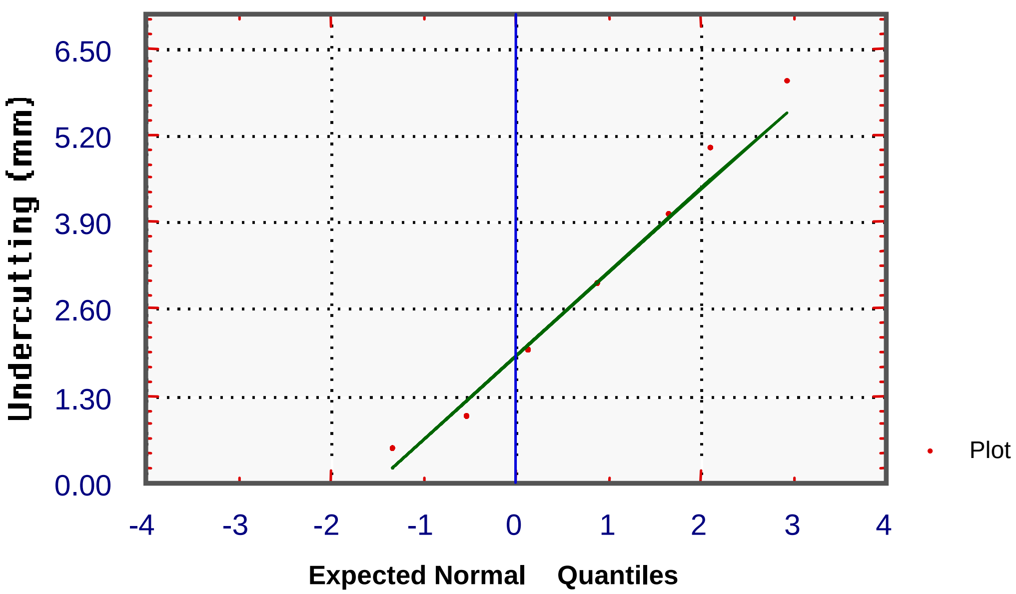


Figure B13: Histogram vs. Normal of System 5

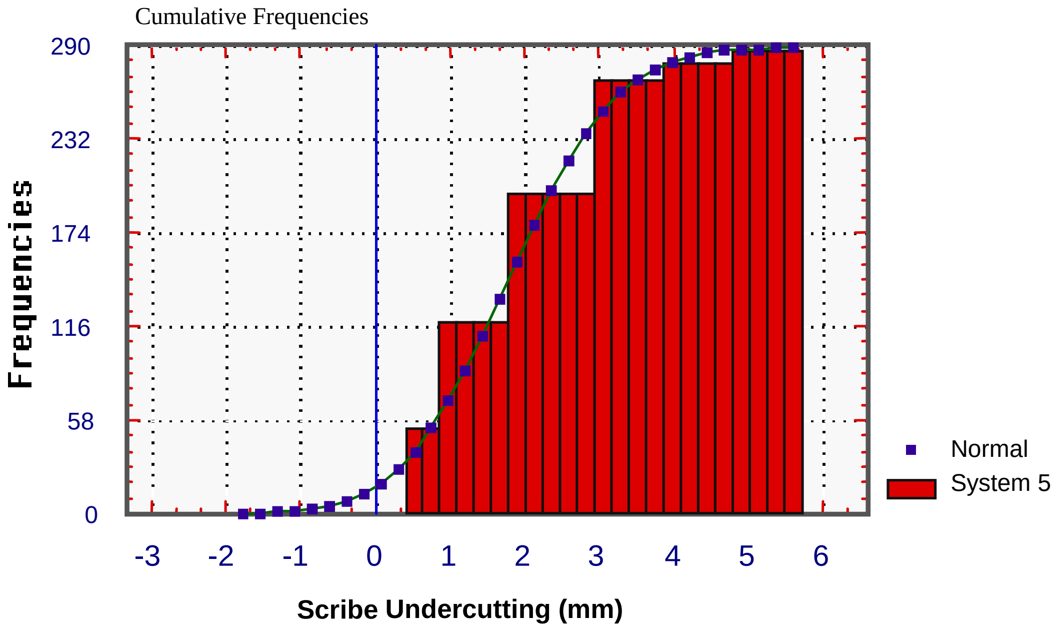


Figure B14: Histogram vs. Normal of System 8

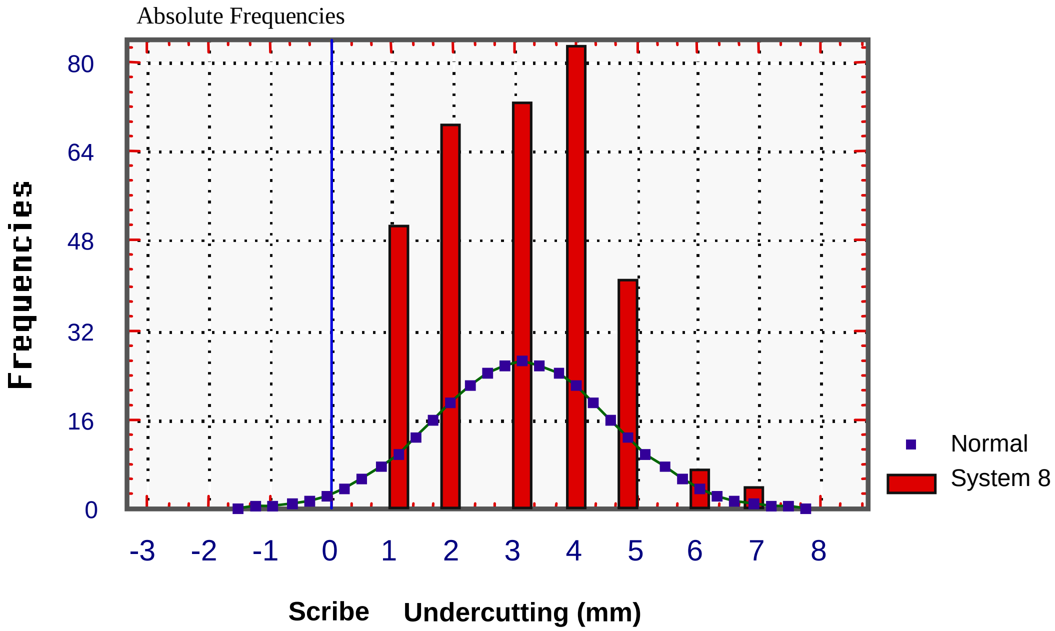


Figure B15: Normal Probability Plot of System 8

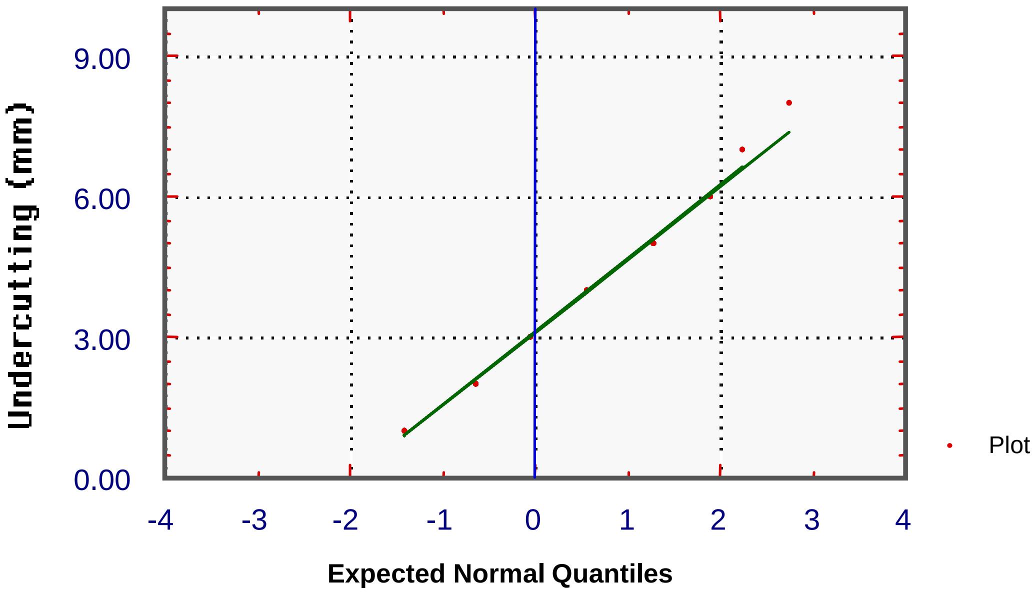
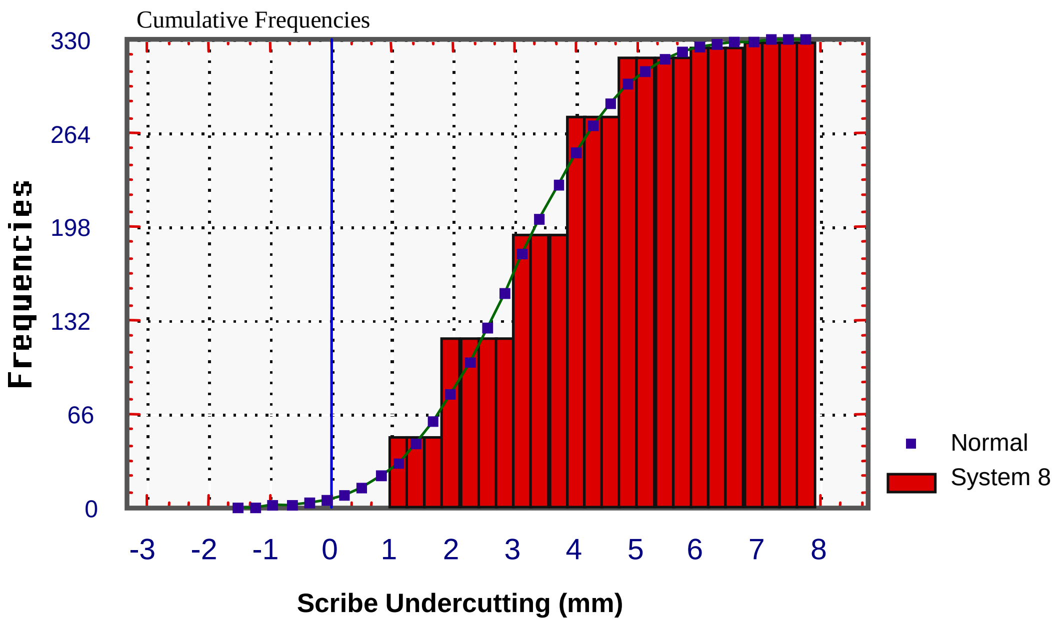


Figure B16: Histogram vs. Normal of System 8



Appendix C - Discussion of the Weibull Distribution (Method 2W)

C.l. ‘BACKGROUND

Weibull analysis is a common technique used to examine the durability test life of components. From a small sample of actual failure and suspended test data, the technique can estimate the expected failure percentage of the population. In this application, Weibull analysis is used to estimate the probability that a given level of undercutting will be measured. The analysis does not require complicated measurements, but the calculations are lengthy. For this reason, it is suggested that a spreadsheet macro be used in the analysis. The following information is a more detailed explanation of the Weibull Distribution analysis.

C.2. THE WEIBULL EQUATION

The Weibull cumulative distribution function is:

$$F(\chi, m, \beta) = 1 - e^{-\left(\frac{\chi}{\beta}\right)^m}$$

Where χ is the value at which to evaluate the function
m is a parameter $0 < m$
β is a parameter $0 < \beta < 1$

C.3. REQUIRED INFORMATION

Maximum undercutting values are determined for each of the twelve scribes. These data points are used to create the parameters m and ß, which determine the shape of the distribution curve.

Weibull distribution can not interpret zero values. The minimum measurable undercutting distance (χ_o) is assumed to be 0.5 mm and is used in place of zero values.

c.4. DATA MANIPULATION

C.4.1 Rank the data in ascending order, i.e., the smallest undercutting distance will be given a rank of 1. Equal distances will receive the same rank.

C.4.2 For each data point four calculations are necessary, as follows:

$$CDF = \frac{\text{Rank- } 0.5}{\text{number of data points}}$$

$$y = \ln[\ln(w)]$$

$$x = \ln(u), \quad \text{where u is a measure of the scribe undercutting}$$

$$w = \frac{1}{1 - CDF}$$

C.4.3 Calculate the slope, m, and the y-intercept, b, of the linear regression line using the x and y values. This computation is most easily done on a calculator or computer. The equation of the linear regression line will be in the form

$$y = mx + b$$

C.4.4 Let $\beta = e^{-\frac{b}{m}}$. Use the slope, m, and intercept, b, from C.4.3.

C.5. EVALUATING THE WEIBULL DISTRIBUTION FOR PROBABILITY

Let χ = (test value1 - χ_o. Choose a test value such as I2 mm. χ_o = 0.5. Hence, χ = II .5

Enter the calculated values of χ, m, and β into the equation in C.2 and solve for the Weibull probability.

C.6. SAMPLE WEIBULL CALCULATIONS WITH TWELVE DATA POINTS

The following example utilizes a spreadsheet program to calculate the Weibull Distribution probability for System 3 after 3360 hours of exposure. The data are the maximum raw scribe undercutting ratings measured in millimeters.

As a numerical example, entries in the first row in the System 3 table are computed as follows:

- I4 — The raw data measurement of I4 means that the maximum undercutting of the first scribe was I4 mm, I.e., u = 14.
- 8 — Since 14 is the 8th smallest measurement, it is given the rank of 8. There are seven other data points smaller than 14. Notice that the other measurement of 14 shares this rank. The next higher rank is IO.
- 0.6250 — $CDF = \frac{\text{Rank-O .5}}{\text{number of data points}} = \frac{8-0.5}{12} = 0.6250$
- 2.6667 — $w = \frac{1}{\text{I-CDF}} = \frac{1}{\text{I-0.6250}} = 2.6667$
- 2.639'1 — $x = \ln(u) = \ln(14) = 2.6391$
- -0.0194 — $y = \ln[\ln(w)] = \ln[\ln(2.6667)]$ = InE0.98081 = -0.0194

The computation for System 3 yields a Weibull probability of 0.321. The spreadsheet calculations are shown below.

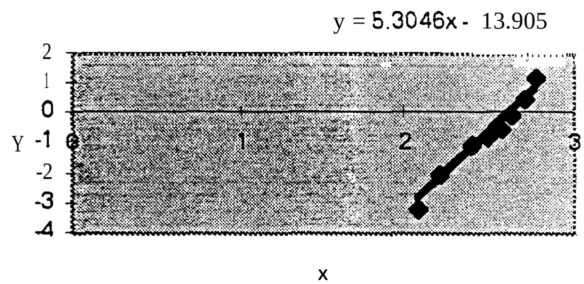
System 3
3360 h

Data (u)	Rank	CDF	w = 1/(1-CDF)	x = ln(u)	y=ln(ln(w))
14	8	0.6250	2.6667	2.6391	-0.0194
8	1	0.0417	1.0435	2.0794	-3.1568
9	2	0.1250	1.1429	2.1972	-2.0134
13	6	0.4583	1.8462	2.5649	-0.4892
15	10	0.7917	4.8000	2.7081	0.4502
15	10	0.7917	4.8000	2.7081	0.4502
14	8	0.6250	2.6667	2.6391	-0.0194
9	2	0.1250	1.1429	2.1972	-2.0134
16	12	0.9583	24.0000	2.7726	1.1563
13	6	0.4583	1.8462	2.5649	-0.4892
11	4	0.2917	1.4118	2.3979	-1.0647
12	5	0.3750	1.6000	2.4849	-0.7550

slope, m = 5.30
y-intercept, b = -13.90
beta = 13.753
χ_0 = 0.5
χ = 11.5
Test Value = 12

Weibull Probability = 0.321

Weibull Regression Plot for System 3



The **Weibull probability of 0.321 is the probability that the maximum undercutting on a scribe will be less than the test value of 12 mm.**

The table below gives the Weibull probability for various test values for System 3.

Test Value	Weibull Probability
12	0.321
13	0.453
14	0.596
15	0.734
16	0.848
17	0.928
18	0.972
19	0.992
20	0.998
21	1.000

Appendix D: Using Fewer Replicates in Benchmarking

This project used panel sets of six replicates with two scribes per panel. Thus, if the maximum undercutting is recorded for each scribe, 12 data points could be used to compute the benchmark in accordance with Method 2 as described in the body of the report. In order to determine if a viable benchmark could be determined using fewer replicates, the following experiment was performed.

The six System 2 replicates were randomly divided into three groups of two panels each. Set 2X consisted of panels 2A and 2F, Set 2Y consisted of panels 2B and 2D, and Set 2Z consisted of panels 2C and 2E. In order to get 12 data points for the benchmark computation, each scribe was divided into three equal parts, the top third, the middle third, and the bottom third. The maximum undercutting in each third of the scribe was measured. In essence, each scribe was treated as three separate scribes. The scribes were again remeasured by the principal observer so that this data is totally independent from the data reported elsewhere in this report. The raw data are given in Table D1

Table D1: Maximum Undercutting (mm) for System 2 Dividing Scribes into Thirds

Data Set	Panel	Upper Scribe			Lower Scribe		
		Top	Middle	Bottom	Top	Middle	Bottom
2X	2A	7	7	7	8	7	8
	2F	8	8	11	10	10	9
2Y	2B	7	9	11	9	12	7
	2D	8	8	7	7	11	9
2Z	2C	7	8	8	10	9	8
	2E	10	7	6	8	7	7

Each set of two panels had 12 data points which were then analyzed to compute the mean and the standard deviation. The corresponding benchmark was then the mean plus two standard deviations. The summary calculations are shown in Table D2.

The benchmarks for the two-panel sets were then compared with the benchmarks for the complete set of six replicates discussed in the body of the report. The summary calculations are displayed in Table D3. When the entire set of six replicates is used, the benchmark tends to be slightly higher. This is not unexpected since only the absolute maximum from each scribe is included among the data when all replicates are considered. For the two-panel data sets, the absolute maximum of each scribe is included along with two lesser entries: If the undercutting is fairly uniform along the length of the scribe, measurements from each third should be reasonably close to each other. This will yield a benchmark close to the six-replicate benchmark. Such is the case for System 2 examined here. When all six replicates were used, the benchmark was 13 mm: when only two panels were used the benchmarks were 10, 11, and 12 mm.

From the data examined here, it appears that a reasonable benchmark for scribe undercutting can be computed by partitioning the two scribes on each panel into thirds before taking measurements. This benchmark will be close to but slightly less than the benchmark computed using more replicates and making only one measurement per scribe. When the added expense of including more replicate panels in an exposure test is weighed against the accuracy of the benchmark, using fewer panels may be a viable option.

Table D2: Maximum Undercutting (mm) for System 2 Dividing Scribes into Thirds

Data Set	2x	2Y	2Z
Undercutting	11	12	10
	10	11	10
	10	11	9
	9	9	8
	8	9	8
	8	9	8
	8	8	8
	8	8	7
	7	7	7
	7	7	7
	7	7	7
	7	7	6
Average, x'	8	9	8
Std Dev, s	1.4	1.8	1.2
Benchmark x' + 2s	11	12	10

Set 2X included panels 2A and 2F.

Set 2Y included panels 2B and 2D.

Set 2Z included panels 2C and 2E.

Data represent a complete new set of measurements.

Table D3: Comparison of Method 2 Benchmarks for System 2 Using Reduced Sample Size with Benchmarks Computed from All 12 Scribes

	Three Measurements per Scribe			One Measurement per Scribe			
Data Set	2x	2Y	2Z	All 6 Panels	All 6 Panels	All 6 Panels	All 6 Panel
Observer	1 **	1 **	1 **	1	1*	2	3
Average, x'	8	9	8	9	10	9	9
Std Dev, s	1.4	1.8	1.2	1.7	1.8	1.9	1.7
Benchmark x' + 2s	11	12	10	13	13	13	13

Data set 2X included panels 2A and 2F.

Data set 2Y included panels 2B and 2D.

Data set 2Z included panels 2C and 2E.

* Remeasured by Observer 1

** Data for 2X, 2Y, and 2Z represent a complete new set of measurements

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14. ABSTRACT

The trend in the coatings industry today is away from composition specifications and toward performance specifications. Standardized levels of coating performance could be promulgated as industry-wide reference points through the establishment of benchmarks.

The objective of this research was to establish as benchmarks a number of well-known coating systems whose performance is widely accepted by users throughout the industry. Nine widely accepted coating systems were selected as benchmarks, and performance levels of these coatings were tested using the scribe undercutting methodology described in ASTM D 5894. Damage to the test specimens was assessed using two alternative methods, and each method was evaluated for reliability and reproducibility.

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