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DEVELOPMENT OF PROPOSED
STANDARD TEST METHOD FOR
SPRAY PAINTING TRANSFER EFFICIENCY
Volume II. Verification Program

Prepared for

Office of Air Quality Planning and Standards

Prepared by

Air and Energy Engineering Research
Laboratory
Research Triangle Park NC 27711

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DEVELOPMENT OF PROPOSED STANDARD TEST METHOD FOR SPRAY PAINTING TRANSFER EFFICIENCY

VOLUME II. VERIFICATION PROGRAM

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ABSTRACT

Over the past 5 years, the Environmental Protection Agency Air and Energy Engineering Research Laboratory has been working to develop a standardized laboratory test method for determining the transfer efficiency of spray painting operations. This document describes the final phase of laboratory experiments conducted to characterize the interlaboratory precision of the transfer efficiency test method developed in earlier efforts.

The test program included extensive experiments conducted at eight industrial spray painting laboratories. Three types of spray equipment (conventional air spray, electrostatic air spray, and airless) were tested at each laboratory. Six replicate transfer efficiency measurements were made for each equipment type at each laboratory.

The results of these experiments document the maturity of the draft standard transfer efficiency test method and the expected ruggedness of the results to differences within and between laboratories. As anticipated from earlier research efforts, the transfer efficiency results for each spray system were different. However, the results for each spray system demonstrated exceptional consistency when expressed as within-laboratory standard deviation. (Standard deviation is expressed in units of transfer efficiency. It can be used for estimating precision at various confidence intervals.) The within-laboratory standard deviation across eight laboratories was:

Conventional air spray 1.52
Electrostatic air spray ... 1.91
Airless spray 1.10

These within-laboratory standard deviations clearly demonstrate the capability of the test method to produce consistent results within a particular laboratory. The within-laboratory standard deviations were well below the value predicted at the onset of this project, 2.5.

The <u>total</u> standard deviations were considered from two standpoints. The first standpoint included the deviations directly attributable to differences among the spray guns used for the tests. These values were based on the <u>total</u> variance, including the within-laboratory portion of the <u>variance</u> (shown in the table above), gun-to-gun portion of the variance, and between-laboratory portion of the variance. The <u>total</u> standard deviations are reported below.

Conventional air spray 6.79
Electrostatic air spray ... 9.42
Airless spray 5.82

The second standpoint included the within-laboratory portion of the variance and the between-laboratory portion of the variance. However, it excluded the gun-to-gun portion of variance (that is, the part attributable directly to differences among the spray guns). The total standard deviation (excluding gun-to-gun differences) are presented below.

Conventional air spray 6.72
Electrostatic air spray ... 8.70
Airless spray 5.26

The exclusion of the gun-to-gun portion of the variance marginally improves the total standard deviation.

While arguments can be made towards including and excluding the gun-to-gun differences in the overall analysis, it makes little impact on the results of this study. Between-laboratory variances accounted for the vast majority of the total standard deviation for all equipment types at all ranges of transfer efficiency observed.

For the convenience of the reader, total standard deviations are referred to in this report as either <u>including gun differences</u> or <u>excluding gun differences</u>.

In classical interlaboratory programs there are two measures of the quality of the method: accuracy and precision. Precision is the measure of variability. The precision goals and results of this research have been discussed above and are presented in detail herein. Accuracy is the measure of how far off the observed values of transfer efficiency are from the <u>true</u> transfer efficiency. In this research there is no known <u>true</u> measure of transfer efficiency; therefore, accuracy cannot be addressed. However, since accuracy is a measure of the bias encountered in estimating the value of a parameter (and because there is no reason to believe that we have a significant bias for the spray system, laboratories, and targets examined), it is believed that the draft transfer efficiency test method is reasonably accurate. The absence of evidence regarding bias may be interpreted as an absence of bias.

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ABBREVIATIONS AND SYMBOLS

LIST OF ABBREVIATIONS AND UNIT CONVERSIONS

ABBREVIATIONS

AOAC	--	Association of Official Analytical Chemists
ASTM	--	American Society for Testing and Materials
EPA	--	United States Environmental Protection Agency
Fan air	--	shaping air or horn air
FP	--	flat panel (target configuration)
PSIG	--	pounds per square inch, lb/in^2, gauge
O&M	--	operating and maintenance
QA/QC	--	quality assurance/quality control
VOC	--	volatile organic compounds

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Exxon Chemical Company
Graco Inc.
Kremlin Incorporated
Nordson Corporation
PPG Industries Incorporated
Ransburg Electrostatic Equipment Inc.
BASF - Inmont (formerly United Technologies - Inmont)

Acknowledgement is made of the interest of the Chemical Coaters' Association in this research; their assistance in locating spray painting laboratories is appreciated.

Special acknowledgement also is made of the contributions of the members of the Transfer Efficiency Project Steering Committee.

SECTION I

INTRODUCTION

Spray painting transfer efficiency is a measurement of that quantity of paint solids which actually coats a surface compared with the total paint solids sprayed. Transfer efficiency measurements can be used to optimize on-line spraying or to develop more efficient spray equipment. More recently, the need to determine transfer efficiency has taken on a new aspect: transfer efficiency can be used to quantify volatile organic compound emissions from spray painting operations.

During the past 5 years, the U.S. EPA has been conducting extensive research on transfer efficiency. The objective of this research has been to develop a laboratory transfer efficiency measurement method. Many companies have developed their own methods for determining efficiency; however, these methods vary widely in capability although most share common elements. The EPA research program was designed and initiated to develop the necessary background and research data to permit development of a standardized laboratory transfer efficiency test method. To ensure as broad participation in the program as possible, numerous sources in the industry were contacted and their assistance solicited where possible.

Earlier research developed a laboratory transfer efficiency measurement method. The approach used was to develop the test method by studying concepts for transfer efficiency determination and methods currently in use and then using the best features of each. Laboratory tests were conducted to provide supporting data and to establish the precision of the formulated method. The tests established the standard deviation (repeatability) of the transfer efficiency results as less than 2.5 within a given laboratory. (Standard deviation is always expressed in the units being measured by the test. In this research it is always expressed in units of transfer efficiency.)

The research program described in this document was conducted to establish the efficiency of the transfer efficiency method using the preliminary draft method defined earlier in this program. Eight field-based laboratories participated in this test program. Electrostatic air spray, conventional air spray, and airless spray systems were tested at each laboratory.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The preliminary draft transfer efficiency test method was used at eight laboratories. Within each participating laboratory the results were repeatable at levels well below the standard deviation goal of 2.5 set by previous research (CENTEC Corporation, 1982).

A statistical analysis of the results showed that the gun portion and the within-laboratory portion of the total variance were small. The between-laboratory portion of the variance was over six times larger than the within-laboratory portion of the variance. This ratio implies that the differences between laboratories were real and resulted in detectable, quantifiable differences in transfer efficiency that can be attributed to differences between participating laboratories.

The toal standard deviations observed from laboratory to laboratory ranged from 5.82 (airless spray) to 9.42 (electrostatic spray). The preliminary results of this research indicate that the probability that the transfer efficiency measured at a random qualifying laboratory would fall within 7.3 to 12.0 transfer efficiency units of the true transfer efficiency, provided that the assumption that bias is nil is correct.

These results must, however, be considered preliminary. A sufficient number of laboratories was not used in the program to comply with an 80 percent probability criteria to establish for method precision.

SECTION 3

BACKGROUND

The EPA has been attempting to develop regulatory strategies to control the emissions of VOC from metal coating processes of the metal finishing industry. In those processes where the emission streams are easily defined and contain relatively high concentrations of VOC, development of regulations has been straight-forward. Those regulations are based primarily upon the ease with which presently available control technologies can be used to control high VOC concentration emission streams. Those technologies include carbon adsorption and incineration.

Although high concentration emission streams can be controlled effectively with available technologies, as VOC concentrations decrease the available control system's economic and technical feasibility also decreases. Questions have also been voiced by representatives of industry and government about the relationship of various metal coating techniques to their VOC emissions potential.

To date no method has been certified as a standard to measure transfer efficiency. Numerous companies and technical organizations, however, have proposed methods for measuring transfer efficiency. These have yet to be shown to have sufficient precision and accurary to define transfer efficiency for most painting scenarios. Thus, tranfer efficiency measurements have not become a part of present control strategies for compliance with VOC emissions regulations. Only when a simple yet accurate and precise method of measuring painting transfer efficiency is developed can TE be used in VOC control strategies.

Beginning in 1982, a contract was authorized by EPA to develop a preliminary transfer efficiency test method. Laboratory studies and evaluations were conducted to define a procedural method to accurately and precisely measure transfer efficiencies from various spray painting equipment. This equipment included conventional air spray, electrostatic air spray, and rotating bell spraying equipment. Results of these studies are presented in Volume I.

The current project was conducted in two parts. The first part addressed the status of the transfer efficiency method for airless spray equipment, which was not researched during previous phases of this program. The second part involved the implementation and validation testing at multiple laboratories to estimate the precision of the transfer efficiency test method.

SECTION 4

PART I - AIRLESS TRANSFER EFFICIENCY TEST METHOD

In the first part of this contract, background information on existing methods for determining the transfer efficiency of airless spray painting equipment was developed. Information from publicly available sources was obtained through a manual and computer literature search. A wide spectrum of private industry sources was contacted, including major spray painting equipment manufacturers, industrial metal finishers and spray painters, and paint formulators. These sources were questioned about different methods for determining the transfer efficiency of airless equipment. The general consensus was that there were no characteristics unique to airless spray which would make the current test method unacceptable except the need to determine mass flow with a meter rather than using scales and a stopwatch. In airless spraying, the paint pot is connected via high pressure hose to a reciprocating pump. This connection, and the action of the pump, make the scales vibrate. This vibration can be severe enough to make reading the scales difficult if not impossible.

Preliminary test results of the transfer efficiency procedure defined in appendix A, found that a reasonable degree of precision could be achieved. The standard deviation of replicate flat panel target test runs using airless spray guns was 1.31 and the standard deviation of replicate vertical cylinder test runs was 0.03, both well within the range of 2.5 that was specified in the preliminary draft test procedure. Therefore, it was concluded that the existing draft transfer efficiency test method was appropriate for airless spraying equipment even though it was not as well developed as for other spray painting systems.

To document this conclusion, a conventional airless spray system was selected as one of the three spray equipment types to be used for the second part of this study. The selection of airless spray equipment also helped to ensure that the preliminary draft transfer efficiency test method would be thoroughly developed across a wide range of transfer efficiencies.

SECTION 5

PART II - DESIGN OF INTERLABORATORY EXPERIMENT

PROGRAM DESIGN

The purpose of the experimental strategy of this effort was to build an interlaboratory test program that allowed estimation of the precision of the draft standard transfer efficiency test method. For this purpose, no operating parameters were intentionally varied during the program.

The strategy was divided into four major components: establishing the number of laboratories for the test program, deciding what equipment types were to be tested at each laboratory, estimating the number of replicates to be made for each equipment type at each laboratory, and establishing the gun portion of the variance. The experimental strategy called for replicate transfer efficiency determinations to be made at each laboratory participating in the program. These determinations were to be made using the same type of equipment (in similar condition) at the same spray conditions (controlled and held constant as provided in the QA/QC plan in Appendix B). These conditions were established during the first laboratory experiment and were held constant for all subsequent laboratory experiments in this program. Equipment operating conditions were set at the first laboratory to provide a good spray pattern and reasonable finish. The spray environment (i.e., the configuration of the laboratory, proximity of grounds, airflow patterns, and so forth) necessarily was less controlled from laboratory to laboratory than were the spray conditions. Ideally, interlaboratory method verification experiments would be conducted at nearly identical laboratories using identical spray equipment and identical operating conditions. However, from a practical standpoint it is impossible to have 100 percent identical laboratories. Thus, it might be expected that the resulting transfer efficiency valves will be somewhat different between laboratories.

ESTABLISH THE NUMBER OF LABORATORIES

The number of laboratories required to determine the precision of a test method within certain estimated confidence limits may be estimated from existing data generated from the same analysis performed at different laboratories. In this program, however, the existing data base could not be used for estimation of the number of laboratories because previous data were not obtained at the same conditions. Known and quantifiable differences existed between transfer efficiency tests conducted at four different laboratories under prior research efforts. Further, other documented transfer efficiency determinations performed by industry could not be documented as meeting required project QA/QC plans; their results also could not be used to estimate the number of laboratories required.

The results of transfer efficiency determinations made during this program at the same laboratories as prior studies could not be compared to the results of the prior research. The spray equipment, paint system, and operating conditions for this program were not the same as for prior efforts; thus, the results are not comparable. They are from different sets.

Since previous data were obtained at inconsistent spray painting conditions, an experimental design was undertaken that was not dependent upon prior data and was most efficient of resources. The experimental methodology meeting these criteria was the sequential experimental design. In the planned sequential experimental design, the same test was conducted at two laboratories. The data from these two laboratories served as a basis for further sample size projection. The results from these two laboratories truly reflected the most current level of knowledge.

Appropriate computations of number of laboratories required were made from the transfer efficiency results of the first two laboratory tests. The data from the first two test laboratories served as a portion of the final data set to be analyzed. This approach was consistent with the current trend in the field of experimental design, i.e., design the experiment in stages, using preliminary stages to make decisions regarding design parameters for the final stage (Steinberg and Hunter, 1984). This sequential experimental design allowed the program to avoid relying too heavily on the use of preliminary data that might be suspect or incompatible with the conditions anticipated in this study.

Based on the preliminary calculation described above, it was expected that this sequential methodology would result in selection of approximately eight laboratories for testing in the interlaboratory program. (The number of laboratories participating under this contract was fiscally limited to eight.) This estimate was also based on recommendations of the American Society for Testing and Materials in their Standard Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods (ASTM E 691-79, Part 41). This estimate was further supported by the Association of Official Analytical Chemists in their statistical manual (Steiner and Youden, 1975).

Selection of laboratories for participation in this program was based primarily upon the availability of necessary facilities; this selection process was necessarily assumed to be random for purposes of the statistical analysis.

ESTIMATE THE NUMBER OF REPLICATES

The number of replicates (n) for each gun type must be sufficient to reduce the variance of the test precision to an acceptable value. In this program, parameters were chosen for an 80 percent confidence interval that the total variability would be within a certain range. In that confidence interval, the element that drives down the total variability is the number of laboratories. The number of replicates at each laboratory (based on within-laboratory estimates of precision from previous experimental data) is not as important. As shown in the equation below, the total variance (excluding gun variance, which is addressed separately) is much more sensitive to the number of laboratories than to the number of replicates.

$$\sigma_T = \frac{2\sigma_w^4}{b(n-1)} + \frac{2(\sigma_w^2 + 2(\sigma_b^2)^2}{n(b-1)}$$

where σ_T = total variance (excluding gun variance)
σ_w = within laboratory variance
σ_b = between-laboratory variance
n = number of replicates at each laboratory
b = total number of laboratories

Based on this equation, one can see that changing the number of replicates from six to ten hardly affects the confidence interval, while increasing the number of laboratories from six to seven shrinks the confidence interval significantly.

Six replicates were considered adequate to meet this criterion based on previous experiments. Thus, six replicate transfer efficiency measurements were made for each equipment type in each laboratory under equivalent conditions for equivalent equipment types, as best as could be controlled.

ESTABLISH EQUIPMENT TYPES FOR TEST PROGRAM

Although the precision of the test method may be estimated by testing a single spray system across a number of independent laboratories, this approach would leave some questions as to the consistency of interlaboratory precision over a wide range of transfer efficiencies. It was important to establish that the test method was as precise at low transfer efficiencies as it was for high transfer efficiency values. To avoid this question, three spray types (having a wide range of anticipated transfer efficiency values) were selected for this research. The spray system types were electrostatic air spray, conventional air spray, and airless. As documented in prior research (cited above), electrostatic air spray and conventional air spray painting systems typically have considerably different transfer efficiencies even when operating in the same booth, using the same test paint and targets. For instance, during testing conducted in June 1983, conventional air spray equipment exhibited transfer efficiencies ranging from 10 percent to 60 percent, while electrostatic air spray equipment exhibited transfer efficiencies from 75 percent to 95 percent. Both spray systems used the same test paint, in the same spray booth, with the same sets of target configurations.

Electrostatic air spray and conventional air spray systems operate on different principles: conventional air spray equipment relies on the paint particle size and mass velocity to carry it to the desired target, while electrostatic air spray equipment uses an electrical attraction in addition to conventional attractive forces to draw the paint to the desired target. These differences make the selection of electrostatic air spray and conventional air spray systems desirable for this research. It allowed demonstration of the ruggedness of the test method to different spray mechanisms across a number of laboratories.

An additional advantage of selecting electrostatic air spray and conventional air spray equipment was that equipment costs were minimized. As recommended by the Spray Painting Transfer Efficiency Project Steering Committee in March 1985, electrostatic air spray equipment was used both as electrostatic equipment and to simulate conventional air spray equipment by turning off the electrostatics. In fact, these types of spray equipment (as offered by one manufacturer) were virtually identical except for the electrode on electrostatic spray guns. The decision to simulate conventional air spray equipment by using electrostatic air spray with the electrostatics turned off saved over $5,200 in equipment costs. It resulted in further savings by eliminating the amount of time needed to change equipment types (twice) at each laboratory.

A third equipment type, (conventional) airless, was also included in the test program as a result of Part I recommendations. Airless spray equipment does not have the test history of other equipment types. In order to ensure that the test method was as well developed for airless spray equipment as it was for other equipment types, airless equipment was included in this test program.

Automatic guns were recommended by the Spray Painting Transfer Efficiency Project Steering Committee, since they had not been fully tested using the draft standard transfer efficiency test method; however, automatic spray equipment was not available within the time frame and budget available for this program. Manual spray equipment was used for all tests in this program. The spray guns were fixed in position using a mounting pole, and were triggered manually with the exception of an actuator (automatic triggering device) used at one laboratory on the manual spray guns.

ESTABLISH THE GUN PORTION OF THE VARIANCE

By nature, the interlaboratory test program involved almost simultaneous testing at up to eight sites. This requirement necessitated the use of different spray guns (of the same make and model) from laboratory to laboratory. It was desirable to know the portion of the between-laboratory variance that was due strictly to differences in spray guns. This variance is called the "gun-to-gun portion of the variance" or "gun portion of the variance." The gun portion of the variance was considered part of the between-laboratory variance; it is never possible to test the identical gun at identical conditions at two laboratories. Even the same gun would have undergone additional wear in the process of being tested.

The gun portion of the variance had to be established to determine whether it was significant and, if so, to determine what portion of the total variance it represented.

The gun portion of the variance was established during the first laboratory test. Eight different spray guns (of same make and model) for each equipment type were subjected to replicate transfer efficiency determinations at the same laboratory. (These same guns were used in subsequent laboratory tests in this program.) Six replicates were conducted for each gun. The data were analyzed to determine how much difference in transfer efficiency was attributable to using different guns.

At the first test, mean transfer efficiencies and standard deviations from each of the three sets (one set for each equipment type) of 48 transfer efficiency determinations (eight guns per equipment type multiplied by six replicates for each gun) were compared. The gun portion of the variance was derived as described in Section 7 - Test Results and Statistical Analysis.

LABORATORY REQUIREMENTS AND SELECTION

Spray painting laboratories were required to meet certain minimum criteria in order to participate in the interlaboratory test program. These criteria included their ability to provide the laboratory conditions and support listed in Table 5-1, their willingness to participate in a timely manner, their laboratory rental cost, and their level of interest in the project. Best professional judgment and previous test experience were used to determine which laboratory conditions could reasonably be controlled from test to test. The Steering Committee contributed to defining laboratory conditions for testing. Part of the between-laboratory variance, then, accounted for uncontrollable differences from laboratory to laboratory. If more laboratory conditions had been specified (such as relative humidity), or condition ranges had been more closely defined (such as booth air rate at 95-105 fpm instead of 80-120 fpm), no known laboratories would have qualified to perform the test. Laboratory selection

TABLE 5-1. LEVEL OF SUPPORT REQUIRED FROM PARTICIPATING LABORATORIES

- Two technicians, knowledgeable and proficient with spray system use and maintenance (minimum)
- Back-draw water wash spray booth or equivalent, with 80-120 fpm air velocity in middle at plane of target (if dry filter booth is used, laboratory must provide sufficient filters to maintain these conditions), associated chemicals and operating costs
- Adjustable speed (20 to 40 fpm) overhead conveyor system capable of hanging EPA targets as specified
- Conveyor speed measurement equipment
- Utilities
- Paint mixing equipment and facilities for documenting paint characteristics (contractor provided Ford viscosity cup)
- Curing oven of sufficient size for curing EPA targets, with temperature control at 375°F
- Curing rack
- Timer
- Cleaning solvents
- Packing and shipping to next facility
- Air rate measurement equipment
- Humidity and temperature measurement equipment
- Foil cutters
- Foil handling facilities
- Laboratory scales (0.001g accuracy)
- Hangers for targets
- Compressed air supply in laboratory
- Temperature control in laboratory (65 - 75°F) Relative humidity was recorded but could not be controlled at available laboratories.
- Spray equipment assembly tools

TABLE 5-1. LEVEL OF SUPPORT REQUIRED FROM PARTICIPATING LABORATORIES (Continued)

- Copying machine (for completed data sheets)
- Work space for record keeping and calculations
- Security for test equipment and supplies
- Miscellaneous hose and fittings

was assumed to be random within the defined sample frame, although there was no absolute method to confirm the assumption.

Participating laboratories were required to supply at least two knowledgeable and conscientious technicians for the test program. Technicians were required to be familiar with the test equipment and capable of performing the tests precisely, as described in the Test Plan supplied to each laboratory.

In previous testing it was found that the transfer efficiency was influenced by the linear booth air velocity. In order to have consistent results, it was necessary to control the air velocity as much as possible. At the suggestion of the Spray Painting Transfer Efficiency Project Steering Committee, it was decided that a qualifying air rate of 100 fpm $\pm$ 20 fpm at the plane of the target in the center of the booth would be required for all participating laboratories.

An adjustable speed overhead conveyor system, a curing oven, and hangers large enough to handle the EPA targets were required to be supplied by the laboratories. The EPA targets consisted of ten 15.24 cm (6 in) wide metal panels mounted 15.24 cm (6 in) apart, and hanging 121.9 cm (48 in) in length (see Volume I). The importance of an adjustable speed overhead conveyor system can not be overemphasized because it provided the means to control the speed of the targets passing through the spray area. Since the conveyor speed is a controlled parameter, it necessitated the need to have conveyor speed measurement equipment at each participating laboratory. The degree of sophistication required was such that using a stopwatch and timing marks was an acceptable measurement method as allowed in the procedure.

Because this testing involved a standard test method, measurement and/or control of other pertinent parameters was essential. The temperature of the testing area could affect the Transfer efficiency and therefore was controlled to within a few degrees centigrade (that is, ± 5°F). Air rate measurement equipment (anemometer), humidity measurement equipment, and laboratory scales with 0.001g accuracy were included as part of the level of support needed from participating laboratories.

Finally, all interested laboratories were required to have paint mixing equipment, cleaning solvents, foil handling facilities, miscellaneous hose and fittings, spray equipment assembly tools, and a copying machine available during the testing period. Utilities, including compressed air and electricity, were also required.

EPA and its representatives, and cooperating equipment manufacturers and suppliers, supplied other test equipment, including but not limited to spray painting equipment and auxiliaries, test method, data books, and technical guidance.

The laboratories agreed that none of the test equipment supplied would be used for any purpose other than was directly related to the EPA transfer efficiency research program. This agreement specifically forbade using, tampering, dismantling, or otherwise examining this equipment except as required for the test program or for proper maintenance. An appropriate amount of security was necessary to ensure that this requirement was enforced.

Each laboratory was required to allow EPA representatives and EPA contract engineers full and complete access to the test area. The laboratories agreed to allow Spray Painting Transfer Efficiency Project Steering Committee members into their facility as observers of the research program.

Suitably equipped industrial laboratories were recommended through the Spray Painting Transfer Efficiency Steering Committee, through outside listings of available laboratories (Thomas' Register of Manufacturers, state-by-state industrial directories, Products Finishing 1984 Directory, and Metal Finishing Guidebook and Directory and Metal Finishing Guidebook and Directory for 1984.)

Participating laboratories were asked to schedule two weeks each for conducting tests except in the case of the first test, which required four weeks of laboratory time. Several additional experiments were conducted during the first test.

TEST EQUIPMENT

Overview of Test Equipment

In this part of the program, three types of spray equipment were tested at up to eight laboratories. One spray equipment type, electrostatic air spray, was used to simulate conventional air spray equipment as well. Thus, two complete spray systems were obtained for electrostatic air spray and for airless. Eight spray guns of the same make and model were obtained for use on the two electrostatic air spray and two airless systems. These equipment types are described in detail below. Spray systems and guns were supplied to participating laboratories in new condition to ensure as nearly identical spray equipment conditions as possible. Each component of the spray system, from the gun tip to hoses and supply tanks, was required to be of the same size, make, and model. This requirement enhanced control of variances from spray system to spray system. Each spray gun was mounted in the proper spray position on a pole. Spray gun operation was manual (hand-triggered), except at one laboratory where a remote actuator was employed.

Other test supplies and equipment described in this section include instrumentation, paint, targets, and foil. The supply of some test equipment was required of participating laboratories. These were described earlier in this section.

Electrostatic/Conventional Air Spray Equipment

A manual mid-range (75 kV) electrostatic air spray gun was selected for use as electrostatic spray equipment and to represent conventional air spray equipment. (As previously described, the same equipment was used but without voltage applied.) The electrostatic air spray gun was equipped with a 1.2 mm (0.047 in) fluid tip. This was the same model spray gun used during a previous test effort conducted to determine how operating and maintenance variables affect transfer efficiency (U.S. EPA, 1985). It was considered representative of manual electrostatic air spray guns available from other manufacturers, although differences exist from manufacturer to manufacturer.

A 75 kV adjustable power supply was used to support the electrostatic air spray gun. This is a mid-range power supply equipped with appropriate cable and connections. A kV meter and ammeter were built into the power supply control panel. Power cables were supplied in 762 cm (25 ft) lengths for each power supply.

Pressure tanks were used to supply paint to the gun through 1524 cm (50 ft) fluid lines. A dual air regulator pressure tank with agitator (to minimize stratification of the paint) was supplied with each electrostatic air spray system. Air hoses were supplied in 1524 cm (50 ft) lengths for each system.

Airless Spray Equipment

A manual airless spray gun was selected for the interlaboratory test program. The spray gun included a 0.38 mm (0.015 in) diameter tip.

An electric pump was the fluid supply mechanism. The small, 1.89 liter per minute (0.5 gpm) pump was used. Fluid hose was obtained in 762 cm (25 ft) lengths for airless transfer efficiency determinations. Two fluid hoses were used in each test, with one segment spanning from the pump to the control panel (see below) and one segment spanning from the control panel to the spray gun.

Instrumentation

Control Panel

Two control panels were constructed to provide adequate process control equipment to participating spray painting laboratories. Each control panel housed air and fluid regulators, an air rotameter, a mass flow meter, and a mass flow totalizer on a movable cart. The regulators had a pressure range of 6.9 to 344.7 kPa (1 to 50 psig). The recommended supply pressure for the regulators was 827.3 kPa (120 psig), with a maximum supply pressure of 1034.2 kPa (150 psig). All connections were 1/4 NPT.

Five pressure gages were mounted in each control panel. These pressure gages monitored air and fluid pressure throughout the spray system. All gages were dead-weight calibrated prior to testing. Dead-weight calibration is a standard method for calibrating pressure gages by applying a static ("dead") pressure. In this case, a series of static pressures (framing the expected test pressures) were applied to each gage being calibrated. Calibration curves were developed and used for all gages used in this research.

A direct scale reading rotameter was included on each control panel to indicate air flow through the system.

A mass flow meter was utilized to indicate the total mass of paint sprayed during each test. Each control panel was equipped with a mass flow meter. This meter was fitted with a digital totalizer, enabling test personnel to read paint mass flow quickly and easily.

Other Instrumentation

An anemometer was available to laboratories not having their own equipment to document the spray booth air velocity.

A sling psychrometer was also available to laboratories not having their own relative humidity or thermal measurement equipment.

A calibrated #4 Ford viscosity cup was supplied for use at each laboratory.

Paint

Certain desirable paint characteristics were necessary for the test program. The same paint was to be sprayed by all spray systems, except that the viscosity of the paint was higher for airless spray equipment. Thus, the paint had to be of relatively high viscosity when uncut but mid-range viscosity when cut. It had to have a simple solvent system, for ease in obtaining and simplicity in cutting (thinning) at test sites. The paint had to be readily available from a large manufacturer's batch to encourage homogeneous characteristics. It had to adhere well to aluminum foil without cracking, peeling, or breaking. It was required to have at least a 6-month shelf life so that a single batch could be used in all experiments in this program. Paint resistivity must be high for electrostatic spraying, or the paint may ground the system. Finally, the paint had to be reasonably priced and readily available.

The selected paint met these criteria as summarized in Table 5-2. It was a highly flexible alkyd base paint commonly used for painting light fixtures. As shown in Table 5-2, the paint was cut to a wide range of viscosities using xylol. Nitration grade xylol was used as the solvent.

TABLE 5-2. PAINT SPECIFICATIONS

Supplier: Glidden 447-W-02133
Resistivity: 360 Megohms/cm
Nonmetallic
Alkyd based
Xylol solvent (titration grade)
Part of a high volume batch
Adheres well to aluminum foil
Cure: 900 s (15 min) at 190.5°C (375°F)
Approximately 52 percent solids by weight, after cutting

A sample of the test paint was sent to the first laboratory for field confirmation of its properties. It met all test requirements.

During the tests, paint weight percent solids were determined several times daily as required by the test method and by the project QA/QC plan (Appendix A and Appendix B, respectively). ASTM Method D-2369, Standard Test Method for Volatile Content of Coatings, was used for all paint weight percent solids determinations, except that the vendor-recommended cure schedule was followed.

Foil

A medium-temper aluminum alloy foil was required by the draft transfer efficiency test method (Appendix A). As described in the test method, 0.0037 cm (1.5 mil) thick foil, 38.1 cm (15 in) wide and on rolls approximately 21336 cm (700 ft) long, was supplied to participating laboratories by the contractor. Over 227 kg (500 lbs) of foil was supplied to test laboratories, or about 28.4 kg (62 lbs) per laboratory.

Targets

As directed by the draft transfer efficiency test method, one EPA target consisted of a set of ten galvanized steel 121.9 cm (48 in) by 15.2 cm (6 in) panels mounted on 30.48 cm (12 in) centers (see Appendix A). A set of ten panels thus configured and hung on an adjustable speed conveyer was used for each transfer efficiency determination. The first two and last two panels in each set of ten were scavengers. Selection of these targets over other configurations is discussed later in this section.

Twelve sets of targets (consisting of ten panels each) were supplied to each participating laboratory to help expedite transfer efficiency testing. By having extra targets on hand, one member of the research team could be weighing and wrapping panels in preparation of testing while other researchers were setting up spray equipment. During testing, as each spray painting pass was completed and the targets removed for curing, another set of prepared targets was ready for mounting and spraying.

Targets were suspended so that the spray pattern fell across the middle of the target, with a minimum 30.5 cm (1 ft) clear space between the edge of the spray pattern and the target top and bottom. This requirement was to prevent excessive overspray. Previous transfer efficiency test results using target configurations ranging from large flat panels (almost prohibiting overspray) to small vertical cylinders hung on wide centers (almost totally overspray) demonstrated that either extreme design tended to desensitize the transfer efficiency test method. That is, target configuration affected the ability of the test method to detect changes in transfer efficiency. The target configuration selected for this research was determined to be the most sensitive target type tested. Therefore, the selected target configuration was most likely to detect changes in transfer efficiency within or between laboratories.

SECTION 6

PERFORMANCE OF EXPERIMENTS

FIRST LABORATORY

Special tests were conducted at the first laboratory in this program. First, base spray conditions were established for each type of equipment. Once established, these conditions were used for all subsequent transfer efficiency determinations in this program. Second, the gun portion of the variance was established through a prescribed set of experiments. Finally, the first interlaboratory test was conducted.

The draft transfer efficiency test method (Appendix A) was used for all transfer efficiency determinations made in this program. The test method as presented in Appendix A has been modified to include base spraying conditions from the first laboratory as part of the test criteria. These criteria were a necessary part of the interlaboratory test program, and are not part of the generic draft transfer efficiency test method.

Establish Base Spray Conditions

Prior to conducting transfer efficiency determinations at the first laboratory, standardized spray conditions were established. (These same conditions were used at all subsequent laboratories.) Spray conditions were established through a trial-and-error procedure to determine an acceptable spray pattern and finish. Extensive previous transfer efficiency testing using the same types of spray equipment and similar paint was used in setting the first rough approximations of spray conditions and in adjusting conditions. Disposable paper targets were used for the rough first approximations of spray conditions. Foil-covered EPA targets were painted at tentative spray conditions to demonstrate their appropriateness for use with the actual test targets.

Of the spray conditions, paint viscosity was one of the hardest to set and control. Paint viscosity was to be set at mid-range (15 s on a #4 Ford cup) for electrostatic air spray and conventional air spray transfer efficiency determinations. Paint viscosity was set at 30 s on a #4 Ford cup for airless spraying. Nitration grade xylol was used to cut the paint to specified conditions. ASTM D-1200-70 was the method used to determine paint viscosity.

Test booth conditions were documented prior to setting spray conditions and prior to conducting transfer efficiency determinations. If booth conditions did not meet test requirements, or if process control systems (booth rate, regulators, mass flow meter, etc.) were not operating, they were repaired prior to setting spray conditions.

Actual spray system operating conditions were set for airless equipment first. Gun-to-target distance, fluid pressure, and paint viscosity adjustments were set at manufacturer's recommendations. Test patterns were shot onto paper and operating conditions were adjusted until a good spray pattern was realized. Once a good spray pattern was realized, foil-covered EPA targets were painted and cured. When the resulting coating was acceptable, spray operating conditions were documented. These spray conditions were fixed for the remainder of airless equipment testing in this program.

Airless testing for gun portion of the variance and for the first interlaboratory test was conducted at base operating conditions.

Electrostatic air spray conditions were set next. Since electrostatic air spray and conventional air spray equipment were physically identical in this program, no equipment changes were required. The same procedure for establishing spray conditions was followed: setting paint characteristics, then making trial-and-error adjustments to operating conditions (including voltage, shaping air, and atomizing air) until an acceptable spray pattern was realized. Once an acceptable spray pattern was achieved, foil-covered test panels were painted and cured to assure an acceptable pattern and finish under the tentative spray conditions. This process was repeated until an acceptable pattern and finish were realized on test panels. Then spray conditions for electrostatic air spray and conventional air spray equipment were documented, fixing them at the same level for all subsequent transfer efficiency determinations in this program.

Establish Gun Portion of the Variance

The following procedure for establishing the gun portion of the interlaboratory variance was performed for each equipment type at the first laboratory. The serial number of the spray gun was recorded for each transfer efficiency determination made. Once standard spray conditions were determined as above, the order of testing was randomized to provide six replicate transfer efficiency determinations--one for each gun and each type of spray system.

The data analysis for determining the gun portion of the interlaboratory variance is described in Section 7 - Test Results and Statistical Analysis.

First Interlaboratory Test

As described above, much of the work conducted at the first laboratory involved start-up operations including: setting up the three different spray systems, paint cutting and documentation, establishing standard operating conditions for each spray system, and conducting tests to determine the gun portion of the variance for each spray system. The first interlaboratory test consisted solely of conducting six replicate transfer efficiency tests on each of the three spray systems. No operating or maintenance variables were altered from test to test.

SUBSEQUENT INTERLABORATORY TESTS

Transfer efficiency tests at subsequent laboratories each consisted of three discrete experiments corresponding to three equipment types--electrostatic air spray, conventional air spray, and airless. Six replicate transfer efficiency determinations were conducted for each type of equipment. Subsequent test series in the interlaboratory program took 5-8 days in each laboratory. The summary of each of these test series, the problems encountered, and the test results follows.

TRANSFER EFFICIENCY TEST AT
LABORATORY NO. 1 - June 3-28, 1985

The transfer efficiency tests were performed at the first laboratory to define and establish spray conditions to be utilized as a standard for subsequent testing, to calculate the gun portion of the variance, and to help determine the number of subsequent sites required to statistically prove the precision requirements of the draft transfer efficiency test method.

At the first laboratory, six replicate transfer efficiency determinations were made for each spray gun (eight each of conventional airless, electrostatic air spray, and conventional air spray). The order of the transfer efficiency determinations was determined using random number tables.

Test Set-Up

Several items were established prior to the testing including paint viscosities, the cure schedule, and the numerous operating pressures. In addition, scales, gages, and meters were calibrated to within the EPA-approved standards (see Appendix B).

Two Ford viscosity cups were calibrated against standardizing oil.

The paint cure schedule was chosen after several weight percent solid tests were performed. The cure schedule was set at 330°F for 11 minutes. It was apparent, however, that this time and temperature did not achieve complete curing. At the suggestion of the manufacturer, conditions were adjusted to 375°F for 15 minutes. Although the painted surface was apparently cured by the new schedule, paint weight continued to decline with additional curing. According to the manufacturer, this phenomenon was caused by the breakdown of a chemical cross-linking mechanism in the coating. This phenomenon was an additional concern in trying to adequately control curing of test targets.

The paint manufacturer also recommended the viscosities for airless and electrostatic air spraying using this type of paint. With the higher weight percent solids, the use of 15 seconds (No. 4 Ford cup) for electrostatic air spraying and conventional air spraying, and 30 seconds for airless spraying was advised.

The pressure gages to be used for the program were high-precision gages. They were dead-weight tested prior to TE testing.

Once the pressure gages were tested, the mass flow meter was calibrated. Several major problems existed. The airless system caused high vibrations due to the airless pump pulsations. The control panel vibrated, causing an even greater problem with the meter stabilization.

After reviewing the mass flow meter installation instructions, it was decided to place steel plates on the control panel to give the meter a more rigid base. After several trial runs, it was determined that these steel plates did dampen the vibration.

The mass flow meter was tested against the paint capture method at various flow rates. It met the accuracy requirement of $\pm$ 0.9 percent defined in the QA/QC Plan (see Appendix B.)

Airless Testing

The airless test actually began one week after the project team's arrival on site. Using random number tables, the order in which the airless tests would be performed was derived. The order and the resultant foil numbers and transfer efficiencies are included as Table 6-1.

The airless gun test was completed in two days. The results are included in Table 6-1. The average transfer efficiency was 44.4, with a standard deviation of 2.50 across all gun types. These numbers do not have any particular value of their own; the values take on significance only when examined in conjunction with the results of the other laboratories.

Electrostatic/Conventional Air Spray Testing

This portion of the test was set up and run according to the operating parameters set up in Appendix A and recorded in the raw data sheets in Appendix E. No major problems were encountered during the testing; however, it appeared that the mass flow meter was becoming increasingly less accurate. This problem forced on-site engineers to request a change in the QA/QC requirements to $\pm$ 10 grams, consistent with other acceptable mass flow measurement methods in Appendix B.

These transfer efficiency determinations were made during the last three weeks of June 1985.

Test Results

The objectives of the first test were to establish operating conditions for the eight-laboratory study, to determine the gun portion of the variance, and to perform the first part of an eight-laboratory study. These objectives were achieved.

Base Operating Conditions

As described in the preceding section, base operating conditions for all three equipment types were established during the first week of testing. They are presented in Appendix E.

TABLE 6-1. ORDER OF AIRLESS GUN TESTING

GUN	FOIL NOS.	TRANSFER EFFICIENCY
61632	31-36	42.2
60838	37-42	45.7
61449	43-48	47.1
61449	49-54	46.1
60838	55-60	44.5
61632	61-66	40.6
60829	67-72	42.4
60429	79-84	43.1
61632	85-90	43.5
61629	91-96	44.9
60829	97-102	44.2
61629	103-108	43.8
61649	109-114	43.3
60865	115-120	44.8
61449	121-126	45.9
61632	127-132	44.1
60865	133-138	45.1
61449	139-144	47.1
61632	145-150	44.8
61449	151-156	45.3
61629	163-168	45.2
61629	169-174	44.2
61644	176-181	46.1
60838	182-187	45.1
61644	188-193	42.2
60865	194-199	44.7
61449	200-205	45.6
61629	206-210	44.2
61649	212-217	43.4
60865	218-223	42.6
--	230-235	--
61649	236-241	43.5
61644	242-247	43.4
61649	248-253	42.8
61644	254-259	43.3
61644	260-265	42.8
61644	266-267	43.9
60865	272-277	44.3
61632	278-283	43.2
60865	284-289	45.5
60838	290-295	45.0
60838	296-301	45.0
60829	302-307	42.4
60829	314-319	43.0
60838	320-325	45.1
60829	326-331	43.2
61629	332-337	44.0

Gun Portion of the Variance

The gun portion of the variance was statistically detectable and significant. Summaries of the order of gun testing, foil numbers, and the transfer efficiency results are presented in Tables 6-1, and 6-3. The variance (not standard deviation) attributable to differences between guns used during this research for the three equipment types was:

Airless	6.22
Conventional air spray . . .	0.88
Electrostatic air spray . . .	13.01

The variances for airless and conventional air spray guns were considered unexpectedly low. In the final analysis, they contributed little to the total (overall) interlaboratory variance. Electrostatic air spray variance was higher, but still accounted only for 15 percent of the total interlaboratory variance for electrostatic air spray transfer efficiency determinations.

Thus, it was concluded that the differences between guns must be accounted for even though they were not a major contributor to the total interlaboratory variance.

The determination of the gun portion of the variance is discussed in more detail in Section 7 - Statistical Analysis.

First Laboratory Test Results

After each test was completed, an outlier analysis was performed on the data (see Appendix C.)

Airless test results from the first laboratory had a mean transfer efficiency value of 44.2, with a standard deviation of 0.821. The data were tightly grouped as shown in Table 6-4. These numbers do not have any extraordinary value of their own; the values take on significance only when examined in conjunction with the results of the other laboratories. They do, however, demonstrate the capability of the draft transfer efficiency test method to produce highly repeatable data at a given facility.

The electrostatic data showed a significantly greater degree of dispersion (see Table 6-2). The reason for this trend could not be technically pinpointed nor statistically modeled; however, it was apparent that there was a constant factor influencing the testing, especially the electrostatic air spray gun tests. Test results are presented in Section 7. There was speculation onsite that the electrical supply changed during the day as heating demands, office lighting demands, and other electrical demands were made on the power supply. This speculation could not be documented.

TABLE 6-2. ORDER OF ELECTROSTATIC AIR SPRAY GUN TESTING

GUN	FOIL NOS.	TRANSFER EFFICIENCY
C1378	573-578	65.27
C1320	585-590	71.04
C1356	597-602	75.50
C1336	609-614	73.70
C1356	621-626	73.64
C1290	633-638	71.65
C1320	561-566	79.63
C1382	717-722	70.56
C1290	729-734	64.39
C1290	741-746	62.46
C1290	747-752	62.86
C1336	759-764	72.20
C1290	771-776	64.68
C1378	783-788	70.32
C1356	417-422	74.60
C1355	429-434	77.83
C1365	441-446	79.24
C1378	453-458	73.75
C1365	465-470	79.04
C1290	477-482	77.06
C1290	489-494	77.37
C1356	501-506	75.10
C1356	513-518	76.99
C1320	525-530	76.45
C1355	537-542	70.58
C1320	549-554	74.54
C1356	1016-1021	77.98
C1382	944-949	73.75
C1382	956-961	72.30
C1336	968-973	77.35
C1336	980-985	74.74
C1382	992-997	74.28
C1336	1004-1009	77.73
C1365	886-891	74.41
C1365	863-868	76.48
C1382	875-879 (+901)	76.15
C1355	908-913	66.50
C1382	920-925	74.90
C1355	932-937	66.98
C1336	795-800	70.03
C1365	807-812	73.89
C1365	819-824	73.71
C1368	832-837	70.76
C1378	844-849	71.68
C1378	857-862	72.11
C1320	356-361	77.61
C1355	369-374	69.71
C1355	381-386	74.10
C1320	393-398	80.30
C1320	405-410	78.83

TABLE 6-3. ORDER OF CONVENTIONAL AIR SPRAY GUN TESTING

GUN	FOIL NOS.	TRANSFER EFFICIENCY
C1378	567-572	32.72
C1320	579-584	39.09
C1356	591-596	29.80
C1336	603-608	37.29
C1356	615-620	34.44
C1290	627-632	41.26
C1320	349-355	36.67
C1355	363-368	36.44
C1355	375-380	37.80
C1320	387-392	39.30
C1320	399-404	40.40
C1356	411-416	34.29
C1355	423-428	35.56
C1365	435-440	34.25
C1378	447-452	36.86
C1365	459-464	34.65
C1290	471-476	39.92
C1290	483-488	39.98
C1356	495-500	31.46
C1356	507-512	33.20
C1320	519-524	38.19
C1355	531-536	33.02
C1320	543-548	38.20
C1320	555-560	38.18
C1382	705-710	33.43
C1290	723-728	37.28
C1290	735-740	39.09
C1336	753-758	35.91
C1290	765-770	38.79
C1378	777-782	35.41
C1336	789-794	36.63
C1365	801-806	30.41
C1365	813-818	32.31
C1378	825-830	34.86
C1378	838-843	33.96
C1378	851-856	33.30
C1365	880-885	30.50
C1365	892-897	31.75
C1382	869-874	34.99
C1355	902-907	34.87
C1382	914-919	31.22
C1355	926-931	34.62
C1382	938-943	35.18
C1382	950-955	34.96
C1336	962-967	35.06
C1336	974-979	34.85
C1382	986-991	34.79
C1336	998-1003	35.08
C1356	1010-1015	29.23

TABLE 6-4. LABORATORY 1 TEST RESULTS

Airless	
Transfer efficiency (%):	44.9
	43.8
	45.2
	44.2
	42.9
	44.0
Mean:	44.2
Standard deviation:	0.821
Electrostatic air spray	
Transfer efficiency (%):	65.3
	70.3
	73.8
	70.8
	71.7
	72.1
Mean:	70.7
Standard deviation:	2.89
Conventional air spray	
Transfer efficiency (%)	32.7
	36.9
	35.4
	34.9
	34.0
	33.3
Mean:	34.5
Standard deviation:	1.53

Electrostatic air spray equipment produced a mean transfer efficiency of 70.7 with a standard deviation of 2.89. These numbers do not have any extraordinary value of their own; the values take on significance only when examined in conjunction with the results of the other laboratories. They do, however, demonstrate the capability of the draft transfer efficiency test method to produce repeatable data at a given facility.

Conventional air spray equipment produced a mean transfer efficiency of 34.5, with a standard deviation of 1.53. Again, these numbers do not have any extraordinary value of their own; the values take on significance only when examined in conjunction with the results of the other laboratories. They do, however, demonstrate the capability of the draft transfer efficiency test method to produce highly repeatable data at a given facility.

TRANSFER EFFICIENCY TEST AT LABORATORY NO. 2

Test Facilities

The second laboratory transfer efficiency tests were conducted in a Binks water-wash spray booth in the spray painting laboratory. The laboratory provided the spray painting laboratory, technicians, conveyor system, curing oven, and other associated test materials.

The engineering laboratory was roughly 1220 cm by 915 cm with 600 cm ceilings (about 40 ft by 30 ft, with 20 ft ceilings). The booth maintained the linear air velocity at 40.6-61.0 cm/s (80-120 ft/min), as required by the proposed laboratory selection criteria. The booth area temperature was controlled at 22.2°C (72°F) during test runs. Paint and solvent were kept in the booth area and their temperatures closely matched booth ambient temperatures. Relative humidity was controlled at 50 percent during the test.

A Mayfran Cableway overhead conveyor system equipped with a Lab-line digital timer was used in all experiments at this site. A Despatch oven was used for curing painted targets.

The laboratory was supplied with the spray gun, 5-gallon pressure tank with agitator, hoses, and 75 kV power supply. The same gun also was used to simulate conventional air spray painting by conducting transfer efficiency determinations with no voltage applied.

Transfer Efficiency Tests

Equipment set-up and instrument calibrations were completed on September 24, 1985. Transfer efficiency testing began on September 24, 1985. Six replicate transfer efficiency determinations were made for each equipment type. Airless tests were completed the first day of testing. Conventional air spray tests and electrostatic air spray tests were completed the following day. Operating conditions are presented in the raw data sheets in Appendix E.

The purpose standard transfer efficiency test method and spray conditions, as set forth in Transfer Efficiency Method Evaluation Plan, were followed for all transfer efficiency determinations. All operating conditions are presented in the raw data sheets in Appendix E. All QA/QC requirements were met, and no special problems were encountered during the experiment.

Test Results

Transfer efficiency results for these tests are presented in Table 6-5. Mean and standard deviations are also summarized in Table 6-5.

Airless test results from the second laboratory had a mean transfer efficiency value of 33.1, with a standard deviation of 1.73. The data were tightly grouped as shown in Table 6-5. These numbers do not have any extraordinary value of their own; the values take on significance only when examined in conjunction with the results of the other laboratories. They do, however, demonstrate the capability of the draft transfer efficiency test method to produce highly repeatable data at a given facility.

Electrostatic air spray equipment produced a mean transfer efficiency of 66.2 with a standard deviation of 0.95. These numbers do not have any extraordinary value of their own; the values take on significance only when examined in conjunction with the results of the other laboratories. They do, however, demonstrate the capability of the draft transfer efficiency test method to produce repeatable data at a given facility.

Conventional air spray equipment produced a mean transfer efficiency of 24.4, with a standard deviation of 0.57. Again, these numbers do not have any extraordinary value of their own; the values take on significance only when examined in conjunction with the results of the other laboratories. They do, however, demonstrate the capability of the draft transfer efficiency test method to produce highly repeatable data at a given facility.

A standard outlier test, using Nalimov's criteria, was conducted on transfer efficiency results for each spray system. One outlier was identified (Run No. 10) in the electrostatic air spray results. No reason for the outlier could be identified. The run was repeated as per the requirements of the QA/QC Plan. According to the QA/QC Plan, outlier transfer efficiency results were replaced by the results of a replacement transfer efficiency determination. Thus, outliers were not included in the final data set from each laboratory and had no effect on the results of the study.

Sequential Analysis Estimating Number of Laboratories

Results of transfer efficiency determinations from the first and second laboratory were used to estimate the number of laboratories required to estimate the method's precision satisfactorily, i.e., to ensure that the probability of the estimated variance differing from the actual variance by less than a specified amount is high. In terms of a mathematical relationship, this means:

$$\Pr[\tilde{\sigma}^2 - \sigma^2 < \delta] > P \qquad (1)$$

TABLE 6-5. LABORATORY 2 TEST RESULTS

Airless	
Transfer efficiency (%):	35.3
	34.4
	33.0
	31.3
	33.6
	30.8
Mean:	33.1
Standard deviation:	1.73
Electrostatic air spray	
Transfer efficiency (%):	65.4
	65.8
	65.2
	67.8
	66.6
	66.2
Mean:	66.2
Standard deviation:	0.95
Conventional air spray	
Transfer efficiency (%)	24.9
	25.2
	24.0
	24.0
	23.8
	24.2
Mean:	24.4
Standard deviation:	0.57

where σ^2 is the square of the method precision, $\tilde{\sigma}^2$ is the estimated variance from the interlaboratory test program, and δ is the degrees of freedom. For estimation of the number of laboratories based on the results of the first two tests, $\tilde{\sigma}^2$ is the total variance between the first two laboratories. The probability (P) was specified as 80 percent by the contract sponsoring this research. Fiscal limitations allowed up to eight laboratories to be tested; if the estimated number of laboratories (based on the first two laboratories' results) exceeded eight to obtain 80 percent confidence, then only eight laboratories could be tested.

The following analysis of variance was performed for each of the three equipment types tested at the first two laboratories:

Analysis of Variance
First Two Laboratories

Source	SS	DF	MS
Between laboratories	SS_a	1	MS_a
Between guns, laboratory 1	SS_b	7	MS_b
Reproducibility within guns, laboratory 1	SS_c	32	MS_c
Reproducibility, laboratory 2	SS_d	9	MS_d
		49	

The sum of squares (SS) divided by the number of degrees of freedom (DF) results in a value for the mean square (MS). The following equations have been derived, based on expected values of the mean squares, to determine the variance components from the test results:

$$\tilde{\tilde{\sigma}}_w^2 = \frac{32\ SS_c + 9\ SS_d}{41} \tag{2}$$

$$\tilde{\tilde{\sigma}}_b^2 = \frac{50}{1700}\left[MS_a + \left(\frac{1}{5} - \frac{32}{41}\right) MS_c - \frac{1}{5}\ MS_b - \frac{9}{41}\ MS_d\right] \tag{3}$$

The desired estimate of test precision is then

$$\tilde{\tilde{\sigma}} = \sqrt{\tilde{\tilde{\sigma}}_w^2 + \tilde{\tilde{\sigma}}_b^2} \tag{4}$$

where the $\approx$ notation indicates the estimate is based on results in the first two laboratories.

The final estimates of the within- and between-laboratory variance components, based on testing at all b laboratories, were given by

$$\tilde{\sigma}_w 2 = MS_w \quad \text{with } b(n-1) \text{ degrees of freedom}$$

$$\tilde{\sigma}_b 2 = MS_b - MS_w / n \text{ with } b-1 \text{ degrees of freedom} \tag{5}$$

Thus the final estimate of the test precision was

$$\tilde{\sigma} = \sqrt{MS_w \left(1 - \frac{1}{n}\right) + \frac{MS_b}{n}} \tag{6}$$

Confidence limits may be placed on this estimate of the test precision based on the fact that the ratio of the variance estimate to the population variance, when multiplied by the number of degrees of freedom, is distributed as chi-square. This allows the variance of the estimate to be written as:

$$\text{Var} \quad (\tilde{\sigma}^2) \doteq \frac{2\,\sigma_w^4}{b\ (n-1)} + \frac{2(\sigma_w^2 + n\ \sigma_b^2)^2}{n\ \ (b-1)} \tag{7}$$

The initial estimate of Var ($\tilde{\sigma}^2$) was based on the results of testing in the first two laboratories, equations (2) and (3):

$$\sigma_w = \tilde{\tilde{\sigma}}_w; \quad \sigma_b = \tilde{\tilde{\sigma}}_b \tag{8}$$

Assuming that the final estimate of the precision is normally distributed with the mean σ^2 and the variance given by equation (7), then equation (1) can be used to determine the number of laboratories (b) required. This was done to determine the approximate number of laboratories that would be required to varify the efficiency of the metho to a defined level. However, the actual number of laboratory test that could be conducted was governed by fiscal constraints. Table 6-6 tabulates the number of laboratories needed to validate the method for n=6, $\tilde{\tilde{\sigma}}_W$=1, $\tilde{\tilde{\sigma}}_b$=2.

Table 6-6. Number of laboratories (b) required to be P% sure that the estimated total variance is within K% of the true value.

P%	20	30	40	50	60	70	80	90	100
				Percent relative error (K%)					
			Airless conventional spray systems (ALC)						
90	>30	23	14	9	7	5	4	4	3
80	31	15	9	6	5	4	3	3	3
70	21	10	6	5	4	3	3	2	2
60	14	7	5	3	3	2	2	2	2
50	10	5	3	3	2	2	2	2	2
			Electrostatic spray systems (ALE)						
90		>30	32	21	15	11	9	7	6
80		>30	20	13	10	7	6	5	4
70	>30	23	13	9	7	5	4	4	3
60	33	15	9	7	5	4	3	3	3
50	22	10	7	5	4	3	3	2	2
			Air atomized conventional spray systems (AAC)						
90		>30	33	22	15	12	9	8	7
80		>30	21	14	10	8	6	5	5
70	>30	24	14	9	7	6	5	4	3
60	>30	16	10	7	5	4	4	3	3
50	23	11	7	5	4	3	3	3	2

The results presented in Table 6-6 indicate that the ALE and AAC require approximately twice the number of laboratories as the ALC to achieve the level of confidence criteria. That criteria had an 80 percent probability of being within 2.5 transfer efficiency units of the mean. As previously indicated, however, the actual number of laboratory tests that could be conducted was governed by fiscal constraints. Thus, only the ALC program approached that criteria. For b=8, i.e., the number of tests conducted, the estimates indicate only approximately 65 percent chance of being within 50 percent of the true values. This lack of laboratory experience, naturally, reduced the scope of conclusions that can presently be made about the defined method.

TRANSFER EFFICIENCY TEST AT LABORATORY NO. 3

Test Facilities

Tests were conducted in a Protect Aire back draw spray booth in the spray painting laboratory. The laboratory provided the spray painting laboratory, technicians, conveyor system, curing oven, and other associated test materials.

The spray painting laboratory was roughly 1220 cm by 915 cm with 600 cm ceilings (about 40 ft by 30 ft, with 20 ft ceilings). The booth was a back draw, water-wash type, which maintained the linear air velocity at 41-61 cm/s (80-120 ft/min), as required by the proposed standard transfer efficiency test method. The booth area temperature was controlled at 22.1-23.3°C (71-74°F) during test runs. Paint and solvent were kept in the booth area; paint and solvent temperatures closely matched booth ambient temperatures. Relative humidity ranged from 44 to 56 percent during the test.

A Rapistan overhead conveyor system equipped with a Century E-Plus speed control was used in all experiments at this site. A Michigan oven was used for curing painted targets.

The laboratory was supplied with a manual airless spray gun, 5-gallon pressure tank with agitator, hoses, and 75 kV power supply. The electrostatic air spray gun also was used to simulate conventional air spray painting by conducting transfer efficiency determinations with no voltage applied.

Transfer Efficiency Tests

Equipment set-up and instrument calibrations were completed on September 30, 1985. Transfer efficiency testing began on October 1, 1985. Six replicate transfer efficiency determinations were made for each equipment type. Operating conditions are detailed in Appendix E.

The proposed standard transfer efficiency test method and spray conditions, as set forth in Transfer Efficiency Method Evaluation Plan, were followed for all transfer efficiency determinations. All QA/QC requirements were met, and no special problems were encountered during the experiment.

Test Results

Transfer efficiency results for these tests are presented in Table 6-7. These transfer efficiency values are only applicable to the particular system (equipment and paint) under test at specified operating conditions. Mean and standard deviations are also summarized in Table 6-7.

TABLE 6-7. LABORATORY 3 TEST RESULTS

Airless	
Transfer efficiency (%):	49.4
	47.5
	44.9
	48.5
	46.4
	50.5
Mean:	47.9
Standard deviation:	2.06
Electrostatic air spray	
Transfer efficiency (%):	68.7
	71.2
	70.2
	70.8
	72.6
	71.6
Mean:	70.9
Standard deviation:	1.33
Conventional air spray	
Transfer efficiency (%)	39.6
	39.4
	39.0
	39.2
	39.1
	38.6
Mean:	39.2
Standard deviation:	0.35

A standard outlier test, using Nalimov's criteria, was conducted on transfer efficiency results for each spray system. One outlier was detected (Run No. 6) during the airless test. No reason for the outlier was determined. The run was repeated as required by the QA/QC Plan; the result was substituted for the original outlier as prescribed by the QA/QC Plan. Thus, the outlier had no effect on the results of the study.

TRANSFER EFFICIENCY TEST AT LABORATORY NO. 4

Test Facilities

Tests were conducted in a spray painting area roughly 427 cm by 305 cm, with 305 cm ceilings (about 14 ft by 10 ft, with 10 ft ceilings). The booth was a back-draw dry filter type, which maintained the linear air velocity at 61 cm/s (120 fpm), as required by the proposed standard transfer efficiency test method. The booth area temperature was 22.2-26.6°C (72-80°F) during test runs. Paint and solvent were kept in the booth area; paint and solvent temperatures closely matched booth ambient temperatures. Relative humidity was 51-58 percent during the test.

An Econo overhead conveyor system was used in all experiments at this site. A Despatch oven was used for curing painted targets. The laboratory was supplied with a manual Wagner G-10 airless spray gun, associated hoses, high-pressure paint pump, and 015 spray tip. For electrostatic air spray transfer efficiency determinations, the laboratory was supplied with a manual spray gun, 5-gallon pressure tank with agitator, hoses, and 75 kV power supply. The electrostatic air spray gun was also used to simulate conventional air spray painting by conducting transfer efficiency determinations with no voltage applied.

Transfer Efficiency Tests

Equipment set-up and instrument calibrations were completed on October 23, 1985. Transfer efficiency testing began on October 24, 1985. Six replicate transfer efficiency determinations were made for each equipment type. Airless tests were completed the first day of testing. Electrostatic air spray and conventional air spray tests were completed the following day. Operating conditions are presented in Appendix E - Raw data.

The proposed standard transfer efficiency test method and spray conditions, as set forth in Transfer Efficiency Method Evaluation Plan, were followed for all tansfer efficiency determinations. All QA/QC requirements were met, and no special problems were encountered during the experiment.

Test Results

Transfer efficiency results for these tests are presented in Table 6-8. These transfer efficiency values are only applicable to the particular system (equipment and paint) under test at specified operating conditions. Mean and standard deviations are also summarized in Table 6-8.

TABLE 6-8. LABORATORY 4 TEST RESULTS

Airless		
	Transfer efficiency (%):	39.9
		42.1
		38.5
		36.2
		35.5
		36.5
	Mean:	38.1
	Standard deviation:	2.54
Electrostatic air spray		
	Transfer efficiency (%):	70.6
		67.1
		68.9
		68.7
		69.7
		69.4
	Mean:	69.1
	Standard deviation:	1.17
Conventional air spray		
	Transfer efficiency (%):	34.9
		35.7
		35.3
		35.6
		34.2
		36.3
	Mean:	35.3
	Standard deviation:	0.723

A standard outlier test, using Nalimov's criteria, was conducted on transfer efficiency results for each spray system. One outlier was identified in these tests. The booth exhaust fan was not running during painting of Run No. 11. The results of this flawed test run were replaced as per the QA/QC Plan, and thus had no effect on the final analysis of the results.

TRANSFER EFFICIENCY TEST AT LABORATORY NO. 5

Test Facilities

Tests were conducted in a Binks spray booth. The laboratory provided the spray painting area, curing oven, and assistance required to complete the transfer efficiency tests.

The spray painting area was roughly 549 cm by 1219 cm with 427 cm ceilings (about 18 ft by 40 ft, with 14 ft ceilings). The booth was a dry back filter type, which maintained the linear air velocity at 56 cm/s (110 ft/min), as required by the proposed standard transfer efficiency test method. The booth area temperature was 23-24°C (73-75°F) during test runs. Paint and solvent were kept in the booth area; paint and solvent temperatures closely matched booth ambient temperatures. Relative humidity was 65-77 percent during the test.

An overhead conveyor system was used in all experiments at this site. A Despatch oven was used for curing painted targets.

The laboratory was supplied with a manual airless spray gun, associated hoses, high-pressure paint pump, and 015 spray tip. For electrostatic transfer efficiency determinations, the laboratory was supplied with a manual spray gun, 5-gallon pressure tank with agitator, hoses, and 75 kV power supply. The electrostatic air spray gun was also used to simulate conventional air spray painting by conducting transfer efficiency determinations with no voltage applied.

Transfer Efficiency Tests

Equipment set-up and instrument calibrations were completed on November 11, 1985. Transfer efficiency testing began on November 12, 1985. Six replicate transfer efficiency determinations were made for each equipment type. Airless and electrostatic air spray tests were completed the first day of testing. Conventional air spray equipment transfer efficiency determinations were completed the following day. Operating conditions are presented in Appendix E - Raw data.

The proposed standard transfer efficiency test method and spray conditions, as set forth in Transfer Efficiency Method Evaluation Plan, were followed for all transfer efficiency determinations. All QA/QC requirements were met, and no special problems were encountered during the experiment.

Test Results

Transfer efficiency results for these tests are presented in Table 6-9. These transfer efficiency values are only applicalbe to the particular system (equipment and paint) under test at

TABLE 6-9. LABORATORY NO. 5 TEST RESULTS

Airless	
Transfer efficiency (%):	30.1
	29.9
	29.5
	30.5
	30.1
	30.7
Mean:	30.1
Standard deviation:	.427
Electrostatic air spray	
Transfer efficiency (%):	50.4
	52.1
	51.2
	50.3
	54.5
	54.6
Mean:	52.2
Standard deviation:	1.94
Conventional air spray	
Transfer efficiency (%)	27.6
	27.8
	29.0
	28.6
	27.2
	27.9
Mean:	28.02
Standard deviation:	.664

specified operating conditions. Mean and standard deviations are also summarized in Table 6-9.

A standard outlier test, using Nalimov's criteria, was conducted on transfer efficiency results for each spray system. No outliers were identified.

TRANSFER EFFICIENCY TEST AT LABORATORY NO. 6

Test Facilities

Tests were conducted in a DeVilbiss spray booth. The laboratory provided the spray painting area, conveyor system, curing oven, and assistance required to complete the transfer efficiency tests.

The spray painting area was roughly 427 cm by 305 cm, with 305 cm ceilings (about 14 ft by 10 ft, with 10 ft ceilings). The booth was a water wash type, which maintained the linear air velocity at 56 cm/s (110 fpm), as required by the proposed standard transfer efficiency test method. The booth area temperature was 23.9°C (75$_0$F) during test runs. Paint and solvent were kept in the booth area; paint and solvent temperatures closely matched booth ambient temperatures. Relative humidity was 45-70 percent during the test.

An overhead conveyor system was used in all experiments at this site. A DeVilbiss oven was used for curing painted targets. The laboratory was supplied with a manual airless spray gun, associated hoses, high-pressure paint pump, and 015 spray tip. For electrostatic air spray transfer efficiency determinations, the laboratory was supplied with a manual spray gun, 5-gallon pressure tank with agitator, hoses, and 75 kV power supply. The electrostatic air spray gun was also used to simulate conventional air spray painting by conducting transfer efficiency determinations with no voltage applied.

Transfer Efficiency Tests

Equipment set-up and instrument calibrations were completed on November 4, 1985. Transfer efficiency testing began on November 5, 1985. Six replicate transfer efficiency determinations were made for each equipment type. Airless tests were completed the first day of testing. Airless and electrostatic air spray equipment transfer efficiency determinations were completed the first day of testing. Conventional air spray transfer efficiency determinations were completed the following day. Operating conditions are presented in Appendix E - Raw data.

The proposed standard transfer efficiency test method and spray conditions, as set forth in Transfer Efficiency Method Evaluation Plan were followed for all transfer efficiency determinations. All QA/QC requirements were met, and no special problems were encountered during the experiment.

Test Results

Transfer efficiency results for these tests are presented in Table 6-10. These transfer efficiency values are only applicable to the particular system (equipment and paint) under test at specified operating conditions. Mean and standard deviations are also summarized in Table 6-10.

A standard outlier test, using Nalimov's criteria, was conducted on transfer efficiency results for each spray system. One possible outlier was identified in run No. 15 of the conventional air spray tests. In accordance with the test plan, no repeat of the run was conducted. No explanation for the possible outlier could be identified.

TABLE 6-10. LABORATORY 6 TEST RESULTS

Airless	
Transfer efficiency (%):	43.1
	43.4
	42.1
	42.8
	42.5
	43.7
Mean:	43.0
Standard deviation:	0.547
Electrostatic air spray	
Transfer efficiency (%):	70.4
	71.3
	71.8
	71.3
	74.6
	69.2
Mean:	71.4
Standard deviation:	1.80
Conventional air spray	
Transfer efficiency (%):	31.1
	31.2
	31.8
	30.9
	30.7
	30.5
Mean:	31.0
Standard deviation:	0.455

TRANSFER EFFICIENCY TEST AT LABORATORY NO. 7

Test Facilities

Tests were conducted in a DeVilbiss spray booth. The laboratory provided the spray painting area, conveyor system, curing oven, and assistance required to complete the transfer efficiency tests.

The spray painting area was roughly 101.6 cm by 76.2 cm with 25.4 cm ceilings (about 40 ft by 30 ft, with 10 ft ceilings). The booth was a dry back filter type, which maintained the linear air velocity at 254-302.26 cm/s (100-119 fpm), as required by the proposed standard transfer efficiency test method. The booth area temperature was 18.3-23.9°C (65-75°F) during test runs. Paint and solvent were kept in the booth area; paint and solvent temperatures closely matched booth ambient temperatures. Relative humidity was 46-60 percent during the test.

An overhead conveyor system was used in all experiments at this site. A Gehnrich oven was used for curing painted targets.

The laboratory was supplied with a manual airless spray gun, associated hoses, high-pressure paint pump, and 015 spray tip. For electrostatic air spray transfer efficiency determinations, the laboratory was supplied with a manual spray gun, 5-gallon pressure tank with agitator, hoses, and 75 kV power supply. The electrostatic air spray gun was also used to simulate conventional air spray painting by conducting transfer efficiency determinations with no voltage applied.

In addition to supplying spray painting systems, the contractor provided paint, solvent, mass flow meter, pressure gauges, control panel, scales, weight percent solids equipment, viscosity cups, 60 test targets, foil, and other miscellaneous test equipment. An engineer and technician were present during all transfer efficiency determinations at Laboratory 7.

Transfer Efficiency Tests

Equipment set-up and instrument calibrations were completed on December 17, 1985. Transfer efficiency testing began on December 18, 1985. Six replicate transfer efficiency determinations were made for each equipment type. Airless tests were completed the first day of testing. Electrostatic air spraying and conventional air spraying tests were completed the following day. Operating conditions are presented in Appendix E - Raw Data.

The proposed standard transfer efficiency test method and spray conditions, as set forth in Transfer Efficiency Manual Evaluation Plan were followed for all transfer efficiency determinations. All QA/QC requirements were met, and no special problems were encountered during the experiment.

Test Results

Transfer efficiency results for these tests are presented in Table 6-11. These transfer efficiency values are only applicable to the particular system (equipment and paint) under test at specified operating conditions. Mean and standard deviations are also summarized in Table 6-11.

A standard outlier test, using Nalimov's criteria, was conducted on transfer efficiency results for each spray system. No outliers were identified.

TABLE 6-11. LABORATORY 7 TEST RESULTS

Airless	
Transfer efficiency (%):	48.8
	46.5
	48.7
	47.7
	48.2
	44.2
Mean:	47.4
Standard deviation:	1.76
Electrostatic air spray	
Transfer efficiency (%):	66.3
	69.9
	68.0
	72.0
	68.7
	69.1
Mean:	69.0
Standard deviation:	1.91
Conventional air spray	
Transfer efficiency (%):	39.7
	38.3
	37.4
	38.5
	39.9
	38.6
Mean:	38.7
Standard deviation:	0.903

TRANSFER EFFICIENCY TEST AT LABORATORY NO. 8

Test Facilities

Experiments were conducted in a DeVilbiss dry filter booth in the engineering laboratory. Laboratory No. 8 provided the spray painting laboratory, technicians, conveyor system, curing oven, and other associated test materials.

The engineering laboratory was roughly 2300 cm by 1100 cm with 600 cm ceilings (about 75 ft by 36 ft with 20 ft ceilings). The booth was a back-draw dry filter type, which maintained the linear air velocity at 40.6-61.0 cm/s (80-120 ft/min), as required by the proposed standard transfer efficiency test method. The booth area temperature was controlled at 21.7-24.4°C (71-76°F) during test runs. Paint and solvent were kept in the booth area; paint and solvent temperatures closely matched booth ambient temperatures. Relative humidity ranged from 58 to 80 percent during the test.

A Unibuilt overhead conveyor system equipped with a Nordson Countamatic timer was used in all experiments at this site. A Grieve (Model SC 550) oven was used for curing painted targets.

The laboratory was supplied with a manual airless spray gun, associated hoses, high-pressure paint pump, and 015 spray tip. For electrostatic air spray transfer efficiency determinations, the laboratory was supplied with a manual spray gun, 5-gallon pressure tank with agitator, hoses, and a 75 kV power supply. The electrostatic air spray gun was also used to simulate conventional air spray painting by conducting transfer efficiency determinations with no voltage applied.

Transfer Efficiency Tests

Equipment set-up and instrument calibrations were completed on December 15, 1985. Transfer efficiency testing began December 16, 1985. Six replicate transfer efficiency determinations were made for each equipment type. Airless and conventional air spray tests were completed December 18, 1985. Electrostatic air spray tests were completed on the subsequent day. Operating conditions are presented in Appendix E - Raw data.

All pressure gages not previously calibrated were calibrated on a dead weight tester. Calibration curves were developed and used for pressure measurements. The mass flow meter was zeroed and calibrated, then checked against paint capture to assure its accuracy. At each flow rate a constant 1.2 percent difference was detected between the meter and paint capture methods. Thus, a calibration adjustment of 1.2 percent was applied to all mass flow measurements from the meter. Although it was not required by the test method or the QA/QC plan, a velocity profile was developed for the test booth. The booth air velocity was well within QA/QC requirements.

The proposed standard transfer efficiency test method and spray conditions, as set forth in Transfer Efficiency Method Evaluation Plan were followed for all transfer efficiency determinations. All QA/QC requirements were met, and no special problems were encountered during the experiment.

Test Results

Transfer efficiency results for these tests are presented in Table 6-12. These transfer efficiency values are only applicable to the particular system (equipment and paint) under test at specified operating conditions. Mean and standard deviations are also summarized in Table 6-12.

TABLE 6-12. LABORATORY 8 TEST RESULTS

Airless		
	Transfer efficiency (%):	46.0
		44.6
		45.7
		44.8
		44.8
		46.0
	Mean:	45.3
	Standard deviation:	0.652
Electrostatic air spray		
	Transfer efficiency (%):	87.6
		88.1
		82.6
		84.0
		86.6
		88.7
	Mean:	86.3
	Standard deviation:	2.44
Conventional air spray		
	Transfer efficiency (%):	25.9
		25.6
		25.4
		25.3
		25.0
		25.9
	Mean:	25.5
	Standard deviation:	0.354

SECTION 7

TEST RESULTS AND STATISTICAL ANALYSIS

TEST RESULTS

The results of the interlaboratory testing of the transfer efficiency test method at eight field laboratories are presented in Tables 7-1, 7-2, and 7-3 for airless, conventional air spray and electrostatic spray equipment respectively. A summary of the statistical results for all test sites and equipment types is presented in Table 7-4.

STATISTICAL ANALYSIS

Introduction

The following statistical analysis is based on three assumptions. First, it is assumed that laboratories were selected randomly from the sample frame. This assumption cannot be tested, since there is no definitive list of members of the sample frame available. Second, it must be assumed that measurements were unbiased and made independently. Finally, it is necessary to assume that the within-laboratory variances are the same from laboratory to laboratory. There is certainly evidence that this assumption does not hold for test results for two equipment types. One possible alternative is to eliminate laboratories whose variances differ significantly from the others. Another is to proceed while noting this anomaly. The statistical analysis has been performed using all laboratories for each equipment type. A special discussion is devoted to this assumption on page 65.

TABLE 7-1. TRANSFER EFFICIENCY RESULTS, AIRLESS
(% Transfer efficiency)

LABORATORY:	# 1	# 2	# 3	# 4	# 5	# 6	# 7	#8
RUN NO. 1:	44.9	35.3	49.4	39.9	30.1	43.1	48.8	46.0
RUN NO. 2:	43.8	34.4	47.5	42.1	29.9	43.4	46.5	44.6
RUN NO. 3:	45.2	32.9	44.9	38.5	29.5	42.1	48.7	45.7
RUN NO. 4:	44.2	31.3	48.5	36.2	30.5	42.8	47.7	44.8
RUN NO. 5:	42.9	33.6	46.4	35.5	30.1	42.5	48.2	44.8
RUN NO. 6:	44.0	30.8	50.5	36.5	30.7	43.7	44.2	46.0
MEAN:	44.2	33.1	47.9	38.1	30.1	43.0	47.4	45.3
STAND. DEV.:	0.821	1.73	2.06	2.54	0.427	0.547	1.76	0.652

SUMMARY

Within-lab variance: 2.30 Standard deviation: 1.53

Between-lab variance (without gun variance): 42.93

Between-lab variance (including gun variance): 43.81

Total variance (without gun variance): 45.23 Standard deviation: 6.72

Total variance (including gun variance): 46.11 Standard deviation: 6.79

TABLE 7-2. TRANSFER EFFICIENCY RESULTS, CONVENTIONAL AIR SPRAY
(% Transfer efficiency)

LABORATORY:	# 1	# 2	# 3	# 4	# 5	# 6	# 7	# 8
RUN NO. 1:	32.7	24.9	39.6	34.9	27.6	31.1	39.7	25.9
RUN NO. 2:	36.9	25.2	39.4	35.7	27.8	31.2	38.3	25.5
RUN NO 3:	35.4	24.0	39.0	35.3	29.0	31.8	33.4	25.4
RUN NO. 4:	34.9	24.0	39.2	35.6	28.6	30.9	38.5	25.3
RUN NO. 5:	34.0	23.8	39.1	34.2	27.2	30.7	39.9	25.0
RUN NO. 6:	33.3	24.2	38.6	36.3	27.9	30.5	38.6	25.9
MEAN:	34.5	24.4	33.2	35.3	28.02	31.0	38.7	25.5
STAND. DEV.:	1.53	0.565	0.345	0.723	0.664	0.455	0.903	0.354

SUMMARY

Within-lab variance: 1.22 — Standard deviation: 1.10

Between-lab variance (without gun variance): 25.41

Between-lab variance (including gun variance): 31.63

Total variance (without gun variance): 26.63 — Standard deviation: 5.16

Total variance (including gun variance): 32.84 — Standard deviation: 5.73

TABLE 7-3. TRANSFER EFFICIENCY RESULTS, ELECTROSTATIC AIR SPRAY
(% Transfer efficiency)

LABORATORY:	# 1	# 2	# 3	# 4	# 5	# 6	# 7	# 8
RUN NO. 1:	65.3	65.4	68.7	70.6	50.4	70.4	66.3	87.6
RUN NO. 2:	70.3	65.8	71.2	67.1	52.1	71.3	69.9	88.1
RUN NO. 3:	73.8	65.2	70.2	68.9	51.2	71.8	68.0	82.6
RUN NO. 4:	70.8	67.8	70.8	68.7	50.3	71.3	72.0	84.0
RUN NO. 5:	71.7	66.6	72.6	69.4	54.5	74.6	68.7	86.6
RUN NO. 6:	72.1	66.2	71.6	69.7	54.6	69.2	69.1	88.7
MEAN:	70.7	66.2	70.9	69.1	52.2	71.4	69.0	86.3
STAND. DEV.:	2.89	0.95	1.33	1.17	1.94	1.80	1.91	2.44

SUMMARY

Within-lab variance: 3.63 Standard deviation: 1.905

Between-lab variance
(without gun variance): 79.44

Between-lab variance
(including gun variance): 85.03

Total variance
(without gun variance): 83.07 Standard deviation: 8.70

Total variance
(including gun variance): 88.66 Standard deviation: 9.42

TABLE 7-4. TRANSFER EFFICIENCY RESULTS

	AIRLESS		ELECTROSTATIC		CONVENTIONAL	
	VARIANCE	STD. DEV.	VARIANCE	STD. DEV.	VARIANCE	STD. DEV.
WITHIN-LAB	1.22	1.1	3.63	1.905	2.3	1.5165
BETWEEN-LAB	26.41		72.02		42.92	
GUN	6.22		13.01		0.88	
TOTAL	33.85	5.82	88.66	9.42	46.1	6.79

Laboratory, Gun, and Within-laboratory Variance Components

For each equipment type, eight laboratories were used and six runs were made for each laboratory. An attempt was made to estimate the "between-laboratory" portion of variance and the "within-laboratory" portion, assuming, of course, a homogeneous within-laboratory variance. In addition, in a single laboratory experiment, the between-gun portion of variance was computed.

With the eight laboratory experiments, a one-way random effects model was assumed, with random laboratories. In other words, it is assumed that the transfer efficiency result is produced from a random effect due to the laboratory and a random effect representing the random "within-laboratory" effect. This model assumption is made simply because there are two components of variation in light of the way the experiment was constructed. This one-way random effects model then assumes that if we call y_{ij} the jth transfer efficiency measurement by the ith laboratory,

$$y_{ij} = \mu + \tau_i + \varepsilon_{ij}$$

where τ_i is a random component contributed because of the ith laboratory, and ε_{ij} is the "within laboratory" error. The reader can view the τ_i and ε_{ij} as having distributions, each having a population mean of zero and some variance. The variances will be called σ_W^2 and σ_L^2 for within laboratory and between laboratory respectively. Thus, there are two variances that require estimation from the data.

A standard analysis of variance procedure is used to estimate these variances and thus the standard deviations. Following elementary procedures in many statistics texts including Ott (1984) and Walpole and Myers (1985), the estimates of these "variance components" come by doing the analysis of variance of the total variation in the data. The sample variance for the two sources of variation is viewed in the experiment as

MS_L (mean square between laboratories, the sample variance between laboratory means)

MS_W (mean square within laboratories, the sample variance within laboratories)

Now the estimates of the two variances σ_W^2 and σ_L^2 are obtained from these two mean squares. Elementary manipulation leads to estimates given by

$$\hat{\sigma}_W^2 = MS_W$$
$$\hat{\sigma}_L^2 = \frac{MS_L - MS_W}{n}$$

where n is the number of runs taken in each laboratory. The "^" type notation signifies that the quantity is an estimate. The main objective of determining the estimates of σ_L^2 and σ_W^2 is to ascertain a total variance or standard deviation of the method of measuring transfer efficiency. This total variance is made up of the sum of the "components of total variance," the latter being σ_L^2 and σ_W^2. The total variance is featured as the standard deviation of a single observation of transfer efficiency taken at a random laboratory. The percentage of the total variance attributed to laboratory and within laboratory is reported. In addition, the coefficient of variation is given, the latter being the precision or "total standard deviation" expressed as a percent of the mean transfer efficiency.

The computation of the estimated variance components was made through the use of the Statistical Analysis System (SAS) PROC VAR COMP. The total variance, of course, is computed as the sum of the two components. In addition, the coefficient of variation is given. The coefficient of variation is defined as

$$C.V. = \left(\frac{\hat{\sigma}_T}{\bar{y}}\right) \times 100$$

and expressed in percentage units. Its purpose is merely to be able to express this standard deviation in a unitless way. The fact that it is expressed as a percent has absolutely nothing to do with the fact that transfer efficiency is expressed as a percent. The purpose of the coefficient of variation is to account for the fact that the precision of the measurement of transfer efficiency may very well depend on the average size of the transfer efficiency. The C.V. is intended as a method of "expressing precision as a function of the size of the measurement."

What is the interpretation of the Total Standard Deviation?

As was suggested earlier, the total standard deviation is a measure of the precision of the transfer efficiency method with a random laboratory. It should be emphasized that the quantity computed is only an estimate. However, if the true standard deviation were known, then it could be said that roughly 95% of transfer efficiency measurements would deviate from the mean by $\pm 2\sigma_T$. Based on the computations made, the bounds

$$\text{mean} \pm 2\hat{\sigma}_T$$

represent estimates of bounds that cover 95% of the transfer efficiency measurements. But it cannot categorically be stated that $\pm 2\hat{\sigma}_T$ covers 95% of transfer efficiency measurements simply because values depend on a finite number of data points.

Airless

The average transfer efficiency for the airless equipment is 41.1167 transfer efficiency units.

$\dot{\sigma}_W^2$ (within-laboratory component of variance) = 2.300

$\dot{\sigma}_L^2$ (between-laboratory component of variance) = 43.8116

$\dot{\sigma}_G^2$ (gun component of variance) = 0.8777

$\dot{\sigma}_L^{2*}$ (between-laboratory variance, minus gun variance) = 42.9339

The gun portion of the between-laboratory variance is 2.01%.

σ_T^2 (total variance) = 46.116.

95.01% of this variance is laboratory variance.

σ_T^2 (minus gun variance) = 45.2339

$\dot{\sigma}_T$ (total standard deviation) = 6.7906 transfer efficiency units

Thus the standard deviation in transfer efficiency at a random laboratory is 6.7906 transfer efficiency units, which is 16.52% of the mean transfer efficiency of the experiment. As indicated earlier, the most important statistic is $\dot{\sigma}_T$, the estimated total standard deviation. An estimate or an approximation of bounds on transfer efficiency measurements is given by $\pm 1.28\dot{\sigma}_T = \pm 9.1$ transfer units. The purpose of the coefficient of variation was indicated earlier.

Thus, if the true standard deviation was known (we have developed an estimate), 80 percent of all transfer efficiency measurements at qualifying laboratories using the same type of spray equipment, paint, targets, and operating conditions would fall within 9.1 units of the true transfer efficiency.*

At a random laboratory, one is concerned with how close the measured transfer efficiency is to the true transfer efficiency. The results of this research indicate an 80 percent probability that the measured transfer efficiency would fall within 9.1 of the true transfer efficiency.*

*Provided that our bias assumption is correct.

Conventional

Average transfer efficiency is 32 transfer efficiency units.

$\dot{\sigma}^2_W$ (within-laboratory component of variance) = 1.2165

$\dot{\sigma}^2_L$ (laboratory component of variance) = 31.6277

$\dot{\sigma}^2_G$ (gun component of variance) = 6.2190

The gun portion of the laboratory variance is 18%.

$\dot{\sigma}^{2*}_L$ (laboratory component of variance - gun variance) = 25.4087

$\dot{\sigma}^2_T$ (total variance) = 32.8442

96.3% of this variance is laboratory variance.

$\dot{\sigma}^2_T$ (minus gun variance) = 26.6252

σ_T (total standard deviation) = 5.731 transfer efficiency units.

Thus the standard deviation in transfer efficiency units at a random laboratory is 17.91% of the mean transfer efficiency of the experiment. It is estimated that $\pm$ 1.282 $\dot{\sigma}_T$ = $\pm$ 1.282(5.731) = $\pm$ 7.33 transfer efficiency units covers roughly 80% of the transfer efficiency readings around the mean.

Thus, if the true standard deviation was known (we have developed an estimate), 80 percent of all transfer efficiency measurements at qualifying laboratories using he same type of spray equipment, paint, targets, and operating conditions would fall within 7.3 units of the true transfer efficiency.*

At a random laboratory, one is concerned with how close the measured transfer efficiency is to the true transfer efficiency. The results of this research indicate an 80 percent probability that the measured transfer efficiency would fall within 7.3 of the true transfer efficiency.*

*Provided that our bias assumption is correct.

Electrostatic

Average transfer efficiency is 69.45 transfer efficiency units.

$\dot{\sigma}^2_W$ (within-laboratory component of variance) = 3.6302

$\dot{\sigma}^2_L$ (laboratory component of variance) = 85.0295

$\dot{\sigma}^2_G$ (gun component of variance) = 5.5912

The gun portion of the laboratory variance is 6.58%.

$\dot{\sigma}^{2*}_L$ (laboratory variance - gun variance) is 79.4383

$\dot{\sigma}^2_T$ (total variance) = 88.6597

95.91% of this total variance is laboratory variance.

$\dot{\sigma}^2_T$ (minus gun variance) = 83.0685

$\dot{\sigma}_T$ (total standard deviation) = 9.4159 transfer efficiency units

Thus the standard deviation in transfer efficiency units at a random laboratory is 13.56% of the mean transfer efficiency of the experiment. As before, $\pm\, 1.282\dot{\sigma}_T$ around the mean covers roughly 80% of the transfer efficiency measurements. In this case $\pm\, 1.282\dot{\sigma}_T = \pm\, 12.03$ transfer efficiency units.

Thus, if the true standard deviation was known (we have developed an estimate), 80 percent of all transfer efficiency measurements at qualifying laboratories using the same type of spray equipment, paint, targets, and operating conditions would fall within 12.0 units of the true transfer efficiency.*

At a random laboratory, one is concerned with how close the measured transfer efficiency is to the true transfer efficiency. The results of this research indicate an 80 percent probability that the measured transfer efficiency would fall within 12.0 of the true transfer efficiency.*

*Provided that our bias assumption is correct.

Confidence Interval on Mean Transfer Efficiency Based on This Experiment

The previous results regarding the precision of the transfer efficiency method give an estimated standard deviation of a single measured transfer efficiency value at a random laboratory. To provide more information regarding accuracy of the method combined with precision or reproducibility, a computation was made which produced an estimate (for all three equipment types) of the transfer efficiency for the conditions of this experiment, along with a standard error of that estimate and an 80% confidence interval on the transfer efficiency.

Based on the one factor analysis of variance, random effects model, an estimate of the mean transfer efficiency for the present experiment is $\bar{y}_{..}$, the average TE over the entire experiment, while the standard deviation of this average is

$$\sigma_{\bar{y}_{..}} = \sqrt{\frac{\sigma_L^2}{\ell} + \frac{\sigma_W^2}{\ell n}}$$

where ℓ is the number of laboratories and n is the number of runs per laboratory. For a sketch of the proof of the above result, see Appendix D.

Now, the standard deviation of $\bar{y}_{..}$ is estimated by $\sqrt{\frac{MS_L}{\ell n}}$, where MS_L is the laboratory mean square in the experiment. (See Appendix D). This produces a t-type confidence interval on the mean transfer efficiency which is the parameter u in the experiment. Thus an 80% confidence interval on the mean transfer efficiency based on the results of this experiment (and for the conditions of this experiment, i.e., point-type, etc.) is given by

$$\bar{y}_{..} \pm t_{0.8,\,\ell-1}\sqrt{\frac{MS_L}{n\ell}}$$

These confidence intervals are as follows:

Airless - For the conditions of this experiment, the mean TE is between 37.709 and 44.493 TE units, with 80% confidence.

Conventional - For the conditions of this experiment, the mean TE is between 29.178 and 34.822 TE units, with 80% confidence.

Electrostatic - For the conditions of this experiment, the mean TE is between 64.825 and 74.084 TE units, with 80% confidence.

The purpose of this work is to get an impression of how much error might be associated with an estimate of transfer efficiency (actually, mean transfer efficiency) from an experiment such as this. It is obvious that if there is a "true transfer efficiency," and it was estimated from a sample mean from an experiment such as this one, a confidence interval on the "population mean transfer efficiency" is a clear way of determining the accuracy of the estimate of "true transfer efficiency." Surely, if the between-and within-laboratory variance is very large, it could be expected that the width of the confidence interval in conjunction with the standard regarding how "tight" the estimate should be is very important. For example, in the case of the conventional equipment, the width of the 80 percent confidence interval is 32.0 + 2.822. The issue then centers around whether missing by + 2.822 is good enough.

Importance of the Homogeneous Variance Assumption

As was indicated earlier, it is assumed that the within-laboratory variance is constant from laboratory to laboratory. It is clear from the sample data that this, indeed, may not be true. It is important that this be acknowledged and that the impact of this be addressed. The fact that the within-laboratory variances differ for at least two equipment types results in the following conclusions:

(a) Laboratories are not equal in the precision with which they measure transfer efficiency. Certainly, any future experimental effort in this area should focus on this.

(b) It was suggested earlier that there are alternatives that could be used. The laboratories could be divided into homogeneous groups, with each group containing laboratories whose precision for measuring transfer efficiency do not differ significantly. Thus, there would be two sets of answers, one for the high precision laboratories and one for the low precision laboratories. This is clearly undesirable. Since the intent of this work was to determine the precision of the method, it must be interpreted as one result and view the answer obtained as one result which has, in a sense, been averaged over laboratories, even though they do not perform with equal capability. Thus, it is felt that the results given are as reasonable as can be produced in the given situation.

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APPENDIX A

PROPOSED STANDARD TRANSFER EFFICIENCY TEST METHOD

APPENDIX A

PROPOSED STANDARD

TRANSFER EFFICIENCY TEST METHOD

1.0 SCOPE

1.1 This method covers method verification testing at multiple laboratories to define the interlaboratory characteristics of the existing method.

1.2 The testing will be accomplished at a number of industrial sites under controlled defined conditions, i.e., the identical test protocol for applicable equipment will be used at different locations. The final evaluation will result in a complete characterization of the interlaboratory characteristics of the TE method.

1.3 A significant number of tests will be conducted to define the performance of the method for three automatic spray equipment types: air atomized conventional, air atomized electrostatic, and airless conventional.

2.0 APPLICABLE DOCUMENTS

2.1 ASTM Standards:

- D-1200 - 70 Viscosity of Paints, Varnishes, and Lacquers by Ford Viscosity Cup
- D-2369 - 81 Standard Test Method for Volatile Content of Coatings
- D-1005 - 51 Measurement of Dry Film Thickness of Organic Coatings
- D-1212 - 79 Measurement of Wet Film Thickness of Organic Coatings
- D-1475 - 60 Density of Paint Varnish, Lacquer, and Related Products
- D-3925 - 81 Sampling Liquid Paints and Related Pigmented Coatings

3.00 TRANSFER EFFICIENCY TEST METHOD

3.01 Inspect all equipment listed on Data Sheet 1 - Equipment Specifications, and complete the data sheet where applicable. All equipment and materials must meet the requirements of the approved Environmental Protection Agency (EPA) quality assurance/quality control (QA/QC) plan.

Note: Place "N/A" in all cells that do not apply. Ensure that the data sheet is dated and initialed by both the person recording the information and the person checking the information. "Type" refers to the design of a given piece of equipment.

3.02 Set up paint supply and mass flow measurement equipment per manufacturer's instructions.

Note:

Paint supply and mass flow measurement equipment must be grounded to avoid problems with static electricity.

3.03 Calibrate the mass flow measurement equipment once per week or each time that it is moved, whichever occurs more frequently.

3.04 Begin agitation of paint at least thirty minutes before any paint samples are taken.

3.05 Using a small glass jar with an airtight lid, take a paint grab sample from the paint pot.

3.06 Record test run number on label of jar. (Each pass of ten targets is a run.)

3.07 Complete Data Sheet 2 - Paint Specifications.

Paint weight percent solids should be determined at the start of each day, at the end of each day, and any other time deemed appropriate.

3.08 Set up the conveyor speed measuring equipment consisting of photoelectric cells or limit switches used in conjunction with a digital timer, or timing marks on the conveyor used in conjunction with a stopwatch.

3.09 Cut an appropriate number of strips of 0.0037 cm (1.5 mil) thick aluminum foil to dimensions of 38.1 cm (15 in) by approximately 127cm (50in) for the testing.

3.10 Consecutively number each precut foil strip on the dull side using a permanent marking pen.

3.11 Weigh each foil strip and record the foil number and mass on Data Sheet 3 - Mass of Solids Applied in the MASS OF FOIL COLUMN.

Note:

Data Sheet 3 - Mass of Solids Applied will hold the information from six runs.

3.12 Attach preweighed labeled foil (dull side to the target) to six targets using the method shown in Figure A-1. Attach unlabeled foil on four scavenger targets. All seams must face away from the spray equipment.

3.13 Mount the foil-covered targets in consecutive order from right to left (facing the booth), as shown in Figure A-2, with the foil seam on each target facing away from the spray gun.

3.14 Adjust all equipment operating parameters to the values desired for testing.

3.15 Complete Data Sheet 4 - Operating Conditions and Calculations.

Note:

Cure time and temperature should be set per manufacturer's instructions.

3.16 Recheck operating parameters to ensure that they are correct.

3.17 For electrostatic spray equipment, measure the operating voltage and adjust according to manufacturer's instructions and record value on Data Sheet 4.

3.18 Inspect conveyor clock, stopwatch, and mass flow measurement equipment to assure that all are prepared to operate.

3.19 Turn on spray booth and conveyor. As the leading edge of the first scavenger target passes in front of the gun, turn on paint spray equipment and simultaneously begin mass flow measurement.

3.20 As the trailing edge of the last scavenger target passes in front of the gun, stop the paint spray equipment and mass flow measurement simultaneously.

3.21 Record the mass flow measurement on Data Sheet 4 - Operating Conditions and Calculations.

3.22 Measure the wet film thickness on the trailing scavenger and record on Data Sheet 4.

3.23 Remove the painted targets from the conveyor and ensure that no paint is lost. Securely hang the coated targets on oven racks so all painted surfaces are exposed for uniform drying. Orient all targets in the same direction in the curing oven.

3.24 Insert racks in oven and bake at recommended schedule per Data Sheet 4. Oven door should be opened for minimum amount of time to prevent cooling.

3.25 Remove targets from oven and record actual cure schedule on Data Sheet 4. Cool foil to room temperature. Remove foil from each target, weigh foil and record mass on each foil and on Data Sheet 3 in the Mass of Foil Plus Paint column.

3.26 After weighing, store foils in appropriately labeled plastic bags, with the appropriate test run number labeled on it. The laboratory shall retain all samples until data analyses are complete. Check all data for correctness and completeness.

3.27 Perform the transfer efficiency calculations indicated on Data Sheet 4.

3.28 Repeat steps 3.05 through 3.27 for each test run.

Note:

> Follow QA/QC plan for equipment calibration and for weight percent solids determinations when multiple runs are anticipated.

3.29 Make sure all data sheets have been checked, dated, and initialed.

3.30 When approximately 70 percent of the runs have been completed, an outlier analysis shall be performed. Data is to be recorded on Data Sheet 5. Repeat any outlier runs.

3.31 As part of Quality Assurance requirements, a QA report is to be submitted to the CENTEC Quality Assurance Officer at the end of each day.

4.0 SAFETY CONSIDERATIONS

4.1 According to Section 9.8 of NFPA 33, when using fixed electrostatic apparatus, the resistance of the equipment to ground should be measured at a resistance of less than 1×10^6 exponent Ohms.

4.2 If electrostatic equipment is being used, the gun-to-target distance should be at least twice the sparking distance. This requirement is in accordance with Section 9-7 NFPA 33.

DATA SHEET 1 - EQUIPMENT SPECIFICATIONS

Test Date: __/__/__ Foil Number: ____ to ____

	TYPE	MANUFACTURER	MODEL NUMBER	SERIAL NUMBER	RATED CAPACITY	RATED ACCURACY
LABORATORY SCALE						
PLATFORM SCALE						
MASS FLOW METER						
CONVEYOR TIMER						
STOPWATCH						
PAINT SUPPLY TANK						
PAINT SPRAY EQUIPMENT						
PAINT SPRAY BOOTH						
CONVEYOR						
FORCED DRAFT OVEN						
PAINT HEATER						

AIR CAP	
FLUID TIP	
NEEDLE	

Data Collected by: ______ Data Checked by: ______

DATA SHEET 2 - PAINT SPECIFICATIONS

Test Date: ___/___/___ Foil Number: _____ to _____

Manufacturer ______________ Manufacturer ID No. ______________
Paint Type ______________ Lot No. ______________
Resin Type ______________ Color ______________
Solvent ______________

DATE	TIME	RESIST-IVITY ($M\Omega/cm^2$)	VISCOSITY (___sec# ___cup at ___°C)	SYRINGE WT. (g) FULL		EMPTY		NET	DISH WT. (g) FULL		EMPTY		NET	WT. % SOLIDS
					-		=			-		=		
					-		=			-		=		
					-		=			-		=		
					-		=			-		=		
					-		=			-		=		
					-		=			-		=		
					-		=			-		=		
					-		=			-		=		
					-		=			-		=		

Data collected by: ________ Data checked by: ________

DATA SHEET 3 - MASS OF SOLIDS APPLIED

FOIL NUMBER	MASS OF FOIL PLUS PAINT (g)	MASS OF FOIL (g)	MASS OF PAINT (g)	FOIL NUMBER	MASS OF FOIL PLUS PAINT (g)	MASS OF FOIL (g)	MASS OF PAINT (g)
	-	=			-	=	
	-	=			-	=	
	-	=			-	=	
	-	=			-	=	
	-	=			-	=	
	-	=			-	=	
RUN NUMBER ___ TOTAL MASS =				RUN NUMBER ___ TOTAL MASS =			
	-	=			-	=	
	-	=			-	=	
	-	=			-	=	
	-	=			-	=	
	-	=			-	=	
	-	=			-	=	
RUN NUMBER ___ TOTAL MASS =				RUN NUMBER ___ TOTAL MASS =			
	-	=			-	=	
	-	=			-	=	
	-	=			-	=	
	-	=			-	=	
	-	=			-	=	
	-	=			-	=	
RUN NUMBER ___ TOTAL MASS =				RUN NUMBER ___ TOTAL MASS =			

TEST DATE: __/__/__ DATA COLLECTED BY: ____ DATA CHECKED BY: ____

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID	ATOM.AIR	ROTATING RPS WI.FLUID	W/O FLUID	OPERATING VOLTAGE (kV)	RESIST.(MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME(s)	TEMP (°C)
to													
to													
to													
to													
to													
to													

								a	b	c	d	e*
FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	Δ (g)	TIME(s)		RATE (g/s)	CONVEYOR SPEED (cm/s)	WEIGHT % SOLIDS	NET DRY SOLIDS (g)	TRANSFER EFFICIENCY (%)
to												
to												
to												
to												
to												
to												

Data Collected by: ______

Data Checked by: ______

$^{*}e=54.6\left(\frac{bxd}{axc}\right)$

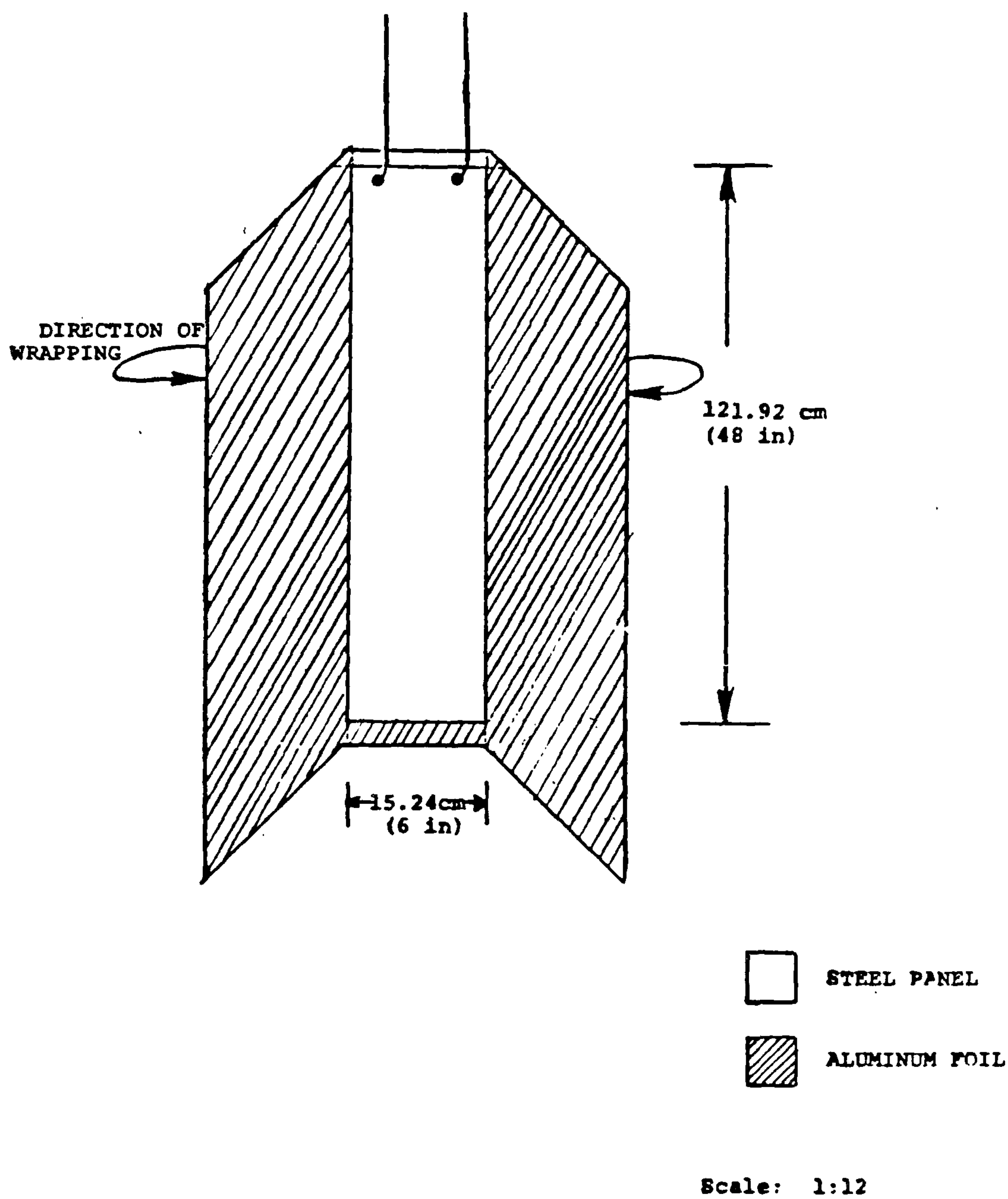

Figure 1. Foil Attachment Technique

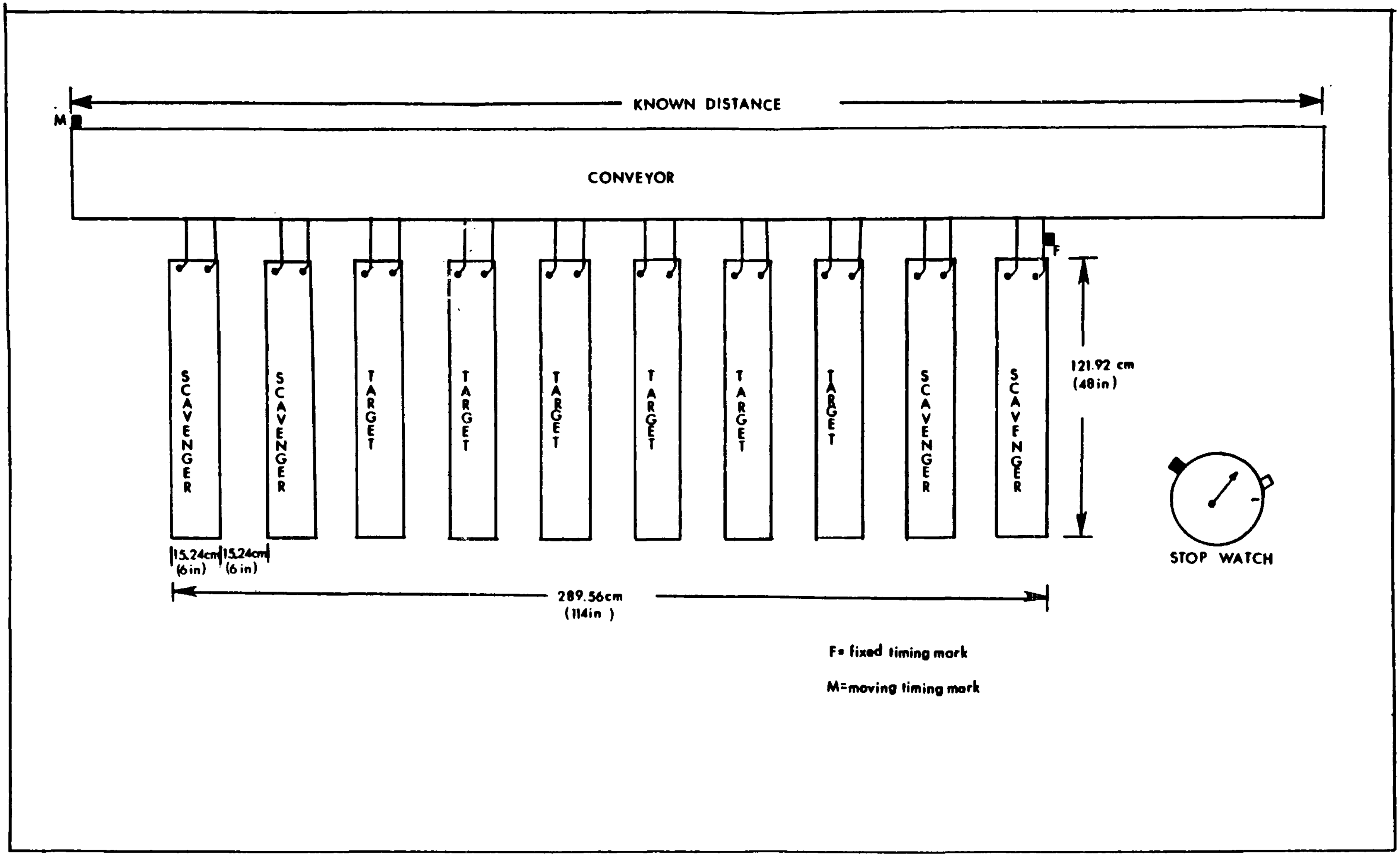

Figure 2. Target Configuration for Transfer Efficiency Determination

APPENDIX B

QUALITY ASSURANCE/QUALITY CONTROL PLAN

APPENDIX B

QUALITY ASSURANCE/QUALITY CONTROL PLAN
TRANSFER EFFICIENCY METHOD VERIFICATION PROGRAM

CENTEC CORPORATION
Reston, Virginia 22090

CONTRACT NO. 68-03-1952, Phase 2

AIR AND ENERGY ENGINEERING
RESEARCH LABORATORY
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May 1985

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SECTION 1

PROJECT DESCRIPTION

INTRODUCTION

This quality assurance/quality control (QA/QC) plan assures collection of high quality data and insures consistent quality control measures for data developed under "Phase II - Method Verification Program," Contract No. 68-03-1952. Under this contract, CENTEC Corporation will be conducting tests to determine the capability of the draft standard transfer efficiency (TE) test method to precisely measure transfer efficiency.

PROJECT DESCRIPTION

This QA/QC plan is designed to ensure collection of high quality data for interlaboratory testing of the draft standard transfer efficiency (TE) test method. It encompasses the determination of the capability of the draft standard TE test method to precisely measure TE. The draft standard TE method (Appendix A) will be used for all tests in this program. The test method consists of passing a prescribed set of preweighed targets in front of spray equipment under rigidly controlled conditions in an industrial laboratory spray booth. The cured painted targets are weighed, and the original weight is subtracted from the final weight to obtain the net dry solids deposited on the targets. The net dry solids are divided by the total solids sprayed at the targets, which is then multiplied by 100 percent to determine TE. A complete description of the draft standard TE test method is provided in Appendix A.

This objective will be accomplished by testing the method at a statistically determined number of industrial sites under controlled conditions, i.e., the same test protocol will be used at each location. Operating conditions for each spray system will be determined at the first laboratory using a trial and error approach to achieve reasonable coating thickness and finish. This technique is used by industrial finishers to set spray conditions, so test conditions are expected to simulate actual industrial practice. Once spray conditions are determined at the first laboratory, the same conditions will be specified for all subsequent laboratories in the test program. The final evaluation will result in a complete characterization of the performance of the draft standard TE test method. This evaluation includes statistical information.

TE results from previous studies using the draft standard test method have revealed information about variables which affected the TE of those particular spray systems. These variables have been shown to affect the TE of different spray systems in varying amounts; their effect is not consistent from spray system to spray system. Thus one of the major factors affecting TE, the spray system, is being held constant in this test program. Three spray systems of different design (air atomized conventional, airless conventional, and air atomized electrostatic) will be tested at each laboratory. A new set of three spray systems (same make and model) will be used at each participating laboratory to ensure all spray equipment is in the same condition. The same coating will be used for all spray systems in this test.

Some of the variables which have been found to significantly affect TE for other spray systems include gun-to-target distance, target design, conveyor speed, linear air velocity, paint mass flow rate, atomizing air pressure, shaping air, gun condition, tip voltage, lag discharge distance, and electrode position. Test parameters which can be controlled at well-equipped painting laboratories (including gun-to-target distance, conveyor speed, paint mass flow rate, gun condition, and target design) will be specified in the test method after they are set in the first test. Special attention has been paid to ensure that difficult-to-control variables (including booth air velocity and shaping air) are consistently controlled and monitored to the extent possible. Parameters which cannot be reasonably controlled (including laboratory temperature and laboratory relative humidity) will be carefully recorded during testing. If parameters which cannot be controlled are later discovered have a significant effect on TE, enough data will be available for assessing which variable(s) might have been the culprit. Part of the objective for this test program is to determine if uncontrollable differences between laboratories are significant.

Testing is scheduled to begin June 3, 1985, and to continue for up to eight months.

SECTION 2

PROJECT ORGANIZATION AND RESPONSIBILITY

This project is administered through CENTEC Corporation structure, as shown in Figure B-1. Day-to-day test program activities will be managed on-site by a CENTEC Project Engineer in direct contact with CENTEC QA management personnel.

At the test site, the CENTEC engineer is responsible for implementing QA throughout the test program. The engineer conducts onsite evaluations to verify the degree of implementation, assures that appropriate QA records are kept, provides QA direction to the laboratory staff, and reports regularly to the Project Manager on the status of QA.

Dr. Ted Handel is the Quality Assurance Officer for this project. Dr. Handel functions independently from Project Management, reporting directly to the Vice President of CENTEC Applied Technology. He continuously monitors the implementation of QA and provides feedback to the CENTEC engineer onsite and to CENTEC management. Daily QA records are kept by the engineer (onsite) and submitted weekly to the Quality Assurance Officer (offsite). These records serve as resources for preparing reports and documenting adherence to QA procedures and specifications.

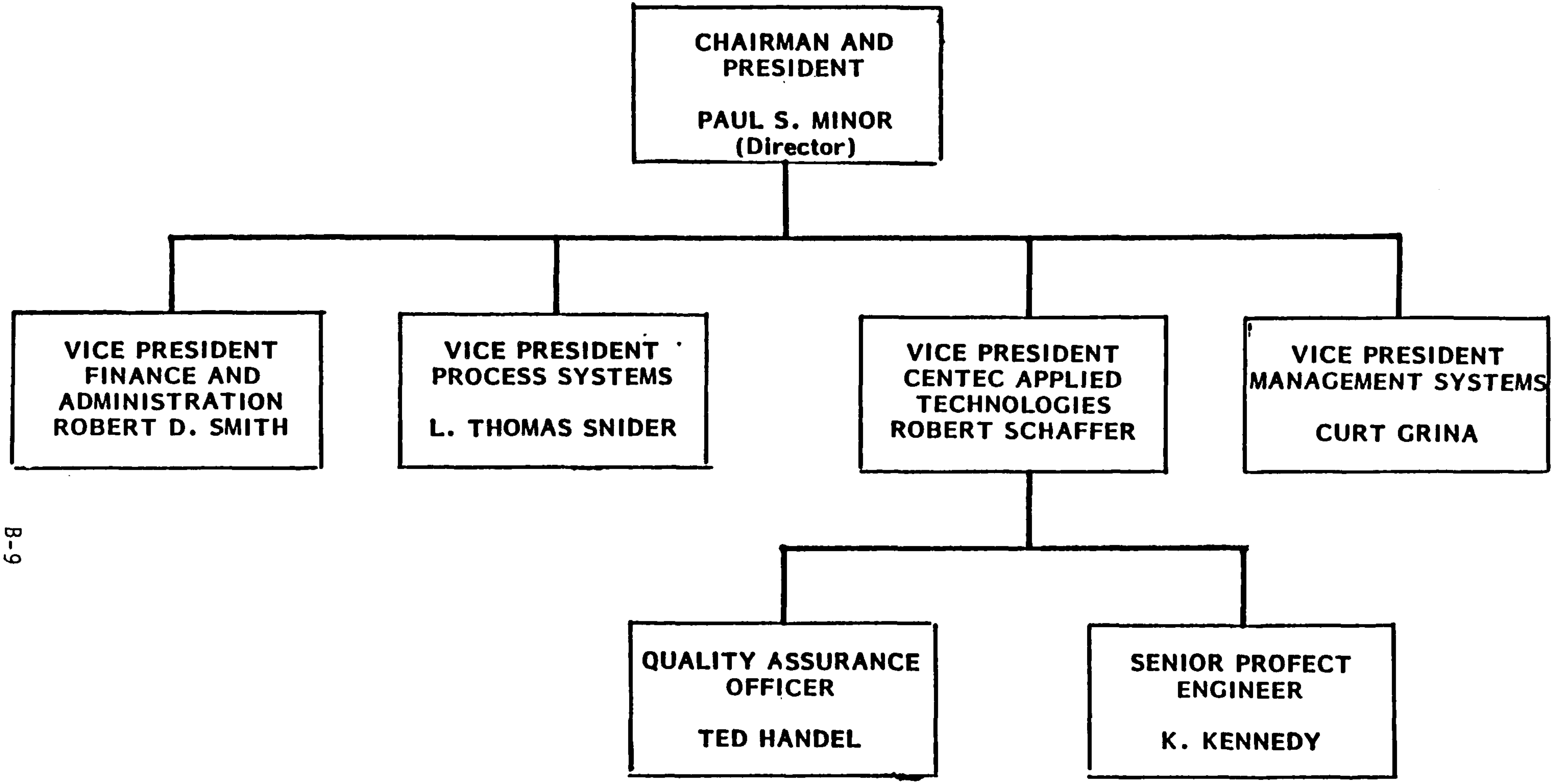

Figure B-1. Project Organization as Related to Corporate Structure

SECTION 3

QA OBJECTIVES FOR MEASUREMENT DATA IN TERMS OF PRECISION, ACCURACY, COMPLETENESS, REPRESENTATIVENESS AND COMPARABILITY

TE test conditions will be set according to a trial and error approach at the first laboratory. Operating conditions will be set at approximate appropriate levels according to experience or manufacturer's recommendations (manufacturers' representatives will be on site for this portion of the first test), then a spray pattern will be taken. Spray conditions will be refined to correct any irregularity in the pattern, then another pattern will be taken. This procedure will be followed until the spray pattern (shape, thickness, and finish) are of reasonable industrial quality. Once an acceptable spray pattern is achieved, spray conditions will be recorded. These spray conditions will be used at all subsequent laboratories in this test program. Specified spray conditions include gun-to-target distance, fluid pressure, air pressure, shaping air, conveyor speed, voltage, pattern size, and paint viscosity. (Refer to Appendix E , Data Sheet 4.)

This technique for determining spray painting conditions is the same as industrial practice, and is therefore expected to be highly representative of operating conditions that might have been set by industry for the systems being tested.

For each major measurement parameter, specific QA objectives for precision, accuracy, and completeness are required. These objectives are detailed in Table B-1. Not all test conditions are measured directly as listed in Table B-1, for instance, mass flow measurements may be derived from weight and time measurements and cure conditions are a combination of time and temperature.

Care must be taken to assure that all measurements are representative of the media (paint) and conditions (spray conditions) being measured. Proven techniques or methods are therefore used for all measurements.

Data quality objectives are based on accuracy and precision of each measurement, as established in Table B-1. Data integrity will be validated through a series of inspections and tests described later in this plan.

Data completeness objectives are 100 percent. This objective will be met by subjecting each data sheet to two reviews, one by a laboratory representative and one by the CENTEC Project Engineer at the test site. If a piece of data cannot be

Table B-1. Spray Painting Transfer Efficiency Precision, Accuracy and Completeness Objective

Measurement Parameter (Method)	Reference Method	Experimental Conditions	Precision (Std. Deviation)	Accuracy	Completeness
o Weight		Laboratory conditions	lab scale 0.01 g plat. scale 5 g	lab scale ±0.01 g plat. scale ±5 g	100% 100%
o Grounding	IEEE Std 32-1972 ANSI/IEEE Std 142-1972 ANSI C2	Laboratory conditions	—	—	100%
o Voltage	IEEE Std 4-1978	Laboratory conditions	0.05 kV	±0.1 kV	100%
o Units	ASTM E 380-76/ IEEE Std 268-1976	Laboratory conditions	—	—	100%
o Distance-length		Laboratory conditions	0.08 cm	0.04 cm	100%
o Time (stopwatch, timer)	(See ASTM 1200-70)	Laboratory conditions	0.1 s	0.2 s	100%
o Wet Film Thickness	ASTM D-1212-79	Laboratory conditions	0.265 mil	0.85 mil	100%
o Dry Film Thickness	ASTM D-1005-51(1079)	Laboratory conditions	2% ±0.1 mil	2%	100%
o Viscosity (Ford cup)	ASTM D 1200-70(1976)		1.5 s	2 s	100%
o Resistivity			0.1 MΩ	0.1 MΩ	100%
o Pressure		Laboratory conditions	±1%	±1%	100%
o Relative Humidity	(Sling psychrometer)	Laboratory conditions	1°F	3%	100%
o Temperature (cure conditions)		Laboratory conditions	0.1°C	0.1°C	100%
o Linear Air Velocity (rotating vane or heated wire anemometer)	ACGIH Recommended Practice, Section 9*	In accordance with NFPA 33	3%	±3%	100%
o Density	ASTM D 1475-60(1980)	To be determined	±0.001 g/mL	0.002 g/mL	100%
o Wt% Solids	ASTM D 2369-81	To be determined	1.5%	4.7%	100%
o Paint Sampling	ASTM D 3925		—	—	
o Condition in Container	ASTM D 3011-1		—	—	
o Conveyor Speed (derived from Time and Distance)		To be determined	—	—	100%
o Mass Flow Measurement (mass flow meter method)		To be determined	+0.4%	±0.9%	100%

*Industrial Ventilation - A Manual of Recommended Practice, American Conference of Governmental Industrial Hygenists, 1972.

obtained, the CENTEC engineer will note the reason for failing to meet completeness objectives (i.e., power failure, broken measurement apparatus) on the data sheet. Every effort will be made to replace faulty measurement apparatus as quickly as possible. The CENTEC Quality Assurance Officer will be notified whenever completeness objectives are in jeopardy.

In the event that a test run is conducted without 100 percent completeness, the QA Project Officer will determine if the missing data are critical or if they are necessary to perform TE calculations. If the missing data are considered critical or necessary, the test run will be voided. Voided test runs will be repeated as soon as the problem is corrected. If the missing data are not integral to performing TE calculations, the QA officer will make a ruling about whether the test run should be voided and repeated, or accepted pending passing an outlier analysis.

SECTION 4

SITE SELECTION AND SAMPLING PROCEDURES

SITE SELECTION

Previous tests have shown the importance of spray booth configuration for transfer efficiency determinations. To minimize this variable, CENTEC has developed a set of requirements that each laboratory must have in order to participate in the test program. These requirements were developed in close consultation with the spray painting transfer efficiency Steering Committee. They represent our collective best professional judgement of how to specify laboratory criteria well enough to control transfer efficiency at a satisfactory precision, but without being so stringent that only a few laboratories in the country would qualify.

First, the laboratory must be equipped with a back-draw spray booth, preferably of water wash design. Dry filter booths may be considered if filters are changed frequently to maintain air flow rates. Air velocity in the booth must be 100 fpm (plus or minus 20 fpm) in the center of the booth. Downdraft booths are not acceptable for this test program.

Participating laboratories must have an adjustable-rate overhead conveyor system capable of hanging the standardized targets as prescribed. Participating laboratories must provide adequate laboratory balances, work areas for foil wrapping and data reduction, hangers, cleaning solvents, utilities, two knowledgeable technicians, and security for test equipment. They must also provide a curing oven capable of accomodating EPA targets and curing them at controlled prescribed temperatures.

Given these restrictions, CENTEC began making contacts with spray equipment manufacturers, coatings companies, other interested manufacturers, paint associations, and other possible operators of spray painting laboratories. Two qualifying laboratories have already been located; they are scheduled for tests in June and July, 1985. Eight other laboratories have shown interest in participating in the test program. Information about qualifying requirements has been sent to these companies.

SAMPLING PROCEDURE

A description of the sampling procedure is provided in Appendix A, draft standard TE method. It includes:

- A description of the test method, including references to standard methods
- Figures illustrating specific operations
- Description of sampling and test equipment
- Data sheets
- Other special conditions and considerations in performing the test
- Data reduction equations

SECTION 5

SAMPLE CUSTODY

This test program does not generate "samples" in the usual sense. This test program produces sets of data sheets and sets of painted foil targets. The data sheets and painted foil targets are considered "samples" for the purposes of this section.

The onsite CENTEC engineer will be responsible for obtaining and recording necessary information on the data sheets, and shall retain all original data generated by the test program. Procedures and forms for data sheets are presented in Appendix A. Data sheets will be stored in an orderly fashion in a Test Noteboook during and after the test. The Test Notebook remains in CENTEC custody from its hand delivery to the test site, through the performance of all tests, and shall be hand carried back to CENTEC's corporate offices in Reston, Virginia. In addition to the Test Notebook, CENTEC engineers will maintain a comprehensive Log Book for special notes and observations during the test program.

Painted foils will be stored by the participating laboratory in sealed plastic bags labeled to indicate the test date, site, equipment type tested, and foil indentification numbers. Foils will be stored by the participating laboratory until all data analysis is complete. Labels may be hand written in indelible ink on the plastic storage bags.

Field tracking reports will be kept daily, and submitted weekly to the CENTEC Quality Assurance Officer (see Table B-2). The CENTEC engineer and laboratory technician will check and sign all data sheets and tracking forms. The laboratory will retain all weighed foils, as described in the draft test method, until the data analysis is complete. Paint grab samples and target storage bag identification numbers will be recorded on sample custody sheets. CENTEC will retain all original data sheets.

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FIELD TRACKING REPORT

Laboratory Location

Field Sample Code Foil Number	Brief Description*	Date	Time(s)	Sampler

*AAC, AAE, ALC

Table B2. Sample of field tracking report form

SECTION 6

ANALYTICAL PROCEDURES, CALIBRATION PROCEDURES, AND FREQUENCY

ANALYTICAL PROCEDURES

Analytical procedures for determining transfer efficiency are discussed in the draft standard TE test method, Appendix A. The draft standard TE test method is not a traditional laboratory procedure; it is performed at industrial spray painting facilities using almost entirely equipment that is readily available on site. The QA/QC plan makes certain accuracy and precision requirements for instrumentation to measure test parameters, but does not specify make or model for instrumentation. Therefore, CENTEC cannot provide detailed operating and/or calibration instructions for each piece of instrumentation at every laboratory. The party responsible for conducting the TE test (in this case CENTEC) must ensure that equipment and instrumentation meet the requirements of Table B-1. The responsible party must also ensure that participating personnel follow manufacturers' instructions regarding equipment calibration, frequency, and use. If calibration or operating instructions are unavailable, CENTEC will attempt to locate instructions from the manufacturer or supplier. If unsuccessful, the engineer will report the problem to the QA Officer for resolution.

CALIBRATION PROCEDURES AND FREQUENCY

Participating laboratories will be provided with pre-calibrated test equipment for determining test pressure, linear air velocity, relative humidity. These instruments will be calibrated before and after each test series, and as deemed appropriate by either the CENTEC engineer (onsite) or the CENTEC QA Officer (offsite).

Complete manufacturer's instructions for calibration of other test equipment (including test equipment such as the mass flow meter supplied by CENTEC to participants) shall be followed for all other equipment.

SECTION 7

DATA REDUCTION, VALIDATION, AND REPORTING

GENERAL

Data will be collected at the test laboratory under the guidance of a CENTEC engineer. The data will be collected and documented according to the requirements of the draft standard TE test method. Equations for reducing the data are also contained in the draft standard TE test method.

DATA REDUCTION, VALIDATION, AND REPORTING

Figure B-2 shows the responsible parties for each data validation and reduction step. Data reduction will be performed using*:

$$TE = \frac{(\text{Weight of cured painted foil} - \text{Weight of clean foil})(100\%)(\text{Total spraying distance})}{(\text{Paint weight fraction solids})(\text{Total solids sprayed})(\text{Effective target width})}$$

which simplifies to:

$$TE = 15{,}833\ \frac{(\text{Weight of cured painted foil} - \text{Weight of clean foil})}{(\text{Paint weight percent solids})(\text{Total solids sprayed})}$$

for the prescribed target configuration.

Any data generated by test runs with known discrepancies in performance (i.e., a smudged test panel, or a test run at different conditions than specified) will be labeled as suspect for later evaluation. Duplicate data for all suspect runs will be obtained whenever resources permit.

*SI Units

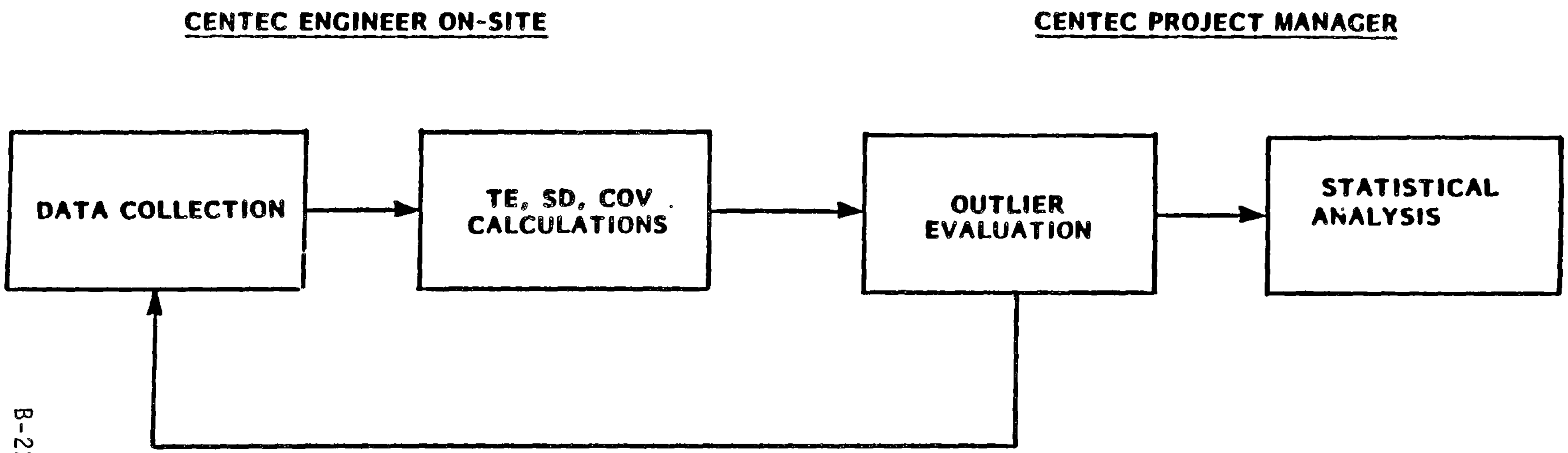

Figure B-2. Data Validation Resposibilities

For each experimental design, the reduced data will be subjected to a series of tests using Nalimov's criteria to evaluate outliers. This evaluation will be performed onsite when a test series is complete, but before taking down the spray equipment. Outliers will be replaced by duplicate runs as resources permit. The CENTEC field engineer will report any questions or problems to the Quality Assurance Officer on a daily basis.

CONSIDERATION OF OUTLIERS

Outliers will be searched for both within the data of each laboratory and among the results of the many laboratories. Nalimov's test for outliers will be utilized. Each suspect data point within a set of data generated at a single laboratory will be tested against the mean of that data set according to Nalimov's Factor*:

$$R = \frac{|x^* - x|^2}{s} \sqrt{\frac{n}{(n - 1)}}$$

where x^* is the suspect value, s is the standard deviation, $\bar{x}$ is the mean of the set, and n is the number of observations in the set. Outliers are classified as possible, probable, or definite according to whether the value of R exceeds its 95 percent, 99 percent or 99.9 percent confidence limit respectively.

Possible outliers will be retained unless a defect in the experiment can be identified. Probable outliers will be identified and replaced with a repeated run whenever possible. Definite outliers will be rejected in every case and an experimental explanation sought.

These considerations will govern the handling of outliers among the various participating laboratories. The mean of all observations for each gun type will be tested against the mean value obtained by all laboratories, and the Nalimov criteria applied.

SECTION 8

INTERNAL QUALITY CONTROL CHECKS AND AUDITS

Internal quality control checks are incorporated into the experimental design and draft standard TE test method. These checks include a battery of six replicates for each type of spray equipment to be tested. Replicates will be examined for outliers as described in Section 8.

The use of blanks, spiked samples, and similar controls is not appropriate for this test program. Due to the nature of conducting transfer efficiency tests, these options are not practical. Since there are no reagents or calibration standards directly applicable to TE determinations, these are ruled out as well.

SECTION 9

RESULTS OF PERFORMANCE AND SYSTEM AUDITS

The performance of the TE tests will be monitored constantly as described in draft standard TE test method.

In addition, performance and system audits will be performed by the Quality Assurance Officer or by his designated representative. This designation is intended to eliminate any question of conflict of interest in the performance of audits.

After the spray painting system is operational, performance audits will be conducted to assure continued acceptable precision during testing. It is the nature of the experimental design for this program that TE results cannot be tested for outliers until a test series is complete. To minimize the likelihood of obtaining poor TE results prior to outlier analyses, internal audits are required twice daily for each major measurement contributing to TE:

- o Net solids on target, g
- o Conveyor speed, cm/s
- o Paint weight fraction solids
- o Paint mass flow rate, g/s
- o Effective target width, cm
- o Target spacing, cm

These measurements are subject to the precision, accuracy, and completeness criteria in Table B-1. They will be examined for precision and accuracy at the beginning and completion of each test series. Instrumentation such as the mass flow meter will be calibrated and checked against paint capture on a twice daily basis. Periodic audits also may be conducted during the test day as deemed appropriate by either the laboratory technician or CENTEC engineer on site. Performance audit requirements are detailed in Table B-1 and in the draft standard TE test method.

SECTION 10

PREVENTATIVE MAINTENANCE

Preventative maintenance practices in the program are those recommended by the manufacturer to the spray equipment user. These practices include keeping the spray equipment and spray area clean, handling equipment carefully to avoid damage, and using appropriate equipment for the given job. These general practices must be observed to prevent inadvertent deterioration of spray equipment condition and to minimize downtime.

In addition to these preventative maintenance practices, extra electrodes and air caps should be kept on hand. Ample supplies for performing TE tests should be available to avert shortages. These include foil, paint, solvent, and other supplies outlined in the test method.

SECTION 11

SPECIFIC ROUTINE PROCEDURES TO ASSESS DATA PRECISION, ACCURACY AND COMPLETENESS

The precision and accuracy of each component the total measurement system will be documented at the beginning and end of each test series. (Refer to Table B-1.) Problems identified by the performance audit will be corrected before continuing with the test program.

Accuracy is calculated based on comparison to a reference. Pressure gages are calibrated against a laboratory-standard gage. Voltage readings obtained with the experimental equipment are calibrated against the laboratory standard, etc. Test instrumentation is adjusted until accuracy criteria in Table B-1 are met, where accuracy is calculated as:

$$\%\text{Error} = \frac{\text{Indicated Value} - \text{True Value}}{\text{True Value}} \times 100$$

Precision is measured as the standard deviation of a series of measurements, thereby determining the repeatability of the measurement. Standard deviation is calculated as:

$$S = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$$

where x is the mean of the series of measurements, x is the value obtained in each measurement, and n is the number of observations making up the series.

Determination of the overall precision of the test method is the objective of the interlaboratory test program. The completeness objective for all readings and data points is 100 percent. The method of testing for outliers presented in Section 8 during the test series, and the fact that outliers will be replaced by duplicates, will insure that completeness objectives are meet.

Completeness requirements are audited continuously and automatically by the dual check-off procedures required on each data sheet in the draft standard TE test method.

SECTION 12

CORRECTIVE ACTION

Performance audits are required twice daily for each measurement contributing to TE. Should any measurement not meet the precision or accuracy requirements laid out in Table B-1, corrective action _must_ be taken. Corrective action includes recalibration, repair, or replacement of the measurement system in question. The CENTEC engineer on site is responsible for initiating the appropriate corrective action, with concurrence from the participating required in writing in the next QA report to management.

Corrective action may also be taken to replace data identified as erroneous by the required data outlier analysis. The CENTEC Project Manager is responsible for initiating corrective action to replace outlier data.

Other corrective action may be taken at the request of onsite CENTEC or laboratory personnel whenever suspect or undocumented conditions occur. The CENTEC engineer is responsible for all such corrective actions.

APPENDIX C

DETECTION OF OUTLIERS BY MEANS OF NALIMOV'S TEST

CONSIDERATION OF OUTLIERS

Outliers were searched for, both within the data of each laboratory and among the results of the eight laboratories. Nalimov's test for outliers was utilized (see below). Each suspect data point within a set of data generated at a single laboratory was tested against the mean of that data set according to Nalimov's Factor:

$$R = \left| \frac{x - \bar{x}}{s} \right|^2 \sqrt{\frac{n}{n - 1}}$$

where x is the suspect value, s is the standard deviation, $\bar{x}$ is the mean of the set, and n is the number of observations in the set. Outliers were classified as possible, probable, or definite according to whether the value of R exceeded its 95 percent, 99 percent, or 99.9 percent confidence limit, respectively.

Possible outliers were retained unless a defect in the experiment was identified. Probable outliers were identified and replaced with a repeated run whenever possible. Definite outliers were rejected in every case and an experimental explanation sought.

Similar consideration governed the handling of outliers among the various participating laboratories. The mean of all observations for each gun type was tested against the mean value obtained by all laboratories, and the Nalimov criteria applied.

APPENDIX D

STATISTICAL ANALYSIS ADDENDUM

Appendix D

The random effects model is given by

$$y_{ij} = \mu + \tau_i + \varepsilon_{ij} \qquad \begin{array}{l} i = 1,\ 2,\ \dots,\ \ell \\ j = 1,\ 2,\ \dots,\ n \end{array}$$

where τ_i is the effect of the ith lab and ε_{ij} is the jth random disturbance within each laboratory. The average $\bar{y}_{..}$ is given by

$$\begin{aligned} \bar{y}_{..} &= \sum_i \sum_j y_{ij}/\ell n \\ &= \sum_i \sum_j (\mu + \tau_i + \varepsilon_{ij})/\ell n \\ &= \ell n\ \mu + n\sum_i \tau_i + \Sigma\Sigma\varepsilon_{ij}/\ell n \end{aligned}$$

Now, $\mathrm{Var}(\tau_i) = \sigma_L^2$ and $\mathrm{Var}(\varepsilon_{ij}) = \sigma_W^2$ If one takes the variance of the right hand side of the above, one obtains, after simplification

$$\mathrm{Var}(\bar{y}_{..}) = \frac{\sigma_L^2}{\ell} + \frac{\sigma_W^2}{n\ell}$$

and thus

$$\sigma_{\bar{y}_{..}} = \sqrt{\frac{\sigma_L^2}{\ell} + \frac{\sigma_W^2}{n\ell}}$$

Now, an estimator of $\sigma_{\bar{y}_{..}}^2$ is given by $\mathrm{MS}_\ell/n\ell$. This is easily verified since standard methods reveal that

$$E(\mathrm{MS}_L) = \sigma_W^2 + n\sigma_L^2$$

thus $\mathrm{MS}_L/n\ell$ is an unbiased estimator of $\dfrac{\sigma_W^2}{n\ell} + \dfrac{\sigma_L^2}{\ell}$.

APPENDIX E

OPERATING CONDITIONS AND RAW DATA SUMMARY

LABORATORY 1

6/7/85

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID Psi	ATOM. AIR	ROTATING RPS WI. FLUID	W/O FLUID	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)
Trial Run 61632	7 to 12	1825	N/A	N/A	N/A	N/A	N/A	24.8°C	25°C	100±20fpm	76%	25.4cm (10in)	15min	191C (375F)
Trial Run 61632	13 to 18	1825						26°C						
61632	19 to 24	1825						26°C						
60838	25 to 30	1800						26°C						
61449	31 to 35							26.8°C			50%			
61449	36 to 41													

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	f Δ (g)	TIME (s)	a RATE (g/s)	b CONVEYOR SPEED (cm/s)	c WEIGHT % SOLIDS	d NET DRY SOLIDS (g)	e* TRANSFER EFFICIENCY (%)
61632	7 to 12	30	0.6 mils		N/A	N/A	163.1	14.4	11.32	(41 ft/min)	58%		
61632	13 to 18	30	—				171.7	14.4	11.92		58%		
61632	19 to 24	30	0.6 mils				162.5	14.0	11.61		58%		
60838	25 to 30	20	0.6 mils				176.6	13.8	12.80		58%		
61449	31 to 35												
61449	36 to 41												

Data Collected by: ______

Data Checked by: ME

$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$

or $e = 15{,}833\left(\frac{d}{c \times f}\right)$

6/11/85

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID (psi)	ATOM. AIR	ROTATING RPS WI. FLUID	W/O FLUID	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)
60838 320 to 325	1810	N/A	N/A	N/A	N/A	N/A	22°C	26°C	100ft/m	70%	25.4 cm (10in)	15m	375
60829 326 to 331	1890						22°C	26°C	100ft/m	64%	25.4 (10in)	15m	375
61629 332 to 337	1840						22°C	26°C	100ft/m	64%	25.4cm (10in)	15m	375
to													
to													
to													

FOIL NUMBERS	VERTICAL COVERAGE (%)	~~FILM~~ (cm) WET	DRY	Micro Flow ~~FLUID MASS FLOW RATE DETERMINATION INIT. (g)~~	FINAL (g)	f Δ (g)	TIME (s)	a RATE (g/s)	b CONVEYOR SPEED (cm/s)	c WEIGHT % SOLIDS	d NET DRY SOLIDS (g)	e* TRANSFER EFFICIENCY (%)
60838 320 to 325	22%	.8mil		593g/m	N/A	141.5	14.25	9.93g/s (595.8g/m)	20.32cm/s 40ft/m	45.10	23.13	45.1
60829 326 to 331	21%	.7mil		477g/m		112.5	14.3	7.86 g/s (472 g/m)	20.32cm/s 40ft/m	43.22	17.55	43.2
61629 332 to 337	20%	.6mil		560		133.7	14.3	9.35g/s 560.9g/m	20.32cm/s 40ft/m	44.01	21.26	44.0
to									20.32cm/s 40ft/m			
to									20.32cm/s 40ft/m			
to									20.32cm/s 40ft/m			

Data Collected by: LPB

Data Checked by: ______

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

or

$$e = 15{,}833\left(\frac{d}{c \times f}\right)$$

6/11/85

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (KPa) FLUID	ATOM.AIR	ROTATING RPS WI.FLUID	W/O FLUID	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME(s)	TEMP (°C)
60865	284 to 289	1810	N/A	N/A	N/A	N/A	N/A	22°C	26°C	100 ft/m	72%	10 in	15 m	375
60838	290 to 295	1810						22°C	26°C	100 ft/m	72%	10 in	15 m	375
60838	296 to 301	1810						22°C	26°C	100 ft/m	72%	10 in	15 m	375
60829	302 to 307	1890						22°C	26°C	100 ft/m	72%	10 in	15 m	375
60829	308 to 313	1890						22°C	26°C	100 ft/m	72%	10 in	15 m	375
60829	314 to 319	1890						22°C	26°C	100 ft/m	72%	10 in	15 m	375

E-5

MASS flow readings

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	f Δ (g)	TIME(s)	a RATE (g/s)	b CONVEYOR SPEED (cm/s)	c WEIGHT % SOLIDS	d NET DRY SOLIDS (g)	e* TRANSFER EFFICIENCY (%)
60865	284 to 289	20%	.6 mil		not measured	NM	144.1	14.4	10.0 g/s 600 g/m	40 f/m	57.4	23.49	45.5
60838	290 to 295	20%	.6 mil		594		142.3	14.3	9.95 g/s 597 g/m	40 f/m	57.4	23.05	44.8
60838	296 to 301	22%	.7 mil		593		141.9	14.3	9.92 595.38	40 f/m	57.4	23.06	45.0
60829	302 to 307	20%	.9 mil		471		112.9	14.3	7.895 g/s 473 g/s	40 f/m	57.4	17.30	42.4
60829	308 to 313	20%	.6 mil		474		112.8	14.3	7.88 g/s [illegible] g/s	40 f/m	57.4	17.58	43.5
60829	314 to 319	21%	.6 m		474		113.0	14.3	7.9 g/s 474.	40 ft/m	57.40	17.51	43.0

[illegible] the scan were [illegible] place

Data Collected by: [illegible]

Data Checked by: ______

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

or

$$e = 15{,}833\left(\frac{d}{c \times f}\right)$$

AAC

6/19/85

Air Flow Rate (SCFH) Atomizing Air Pressure (PSI)

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (~~kPa~~) FLUID	ATOM.AIR	~~ROTATING RPS~~ W/ FLUID	~~W/O FLUID~~	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)	
C1378	567 to 572	7 psi	23 psi	300	46	N/A	N/A	71.5F	25.3C	100 fpm	59%	10 in	15m	475F	✓
C1320	579 to 584	10 psi	21 psi	300	46			71.0F	25.4C	100 fpm	59%	10 in	15m	475F	
C1356	591 to 592	10.5 psi	23.5 psi	300	46			71.5F	25.4C	100 fpm	57%	10 in	15m	475F	✓
C1336	603 to 608	10 psi	20.5 psi	305	46			71.5F	25.4C	100 fpm	57%	10 in	15m	475F	✓
C1356	615 to 6[illegible]8	11 psi	22.5 psi	300	46			71.5F	25.4C	100 fpm	58%	10 in	15m	475F	✓
C1290	627 to 632	10 psi	21 psi	300	46			73 F	25.5C	100 fpm	55%	10 in	15m	475F	✓

E-6

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	f Δ (g)	TIME (s)	a RATE (g/s)	b CONVEYOR SPEED (cm/s)	c WEIGHT % SOLIDS	d NET DRY SOLIDS (g)	e* TRANSFER EFFICIENCY (%)	
C1378	567 to 572	18	0.3 mils		353	N/A	166.5	28.4 s	5.86	10.16 cm/s	47.2	17.07	32.72	6.14
C1320	579 to 584	16	0.6 mils		370		175.7	28.55	6.15		47.2	21.42	39.09	6.45
C1356	591 to 596	21	0.3 mils		351		166.5	28.6	5.82		47.2	17.19	29.80	6.10
C1336	603 to 608	19	0.6 mils		390		185.8	28.7	6.47		47.2	21.51	37.29	6.77
C1356	615 to 620	21.5	0.4 mils		365		173.9	28.6	6.08		47.2	18.64	34.44	6.37
C1290	627 to 632	18	0.4 mils		399		190.2	28.6	6.65		47.2	24.17	41.26	6.98

Data Collected by: MDE

Data Checked by: ______

$*e=54.68\left(\frac{b \times d}{a \times c}\right)$

or $e=15,833\left(\frac{d}{c \times f}\right)$

Date ______

Air Flowrate (SCFH)

Control Panel Air Maximum Pressure (psig)

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID	ATOM.AIR	~~ROTATING RPS~~ ~~WI. FLUID~~	W/O FLUID	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)	
Dummy 1320	358 to 343	10 psi	15.5 psi	290	36	N/A	N/A	72F	25.4C	100 fpm	58%	10 in	15 min	475°F	X
C1320	354 to 357	9 psi	21 psi	300	46	↓	↓	68.1F	25.2C	90 fpm	71.5	10 in	15 m	475F	✓
C1355	3[illegible] to 368	9 psi	22.5 psi	295	46			68.0F	25.2C	90 fpm	76.0	10 in	15 m	475F	See ✓ NOTE
C1355	373 to 380	9 psi	22.5 psi	295	46			68.5F	25.3 C	90 fpm	71.0%	10 in	15 m	475F	✓
C1320	388 to 392	9 psi	20.5 psi	300	46			68.2F	25.4C	90 fpm	68.0%	10 in	15 m	475F	✓
C1320	399 to 404	9.0 psi	21.0 psi	305	45	↓	↓	68.2F	25.4°C	100 fpm	67.0%	10 in	15 m	475F	✓

E-7

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	Flowmeter Flow ~~INIT. (g)~~	FINAL (g)	f FLUID MASS FLOW RATE DETERMINATION Δ (g)	TIME (s)	a calculated RATE (g/s)	b CONVEYOR SPEED (cm/s)	c WEIGHT % SOLIDS	d NET DRY SOLIDS (g)	e* TRANSFER EFFICIENCY (%)	
Dummy C1320	~~356 to [illegible]~~	~~18/48 = 37.5~~	~~0.5 mils~~		~~336 g/m~~	~~N/A~~	~~160.2~~	~~28.2~~	~~5.68 g/s (340.9 g/m)~~	10.16	~~49.5~~			5.95
C1320	354 to 355	18.5/48 = 38.5	0.6 mils		340 g/m	↓	155.7	28.2	5.52 g/s (331.3 g/m)	↓	46.6	17.78	36.67	5.78
C1355	36[illegible] to 368	18.5/48	0.7 mils		332 g/m		160.5	28.9	5.55 g/s (333.2 g/m)		46.6	17.76	36.44	5.81
C1355	373 to 380	18	0.6 mils		332 g/m		160.1	28.9	5.54 g/s (332.4 g/m)		46.6	18.37	37.8	5.80
C1320	387 to 397	18	0.7 mils		329 g/m		158.6	28.85	5.50 g/s (329.8 g/m)		46.6	19.01	39.3	5.76
C1320	399 to 404	19	0.7 mils		331 g/m	↓	159.7	28.9	5.53 g/m (331.6 g/m)	↓	46.6	19.64	40.4	5.79

Data Collected by: MDE

Data Checked by: ______

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

or

$$e = 15,833\left(\frac{d}{c \times f}\right)$$

AAC

6/18/85

Air Flow rate (SCFM) Air Atomizing Pressure (psi)

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID	ATOM. AIR	~~ROTATING RPS~~ ~~W/ FLUID~~	~~W/O FLUID~~	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)
C1356	411 to 416	9 psi	22.5 psi	300	46	N/A	N/A	68.2F	25.4C	100 fpm	64.%	10 in	15m	475F
C1355	423 to 428	9 psi	23 psi	295	45.9			69.0F	25.5C	100fpm	64.%	10 in	15m	475F
C1365	435 to 440	9 psi	22 psi	295	46			69.0F	25.5C	100 fpm	60%	10 in	15 m	475F
C1378	447 to 452	9 psi	22 psi	300	46			69.2F	25.5 C	100 fpm	64%	10 in	15m	475F
C1365	453 to 464	9 psi	23 psi	295	46			70.0F	25.6C	100 fpm	62%	10 in	15 m	475F
C1290	471 to 476	9 psi	21 psi	305	46			70.5F	25.6C	100 fpm	60%	10 in	15 m	475F

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	Δ (g) f	TIME (s)	RATE (g/s) a	CONVEYOR SPEED (cm/s) b	WEIGHT % SOLIDS c	NET DRY SOLIDS (g) d	TRANSFER EFFICIENCY (%) e*	
C1356	411 to 416	20	0.5 mils		321 g/m	N/A	153.4	28.8	5.33 g/s (319.6 g/m)	28.4 ft/m	47.5	16.36	34.29	5.58
C1355	423 to 428	20.5	0.6 mils		340 g/m		162.9	28.75	5.67 g/s (340.0 g/m)		47.5	18.06	35.56	5.94
C1365	435 to 440	22	0.6 mils		336 g/m		160.3	28.75	5.58 g/s (334.5 g/m)		47.5	17.10	34.25	5.84
C1378	447 to 452	19	0.5 mils		325 g/m		156.0	28.7	5.44 g/s (326.1 g/m)		47.5	17.93	36.86	5.69
C1365	459 to 464	19.5	0.7 mils		335 g/m		158.9	28.5	5.58 g/s (334.5 g/m)		47.5	17.30	34.65	5.94
C1290	471 to 476	15	0.7 mils		349 g/m		165.6	28.6	5.79		47.5	20.72	39.92	6.07

Data Collected by: MDE

Data Checked by:______ $^*e=54.68\left(\frac{b\times d}{a\times c}\right)$

or $e=15,833\left(\frac{d}{c\times f}\right)$

HHC

6/18/85

Air Flow rate (SCFH) Air Atom [illegible] ([illegible])

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID	ATOM. AIR	~~ROTATING~~ RPS WI. FLUID	~~W/O FLUID~~	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)	
C1296	483 to 488	9 psi	21 psi	310	46	N/A	N/A	71.0 F	25.6C	110 fpm	61%	10 in	15m	475F	✓
C1356	495 to 500	10 psi	22.75 psi	300	46			71.0 F	25.6C	100 fpm	58%	10 in	15m	475F	✓
C1356	507 to 512	10 psi	23 psi	300	46			70.5 F	25.6C	100 fpm	55%	10 in	15m	475F	✓
C1320	519 to 524	9 psi	21 psi	305	46			71.0 F	25.6C	100 fpm	54%	10 in	15m	475F	✓
1355	531 to 536	7 psi	23.75 psi	295	46			73.5 F	25.7C	100 fpm	57%	10 in	15m	475F	✓
C1326	543 to 548	9 psi	21 psi	305	46			73.0 F	25.8C	100 fpm	70%	10 in	15m	475F	✓

E-6

							f		a	b	c	d	e*	
	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	Δ (g)	TIME (s)	RATE (g/s)	CONVEYOR SPEED (cm/s)	WEIGHT % SOLIDS	NET DRY SOLIDS (g)	TRANSFER EFFICIENCY (%)	
C1290	483 to 488	17.5	0.6 mils		346	N/A	164.3	28.65	5.73 g/s (344.1 g/m)	28 ft/m	47.5	20.46	39.88	6.00
C1356	495 to 500	18.5	0.5 mils		319		151.8	28.5	5.36 g/s (319.6 g/m)		47.5	15.09	31.46	5.61
C1356	507 to 512	19	0.4 mils		319		150.8	28.55	5.28 g/s (316.9 g/m)		47.5	15.70	33.20	5.53
C1320	519 to 524	18	0.7 mils		345		163.8	28.6	5.73 g/s (343.6 g/m)		47.5	19.59	38.19	6.00
C13[illegible]	531 to 536	20	0.6 mils		364		173.1	28.5	6.07 g/s (364.4 g/m)		47.5	17.96	33.02	6.36
C1320	543 to 548	18	0.6 mils		356		169.0	28.5	5.93 g/s (355.8 g/m)		47.5	20.55	38.70	6.21

Data Collected by: MDE

Data Checked by: ______

$$*e=54.68\left(\frac{b\times d}{a\times c}\right)$$

or

$$e=15{,}833\left(\frac{d}{c\times f}\right)$$

MAC

Air Flow Rate (SCFH) Atomizing Air Pressure (psi)

6/18/85

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID	ATOM. AIR	~~ROTATING~~ RPS WI. ~~FLUID~~	~~W/O FLUID~~	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)
C1320	553 to 560	9 psi	21 psi	305	46	N/A	N/A	73 F	25.7C	100 fpm	67%	10 in	15m	475F
C1378	to							74.5F		100 fpm	56%	10 in	15m	475F
	to											10 in	15m	475F
	to											10 in	15m	475F
	to											10 in	15m	475F
	to											10 in	15m	475F

E-10

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	Δ (g) f	TIME (s)	RATE (g/s) a	CONVEYOR SPEED (cm/s) b	WEIGHT % SOLIDS c	NET DRY SOLIDS (g) d	TRANSFER EFFICIENCY (%) e*	
C1320	553 to 560	18.5	0.5 mils		356	N/A	169.6	28.6	5.93 g/s (355.8 g/m)	28.4 ft/m	47.5	20.27	38.18	6.21
C1378	to													
	to													
	to													
	to													
	to													

Data Collected by: ______

Data Checked by: ______ $*e=54.68\left(\frac{b \times d}{a \times c}\right)$

or $e=15,833\left(\frac{d}{c \times f}\right)$

Date: 6/29/85

DATA SHEET 4

Data Checked By:

DAY Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid (psi)	Atom. Air (psi)	Operating Voltage (kV)	Current (μA)	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Atom. Air (psi)	Paint Pot (psi)	Air Flow (scfm) (scfh)	
1	1382	705-710	13 psi	21.5 psi	N/A	N/A	77°F	25.6	100ft/s	52%	98 psi	46 psi	26.8	295	✓
2	1290	723-728	10 psi	21.0 psi			75°F	25.6	100ft/s	54 %	100 psi	46	26.8	300	✓
3	1290	735-740	10 psi	21.0 psi			76°F	25.6	100ft/s	52%	100 psi	46	26.8	300	
4	1336	753-758	10 psi	21 psi			76°F	25.6°C	100ft/s	60%	94 psi	45	26.8	300	✓
5	1290	765-770	11 psi	21 psi			77°F	25.6°C	100ft/s	59%	95 psi	46.5	26.8	295	✓
6	1378	777-782	11	22			77°F	25.8	100ft/s	54%	98 psi	46.5	26.8	290	✓

DAY Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/m)	Fluid Mass Flow Total Mass (g)	Time (s)	Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)	
1	20/48	0.5	353 g/m	170.5 g	29 s	5.89 g/s 352.76 g/m	20 f/m	48.05	17.84	33.43	6.17
2	22/48	0.7	436 g/m	209 g	28.85	7.25 g/s 435.4 g/m	20 f/m		24.54	37.28	7.61
3	24/48	0.7	424 g/m	204.5 g	29.05	7.03 g/s 422 g/m	20 f/m		24.95	39.09	7.38
4	21/48	0.7	431 g/m	208.5 g	29.05	7.18 g/s 430 g/m	20 f/m		23.42	35.91	7.54
5	20/48	.7	431 g	207.4	28.9	7.17 g/s 430 g/m	20 f/m		25.26	38.79	7.53
6	21/48	.7	418	201.8	29.0	6.96 g/s 417 g/s	20 f/m		23.37	35.41	7.31

AAC

Date: 6/24/85

DATA SHEET 4

Data By: dKD

Data Checked By: ____________

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Atom. Air	Operating Voltage (kV)	Current (10 µA)	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures (PSI) Supply Air	Atom. Air	Paint Pot	Air Flow (scfm)
7	1336	789 - 794	10 psi	20 psi	NA	N/A	76.5°F	25.8 °C	100 ft/m	60%	98	46.5	26.8	300 ✓
8	1365	801 806	11 psi	24 psi			77°F	25.8°C		61%	98	46.5	26.8	285 ✓
9	1365	813 818	11 psi	23.5 psi			77°F	25.8°C		60%	98	46.5	26.8	290 ✓
10	1378	825 830	12 psi	22.5 psi			77°F	25.8°C		60%	99	46.5	26.8	290
11	1378	838 843	13 psi	23 psi			77°F	25.8°C		60%	100	46.5	26.8	290 ✓
12	1378	851 856	12	23			77°F	25.8°C		60%	101	46.5	26.8	300 ✓

E-12

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Time (s)	Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)	
7	22/48	.7	435 g/m	209.8	29.0 s	7.2 g/s 432 g/m	20 f/m	48%	23.95	36.63	7.56
8	26/48	.6	426 g/m	204.7	28.9 s	7.08 g/s 424 g/m		48%	19.54	30.41	7.43
9	26/48	.7	426 g/m	205.5	29.0 s	7.06 g/s 460 g/m		48%	20.71	32.31	7.41
10	24/48	.7	385 g/m	185.8	29.95 s	6.2 g/s 372 g/m		48%	19.60	34.86	6.50
11	21/48	.7	385 g/m	186.1	29.0 s	6.41 g/s 385 g/m		48%	19.71	33.96	6.72
12	21/48	.7	388	186.1	28.95	6.44 g/s 386.4 g/m		48%	19.47	33.30	6.76

Date: 6/25/85

DATA SHEET 4

Data Checked By: MDL

DAY Run No.	Gun No.	Foil No.'s	Pressure at Gun (psi) Fluid	Atom. Air	Operating Voltage (kV)	Current ( )	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures (psi) Supply Air	Atom. Air	Paint Pot	Air Flow (scfm)	
1/12	1365	880-885	10 psi	23 1/2	NA	MA $\times 10^{-6}$ A	22 °C	25.5 °C	100 f/m	58%	119	46	26.8	285	✓
2/12	1365	892-897	10	23.5		$\times 10^{-6}$ A	22	25.8		58%	101	46	26.8	290	✓
3/12	1382	869-874	11	22		$\times 10^{-6}$ A	22	25.6		58%	101	46	26.8	290	✓
4/12	1355	902-907	10	23		$\times 10^{-6}$ A	23.5	25.6		57%	101	46	26.8	290	✓
5/12	1322	914-919	12.5	21.5		$\times 10^{-6}$ A	24 °C	26°		58%	92	46	26.8	290	✓
6/12	1355	926-931	10	23		$\times 10^{-6}$ A	25°	26°		70%	93	46	26.8	290	✓

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Time (s)	Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)	
1/12	23/48	.7	355 g/s	169.4	28.6	5.95 g/s 353.38 g/m	30 f/m	50%	17.10	30.50	6.23
2/12	25/48	.7	357	172.4	28.9	5.97 g/s 357 g/m		50%	17.89	31.75	6.26
3/12	24/48	.7	337	162.9	29.2	5.58 g/s 334.7 g/m		50%	18.39	34.99	5.84
4/12	22/48	.7	374	179.6	28.7	6.26 g/s 375		50%	20.59	34.87	6.56
5/12	22/48	1.0	305	152.5	28.0	5.446 326.76		50%	16.02	31.22	5.70
6/12	27/47	.7	381	183	28.9	6.33 379.9		50%	20.69	34.62	6.4

Data By: DHB

Date: 6/25/85 DATA SHEET 4 AAC

Data Checked By: MDC

Run No.	Gun No.	Foil No.'s	Pressure at Gun (PSI) Fluid	Atom. Air	Operating Voltage (kV)	Current ( )	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures (psi) Supply Air	Atom. Air	Paint Pot	Air Flow (scfm)	
7/12	1382	938-943	12	21.5	NA	NA	25	25.8	100 ft/m	78%	95	46	26.8	290	✓
8/12	1382	950-955	12	22			26	25.8		76%	95	46	26.8	295	✓
9/12	1336	962-967	10	20			26	26		76%	96	46	26.8	300	✓
10/12	1336	974-979	10	20.5			26	26		78%	96	46	26.8	305	✓
11/12	1382	986-991	12	22			26	26		78%	96	46	26.8	290	✓
12/12	1336	998-1003	10	20			26	26		78%	96	46	26.8	300	

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Time (s)	Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)	
7/12	20/48	.6	325	156.3	28.95	5.40 g/s 323.94 g/m	20 ft/s	50%	17.89	35.18	5.65
8/12	27/48	.7	326	157.2	29.0	5.42 g/s 325 g/m		50%	17.84	34.96	5.67
9/12	27/48	.7	383	184.6	29.0	6.37 g/s 381.92		50%	21.08	35.06	6.68
10/12	28/48	.7	382	184.5	28.95	6.37 g/s 382.38		50%	20.95	34.85	6.68
11/12	26/48	.7	336	162.5	29.0	5.60 g/s 336.2		50%	18.35	34.79	5.86
12/12	28/48	.7	385	185.5	28.9	6.42 g/s 385		50%	21.35	35.08	6.73

Date: 6/27/85

DATA SHEET 4

Data Checked By: ____________

Run No.	Gun No.	Foil No.'s	(psi) Pressure at Gun: Fluid	Pressure at Gun: Atom. Air	Operating: Voltage (kV)	Operating: Current ( )	Temperature (°C): Booth	Temperature (°C): Fluid	Booth Air Rate (cm/s)	Relative Humidity	(psi) Control Panel Pressures: Supply Air	Control Panel Pressures: Atom. Air	Control Panel Pressures: Paint Pot	Air Flow (scfm)
1/1	1356	1010–1015	11 ~~22.5~~	22.5 ~~4~~	N/A	N/A		25.6	100 ft/s	76%	100	46	26.8	2.5

E-15

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/m)	Fluid Mass Flow: Total Mass (g)	Fluid Mass Flow: Time (s)	Fluid Mass Flow: Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)
1/1	26/48	.6	311	148.4	28.7	5.17 g/s 310 g/m	10.16 cm/s	49.28	14.0	29.23

5.40

AAE

6/19/85

Air Flow Rate (SCFM) Control Rate Atomizing Air Pressure (psi)

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID	ATOM. AIR	~~ROTATING RPS~~ WI. FLUID	~~W/O FLUID~~	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)	
C1378	573 to 578	7 psi	23 psi	300	46	74kV 30uA	250	72F	25.2C	100 fpm	59%	10 in	15m	475F	✓
C1320	585 to 590	10 psi	21 psi	305	46	74kV 32uA	250	71.5F	25.4C	100 fpm	55%	10 in	15m	475F	✓
C1356	591 to 602	10.5 psi	23.5 psi	300	46	74kV 30uA	250	71.5F	25.4C	100 fpm	59%	10 in	15m	475F	✓
C1336	609 to 614	10 psi	20.5 psi	305	46	74kV 30uA	250	72F	25.5C	100 fpm	58%	10 in	15m	475F	
C1356	621 to 626	11 psi	22.5 psi	300	46	74kV 29uA	250	73F	25.5C	100 fpm	58%	10 in	15m	475F	✓
C1290	633 to 638	10 psi	21 psi	305	46	74kV 25uA	250	73F	25.5C	100 fpm	55%	10 in	15m	475F	✓

E-16

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	f Δ (g)	TIME (s)	a RATE (g/s)	b CONVEYOR SPEED (cm/s)	c WEIGHT % SOLIDS	d NET DRY SOLIDS (g)	e* TRANSFER EFFICIENCY (%)	ṁ (g/s)
C1378	573 to 578	20.5		0.6 mil	357	N/A	169.6	28.55	5.94 g/s	10.16	47.2	34.55	65.27	6.23
C1320	585 to 590	17.5		0.6 mil	367	↓	175.1	28.55	6.13	10.16	47.2	38.81	71.04	6.43
C1356	591 to 602	21		0.3 mil	352	↓	167.2	28.6	5.85	↓	47.2	39.32	75.50	6.13
C1336	609 to 614	21		0.6 mil	392	↓	186.5	28.7	6.50	↓	47.2	42.70	73.70	[illegible]
C1356	621 to 626	22		0.5 mil	366	↓	174.2	28.55	6.10	↓	47.2	40.04	73.64	6.40
C1290	633 to 638	17		0.6 mil	401	↓	171.0	23.75	6.64	↓	47.2	42.43	71.65	6.97

Data Collected by: MDE

Data Checked by:______

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

or

$$e = 15,833\left(\frac{d}{c \times f}\right)$$

AAE

6/18/85

Air Flow Rate (SCFM) Atomizing Air Pressure (psi)

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID	ATOM. AIR	~~ROTATING RPS~~ WI. FLUID	~~W/O FLUID~~	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)	
C1320	5 to 5	9 psi	21 psi	310	46	74 kV	35 MΩ 250	74 °F	25.7 C	100 fpm	68%	10 in	15 m	475 F	✓
C1378	to						250					10 in	15 m	475 F	
	to						250					10 in	15 m	475 F	
	to						250					10 in	15 m	475 F	
	to						250					10 in	15 m	475 F	
	to						250					10 in	15 m	475 F	

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	f Δ (g)	TIME (s)	a RATE (g/s)	b CONVEYOR SPEED (cm/s)	c WEIGHT % SOLIDS	d NET DRY SOLIDS (g)	e* TRANSFER EFFICIENCY (%)	
C1320	5 to 5	19	0.6		357	N/A	169.5	28.65	5.92 g/s (355.0 g/m)	10.16 cm/s	47.5	42.21	79.63	6.20
C1378	to													
	to													
	to													
	to													
	to													

Data Collected by: ______

Data Checked by: ______

$$*e=54.68\left(\frac{b\times d}{a\times c}\right)$$

or

$$e=15,833\left(\frac{d}{c\times f}\right)$$

AAt[illegible]

Data By: [illegible]

Date: 6/24/85

DATA SHEET 4

Data Checked By: ____________

this run was performed again here

voltage, current not set

[illegible]

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid (psi)	Pressure at Gun Atom. Air (psi)	Operating Voltage (kV)	Operating Current (10⁻⁶A)	Temperature (°C) Booth	Temperature (°C) Fluid	Booth Air Rate (cm/s)	Relative Humidity (psi)	Control Panel Pressures Supply Air (psi)	Control Panel Pressures Atom. Air (psi)	Control Panel Pressures Paint Pot (psi)	Air Flow (acfm)
~~1a~~	~~1382~~	~~711-716~~	~~13 psi~~	~~21.5 psi~~	~~30~~	~~0~~	~~25.6~~	~~77°F~~	~~100 ft/m~~	~~52%~~	~~100~~	~~46~~	~~26~~	~~300~~
1b	1382	717-722	13 psi	21.5 psi	75	30	75°F	25.6°C	100 ft/m	56%	98	46	26.8	300 ✓✓
2	1290	729-734	10 psi	21.0 psi	75	30	75°F	25.6°C	100 ft/m	60%	98	46	26.8	300 ✓
3a	1290	741-746	10 psi	21.0 psi	74	32	76°F	25.6°C	100 ft/m	56%	98	46	26.8	300
3b	1290	747-752	10 psi	21.0 psi	75	35	76°F	25.6°C	100 ft/m	60%	98	46	26.8	300 ✓
4	1330	759-764	10 psi	21 psi	74	28	76°F	25.6°C	100 ft/m	61%	98	46.5	26.8	305
5	1290	771-776	11 psi	21 psi	74	35	76°F	25.6°C	100 ft/m	58%	98	46 psi	26.8	300 ✓
6	1378	783-788	11 psi	22	75	35	76°F	25.6°C	100 ft/m	58%	98	46	26.8	300 ✓

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Fluid Mass Flow Time (s)	Fluid Mass Flow Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)	Adjusted mass flow
1a	20	0.7	353 g/s	171.0 g	28.8 s	5.94 g/s (356.25 g/m)	10.16 cm/s 20 ft/m	48%			6.22
1b	20/48	0.7	362 g/s	173.8 g	28.9	6.01 g/s (360.83 g/m)	20 ft/m	48%	38.41	70.56	6.30
2	21/48	0.7	422	204.4	29.0	7.05 g/s 422 g/m	20 ft/m	49%	41.17	64.39	7.40
3a	20/48	0.6	424	205.4	29.0	7.08 g/s 424.96 g/m	20 ft/m	49%	40.10	62.46	7.43
3b	20/48	0.7	423	205.3	29.1	7.05 g/s 423.3 g/m	20 ft/m	48%	40.19	62.86	7.40
4	25/48	0.7	434	209.5	29.0	7.22	20 ft/m	48%	47.30	72.2	7.59
5	21/48	0.7	429	207.4	29.0	7.15 g/s 429.1 g/m	20 ft/m	48%	41.97	64.68	7.51
[illegible]			[illegible]	200.9	[illegible]						

HILL

6/18/85

Air Flow rate (SCFH) Air Atomizing Pressure (psi)

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID	ATOM. AIR	~~ROTATING RPS~~ WI. FLUID	W/O FLUID	OPERATING VOLTAGE (kV)	GUN RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)	
C1356	417 to 422	9 psi	22.5 psi	300	45.5	73 kV / 30 mA	250	68.2 F	25.5 C	90 ft/m	64 %	10 in	15 m	475 F	
C1355	429 to 434	9 psi	23 psi	300	46	74 kV / 30 mA	250	69.0 F	25.5 C	100 ft/m	60 %	10 in	15 m	475 F	✓
C1365	441 to 446	9 psi	22 psi	300	46	74 kV / 30 mA	250	[illegible] F	25.5 C	100 ft/m	60%	10 in	15 m	475 F	✓
C1378	453 to 458	9 psi	22 psi	300	46	74 kV / 30 uA	250	67.0 F	25.5 C	100 ft/m	64%	10 in	15 m	475 F	✓
C1365	465 to 470	9 psi	23 psi	295	46	74 kV / 35 A	250	71.5 F	25.5 C	100 ft/m	60%	10 in	15 m	475 F	✓
C1290	477 to 482	9 psi	21 psi	305	46	74 / 31	250	71.0 F	25.5 C	110 ft/m	61 %	10 in	15 m	475 F	✓

E-19

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	Δ (g) f	TIME (s)	RATE (g/s) a	CONVEYOR SPEED (cm/s) b	WEIGHT % SOLIDS c	NET DRY SOLIDS (g) d	TRANSFER EFFICIENCY (%) e*	
C1356	417 to 422	21	0.5 mils		324	N/A	153.7	28.9	5.32 g/s (319.1 g/m)	10.16 cm/s	47.5	35.53	74.40	5.57
C1355	429 to 433	[illegible]	0.7 mils		340	↓	163.8	29.9	5.67 g/s (340.1 g/m)	↓	47.5	39.53	77.83	5.94
C1365	441 to 446	24	0.6 mils		336		160.9	28.75	5.60 g/s (335.8 g/m)		47.5	39.70	79.24	5.86
C1378	453 to 458	19.5	0.6 mils		327		156.7	28.8	5.44 g/s (326.5 g/m)		47.5	35.88	73.75	5.6[illegible]
C1365	465 to 470	21	0.7 mils		338		161.4	28.8	5.60 g/s (336.3 g/m)		47.5	39.60	79.04	5.8[illegible]
C1290	477 to 482	17.5	0.7 mils		351	↓	166.4	28.7	5.80 g/s (347.7 g/m)	↓	47.5	40.06	77.06	6.08

Data Collected by: MDE

Data Checked by:______

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

or

$$e = 15{,}833\left(\frac{d}{c \times f}\right)$$

AAE 6/18/85

Air flow rate [illegible] per flowmeter [illegible]

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

FOIL NUMBERS		PRESSURE AT GUN (kPa) FLUID	ATOM. AIR	~~ROTATING~~ RPS WI. FLUID	~~W/O FLUID~~	OPERATING (Cont.) VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)	
C1290	489 to 494	9 psi	21 psi	310	46	~~74 kV~~ 36 MΩ	250	71.0F	25.6C	100 ft/m	60%	10 in	15 m	475F	✓
C1356	501 to 506	10 psi	22.75 psi	305	46	~~74 kV~~ 30 MΩ	250	71.0F	25.6C	100 ft/m	58%	10 in	15 m	475F	✓
C1356	513 to 518	10 psi	23 psi	300	46	~~74 kV~~ 30 MΩ	250	70.5F	25.6C	100 ft/m	54%	10 in	15 m	475F	✓
C1320	525 to 530	9 psi	21 psi	305	46	~~73 kV~~ 35 MΩ	250	71.0F	25.6C	100 ft/m	54%	10 in	15 m	475F	✓
C1355	537 to 542	9 psi	23.75 psi	295	46	~~74 kV~~ 28 MΩ	250	73.0F	25.6C	100 ft/m	70%	10 in	15 m	475F	✓
C1320	549 to 554	9 psi	21 psi	305	46	~~74 kV~~ 32 MΩ	250	73.5F	27.0C	100 ft/m	70%	10 in	15 m	475F	

E-20

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	Δ (g)	TIME (s)	f RATE (g/s)	a CONVEYOR SPEED (cm/s)	b WEIGHT % SOLIDS	c NET DRY SOLIDS (g)	d TRANSFER EFFICIENCY (%) e*	
C1290	489 to 494	18	0.7 mils		345	N/A	164.2	28.65	5.71 g/s (343.9 g/m)	10.16 cm/s	47.5	39.56	77.37	5.98
C1356	501 to 506	22	0.4 mils		317	↓	150.7	28.55	5.28 g/s (316.7 g/m)	↓	47.5	35.51	75.10	5.53
C1356	513 to 518	~22	0.6 mils		324	↓	154.4	28.7	5.38 g/s (322.8 g/m)	↓	47.5	37.06	76.99	5.63
C1320	525 to 536	18.5	0.7 mils		349	↓	165.2	28.6	5.78 g/s (346.6 g/m)	↓	47.5	39.61	76.45	6.06
C1355	537 to 542	24	0.6 mils		363	↓	172.8	28.6	6.04 g/s (362.5 g/m)	↓	47.5	38.20	70.58	6.33
C1320	549 to 551	17.5	0.7 mils		355	↓	168.7	28.55	5.91 g/s (354.5 g/m)	↓	47.5	39.45	74.54	6.19

Data Collected by: MDE

Data Checked by: ______

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

or

$$e = 15{,}833\left(\frac{d}{c \times f}\right)$$

Date: 6/27/85

DATA SHEET 4

Data Checked By: [illegible]

Run No.	Gun No.	Foil No.'s	Pressure at Gun (psi) Fluid	Atom. Air	Operating Voltage (kV)	Current ( )	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures (psi) Supply Air	Atom. Air	Paint Pot	Air Flow (scfm)
1/1	1356	1016 ~~1021~~	·22.5	11	74	35	20.5	25.6	10.4/5	76%	100	46	26.8	290

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Time (s)	Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)
1/1			315	151.0 ~~[illegible]~~	29.0	[illegible] 1	10.16	49.28	37.1	77.98

5.45

AAL

Date: 6/25/85

DATA SHEET 4

Data By: [illegible]

Data Checked By: ______

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Atom. Air	Operating Voltage (kV)	Current ( )	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures (PSI) Supply Air	Atom. Air	Paint Pot	Air Flow (scfm)
7/12	1382	944–949	12	21.5	75	35×10^{-6}	25°	26°	100 f/s	76%	96	46	26.8	295
8/12	1382	956–961	12	22	74	32	25°	26°		72%	96	46	26.8	300
9/12	1336	968–973	10	20	74	30	26°	26°		74%	96	46	26.8	305
10/12	1336	980–985	10	20.5	74	30	26.5	26		72%	96	46	26.8	310
11/12	1382	992–997	12	22	74	35	27	27		74%	96	46	26.7	295
12/12	1336	1004–1009	10	20	74	35	27	27		76%	96	46	26.8	310

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Time (s)	Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)	
7/12	26/48	1.2	325	156.4	29.0	5.40 g/s 324 g/M	20 f/s	50%	37.50	73.75	5.65
8/12	24/48	.7	327	156.8	28.9	5.43 g/s 325.5 g/M		50%	36.96	72.30	5.68
9/12	26/48	.7	384	185.7	29.05	6.39 g/s 383.5 g/M		50%	46.64	77.35	6.70
10/12	27/48	.6	381	184.9	29.1	6.35 g/s 381.23 g/M		50%	44.80	74.74	6.66
11/12	27/48	.6	339	162.9	28.8	5.64 g/s 338.8 g/M		50%	39.51	74.28	5.11
12/12	28/48	.4	386	186.9	29.1	6.42 g/s 385.4 g/M		50%	47.06	77.73	6.73

Date: 6/25/85

DATA SHEET 4

Data Checked By: ____________

DAY Run No.	Gun No.	Foil No.'s	(PSI) Pressure at Gun: Fluid	Pressure at Gun: Atom. Air	Operating Voltage (kV)	Operating Current (A)	Temperature (°C): Booth	Temperature (°C): Fluid	Booth Air Rate (cm/s)	Relative Humidity	Psi Control Panel Pressures: Supply Air	Control Panel Pressures: Atom. Air	Control Panel Pressures: Paint Pot	Air Flow (scfm)
1/12	1365	886-~~901~~ 891	10	23.5	74	30×10^{-6} A	22	25.5	100 ft/m	58%	100	46	26.8	290
2/12	1365	843-848	10	23.5	74	30×10^{-6}	22	25.5		58%	100	46	26.8	295
3/12	1382	875-879 + 901	11	22	74	35×10^{-6}	23	25.5		58%	102	46	26.8	295
4/12	1555	907-913	10	23	74	30×10^{-6}	22	25.5		60%	101	46.5	26.8	290
5/12	1582	920-925	12.5	21.5	75	35×10^{-6}	24	26		70%	101	46	26.8	300
6/12	1355	932-937	10	23	74.5	35×10^{-6}	25	26		72%	100	46	26.8	290

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow: Total Mass (g)	Fluid Mass Flow: Time (s)	Fluid Mass Flow: Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)	
1/12	23/48	.7	357	171.5	28.85	5.94 g/s 356.4 g/m	20 f/m	50%	41.72	74.41	6.23
2/12	27/48	.7	360	173.5	29.05	5.97 g/s 358.3 g/m		50%	43.09	76.48	6.26
3/12	25/48	.7	333	160.8	29.0	5.54 g/s 332.7 g/m		50%	39.75	76.15	5.80
4/12	26/48	1.0	377	180.7	28.9	6.25 g/s 375 g/m		50%	39.20	64.50	6.55 ?
5/12	29/47	.7	308	144.2	28.9	5.13 g/s 307.7 g/m		50%	36.20	74.90	5.37
6/12	28/47	.7	384	185.0	29.0	6.38 g/s 382.7 g/m		50%	40.33	66.98	6.69 ?

Data By: OMD

AAE

Date: 6/24/85 DATA SHEET 4

Data Checked By:

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid (PSI)	Pressure at Gun Atom. Air (PSI)	Operating Voltage (kV)	Operating Current (μA)	Temperature (°C) Booth	Temperature (°C) Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures (PSI) Supply Air PSI	Control Panel Pressures (PSI) Atom. Air PSI	Control Panel Pressures (PSI) Paint Pot	Air Flow (acfm)	
7	1336	795-mD	10	20	35 kV	74×10^{-6} A	76.5°	25.8°C	100 ft/m	58%	98	46.5	26.8	300	✓
8	1365	807-812	11 psi	24 psi	30 kV	74.5 A	77.5°F	26.4°C		60%	98	46.5	26.8	290	✓
9	1365	819-824	11 psi	24 psi	30 kV	75 A	77.5	26.4°C		59%	100	46.5	26.8	280	✓
10	1378	832 837	12 psi	22.5 psi	30 kV	74 A	77.5	26.4		59%	100	46.5	26.8	290	✓
11	1378	844-849	12 psi	23 psi	30 kV	75×10^{-6}	77.5	26.4		61%	98	46.5	26.8	285	✓
12	1378	857-862	12 psi	23 psi	35 kV	75	77.5	26.4		58°	98	46.5	26.8	285	✓

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/m)	Fluid Mass Flow Total Mass (g)	Time (s)	Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)	
7	26/48	.7	435 g/m	210.1	28.9 (s)	7.27 g/s	20 f/m	48%	46.23	70.03	7.64
8	27/48	.7	425 g/m	204.6	28.85 s	7.09 g/s			47.50	73.89	7.44
9	28/48	.7	426 g/m	205.4	29.0	7.08 g/s 424 g/m			47.32	73.71	7.43
10	21/48	.7	384	185.9	29.5	6.30 g/s 378.9 g/m			40.80	70.76	6.61
11	21/48	.7	387	187.	29.1	6.45 g/s 389 g/m			41.93	71.68	6.77
12	25/48	.7	388	187	29.0	6.44 g/s 386 g/m			42.12	72.11	6.76

AAE 6/18/85

Air Flowrate (cfm) Air Atomizing pressure (psi)

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID	ATOM.AIR	~~ROTATING RPS~~ ~~W/ FLUID~~	~~W/O FLUID~~	OPERATING VOLTAGE (kV)	GUN RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)	
Dummy 1320	344 to 349	10 psi	155 psi	285	36	75 kV / 35 mA	250	69.0F	25.2C	100 fpm	58%	10 in	15 m	475F	✓
1320	356 to 361	9 psi	21 psi	300	46	73 kV / 35 mA	250	68.0F	25.2C	90 fpm	72%	10 in	15 m	475F	✓
1355	367 to 374	9 psi	22.5 psi	275	46	73 kV / 35 mA	250	68.0F	25.2C	100 fpm	73%	10 in	15 m	475F	✓
1355	375 to 382	9 psi	22.5 psi	295	46	73 kV / 35 mA	250	68.0F	25.4C	90 fpm	69%	10 in	15 m	475F	✓
1320	393 to 398	9 psi	20.5 psi	305	45	73 kV / 35 mA	250	68.5F	25.4C	100 fpm	69%	10 in	15 m	475F	✓
1320	405 to 410	9.0 psi	21.0 psi	305	45	73 kV / 36 mA	250	68.2F	25.4C	100 fpm	65%	10 in	15 m	475F	✓

E-25

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	Δ (g) f	TIME (s)	RATE (g/s) a	CONVEYOR SPEED (cm/s) b	WEIGHT % SOLIDS c	NET DRY SOLIDS (g) d	TRANSFER EFFICIENCY (%) e*	$\dot{m}$ g/s
Dummy 1320	344 to 349	16/48 = 33.3	0.7 mils		334 g	N/A				10.16 cm/s	49.5			
1320	356 to 361	18/48	0.7 mil		329	↓	158.3	28.2	5.61 g/s (336.85 g/m)	↓	46.6	38.28	77.61	5.88
1355	367 to 374	19/	0.7 mil		333		160.4	28.85	5.56 g/s (333.6 g/m)		46.6	34.03	69.71	5.82
1355	375 to 382	20/	0.7 mils		336		161.9	28.85	5.61 g/s (336.7 g/m)		46.6	36.55	74.10	5.88
1320	393 to 398	18	0.7 mils		329		158.8	28.9	5.49 g/s (329.7 g/m)		46.6	38.73	80.30	5.75
1320	405 to 410	18	0.6		331	↓	159.6	28.9	5.52 g/s (331.3 g/m)	↓	46.6	38.22	78.83	5.78

Data Collected by: MDE

Data Checked by: ______

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

or

$$e = 15{,}833\left(\frac{d}{c \times f}\right)$$

Date 6/10/85

Team M. Eberth, L. Berry, G. Olson

ALC #1

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

Gun #	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID (PSI)	PRESSURE AT GUN (kPa) ATOM. AIR	ROTATING RPS WI. FLUID	ROTATING RPS W/O FLUID	OPERATING VOLTAGE (kV)	OPERATING RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	TEMPERATURE (°C) FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	CURE TEMP (°C)
61632	31 to 36	1825	N/A	N/A	N/A	N/A	N/A	21°C	26.3°C	(100 ft/m)	56%	25.4cm (10 in)	(15m	(375°F)
60838	37 to 42	1800						21°C	26.4°C	(100 ft/min)	61%	25.4cm (10 in)	15 min	375°F
61449	43 to 48	1825						20.5°C	26.4°C	(100 ft/m)	61%	25.4cm (10 in)	15 min	375°F
61449	49 to 54	1825						21°C	26.4°C	(100 ft/m)	61%	25.4cm (10 in)	15 min	375°F
60838	55 to 60	1800						21°C	26.4°C	(100 ft/m)	61%	25.4cm (10 in)	15 min	375°F
61632	61 to 66	1825						20.5°C	26.5°C	(100 f/m)	62%	25.4cm (10 in)	15 m	375°F

Gun #	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	FILM (cm) DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g) From Meter Flow Rate	FINAL (g)	Δ (g) f	TIME (s)	CALCUL RATE (g/s) a	CONVEYOR SPEED (cm/s) b	WEIGHT % SOLIDS c	NET DRY SOLIDS (g) d	TRANSFER EFFICIENCY (%) e*
61632	31 to 36	25%	6 mils		8.83 g/s 530 g/m		125.8 g	14.1 s	8.92 g/s (535.2)	41 ft/m	57.25	18.97	42.2
60838	37 to 42	16%	6 mils		580 g/m		138.2	14.25	9.73 g/s (583.9 g/m)	41 ft/m	57.25	22.38	45.7
61449	43 to 48	16%	6 mils		Not taken		125.3	14.15	8.89 g/s (533.2 g/m)	41 ft/m	57.25	21.08	47.1
61449	49 to 54	15%	6 mils		548 g/m		129.3	14.15	9.2 g/s (550 g/m)	41 ft/min	57.25	21.35	46.1
60838	55 to 60	17%	7 mils		590 g/m		140.4	14.1	9.96 g/s (597.45 g/m)	41 ft/min	57.25	22.32	44.5
61632	61 to 66	17%	6 mils		543 g/m		128.9	14.1	9.14 g/s 548.5 g/m	41 ft/m	57.25	18.70	40.64

Data Collected by: JPB

Data Checked by: ______

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

or

$$e = 15{,}833\left(\frac{d}{c \times f}\right)$$

6/10/85

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID	ATOM. AIR	ROTATING RPS WI. FLUID	W/O FLUID	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)
60829	67 to 72	1860	NA	N/A	N/A	N/A	N/A	21.0°C	26.4°C	100ft/m	60%	25.4cm (10in)	15m	375°C
60829	73 to 78	1860						21.0°C	26.4°C	100ft/min	60%	25.4cm (10in)	15m	375°C
60829	79 to 84	1860						21.0°C	26.4°C	100ft/min	60%	25.4cm 10in	15m	375°C
61632	85 to 90	1825						21.0°C	26.6°C	100ft/min	60%	25.4cm 10in	15m	375°C
61629	91 to 96	1825						21.0°C	26.5°C	100ft/m	60%	25.4cm	15m	375°C
60829	97 to 102	1860						21.0°C	26.5°C	100ft/m	60%	25.4cm	15m	375°C

E-27

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	From Meter Flowrate ~~INIT. (g)~~	FLUID MASS FLOW RATE DETERMINATION FINAL (g)	f Δ (g)	TIME (s)	a CALCULATED RATE (g/s)	b CONVEYOR SPEED (cm/s)	c WEIGHT % SOLIDS	d NET DRY SOLIDS (g)	e* TRANSFER EFFICIENCY (%)
60829	67 to 72	17%	(.6mil)		466g/s		110.4	14.25	7.74g/s (466g/m)	41ft/m	57.25	16.53	42.4
60829 Rerun of	73 to 78	17%	.6mil		463g/s		142.3	14.25	10.02g/s (601)	41ft/m	57.25	16.86	33.4 in let.
N' 60829	79 to 84	18%	.7mil		460g/s		109.6	14.25	7.718 (463.1)	41ft/m	57.25	16.73	43.1
61632	85 to 90	17%	.7mil		540g/s		128.0	14.25	9.014g/s (540.8)	41ft/m	57.25	19.75	43.5
61629	91 to 96	16%	.7mil		531g/s		126.1	14.25	8.88g/s (532.8)	41ft/m	57.25	20.08	44.9
60829	97 to 102	15%	.5mil		464g/s		110.2	14.25	7.73g/s 464	41ft/m	57.25	17.20	44.2

Data Collected by: DPB

Data Checked by: ______

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

or

$$e = 15{,}833\left(\frac{d}{c \times f}\right)$$

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

6/10/85

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID psi	ATOM. AIR	ROTATING RPS WI. FLUID	W/O FLUID	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)
61629	103 to 108	1825	N/A	N/A	N/A	N/A	N/A	20.8°C	26.5°C	(100 f/m)	62%	25.4 cm (10 in)	15 m	375°C
61649	109 to 114	1825						20.8°C	26.5°C	(100 f/m)	62%	25.4 cm 10 in	15 m	375°C
6/11/85 60865	115 to 120	1850						21°C	24.8°C	(100 f/m)	60.5%	25.4 cm 10 in	15 m	375°C
61449	121 to 126	1840						22°C	25.7°C	100 f/m	62%	25.4 cm 10 in	15 m	375°C
61632	127 to 132	1840						21°C	25.7°	100 f/m	61%	25.4 cm	15 m	375°C
60865	133 to 138	1810						21°C	25.6°	100 f/m	72%	25.4		

From Marlin

Micro Edge

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	f Δ (g)	TIME (s)	a RATE (g/s)	b CONVEYOR SPEED (cm/s)	c WEIGHT % SOLIDS	d NET DRY SOLIDS (g)	e* TRANSFER EFFICIENCY (%)
1629	103 to 108	17%	(.6 mils)		546 g/m		128.8	14.15s	9.10 g/s (546.15)	40 ft/m	57.25	20.53	43.78
1649	109 to 114	18%	(.7 mils)		563 g/m		133.1	14.85	9.37 g/s (562.4)	40 ft/m	57.25	20.92	43.3
0865	115 to 120	20%	(.7 mils)		610 g/m		144.6	14.4s	10.04 g/s 602.5 g/m	40 ft/m	57.40	23.26	44.8
1449	121 to 126	15%	.6 mils		542 g/m		130.0	14.3s	9.09 g/s 545.5 g/m	40 ft/m	57.40	21.57	45.9
1632	127 to 132	15%	(.7 mils)		544 g/m		130.2	14.3s	9.10 g/s 546 g/m	40 ft/m	57.40	20.73	44.1
0865	133 to 138	18%	(.7 mils)		599 g/m		143.8	14.3s	10.06 g/s 603.4	40 ft/m	57.40	23.45	45.1

Data Collected by: RB

Data Checked by: ______

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

or

$$e = 15{,}833\left(\frac{d}{c \times f}\right)$$

6/11/85

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID ([illegible])	ATOM. AIR	ROTATING RPS WI. FLUID	W/O FLUID	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)
61449	139 to 144	1830	N/A	N/A	N/A	N/A	N/A	20.5°C	26°C	100f/s	78%	25.4cm (10in)	15m	375
61632	145 to 150	1840						21°C	26.2°C	100f/s	70%	25.4cm (10in)	15m	375
61449	151 to 156	1840						21°C	26.2°C	100f/s	70%	25.4cm (10in)	15m	375
61649	157 to 162	1840						21°C	26.2°C	100f/s	70%	25.4cm (10in)	15m	375
61629	163 to 168	1850						21°C	26.2°C	100f/s	70%	25.4cm 10in	15m	375
61629	169 to 174	1850	↓	↓	↓	↓	↓	21°C	26.2°C	100ft	70%	25.4cm 10in	15m	375

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	MASS FLOW METER FLUID MASS FLOW RATE DETERMINATION ~~INIT. (g)~~	FINAL (g)	f Δ (g)	TIME (s)	a RATE (g/s)	b CONVEYOR SPEED (cm/s)	c WEIGHT % SOLIDS	d NET DRY SOLIDS (g)	e* TRANSFER EFFICIENCY (%)
[illegible]	139 to 144	20%	(.7mils)		not recorded	N/A	130.2	14.35	9.10 g/s (546.2 g/m)	(40 f/m)	57.40	21.14	45.0
[illegible]	145 to 150	22%	(.8mils)		545 g/m		130.1	14.3	9.097 g/s (545.87 g/m)	40 f/m	57.40	21.06	44.8
61449	151 to 156	20%	(.6mils)		548 g/m		131.1	14.3	9.16 g/s 550.1 g/m	(40 f/m	57.40	21.42	45.3%
61449	157 to 162	16%	(.6mils		570 g/m		136.1	14.3	9.52 g/s [illegible] g/m	(40 f/m	57.40	22.15	45.0%
61629	163 to 168	15%	(.7mils)		551 g/m		131.6	14.3	9.20 g/s 552.16	(40 f/m)	57.40	21.48	45.2%
61629	169 to 174	20%	(.7mils)		555 g/m	↓	132.5	14.3	9.26 g/s 555.94	40 f/m	57.40	21.13	44.2%

Data Collected by: XPB

Data Checked by:______

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

or

$$e = 15{,}833\left(\frac{d}{c \times f}\right)$$

6/11/85

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID (PSI)	ATOM. AIR	ROTATING RPS WI. FLUID	W/O FLUID	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)
1644	176 to 181	1830	N/A	N/A	N/A	N/A	N/A	20.5°C	26.4°C	100 ft/s	70%	10 in	15 m	375°F
0838	182 to 187	1810						20.5°C	26.9°C	100 ft/s	70%	10 in	15 m	375°F
1644	188 to 193	1840						20.5°C	25.6°C	100 ft/s	80%	10 in	15 m	375
0865	194 to 199	1800						21.0°C	25.6°C	100 ft/s	74%	10 in	15 m	375°
01449	200 to 205	1830						21.0°C	25.6°C	100 ft/s	69%	10 in	15 m	375°F
61429	206 to 211	1840						21.0°C	25.8	100 ft/s	62%	10 in	15 m	375°F

E-30

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	Micro motion Reading FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	f Δ (g)	TIME (s)	a RATE (g/s)	b CONVEYOR SPEED (cm/s)	c WEIGHT % SOLIDS	d NET DRY SOLIDS (g)	e* TRANSFER EFFICIENCY (%)
01644	176 to 181	15%	(.6 mils)		540 g/m	N/A	128.9	14.3	9.01 g/s 540.98 g/m	40 f/m	57.40	21.47	46.1
0838	182 to 187	18%	(.7 mils)		not recorded		141.7	14.3	9.87 g/s 592.0	40 f/m	57.40	23.04	45.1
01644	188 to 193	20%	(.7 mils)		541 g/m		129.3	14.2	9.1 g/s 546.3 g/m	40 f/m	57.40	19.85	42.2
00865	194 to 199	18%	(.7 mils)		599 g/m		142.6	14.25	10.00 g/s 600 g/s	40 f/m	57.40	23.09	44.7
61449	200 to 205	17%	(.7 mils)		545 g/m		130.0	14.3	9.09 545.5 g/m	40 f/m	57.40	20.78	44.2
61629	206 to 211	25%	(.7 mils)		557		132.6	14.2	9.33 g/s 560.28	40 f/m	57.40	20.70	42.9

Data Collected by: DPB

Data Checked by: ______

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

$$\text{or} \quad e = 15,833\left(\frac{d}{c \times f}\right)$$

6/11/85

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID	ATOM. AIR	ROTATING RPS WI. FLUID	W/O FLUID	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)
61649	212 to 217	1840	N/A	N/A	N/A	N/A	N/A	21°C	25.8	100 ft/m	62%	10 in	15m	375
60865	218 to 223	1810						21°C	25.8	100 ft/m	62%	10 in	15m	375
61649	224 to 229	1840						21.5°C	25.8	100 ft/m	61%	10 in	15m	375
61629	230 to 235	1840						21.5°C	25.8°C	100 ft/m	61%	10 in	15m	375
61649	236 to 241	1840						21.5°C	25.8°C	100 ft/m	61%	10 in	15m	375
61649	242 to 247	1840						21.5°C	25.8°C	100 ft/m	61%	10 in	15m	375

micro mil

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	FLUID MASS FLOW RATE DETERMINATION INIT. (g)	FINAL (g)	f Δ (g)	TIME (s)	a RATE (g/s)	b CONVEYOR SPEED (cm/s)	c WEIGHT % SOLIDS	d NET DRY SOLIDS (g)	e* TRANSFER EFFICIENCY (%)
61649	212 to 217	20%	.7 mils		568 g/m	N/A	135.8	14.3	9.49 g/s (569.7 g/m)	40 f/m	57.4	21.16	43.11
60865	218 to 223	20%	.6 mils		600 g/m		143.8	14.3	10.06 g/s (603 g/m)	40 f/m	57.4	22.77	44.0
61649	224 to 229	22%	.7 mils		569 g/m		135.8	14.25	9.53 g/s 571.79 g/m	40 f/m	57.4	20.99	42.6
61629	230 to 235	20%	.7		558 g/m		133.3	14.3	9.32 g/s 559.30	40 ft/m	57.4	19.31	40.1 Foil 232 dripped
61649	236 to 241	23%	.7 mils		566 g/m		135.8	14.3	9.49 g/s 569 g/m	40 ft/m	57.4	21.36	43.5
61649	242 to 247	25%	.7 mils		544 g/m		129.8	14.3	9.07 g/s 544.6 g/m	40 ft/m	57.4	20.34	43.4

Data Collected by: DPB

Data Checked by: ______ $^*e = 54.68\left(\frac{b \times d}{a \times c}\right)$

or $e = 15{,}833\left(\frac{d}{c \times f}\right)$

6/11/85

DATA SHEET 4 - OPERATING CONDITIONS AND CALCULATIONS

	FOIL NUMBERS	PRESSURE AT GUN (kPa) FLUID (psi)	ATOM. AIR	ROTATING RPS WI. FLUID	W/O FLUID	OPERATING VOLTAGE (kV)	RESIST. (MΩ)	TEMPERATURE (°C) AMBIENT	FLUID	BOOTH AIR RATE (cm/s)	RELATIVE HUMIDITY	GUN TO TARGET DISTANCE (cm)	CURE TIME (s)	TEMP (°C)
61649	248 to 253	1840	N/A	N/A	N/A	N/A	N/A	22°C	26.5	100 ft/m	72%	10 in	15 m	375
61644	254 to 259	1840						22°C	26.5°C	100 ft/m	72%	10 in	15 m	375
61644	260 to 265	1840						22°C	26.3°C	100 ft/m	72%	10 in	15 m	375
61649	266 to 271	1840						22°C	26.0°C	100 ft/m	72%	10 in	15 m	375
60865	272 to 277	1810						22°C	25.8°C	100 ft/m	72%	10 in	15 m	375
61632	278 to 283	1890						22°C	25.8°C	100 ft/m	72%	10 in	15 m	375

	FOIL NUMBERS	VERTICAL COVERAGE (%)	FILM (cm) WET	DRY	Flow rate FLUID MASS FLOW RATE DETERMINATION ~~INIT. (g)~~	FINAL (g)	Δ (g) g/	TIME (s)	RATE (g/s) a	CONVEYOR SPEED (cm/s) b	WEIGHT % SOLIDS c	NET DRY SOLIDS (g) d	TRANSFER EFFICIENCY (%) e* f
61649	248 to 253	30%	(.7 mils)		565 g/m	N/A	136.7	14.3	9.56 g/s (573.6 g/m)	40 f/m	57.4	21.15	42.8
61644	254 to 259	30%	.7 mils		545 g/m		130.3	14.3	9.11 g/s 546.7 g/m	40 f/m	57.4	20.41	43.3
61644	260 to 265	18%	.7 mils		540 g/m		130.4	14.3	9.09 g/s 545.5 g/m	40 f/m	57.4	20.11	42.8
61644	266 to 271	28%	.8 mils		544 g/m		130.0	14.3	9.09 g/s 545.5	40 f/m	57.4	20.42	43.9
60865	272 to 277	26%	.7 mils		597		143.0	14.3	10.0 g/s 600 g/s	40 f/m	57.4	22.92	44.3
61632	278 to 283	22%	.9 mils		543.0		134.2	14.8	9.06 544.05	40 f/m	57.4	20.68	44.1

Data Collected by: DPB

Data Checked by: ______

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

$$\text{or} \quad e = 15{,}833\left(\frac{d}{c \times f}\right)$$

LABORATORY 2

Date: July 30, 1985

Airless Gun 1632

DATA SHEET 4

Time	Run No.	Gun No.	Foil No.'s	Pressure at Gun: Fluid	Pressure at Gun: Atom. Air	Operating Voltage (kV)	Operating Current	Temperature (°C) Booth	Temperature (°C) Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures: Supply Air	Control Panel Pressures: Atom. Air	Control Panel Pressures: Paint Pot	Air Flow (acfm)
	D*	~~1290~~ 1632	DHS	1825	N/A	N/A	N/A	71°F	71°F	80-100 ft/s	59%	N/A	N/A	N/A	N/A
~~14:40~~	~~1~~	~~1632~~	~~1-6~~	~~1825~~				~~71°F~~	~~71°F~~	~~80-100~~	59%				
15:00	2	1632	7-12	1825				76°F	76°F	80-100	59%				
15:15	3	1632	13-18	1825				76.0	76.0°F	80-100	61%				
15:30	4	1632	19-24	1825				76°F	76°F	80-100	58%				
15:47	5	1632	25-30	1825				74°F	74°F	80-100	58%				

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/m)	Fluid Mass Flow: Total Mass (g)	Fluid Mass Flow: Convey. Time (s)	a Rate (g/s)	d Conveyor Speed (cm/s)	c Wt. % Solids	b Net Dry Solids (g)	Transfer Efficiency (%)	
D	25%	N/M	530	164.1	[illegible]	530 g/m / 60 s/m =	40 ft/s 2.99 s for 2 ft	58.09	—	—	
~~1~~	~~95%~~	~~N/M~~	~~530 g/m~~	~~164.1~~	~~N/A~~	~~530 g/m / 60 s/m =~~	~~40 ft/s 2.99 s for 2 ft~~	~~58.09~~			
2	30%	.7	528 g/m	130.9 g	14.55	8.80 g/s	2.97 s for 2 ft 20.52 cm/s	58.09	20.98 g	~~45.0~~ 46.0	
3	11/48	.7	530 g/m	N/M	N/M	530 g/m / 60 s/m = 8.83 g/m	3.01 s/2 ft 20.25 cm/s	58.09	22.26 g	~~45.0~~ 44.58	44.4
4	12/48	.7	531 g/m	134.8	15.03	531 g/m / 60 = 8.85	2.99 s/2 ft 20.39 cm/s	58.09	21.68 g	45.72	45.7
5	13/48	.7	528 g/m	133.1	15.31	528 g/m / 60 =	2.99 s/2 ft 20.39 cm/s	58.09	20.55 g	44.82	44.8

*$e = 54.68\left(\frac{b \times d}{a \times c}\right)$

or $e = 15{,}833\left(\frac{d}{c \times f}\right)$

Data By: [illegible] Data Checked By: ______

Date: July 30 1985

Airless Gun 1632

DATA SHEET 4

	Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Atom. Air	Operating Voltage (kV)	Current ( )	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Atom. Air	Paint Pot	Air Flow (acfm)
6:00	6	1632	31-36	1825	N/A	N/A	N/A	71°F	71°F	N/A	61%	N/A	N/A	N/A	N/A
6:15	7	1632	37-42	1825				71°F	71°F		61%				

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Time (s)	Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)
6	12/48	.8	530 g/m	132.8 g	15.15 s	2.98 s/2 ft 530 g/m =	2.98 s/2 ft 20.46	58.09	20.52	44.76
7	10/48	.8	527 g/m	134.4	15.20 s	527/60	2.99 s/2 ft 20.39	58.09	20.63	45.097

Data By:__________ Data Checked By:__________

$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$ or $e = 15{,}833\left(\frac{d}{c \times f}\right)$

Date: July 31

Conventional

DATA SHEET 4 Gun 1365

	Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Atom. Air	Operating Voltage (kV)	Current ( )	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Atom. Air	Paint Pot	Air Flow (acfm) % of Flow
(6)	~~1~~	~~1365~~	~~43-48~~	~~10psi~~	~~20psi~~	~~N/A~~	~~N/A~~	~~75°F~~	~~75~~	~~80-100 ft/s~~	~~79%~~	~~110~~	~~42~~	~~22.5~~	43
12:00	2	1365	49-54	10psi	20psi			74°F	74F	80-100	80%	102	42	26.5	43%
12:15	3	1365	55-60	10psi	20			74°F	74°F	80-100	80%	104	42	26.4	42%
12:20	4	1365	61-66	10psi	20			74.5	74.5F	80-100	80%	100	41.5	26.6	42.5
12:35	5	1365	67-72	10psi	20			74.5	74.5	80-100	81%	103	41.5	26.6	42.0
12:45	6	1365	72-78	10psi	20			74.5	74.5	80-100	80%	102	41.5	26.6	42.0

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Time (s)	Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)
~~1~~	~~NR~~	~~NR~~	~~267 g/m~~	~~136g~~	~~N/M~~	~~267 g/m~~	~~6.01s/2ft~~	~~50%~~		
2	34/48	.7	363 g/m	191.2g	31.55s	6.05 g/s	5.97s/2ft	50%	14.02	25.87
3	35/48	.7	363 g/m	191.0g	31.50s	6.05 g/s	5.99s/2ft	50%	14.38	26.45
4	35/48	.7	362 g/m	189.2	NR	6.03 g/s	5.97s/2ft	50%	13.70	25.37
5	36/48	.7	359 g/m	186.6	NR	6.02 g/s	6.02/2ft	50%	13.77	25.33
6	38/48	.7	360 g/m	184.5	30.73	6.00 g/s	6.01/2ft	50%	13.51	24.98

$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$

or $e = 15{,}833\left(\frac{d}{a \times c}\right)$

Data By: RPB

Data Checked By:

E-36

Date: July 31, 1985

Conventional Gun B65

DATA SHEET 4

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Atom. Air	Operating Voltage (kV)	Current (	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Atom. Air	Paint Pot	Air Flow (scfm)
7	1365	79-84	10 psi	20 psi	NA	NA	79°F	79°F	85-100	80%	109	41.5	26.6	42.5%

% full flow at 11.4 scfm

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Time (s)	Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)
7	37/48	.7	360g/M	182g	NR	6.0	6025/2ft	50%		25.85

Data By: JRB

Data Checked By: ____________

$$*e=54.68\left(\frac{b \times d}{a \times c}\right)$$

or $$e=15,833\left(\frac{d}{c \times e}\right)$$

Date: 7/31/85

Electrostatic Gun 1365

DATA SHEET 4

	Run No.	Gun No.	Foil No.'s	Pressure at Gun: Fluid	Pressure at Gun: Atom. Air	Operating: Voltage (kV)	Operating: Current ( )	Temperature (°C): Booth	Temperature (°C): Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures: Supply Air	Control Panel Pressures: Atom. Air	Control Panel Pressures: Paint Pot	Air Flow (scfm)	% Full Flow (11.4)
3:55	8	1365	85-90	10 psi	20 psi	74 kV	35 mA	74°F	74°F	~~80~~ 100 ft/s	81%	104	42	26.6	42%	
4:15	9	1365	91-96	10 psi	20 psi	74	35	75°F	75°F	~~100~~ 80 ft/s	80%	102	42	26.6	42%	
4:55	10	1365	97-102	10 psi	20 psi	74	35	75°F	75°F	~~100~~ 80 ft/s	81%	104	42	26.6	42	
5:05	11	1365	103-108	10 psi	20 psi	74	55	75.5	75.5	~~100~~ 80	81%	104	42	26.6	42.5	
5:35	12	1365	109 114	10 psi	20 psi	74	35	74.5	74.0	~~100~~ 80 ft/s	81%	104	42	26.6	42	
5:55	13	1365	115 120	10 psi	20 psi	74	35	74.5	74.0	80 ft/s ~~100~~ ft/s	81	100	42	26.6	42	

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow: Total Mass (g)	Fluid Mass Flow: Time (s)	Fluid Mass Flow: Rate (g/s)	Conveyor Speed (cm/s)	Wt. % Solids	Net Dry Solids (g)	Transfer Efficiency (%)
8	42/48	.6	~~360~~ 361	1995	NR	361/60 = 6.01 g/s	6.05 s/2ft	50%	~~47.64~~ 47.77	87.62
9	43/48	.6	361/60	1990	NR	361/60 = 6.01	6.05 s/2ft	50%	48.05	88.1
10	44/48	.6	361/60	199	NR	361/60 6.01	6.01 s/2ft	50%	~~49.49~~ 45.01	82.6
11	45/48	.6	359/60	180	N/R	359/60 5.98	6.01 s/2ft	50%	45.09	84.0
12	46/48	.6	359/60	173.8	N/R	~~5.98~~ 359/60	6.02/2ft	50%	46.75	86.6
13	46/48	.6	359	178	N/R	359/60	6.03/2ft	50%	47.97	88.7

$\bar{x} = 86.3$

$s = 2.41$

Data By: [illegible]

Data Checked By:

$$*e = 54.68\left(\frac{bxd}{axc}\right)$$

or $e = 15{,}833\left(\frac{d}{axf}\right)$

LABORATORY 3

Date: ____________

DATA SHEET 4

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Atom. Air	Operating Voltage (kV)	Current ( )	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Atom. Air	Paint Pot	Air Flow (scfm)
1	61649	1-6	1825	NA.	NA	NA	22.2	26.7	60.96 (120 fpm)	50%	NA	NA	NA	
3		13-18	1825	NA	NA	NA	22.2	26.7	60.96					
4		19-24	1825	NA	NA	NA	22.2	26.7	60.96		NA	NA	NA	
5		25-30	1825						60.96					
6		31-36												
7		37-42							60.96					

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Time (s)	a Rate (g/s)	d Conveyor Speed (cm/s)	c Wt. % Solids	b Net Dry Solids (g)	e Transfer Efficiency (%)
1	12"	8	569	176.7	16.6	10.64	20.15	52.96	18.04	35.27
3	12"	8	567	188.7	16.6	11.37	20.15	52.96	18.79	34.38
4	12"	8	567	200.6	16.6	12.08	20.15	52.96	19.13	32.95
5	12"	8	565	201.2	16.6	12.12	20.15	52.96	18.24	31.31
6	12"	8	569	199.9	16.29					
7	12	8	575	196.7	16.6	11.85	20.15	52.96	19.13	33.58

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

Data By: ____________ Data Checked By:

Date:____________

DATA SHEET 4

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Atom. Air	Operating Voltage (kV)	Current ( )	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Atom. Air	Paint Pot	Air Flow (scfm)
8	61649	43-48	1825	NA	NA	NA			60.96					

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Time (s)	a Rate (g/s)	d Conveyor Speed (cm/s)	c Wt. % Solids	b Net Dry Solids (g)	e Transfer Efficiency (%)
8	12"	7	570	194.9	15.95	12.22	21.02	55.21	18.09	30.81

mean = 33.05
S = 1.73

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

Data By:__________ Data Checked By:

Date: 9-26-85

DATA SHEET 4

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Pressure at Gun Atom. Air	Operating Voltage (kV)	Operating Current (μA)	Temperature (°C) Booth	Temperature (°C) Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Control Panel Pressures Atom. Air	Control Panel Pressures Paint Pot	Air Flow (scfm)
9	C-1355	49-54	9 DH ~~10~~	20	74	29	DH 23.8 ~~23.9~~	23.3	55.88	51%	93.5	40.5	24.0	39.0
10	C-1355	55-60	11.75	20	74	~~29~~	~~23.8~~	~~23.3~~	~~55.88~~	~~51~~	~~89.0~~	~~41.0~~	~~24.0~~	~~39.0~~
11	C-1355	61-66	9.5	20	74	29	23.8	23.3	55.88	51	80.0	42.0	22.0	39.0
12	C-1355	67-72	9.5	20	74	29	23.8	23.3	55.88	51	80.0	42.0	22.0	39.0
13	C-1355	73-78	11.25	20	74	29	23.8	23.3	55.88	51	82.0	~~42.5~~	~~22.0~~	~~39.0~~
14	C-1355	79-84	10.0	20	74	29	23.8	23.3	55.88	51	84.0	42.0	23.0	39.0

Run No.	in Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/min)	Fluid Mass Flow Total Mass (g)	Fluid Mass Flow Time (s)	a Rate (g/s)	d Conveyor Speed (cm/s)	c Wt. % Solids	b Net Dry Solids (g)	e Transfer Efficiency (%)
9	27	7	284	142.1	29.91	4.75	10.18	47.35	DH 26.72 ~~66.02~~	65.39 ~~54.28~~ DH
~~10~~	~~27~~	~~7~~	~~353~~	~~174.7~~	~~29.36~~	~~5.95~~	~~10.18~~	47.35	35.45 ~~35.22~~	70.04 ~~69.59~~
11	27	6	300	148.4	29.70	5.00	10.20	47.35	27.95	65.84
12	27	6	301	150.6	29.63	5.08	10.20	47.35	28.10	65.16
13	27	7	354	177.2	30.81	5.74	10.20	47.35	33.02	67.76
14	27	7	310	152.1	29.58	5.14	10.20	47.35	29.08	66.64

outlier

mean = 66.16
s = 0.95

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

Data By: DSM

Data Checked By:

Date: 9-26-85

DATA SHEET 4

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Pressure at Gun Atom. Air	Operating Voltage (kV)	Operating Current ( )	Temperature (°C) Booth	Temperature (°C) Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Control Panel Pressures Atom. Air	Control Panel Pressures Paint Pot	Air Flow (scfm)
15	C-1355	85-90	9.5	20	74	29	23.8	23.3	55.88	51	84	42	22.5	39

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Fluid Mass Flow Time (s)	a Fluid Mass Flow Rate (g/s)	d Conveyor Speed (cm/s)	c Wt. % Solids	b Net Dry Solids (g)	e Transfer Efficiency (%)
15	27	6	285	141.5	29.62	~~9.54~~ 4.78	10.16	47.35	26.97	66.20

$$^{*}e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

Data By: ____________ Data Checked By:

Date: 9-26-85

DATA SHEET 4 Conventional

Run No.	Gun No.	Foil No.'s	Pressure at Gun: Fluid	Pressure at Gun: Atom. Air	Operating: Voltage (kV)	Operating: Current ( )	Temperature (°C): Booth	Temperature (°C): Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures: Supply Air	Control Panel Pressures: Atom. Air	Control Panel Pressures: Paint Pot	Air Flow (scfm)
16	C-1355	91-96	10.5	20.0	NA	NA	23.8	23.3	55.88	51	82	42	22.0	39
17	C-1355	97-102	10.0	20.0	NA	NA	23.8	23.3	55.88	51	82	42	23.0	39
18	C-1355	103-108	10.5	20.0	NA	NA	23.8	23.3	55.88	51	82	43	22.5	39
19	C-1355	109-114	10.5	20.0	NA	NA	23.8	23.3	55.88	51	82	43	22.[illegible]	39
20	C-1355	115-120	10.5	20.0	NA	NA	23.8	23.3	55.88	51	82	43	23.0	39
21	C-1355	121-126	10.5	20.0	NA	NA	23.8	23.3	55.88	51	81	44	23.0	39

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow f: Total Mass (g)	Fluid Mass Flow f: Time (s)	Fluid Mass Flow f: Rate^a (g/s)	d Conveyor Speed (cm/s)	c Wt. % Solids	b Net Dry Solids (g)	e Transfer Efficiency (%)
16	21	6	308	153.4	29.65	5.17	10.16	47.35	10.98	24.92
17	21	6	313	155.3	29.56	5.25	10.16	47.35	11.28	25.21
18	21	5	311	153.7	29.62	5.19	10.16	47.35	10.61	23.98
19	21	5	309	151.1	29.01	5.21	10.16	47.35	10.64	23.96
20	21	5	309	152.3	29.22	5.21	10.18	47.35	10.54	23.78
21	21	6	310	154.0	30.29	5.08	10.16	47.35	10.48	24.20

mean = 24.34
s = 0.58

$^*e = 54.68\left(\frac{b \times d}{a \times c}\right)$

Data By:

Data Checked By:

E-44

LABORATORY 4

Date: 10-1-85

DATA SHEET 4

Air Cian

Run No.	Gun No.	Foil No.'s	Pressure at Gun: Fluid	Pressure at Gun: Atom. Air	Operating: Voltage (kV)	Operating: Current ( )	Temperature (°C): Booth	Temperature (°C): Fluid	Booth Air Rate (cm/s)	% Relative Humidity	Control Panel Pressures: Supply Air	Control Panel Pressures: Atom. Air	Control Panel Pressures: Paint Pot	Air Flow (scfm)
1	60829	1-6	1825	NA	NA	NA	23.2 (73.7)	21.6	50.8	56	NA	NA	NA	NA
2	60829	7-12	1850	NA	NA	NA	22.2	21.6	50.8	45.5	NA	NA	NA	NA
3	60829	13-18	1850	NA	NA	NA	22.7	21.6	50.8	46.0	NA	NA	NA	NA
4	60829	19-24	1825	NA	NA	NA	22.7	21.6	50.8	46.0	NA	NA	NA	NA
5	60829	25-30	1860	NA	NA	NA	22.7	21.6	50.8	46.0	NA	NA	NA	NA
~~6~~	~~60829~~	~~31-36~~	~~1860~~	~~NA~~	~~NA~~	~~NA~~	~~22.7~~	~~21.6~~	~~50.8~~	~~46.0~~	~~NA~~	~~NA~~	~~NA~~	~~NA~~

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow: Total Mass (g)	Fluid Mass Flow: Time (s)	Fluid Mass Flow: a Rate (g/s)	d Conveyor Speed (cm/s)	c Wt. % Solids	b Net Dry Solids (g)	e Transfer Efficiency (%)
1	9.5	14	490	115.0	14.41	7.98	22.21	58.76	19.07	49.39
2	8.0	~~12~~ 10 DH	580	144.8	14.45	10.02	22.15	58.76	23.08	47.48
3	8.0	10	539	133.6	14.80	9.02	~~29.05~~ 21.62 DH	58.76	20.11	44.85
4	8.0	8	552	131.6	14.24	9.24	22.47	58.76	21.45	48.54
5	8.0	8	560	134.0	14.36	9.33	22.29	58.76	20.86	46.38
6	8.0	8	507	117.5	14.23	~~8.26~~	~~22.49~~	~~58.76~~	~~20.91~~	~~52.98~~

outlier

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

Data By:________ Data Checked By:

Date: 10-1-85

DATA SHEET 4

Airless

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Pressure at Gun Atom. Air	Operating Voltage(kV)	Operating Current( )	Temperature (°C) Booth	Temperature (°C) Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Control Panel Pressures Atom. Air	Control Panel Pressures Paint Pot	Air Flow (scfm)
7	60829	37-42	1875	NA	NA	NA	23.3	21.6	50.8	45.0	NA	NA	NA	NA

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Fluid Mass Flow Time (s)	a Fluid Mass Flow Rate (g/s)	d Conveyor Speed (cm/s)	c Wt. % Solids	b Net Dry Solids (g)	e Transfer Efficiency (%)
7	80	8	482.0	116.7	14.43	8.09	22.18	58.76	19.76	50.53

mean = 47.86

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

Data By: ____________ Data Checked By:

Date: 10-2-85

DATA SHEET 4

Conventional

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Pressure at Gun Atom. Air	Operating Voltage (kV)	Operating Current ( )	Temperature (°C) Booth	Temperature (°C) Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Control Panel Pressures Atom. Air	Control Panel Pressures Paint Pot	Air Flow (acfm)
14	C-1336	79-84	9.75	20	NA	NA	22.7	22.8	55.9	44	90	44	28.5	72
15	C-1336	85-90	10.0	20	NA	NA	22.7	22.8	55.9	44	87	43	27.8	72
16	C-1336	91-96	9.75	20	NA	NA	22.7	22.8	55.9	44	88	43	27.8	73
17	C-1336	97-102	10.0	20	NA	NA	22.7	22.8	55.9	44	90	44	27.8	73
18	C-1336	103-108	9.75	20	NA	NA	22.7	22.8	55.9	44	90	45.5	28.0	73
19	C-1336	109-114	9.75	20	NA	NA	22.7	22.8	55.9	44	89	45.5	28.0	73

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Fluid Mass Flow Time (s)	a Rate (g/s)	d Conveyor Speed (cm/s)	c Wt. % Solids	b Net Dry Solids (g)	e Transfer Efficiency (%)
14	21"	8	390	184.6	28.21	6.54	10.26	48.77	22.53	39.63
15	21"	8	391	184.9	28.28	6.54	10.23	48.77	22.47	39.44
16	21"	8	393	185.5	28.24	6.57	10.25	48.77	22.41	39.02
17	21	8	393	186.4	28.42	6.56	10.19	48.77	22.46	39.17
18	21	8	393	186.4	28.44	6.55	10.18	48.77	22.44	39.10
19	21	8	388	185.0	28.56	6.48	10.14	48.77	21.98	38.56

DB -

(TB)

$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$

Data By: ____________ Data Checked By:

Date: 10-2-85

DATA SHEET 4

Electrostatic

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Pressure at Gun Atom. Air	Operating Voltage (kV)	Operating Current (μA)	Temperature (°C) Booth	Temperature (°C) Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Control Panel Pressures Atom. Air	Control Panel Pressures Paint Pot	Air Flow (acfm)
8	C-1336	43-48	10	20	74	10	23.3	22.8	55.9	44	100	45	30	72
9	C-1336	49-54	10	20	74	10	23.3	22.8	55.9	44	89	42	28	71
10	C-1336	55-60	9.75	20	74	25	23.3	22.8	55.9	44	88	44	28	72
11	C-1336	61-66	10.0	20	74	25	22.1	22.8	55.9	44	90	45	30	71
12	C-1336	67-72	9.75	20	74	24	22.7	22.8	55.9	44	87	44	29	71
13	C-1336	73-78	10.0	20	74	24.5	22.7	22.8	55.9	44	89	45	27.8	71

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g)	Fluid Mass Flow Time (s)	a Rate (g/s)	d Conveyor Speed (cm/s)	c Wt. % Solids	b Net Dry Solids (g)	e Transfer Efficiency (%)
8	24"	8	423	204.6	28.88	7.08	10.02	48.77	43.32	68.79
9	24	8	400	192.2	29.48	6.52	9.82	48.77	42.19	71.17
10	24	8	380	187.8	29.02	6.47	9.98	48.77	40.62	70.23
11	24	8	389	187.0	28.71	6.51	10.08	48.77	40.78	70.72
12	24	8	391	186.6	28.66	6.51	10.10	48.77	[illegible]	72.55
13	24	8	391	186.0	28.44	6.54	10.18	48.77	41.03	71.60

mean = 70.85
s = 1.30

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

Data By: ___________ Data Checked By:

LABORATORY 5

DATA SHEET 4 Airless

Run No.	Gun No.	Pail No.'s	Pressure at Gun Fluid	Atom. Air	Operating Voltage (kV)	Current ( )	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Atom. Air	Paint Pot	Air Flow (scfm)
1	60865	1-6	1825	NA			25.0							
2	"	7-12	1825	NA			25.0							
3	"	13-18	1840	NA			25.0							
4	"	19-24	1830	NA			25.0							
5	"	25-~~30~~	1825	NA			25.0							
6	"	31-36	1828	NA			25.1							

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g) f	Time (s)	a Rate (g/s)	b Conveyor Speed (cm/s)	c Wt. % Solids	d Net Dry Solids (g)	e Transfer Efficiency (%)
1	8"	6	590	139.5	14.18	9.84	20.42	58.94	20.70	39.~~86~~ 96
2	8"	8		139.3	14.08	9.89	20.56	58.94	21.82	42.~~08~~ 18
3	8"	11		143.7	14.81	9.70	19.55	58.94	20.60	38.~~51~~ 55
4	8"	8		131.6	13.24	9.94	21.87	58.94	17.73	36.492
5	8"	8		139.1	13.62	10.21	21.26	58.44	18.40	35.53
10	8"	8		136.2	12.87	10.58	22.50	58.94	18.49	36.~~47~~ 45

$\bar{X} = 38.107$
$s = 2.534$

$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$

or $e = 15,833\left(\frac{d}{c \times f}\right)$

Data By: DJH/DEB Data Checked By: DEB/DJH

Conventional (Electrostatic make up) Run 4

Date: 1 24 85

DATA SHEET 4

Data By: OGS

Data Checked By: JSD

? JSD

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Pressure at Gun Atom. Air	Operating Voltage (kV)	Operating Current ( )	Temperature (°C) Booth	Temperature (°C) Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Control Panel Pressures Atom. Air	Control Panel Pressures Paint Pot	Air Flow (scfm)
13	C1320	73-78			N/A				120		150	42	28.5	39
Electostatic → 14	C1320	78-84			N/A				120		132	42	38.6	39
15	C1320	85-90			N/A				121		123	42	38.8	39
VOID 16	C1320	91-96			N/A				121		150	42	38.8	39
VOID 17	C1320	97-102			N/A				120		117	42	28.8	39
VOID 18	C1320	103-108			N/A				121				~~27.70~~ 28.5	

E-52

7/19/85 JSD

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g) F	Fluid Mass Flow Time (s)	Fluid Mass Flow Rate (g/s) A	Conveyor Speed (cm/s) B	Wt. % Solids C	Net Dry Solids (g) D	Transfer Efficiency (%) E
13	17	6	396	188.0	28.45	~~20.32~~ 6.61	10.18	51.46	21.55	34.98
Electrostatic → 14	16.5	10	392.6	183.4	28.11	6.52	10.30	51.96	41.78	69.42 ← Electrostatic
15	17	9	392.6	183.9	28.10	6.54	10.30	51.96	21.53	35.67
VOID 18	17	9		189.2	28.90	6.55	10.02	51.96		
VOID 17	17	9		182.7	27.84	6.56	10.40	51.96		
VOID 16	17	11		183.2	27.70	6.61	10.45	51.96	~~21.53~~ 21.38	35.56

?c JSD

DATA SHEET 4

Run No.	Gun No.	Roll No.'s	Pressure at Gun: Fluid	Atom. Air	Operating: Voltage (kV)	Current	Temperature (°C): Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures: Supply Air	Atom. Air	Paint Pot	Air Flow (scfm)
19	C1320	109-114							120		122	42	38.8	39
* 16	C1320	91-96							121		150	42	38.8	39
* 17	C1320	97-102							120		140	42	38.8	39
* 18	C1320	103-108							121		117	42	28.8	39
													* → number transposal 38.8	

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s) a	Fluid Mass Flow: Total Mass (g) f	Time (s)	Rate (g/s) A	b Conveyor Speed (cm/s)	c Wt. % Solids	d Net Dry Solids (g)	e Transfer Efficiency (%)
19		10		189.2	28.91	6.54	10.02	51.96	21.91	35.293
* 16		11	396.8	183.2	27.70	6.61	10.45	51.96	21.38	35.56
* 17 ~~18~~		10	392.8	189.2	28.90	6.55	10.02	51.96	21.21	34.162
* 18		9	393.757	182.7	27.84	6.56	10.40	51.96	21.74	36.263

mean 35.3

SD 0.72

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right) \text{ or } 15{,}833\left(\frac{d}{c \times f}\right)$$

Data By: [signature] Data Checked By:

Electostatic

DATA SHEET 4

Run No.	Gun No.	Foil No.'s	Pressure at Gun: Fluid	Pressure at Gun: Atom. Air	Operating Voltage (kV)	Operating Current	Temperature (°C): Booth	Temperature (°C): Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures: Supply Air	Control Panel Pressures: Atom. Air	Control Panel Pressures: Paint Pot	Air Flow (acfm)
7	C1320	37-42	10	20	74	25			120 fpm		145	42	28.5	39
8	C1320	43-48	10	20	74	25			120		~~145~~	42	28.5	39
9	C1320	49-54	10	20	74	25			120		130	42	28.8	39
10	C1320	55-60	10	20	74	25			120		130	42	28.6	39
~~11~~	~~C1320~~	~~61-66~~	~~10~~	~~20~~	~~74~~				~~000~~		~~117~~	~~42~~	~~28.6~~	~~39~~
12	C1320	67-72	10	20	74	25			120		123	42	28.00	39

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow: Total Mass (g) f	Fluid Mass Flow: Time (s)	A Rate (g/s)	b Conveyor Speed (cm/s)	c Wt. % Solids	d Net Dry Solids (g)	e Transfer Efficiency (%)
7	21	9	405.75 ~~180.9~~	310H 180.9	26.75	6.76	10.82	51.96	41.89	70.566
8	21	8	400.79	185.9	27.83	6.68	10.40	51.96	40.96	67.14
9	21	8	385.75	183.3	28.51	6.43	10.16	51.96	41.44	68.89 (9)
10	21	10	387.6	183.8	28.45	6.46	10.18	51.96	41.42	68.67
VOID ~~11~~	~~21~~	~~9~~	VOID	~~183.7~~	~~28.04~~	~~6.55~~	~~10.33~~	~~51.96~~	~~46.53~~	~~77.18~~ fan off VOID
12	21	11	397.8	185.0	27.90	6.63	10.38	51.96	42.30	69.67

$\bar{x} = 69.05$

$s = 1.15$

69.4

$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$

or $e = 15{,}833\left(\frac{d}{c \times f}\right)$

Data By: DEH/NSH

Data Checked By: DSH/DEB

LABORATORY 6

DATA SHEET 4

Airless

Run No.	Gun No.	Foil No.'s	Pressure at Gun: Fluid	Pressure at Gun: Atom. Air	Operating: Voltage (kV)	Operating: Current	Temperature (°C): Booth	Temperature (°C): Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures: Supply Air	Control Panel Pressures: Atom. Air	Control Panel Pressures: Paint Pot	Air Flow (acfm)
1	60838	1–6	1850	NA	NA	NA	28.8	28.8	55.88	70%	NA	NA	NA	NA
2	60838	7–12	1850	NA	NA	NA	28.8	28.8	55.88	70%	NA	NA	NA	NA
3	60838	13–18	1850	NA	NA	NA	28.8	28.8	55.88	70%	NA	NA	NA	NA
4	60838	19–24	1850	NA	NA	NA	28.8	28.8	55.88	70%	NA	NA	NA	NA
5	60838	25–30	1850	NA	NA	NA	28.8	28.8	55.88	70%	NA	NA	NA	NA
6	60838	31–36	1850	NA	NA	NA	28.8	28.8	55.88	70%	NA	NA	NA	NA

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/min)	Fluid Mass Flow: Total Mass (g)	Fluid Mass Flow: Time (s)	a Rate (g/s)	b Conveyor Speed (cm/s)	c Wt. % Solids	d Net Dry Solids (g)	e Transfer Efficiency (%)
1	8"	7.0	509	120.3	14.29	8.42 ~~505.14~~	20.26	55.38	18.15 ~~55.38~~	43.12
2	8"	9.0	515	120.1	14.19	8.46	20.40	55.38	18.22 ~~55.38~~	43.38
3	8"	9.0	510	121.6	14.29	8.51	20.26	55.38	17.93 ~~55.38~~	42.14
4	8"	9.0	509	126.5	14.91	8.48	19.42	55.38	~~19.578~~ ~~55.38~~	42.76 ~~44.25~~
5	8"	9.0	508	121.9	14.40	8.46	20.11	55.38	18.12 ~~55.38~~	42.57
6	8"	8	510	122.6	14.47	8.51	20.01	55.38	18.81 ~~55.38~~	43.67

~~$\bar{X} = 43.18$~~ 43.2

~~$S = 0.76$~~ 0.74

DA

$\bar{X} = 42.9$

$S = 0.59$

$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$

or $= 15,833\left(\frac{d}{c \times f}\right)$

Data By: DAH   Data Checked By: DAH

E-56

DATA SHEET 4 *Electrostatic*

Run No.	Gun No.	Pail No.'s	Pressure at Gun Fluid	Atom. Air	Operating Voltage (kV)	Current (µA)	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Atom. Air	Paint Pot	Air Flow (scfm)
7	C-1356	37-42	10	20	74	20	28.8	28.8	55.88	45%	95	47	27	68
8	C-1356	43-48	10	20	74	20	28.8	28.8	55.88	45%	99	47	27	68
9	"	49-54	10	20	74	20	28.8	28.8	55.88	45%	105	44	27	68
10	"	55-60	10	20	74	20	28.8	28.8	55.88	45%	95	44	27	68
11	"	61-66	10	20	74	20	28.8	28.8	55.88	45%	89	44	27	68
12	"	67-72	10	20	74	20	28.8	28.8	55.88	45%	100	44	27	68

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow Total Mass (g) f	Time (s)	(a) Rate (g/s)	b Conveyor Speed (cm/s)	c Wt. % Solids	d Net Dry Solids (g)	e Transfer Efficiency (%)
7	26"	7	380	184.7	29.15	6.34	9.93	53.0	43.55	70.~~3~~4 7
8	26	7	375	181.3	29.06	6.23	9.96	53.0	43.21	71.~~2~~3 7
9	26	7	373	179.8	28.89	6.22	10.02	53.0	43.19	71.~~7~~8 8
10	26	7	369	178.4	28.97	6.16	10.00	53.0	42.57	71.30
11	26	7	367	175.8	28.73	6.12	10.08	53.0	43.93	74.65
12	26	7	376	181.5	28.94	6.27	10.00	53.0	42.08	69.24

~~71.4~~

$\bar{X} = 71.\cancel{44}5$

~~1.80~~

$S = \cancel{1.81}$ 1.84

$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$

or $15{,}833\left(\frac{d}{c \times f}\right)$

Data By: DSH   Data Checked By: DLH.

11-6-85

DATA SHEET 4

Conventional

Run No.	Gun No.	Foil No.'s	Pressure at Gun: Fluid	Pressure at Gun: Atom. Air	Operating: Voltage (kV)	Operating: Current	Temperature (°C): Booth	Temperature (°C): Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures: Supply Air	Control Panel Pressures: Atom. Air	Control Panel Pressures: Paint Pot	Air Flow (acfm)
13	C-1356	73-78	10	20	NA	NA	28.8	28.8	55.88	45	97	44	26.5	68
14	"	79-84	10	20	NA	NA	28.8	28.8	55.88	45	95	44	26.5	68
15	"	85-90	10	20	NA	NA	28.8	28.8	55.88	45	100	44	26.5	68
16	"	91-96	10	20	NA	NA	28.8	28.8	55.88	45	95	44	26.5	68
17	"	97-102	10	20	NA	NA	28.8	28.8	55.88	45	95	44	26.5	68
18	"	103-108	10	20	NA	NA	28.8	28.8	55.88	45	101	44	26.5	68

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s)	Fluid Mass Flow: Total Mass (g) f	Fluid Mass Flow: Time (s)	a Rate (g/s)	b Conveyor Speed (cm/s)	c Wt. % Solids	d Net Dry Solids (g)	e Transfer Efficiency (%)
13	25	5	371	176.8	28.58	6.19	10.13	52.63	18.28	31.~~08~~ 1
14	25	6	367	175.1	28.64	6.11	10.11	52.63	18.13	31.~~17~~ 2
15	25	6	371	176.7	28.56	6.19	10.14	52.63	18.70	31.83
14	25	7	366	174.6	28.66	6.09	10.10	52.63	17.91	30.~~86~~ 9
17	25	7	354	168.9	28.59	5.91	10.13	52.63	17.22	30.~~66~~ 7
18	25	7	362	174.3	28.86	6.04	10.03	52.63	17.67	30.~~48~~ 5

31.0

$\bar{X}$ = 31.0%

~~.458~~

S = ~~.475~~ 0.45

$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$ or $e = 15{,}833\left(\frac{d}{a \times c}\right)$

Data By: DSH

Data Checked By: DSH

1522

LABORATORY 7

DATA SHEET 4

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Atom. Air	Operating Voltage (kV)	Current	Temperature (°C) Booth	Fluid	DH Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Atom. Air	Paint Pot	Air Flow (acfm)
1	61449	1-6	1825	NA	NA	NA	22.7	23.9	55.88 ~~4.66~~	65.5	NA	NA	NA	NA
2		7-12	1825		NA		22.7	23.9	55.88 ~~4.66~~	65.5				
3		13-18	1825		NA		22.7	23.9	55.88 ~~4.66~~	65.5				
4		19-24	1825		NA		22.7	23.7	55.88 ~~4.66~~	65.5				
5	DH	31-36 ~~25-30~~	1825		NA		22.7	23.9	55.88 ~~4.66~~	65.5				
6	DH 61449	37-42 ~~31-36~~	1825		NA		22.7	23.9	55.88 ~~4.66~~	65.5				

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/min) a	Fluid Mass Flow Total Mass (g) f	Time (s)	a Rate (g/s)	b Conveyor Speed (cm/s)	c Wt. % Solids	d Net Dry Solids (g)	e Transfer Efficiency (%)
1	7	7	489	127.4	13.98	9.11	20.73 ~~28.15~~	56.27	13.62	30.08
2	7	7	535	124.7	13.97	8.93	20.73	56.27	13.27	29.94
3	7	7	539	125.1	13.92	8.99	20.80	56.27	13.13	29.53
4	7	7	539	125.4	13.96	8.98	20.74	56.27	13.61	30.54
5	7	8	531	123.5	13.94	8.86	20.77	56.27	13.23	30.13
6	7	7	535	123.5	13.85	8.92	20.91	56.27	13.46	30.67

$\bar{X} = 30.15$

$\bar{s} = .413$

$^*e = 54.68\left(\frac{b \times d}{a \times c}\right)$ or $= 15,833\left(\frac{d}{c \times f}\right)$

Data By: ____________ Data Checked By:

E-61

DATA SHEET 4

Run No.	Gun No.	Foil No.'s	Pressure at Gun: Fluid	Pressure at Gun: Atom. Air	Operating Voltage (kV)	Operating Current (μa)	Temperature (°C): Booth	Temperature (°C): Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures: Supply Air	Control Panel Pressures: Atom. Air	Control Panel Pressures: Paint Pot	Air Flow (acfm)
7	C-1382	43-48	10	20	74	20	24.4	23.9	55.88 ~~14.~~	71	105	48	38.5	44
8		49-54	10	20	74	20	24.4	23.9	55.88	71	110	49	38.5	44
9		55-60	10	20	74	20	24.4	23.9	55.88	71	110	49	38.5	44
10		61-66	10	20	74	20	24.4	23.9	55.88	71	110	49	38.5	44
11		67-72	10	20	74	20	24.4	23.9	55.88	71	108	49	38.5	44
12		73-78	10	20	74	20	24.4	23.9	55.88	71	108	49	38.5	44

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s) a	Fluid Mass Flow: Total Mass (g) f	Fluid Mass Flow: Time (s)	Fluid Mass Flow: Rate (g/s)	b Conveyor Speed (cm/s)	c Wt. % Solids	d Net Dry Solids (g)	e Transfer Efficiency (%)*
7	20	6	386	206.9	32.16	6.43	JH 9.00 ~~6.43~~	51.36	33.80	50.36
8	20	6	381	203.7	32.07	6.35	9.03	51.36	34.45	52.14
9	20	6	383	205.7	32.24	6.38	8.98	51.36	34.18	51.22
10	20	6	383	204.1	32.06	6.38	9.03	51.36	33.43	50.34
11	20	6	381	203.0	31.97	6.35	9.06	51.36	35.87	54.47 PB
12	20	6	383	204.3	32.04	6.38	9.04	51.36	36.22	54.65

52.20
51.98
51.78
52.71
2.35 (-)
1.94 (+)
1.83

$$^{*}e = 54.68\left(\frac{b \times d}{a \times c}\right) \text{ or } 15{,}833\left(\frac{d}{c \times f}\right)$$

Data By: ____________ Data Checked By:

DATA SHEET 4

Run No.	Gun No.	Foil No.'s	Pressure at Gun Fluid	Atom. Air	Operating Voltage (kV)	Current	Temperature (°C) Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures Supply Air	Atom. Air	Paint Pot	Air Flow (acfm)
13	C-1382	79-84	10	20	NA	NA	23.3		55.88	77	108	49	28.2	44
14		85-90	10	20			23.3			77	108	49	28.2	44
15		91-96	10	20			23.3			77	108	49	28.2	44
16		97-102	10	20			23.3			77	108	49	28.2	44
17		103-108	10	20			23.3			77	108	49	28.2	44
18		109-124	10	20			23.3			77	108	49	28.2	44

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate a	Fluid Mass Flow Total Mass (g) f	Time (s)	Rate (g/s)	b Conveyor Speed (cm/s)	c Wt. % Solids	d Net Dry Solids (g)	e Transfer Efficiency (%)
13	22.5	6	389	213.4	32.84	6.50	8.82	50.55	18.82	27.62
14	22.5	6	396	215.3	32.64	6.60	8.87	50.55	19.08	27.76
15	22.5	6	398	216.8	32.68	6.63	8.86	50.55	20.06	28.98
16	22.5	6	403	217.5	32.40	6.71	8.94	50.55	19.85	28.5[illegible]
17	22.5	6	403	219.9	32.71	6.72	8.85	50.55	19.06	27.15
18	22.5	6	405	219.4	32.52	6.75	8.90	50.55	19.54	27.90

Data By:____________ Data Checked By:

$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$ or $e = 15,833\,(\underline{\ d\ })$

LABORATORY 8

96.5 : 61 ~~60.9~~
uni'r conv.
.508

airless

DATA SHEET 4

Run No.	Gun No.	Pail No.'s	Pressure at Gun: Fluid	Pressure at Gun: Atom. Air	Operating Voltage (kV)	Operating Current	Temperature (C) Booth	Temperature (C) Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures: Supply Air	Control Panel Pressures: Atom. Air	Control Panel Pressures: Paint Pot	Air Flow (scfm)
1	61644	1-6	1825	NA	NA	NA	~~23.8~~ 75°	75°	190-120 fpm	21% *	NA	NA	NA	NA ← 60°deg some panels fel
2	61644	7-12	1825				"	"	"	42%				← gun spit some
3	61644	13-18	1825				"	"	"	(34%)				
4	61644	19-24	1825				75	75	"	25%				
5	61644	25-30	1825				"	"	"	—				
6	61644	31-36	(read) 1825				75°	~~73~~	"	25%				

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s) a	Fluid Mass Flow: Total Mass (g) f	Time (s)	Rate (g/s)	b Conveyor Speed (cm/s)	c Wt. % Solids	d Net Dry Solids (g)	e Transfer Efficiency (%)
1	7"	9	500	125.3	15.12	8.28	20.32 cm/s ~~40 fpm~~	56.82	21.94	48.8
2	7"	9	502	127.4	—	—	"	56.82	21.27	46.5
3	7	9	502	124.7	15.02	8.30	"	56.82	21.80	48.7
4	7	9	502	124.9	1.1	8.46	"	56.82	21.37	47.7
5	7	9	512	126.6	—	—	"	56.82	21.89	48.2
6	7	9	526	133.3	15.37	8.67	"	56.82	21.15	44.2

m = 47.4
s = 1.76

Humidity *Bad?

$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$ or ___ $= 15,833\,(d\ ...)$

Data By: LCK DH DB

Data Checked By:

E-64

Conventional
Electrostatic

DATA SHEET 4

Run No.	Gun No.	Roll No.'s	Pressure at Gun: Fluid	Pressure at Gun: Atom. Air	Operating: Voltage (kV)	Operating: Current	Temperature (°C): Booth	Temperature (°C): Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures: Supply Air	Control Panel Pressures: Atom. Air	Control Panel Pressures: Paint Pot	Air Flow (scfm)
* ~~8~~	C-1290	43-48 ~~37-42~~	10	20	74	30	67°F ~~67~~	65		60	84	43	12	68
* 9 8	C-1290	49-54 43-48	10	20	74	30	67	65		60	84	43	12	68
* ~~9~~	C-1290	37-42 49-54	10	20	74	30	67	65		60	84	43	12	69
10	C-1290	55-60	10	20	74	30	67	65		60	80	42	11.6	69
11	C-1290	61-66	10	20	74	30	67	65		60	80	42	12	70
12	C-1290	67-72	10	20	74	30	67	65		46	82	42	12	

E-65

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s) a	Fluid Mass Flow: Total Mass (g) f	Time (s)	Rate (g/s)	b Conveyor Speed (cm/s)	c Wt. % Solids	d Net Dry Solids (g)	e Transfer Efficiency (%)	
7	17	10	206	110.9				47.00	~~21.64~~ 21.82	~~65.73~~	66.28
8	17	9	199	100.0				47.00	~~21.82~~ 20.75	~~66.02~~ 73.51	69.90
9	17	9	205	107.2				47.00	~~20.75~~ 21.64	~~65.21~~	68.00
10	17	9	202	103.7				47.00	~~22.16~~ 22.16	~~66.71~~ 71.99	71.99
11	17	9	200	111.9				47.00	22.82	68.70	
12	17	9	200	107.1				47.00	21.96	69.07	

wrong colors added see *

68.99
S = 1.91
Dm = 3

(Average 68.99)
R = 1.76

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right) \text{ or } 15{,}833\left(\frac{d}{c \times f}\right)$$

Data By: [illegible] Data Checked By: [illegible]

Conventional

DATA SHEET 4

Run No.	Gun No.	Foil No.'s	Pressure at Gun: Fluid	Atom. Air	Operating: Voltage (kV)	Current	Temperature (°C): Booth	Fluid	Booth Air Rate (cm/s)	Relative Humidity	Control Panel Pressures: Supply Air	Atom. Air	Paint Pot	Air Flow (scfm)
13	C-1290	73-78	10	18	—	—	72				80	40	23	69
14	C-1290	79-84	10	18	—	—	72				81	42	23.8	69
15	C-1290	85-90	10	18	—	—	72				81	42	23	69
16	C-1290	91-96	10	18	—	—	74				90	41	23	69
17	C-1290	97-102	10	18	—	—	74				80	40	23	69
18	C-1290	103-108	10	18	—	—	74				81	41	22.5	69

Dm. 1.28

Run No.	Vert. Coverage	Thick. Wet Film (mils)	Meter Flow Rate (g/s) a	Fluid Mass Flow: Total Mass (g) f	Time (s)	Rate (g/s)	b Conveyor Speed (cm/s)	c Wt. % Solids	d Net Dry Solids (g)	e Transfer Efficiency (%)	
13	12	9	334	191.6				47.45		22.77	39.65
14	12	9	358	178.2						20.44	38.27
15	12	9	345	182.2						20.44	~~37~~ 38.43
16	12	9	339	179.0						20.66	38.51
17	12	9	353	181.6						21.69	39.85
18	12	9	355	180.8					20.90	38.57	

$\bar{x}$ 38.71
s = .903
R = 1.59

$$*e = 54.68\left(\frac{b \times d}{a \times c}\right)$$

or $e = 15{,}833\left(\frac{d}{\ }\right)$

Data By: DSH/DB Data Checked By: DB

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-88-026b	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Development of Proposed Standard Test Method for Spray Painting Transfer Efficiency; Volume II. Verification Program		5. REPORT DATE April 1988 6. PERFORMING ORGANIZATION CODE
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15. SUPPLEMENTARY NOTES AEERL project officer is Charles H. Darvin, Mail Drop 62b, 919/541-7633. Volume I describes laboratory development of the method.

16. ABSTRACT The two-volume report gives results of a program to develop and verify a standardized spray-painting transfer-efficiency test method. Both review of the literature and laboratory research were conducted. Transfer efficiency measurement methods presently used by industry were evaluated and compared. The best characteristics of these methods were incorporated into the final proposed standard method. The resulting method was determined to be viable for laboratory evaluations. It still awaits adaptation and verification for production line applications.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Spray Painting	Stationary Sources	13H
Tests	Transfer Efficiency	14B

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