AN ASSESSMENT OF INTERLABORATORY REPEATABILITY IN FENESTRATION ENERGY RATINGS—PART 2: INTERLABORATORY COMPARISON OF TEST RESULTS

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ABSTRACT

This paper presents the results from the first interlaboratory comparison (round-robin) of fenestration thermal transmission ratings (U-factors) acquired in accordance with NFRC 100-91^{SM}: Procedure for Determining Fenestration Product Thermal Properties. *The round-robin involved 10 thermal testing laboratories and 12 simulation laboratories. This paper presents only the results from the test laboratory round-robin. A second paper presents the results from the simulation laboratory round-robin.*

Two different products were evaluated. One product was an aluminum-framed horizontal sliding window incorporating an insulating glass unit constructed of two lites of clear glass separated by an air space of 0.55 inches. The other product was a calibration transfer standard (CTS) panel constructed of homogeneous polystyrene and sandwiched between two layers of polycarbonate facing. The CTS panel was constructed to exacting specifications and designed for traceability to standard reference materials tested at a national laboratory.

The results of the round-robin show fairly good agreement among laboratories for the window specimen. Specific components of the reported data are analyzed to identify areas for laboratory improvement and test method training in future NFRC laboratory workshops. Surface temperature measurement and wind-speed calibration have been identified as two specific areas for improvement. Recommendations for improving the test method for better standardization among laboratories are provided. Recommendations for future interlaboratory round-robin designs are provided.

BACKGROUND

The National Fenestration Rating Council (NFRC) conducts annual interlaboratory round-robin evaluations as part of its Laboratory Accreditation Program (LAP) for NFRC-accredited simulation and testing laboratories. This report presents the findings of the 1994 round-robin of all NFRC-accredited testing laboratories.

A total of 10 different thermal testing laboratories participated in the first testing round-robin. Nine of the 10 testing laboratories were accredited by the NFRC to conduct thermal performance testing using *NFRC 100-91^{SM}: Procedure for Determining Fenestration Product Thermal Properties (Currently Limited to U-Values)* and *Attachment A: Interim Standard Test Method for Measuring the Steady-State Thermal Transmittance of Fenestration Systems Using Hot Box Methods.* The remaining laboratory, that of the National Research Council of Canada (NRC), tested the sample window to a different test standard, *DBR's Approach for Determining the Heat Transmission Characteristics of Windows*, by R.P. Bowen (1985). NRC Canada's test results were used for comparative purposes and are not included in the data analysis of the nine NFRC-accredited laboratories using NFRC procedures.

Round-robin testing was carried out in two phases. The first phase had each of the laboratories conduct thermal performance tests on an aluminum horizontal sliding window with a nonthermally broken aluminum frame and clear glazing. (The second phase involved testing a calibrated transfer standard traceable to the National Institute of Standards and Technology (NIST), the results of which will be reported in a future paper.) The test window also was one of the windows used for the first interlaboratory round-robin of NFRC-accredited simulation laboratories. Each participating testing laboratory received the same specimen to be tested for thermal transmittance, shipped to each testing facility via a common freight carrier. Every laboratory was directed to keep all test results confidential. All questions pertaining to the testing round-robin were to be directed to NFRC staff only. The testing began in March 1994 and was completed in August 1994.

Laboratories were required to present thermal transmittance (U-factor) data using three different analytical techniques—U_s (the air-to-air measured U-factor), $U_{s l[AW]}$

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(the area-weighted calculation approach referred to as method A), and $U_{st[CTS]}$ (referred to as method B, which uses calibration data from the CTS specimen). The results of each thermal test performed were reviewed and placed in a spreadsheet for analysis and comparison of data. ASTM E691, *Interlaboratory Data Analysis Software*, was used to determine a level of statistical agreement for several sets of reported data from the participating laboratories.

TESTING METHODS

NFRC-Accredited Laboratories

NFRC 100-91: Procedure for Determining Fenestration Product Thermal Properties (Currently Limited to U-Values) and *Attachment A (Mandatory Information), Interim Standard Test Method for Measuring the Steady-State Thermal Transmittance of Fenestration Systems Using Hot Box Methods.*

NRC Canada

DBR's Approach for Determining the Heat Transmission Characteristics of Windows by R.P. Bowen (1985).

TERMINOLOGY

For the purposes of this paper, the following terms are used.

U-factor—thermal transmittance in Btu/h·ft^2·°F.

U_s—the measured air-to-air (nonstandardized) U-factor in Btu/h·ft^2·°F. This value is dependent on each laboratory's ability to control temperature and environmental conditions to near standard conditions during testing.

$U_{st[AW]}$—the area-weighted calculation approach for standardizing U-factor reporting, referred to as method A. Assigns areas to each surface temperature measurement to calculate interior and exterior film coefficients.

$U_{st[CTS]}$—the calculation approach for standardizing U-factor reporting based on temperature and film coefficient data from chamber calibration with a CTS panel.

PLANNING AND SCHEDULES FOR ROUND-ROBIN TESTING

Each NFRC-accredited testing laboratory was notified by letter explaining the details of the round-robin testing prior to the actual start of physical testing. A test schedule was established and each laboratory was assigned a specific set of dates for testing. A schedule was established for preliminary data submittals and issuance of final reports to NFRC.

REPORTING AND INFORMATION MATERIALS

Standardized report forms were developed for use by all participants to help ensure accuracy and uniformity in data reporting and subsequent analysis. Laboratories were invited to provide any other supporting materials and information that were deemed useful to the round-robin.

Each testing laboratory was provided a set of identical product drawings and bills of materials for use in the data calculation and report generation.

TEST SAMPLE DESCRIPTION

The first test specimen was a typical residential horizontal sliding window constructed of a nonthermally broken aluminum frame and double-glazed with clear insulating glass and an air space of 0.55 in. The test specimen was supplied by a manufacturer currently enrolled in the NFRC Product Certification Program, with this particular product having completed the NFRC validation process. This means the product was previously simulated and tested by NFRC-accredited laboratories, with each individual report submitted to an independent certification and inspection agency (IA) for validation.

This product also was well characterized through its use in the NFRC simulation round-robin. A total of 18 NFRC-accredited simulators modeled the window specimen, as required under the LAP, using exacting specifications. The average simulated U-factor of the test specimen was 0.72 Btu/h·ft^2·°F, with a range from 0.70 Btu/h·ft^2·°F to 0.73 Btu/h·ft^2·°F, and a standard deviation of 0.006. (See related paper for details concerning the simulation round-robin.)

CONFIDENTIALITY

All participating testing laboratories were directed to keep all testing files, questions, correspondence, and any other issue relating to the round-robin thermal tests confidential. Any and all correspondence was to be directed to NFRC staff only.

TEST SPECIMEN CONTROL PROCEDURES

The window test specimen was shipped from one testing facility to another using several different modes of transportation. Each laboratory was instructed to keep a record of the condition of the test specimen upon arrival at its facility and prior to shipment. Upon arrival at its final destination, the window was in good condition with no apparent damage to any component.

REPORTED RESULTS AND DATA ANALYSIS

Table 1 shows the three U-factors reported by each participating NFRC-accredited laboratory. These results are shown compared to the simulated results of the identical product from the NFRC simulation round-robin. The simulated U-factor of the test specimen from the simulated round-robin was 0.72, with a standard deviation of 0.006.

The results from NRC Canada are not reported in the same manner as the results from the nine NFRC-accred-

TABLE 1 Test Round-Robin Results

Laboratory	Reported U-Factors Btu/h·ft²·°F U_s	$U_{st(AW)}$	$U_{st(CTS)}$	Percent difference from simulated U-Factor of 0.72 U_s	$U_{st(AW)}$	$U_{st(CTS)}$
1	0.68	0.69	0.69	−5.5	−4.2	−4.2
2	0.64	0.60	0.61	−11.1	−16.7	−15.3
3	0.72	0.73	0.69	0.0	1.4	−4.2
4	0.71	0.63	0.69	−1.4	−12.7	−4.2
5	0.71	0.65	0.71	−1.4	−9.7	−1.4
6	0.85	0.67	0.67	18.0	−6.9	−6.9
7	0.70	0.71	0.68	−2.8	−1.4	−5.5
8	0.71	0.68	0.65	−1.4	−5.5	−9.7
9	0.64	0.60	0.64	−11.1	−16.7	−11.1
Average:	0.71	0.66	0.67	−1.4%	−8.3	−6.9
High:	0.85	0.73	0.71	18.0%	1.4	−1.4
Low:	0.64	0.60	0.61	−11.1%	−16.7	−15.3
Std. Deviation:	0.062	0.046	0.035			

ited testing laboratories. NRC Canada reports what it terms as a "design coefficient of heat transmission through the test specimen" (U_D). This value is equivalent to the standardized thermal transmittance (U_{st}) as derived in NFRC Attachment A. The "design U-factor" (U_D) reported by NRC Canada was 0.68 Btu/h·ft²·°F. This value is within 6% of the reported simulated U-factor of the test product, 0.72 Btu/h·ft²·°F, as derived from the average U-factor of 18 simulators. Although the calculational methods employed to derive a standardized U-factor are different, the reported standardized U-factor from NRC Canada still shows good agreement with the simulated U-factor from the simulation round-robin, as well as the reported U_{st} values from those laboratories that met the validation criteria stipulated in NFRC 100-91.

Statistical analysis for each NFRC-accredited testing laboratory of the round-robin test data U-factor results were performed using ASTM E-691 procedures. While this data set is too small for conclusive summation, several important observations that can be made are reported herein. Recommendations for future round-robins and laboratory investigations also are made.

ANALYSIS OF OTHER REPORTED TEST DATA

Additional analyses were conducted on a variety of reported data. These analyses allowed further investigation of possible sources of error and helped to identify specific measurements or procedures that might need improvements at each laboratory.

Heat Flows

Each laboratory was requested to provide data for five different categories pertaining to total power measurement and heat loss attributes. Total power measurement (Q_{total}) varied from each laboratory. This would be expected because of the differing design characteristics of each thermal chamber test facility. The surround panel and metering box wall heat flows also are variable due to construction techniques, materials used, and overall area of the surround panel exposed to the metering chamber.

TABLE 2 Net Specimen Heat Loss Reported

Laboratory	Net Specimen Heat Loss Reported (Q) Btu/h	Percent Difference From the Average Reported for all Labs	Percent Difference from Q Derived from Simulated Value
1	1125.80	−3.6%	−5.5%
2	1051.26	−10.0%	−11.7%
3	1186.50	1.6%	−0.4%
4	1171.89	0.4%	−1.7%
5	1163.79	−0.3%	−2.3%
6	1405.50	20.4%	18.0%
7	1159.12	−0.7%	−2.7%
8	1196.00	2.4%	3.8%
9	1048.87	−10.2%	−12.0%
10	1051.30	−10.0%	−12.0%
Average	1167.64	N/A	−2.0%
High	1405.50	20.4%	18.0%
Low	1048.87	−10.2%	−12.0%
Std. Deviation	104.43		

Four laboratories did not report any flanking loss, the loss attributed to heat loss around the perimeter of the surround panel. These laboratories may have guarded hot boxes, not calibrated hot boxes. At this time, it is unknown if this is true for each of the four labs. For these four laboratories, it is currently assumed that any flanking loss is being contained in the surround panel heat loss. Of the other nine laboratories, the flanking loss (gain) values ranged from −33.30 Btu/h to 210.35 Btu/h. Flanking loss also varies due to chamber design characteristics.

Net specimen heat loss (Q_s) of the specimen, which is the amount of heat flow attributed to the test specimen, should be fairly consistent among laboratories. Table 2 shows the range of reported values for the net specimen heat loss (Q) and the percent variance from the expected value based on the simulated product U-factor of 0.72 Btu/h·ft²·°F.

The range of values reported was from a low of 1048.87 Btu/h to a high of 1405.50 Btu/h, representing a total range of 356.6 Btu/h. The average reported value for net specimen heat flux by all nine laboratories is 1167.64 Btu/h, with a standard deviation of 104.43.

Using the average heat flux reported by all laboratories (Q_{avg}) and dividing by the area of the specimen (23.64 ft²) and the test temperature difference of 70°F, the average U_s of the specimen would calculate to be 0.70 Btu/h·ft²·°F.

Comparing this average value to the simulated value of 0.72 Btu/h·ft^2·°F, a difference of 2.8% is noted.

Product Areas

The area of the specimen was divided into three specific categories: projected area, interior three-dimensional exposed surface area, and exterior three-dimensional exposed surface area.

The reported nominal projected product area from all laboratories, derived from the overall measured width and height of the specimen, had a range from 23.58 ft^2 to 23.80 ft^2, a difference of 0.22 ft^2. The average projected area was 23.64 ft^2. The test specimen was reported to be a nominal 71½ in. wide by 47½ in. high, which is a projected area of 23.58 ft^2. The difference between the nominal specimen interior projected area and the average of the laboratories was less than 1%.

Each participating NFRC-accredited laboratory was required to determine the actual interior and exterior exposed surface areas of the specimen. The interior and exterior exposed areas of the frame of this product are three-dimensional. Two ways of accomplishing this task are by either adding the dimensions on the product extrusion drawings or by taking physical measurements from the test specimen. These areas are then used in method A, or the area-weighting method for determining $U_{st[AW]}$. The glazing surfaces are planar in nature (only two-dimensional). The total interior area, including the three-dimensional frame areas as reported from all laboratories ranged from 25.00 ft^2 to 27.35 ft^2, with an average of 26.39 ft^2. The exterior three-dimensional areas as reported from all laboratories ranged from 25.00 ft^2 to 27.80 ft^2, with an average of 26.64 ft^2.

It appears that a variety of measurement techniques were employed to determine the three-dimensional areas. Other methods of measurement that may have been used include using a tape measure or applying pieces of tape to the contour of the area of the product being measured and measuring the piece of tape after it is removed. There currently is no specifically required method of determining three-dimensional areas.

Test Conditions

All laboratories reporting data were in compliance with the requirements of being within ±0.5°F of the interior ambient temperature of 70.0°F and the exterior ambient temperature of 0.0°F.

The average warm-side baffle surface temperature for each laboratory was recorded on the data information sheets. The warm-side baffle temperatures ranged from a low of 66.60°F to a high of 70.30°F. The current requirement of warm-side baffle temperatures is described on page 21 of Attachment A, Note 11. The warm-side baffle temperature is to be within ±1°F of the interior ambient surface temperature. Four laboratories reported average warm-side baffle temperatures that did not comply with this requirement.

TABLE 3 **Surface Temperature Ranges Reported (°F)**

Surface Location	Low	High	Difference
Area-Weighted Interior	36.16	44.10	7.94
Area-Weighted Exterior	4.50	9.20	4.70
Average Interior Frame	19.85	27.83	7.98
Average Exterior Frame	4.90	11.90	7.00
Average Interior Edge Glass	31.31	48.80	17.49
Average Exterior Edge Glass	2.98	8.10	5.12
Average Interior Center Glass	43.61	51.10	7.49
Average Exterior Center Glass	3.77	8.60	4.83

Surface Temperature Data

Every laboratory reported calculated area-weighted interior and exterior surface temperatures based on surface thermocouple temperature measurements. Table 3 illustrates the ranges reported for all surface temperature data and the difference between the low and high values.

The temperature differences stated in Table 3 indicate that the current methods being employed by some or all of the laboratories to measure surface temperatures are not producing consistent surface temperatures from laboratory to laboratory. Temperature measurements, especially center-of-glass temperatures, varied by 7.5°F. Edge-of-glass temperatures varied by 17.5°F.

The temperature-measuring equipment, calibration practices of the temperature-sensing equipment, type of thermocouple wire being used, convective airflow patterns on the warm side, exterior wind velocities on the cold side, thermocouple placement location on the specimen, or type of tape being used to apply the thermocouples may, in combination or individually, be responsible for the variance in reported surface temperatures.

Calculated Test Data

Method A (Modified) Procedure—Area-Weighted The warm-side and cold-side surface conductances, as well as the surface-to-surface conductance of the test specimen, are calculated from the surface temperature measurements. The warm-side surface conductances (h_i) reported ranged from a low of 1.28 Btu/h·ft^2·°F to a high of 2.00, with the average value being 1.56. The cold-side surface conductances ranged from a low of 4.75 Btu/h·ft^2·°F to a high of 11.40, with the average value being 7.13. The test specimen surface-to-surface conductance reported ranged from a low of 1.29 Btu/h·ft^2·°F to a high of 2.11, with the average of all labs being 1.65 Btu/h·ft^2·°F.

The standardized warm-side surface conductances reported from all participating laboratories ranged from 1.40 to 1.47 Btu/h·ft^2·°F, with an average of 1.42. The ASHRAE standard value is 1.46 Btu/h·ft^2·°F. The

TABLE 4 Convection Coefficient *K* Values Reported

Laboratory	Convection Coefficient Reported (*K*) Btu/h·ft²·°F	Percent Variance from Average *K* Reported
1	0.34	−17.1%
2	0.42	2.4%
3	0.34	−17.1%
4	0.32	−22.0%
5	0.31	−24.4%
6	0.85	107.3%
7	0.32	−22.0%
8	0.47	14.6%
9	0.30	−26.8%
10	N/A	N/A
Average (9)	0.41	
Std. Deviation	0.18	
High	0.85	
Low	0.30	

cold-side surface coefficient reported by all laboratories was the ASHRAE standard value of 5.10 Btu/h·ft²·°F.

The standardized U-factor (U_{st}) results from method A (modified) were reported earlier in this paper.

Method B Results—Equivalent CTS Method The warm-side and cold-side surface film heat transfer coefficients, as well as the surface-to-surface conductance of the test specimen, are calculated from equations found in NFRC 100-91 Attachment A. The actual measured room-side surface coefficients ranged from a low of 1.38 to a high of 2.70, with the average value being 1.65. The actual measured cold-side surface coefficients ranged from a low of 4.45 to a high of 5.53, with the average value being 4.65. The measured test specimen surface-to-surface conductance values ranged from a low of 1.34 to a high of 1.86, with the average of all labs being 1.68.

The standardized U-factor (U_{st}) results from method B (Equivalent CTS Method) were reported earlier in the paper.

The convection constant, *K*, is derived from CTS panel calibration testing (a requirement for NFRC accreditation), which is performed by each NFRC-accredited laboratory. Table 4 shows the range of *K* values reported.

The *K* numbers reported ranged from a low of 0.30 to a high of 0.85. This is a considerable difference for the convection constant. Investigation is needed to determine the cause of this apparent fluctuation in this value. This situation will be addressed in greater detail during the second phase of the 1994 round-robin testing, which involves a nominal 6-ft by 4-ft CTS panel. Determination of *K* values from the CTS panel will be reported in the report of the second phase of the 1994 round-robin.

ADDITIONAL DATA ANALYSIS

Lab 2 reported U-factor results that fall outside the required 10% agreement range for all three reported U-factors, all of which were consistently lower than the simulated value and values reported by the other participating laboratories. Possible areas of investigation include power measurement, surround panel values, flanking loss heat flows, temperature-measuring equipment, exterior airflow patterns, interior airflow patterns, metering box design, etc.

Lab 6 exhibits a rather uncharacteristic phenomenon in that it reports a U_s value of 0.85, the highest of any laboratory, but has U_{st} values from both methods of calculation that validate the simulation number. The *K* (convection constant) value is considerably higher than that of any other lab, 0.85, while the next closest value from any other lab is 0.47. Calibration procedures at this laboratory need to be investigated.

This particular laboratory also reported the highest U_s value (0.85), but also has the highest interior area-weighted surface temperature (44.1°F), the highest center-of-glass temperature (51.1°F), and the highest reported interior surface coefficients for both methods A and B. The reasons for these occurrences need to be investigated before further conclusions can be reached.

Lab 9 also reported all three U-factor results outside the 10% agreement range. All U-factors reported are consistently lower than the simulated value and values reported by the other laboratories. Possible areas of investigation include power measurement, surround panel values, flanking loss heat flows, temperature-measuring equipment, exterior airflow patterns, interior airflow patterns, metering box design, etc.

SUMMARY AND RECOMMENDATIONS

The National Fenestration Rating Council (NFRC) conducts annual interlaboratory round-robin evaluations as part of its Laboratory Accreditation Program (LAP) for NFRC-accredited simulation and testing laboratories. In 1994, 10 different thermal testing laboratories participated in the first testing round-robin.

Round-robin testing was carried out in two phases. The first phase had each of the laboratories conduct thermal performance tests on an aluminum horizontal sliding window with a nonthermally broken aluminum frame and clear glazing. (The second phase involved testing a calibrated transfer standard traceable to NIST, the results of which will be reported in a future paper.) The test window also was one of the windows used for the first interlaboratory round-robin of NFRC-accredited simulation laboratories. Each participating testing laboratory received the same specimen to be tested for thermal transmittance; it was shipped to each testing facility via a common freight carrier. Every laboratory was directed to keep all test results confidential. All questions pertaining to the testing round-robin were to be directed to NFRC staff only. The testing began in March 1994 and was completed in August 1994.

Laboratories were required to present thermal transmittance (U-factor) data using three different analytical techniques—U_s (the air-to-air measured U-factor), $U_{st[AW]}$ (the area-weighted calculation approach referred to as method A), and $U_{st[CTS]}$ (referred to as method B, which uses calibration data from the CTS specimen). Each technique is described later in the report.

The results of each thermal test performed were reviewed and placed in a spreadsheet for analysis and comparison of data. *ASTM E691, Interlaboratory Data Analysis Software*, was used to determine a level of statistical agreement for several sets of reported data from the participating laboratories.

The round-robin results showed U_s values ranging from 0.64 to 0.85 Btu/h·ft²·°F, the largest overall range, with an average of 0.71 Btu/h·ft²·°F and a standard deviation of 0.06. The two standardized U-factor calculation methods employed resulted in $U_{st[AW]}$ values ranging from 0.60 to 0.73 Btu/h·ft²·°F, with an average value of 0.66 and a standard deviation of 0.05; $U_{st[CTS]}$ values ranged from 0.61 to 0.71 Btu/h·ft²·°F, with an average of 0.67 and a standard deviation of 0.03. These results also were compared to the results from the NFRC simulation round-robin for the same specimen, which showed a predicted U-factor of 0.72 with a standard deviation of 0.006.

To the authors' knowledge, this interlaboratory round-robin investigation is the first ever conducted for fenestration thermal testing using a standard test procedure. Previous evaluations comparing the (proposed) NFRC calculational procedures to test methods involved government and university research facilities (Elmahdy 1990, 1992). This is the first evaluation of NFRC's standardized rating procedure among independent laboratories.

Several observations and recommendations can be made based on the findings of this round-robin.

1. In general, good agreement exists (±8.3% of the average) between simulated and tested U-factors reported for the same product among laboratories participating in NFRC's Laboratory Accreditation Program. This supports the fundamental structure of the NFRC rating system for U-factors, providing further confidence in the accuracy of product U-factors derived using the NFRC system.
2. Several issues of test method employment and test chamber calibration need further review and refinement to increase the agreement among participating laboratories. Some of the items that need further investigation and clarification include heat flux measurement tolerances, additional chamber calibration guidelines, temperature control parameters, exterior wind speed control and monitoring, and flux and temperature measurement techniques.
3. The variance reported on the window test specimen suggests that test chamber calibrations may need to be further investigated. It is believed that calibration by all laboratories using a well-characterized calibration specimen (CTS) will help improve the accuracy and interlaboratory agreement of all participating laboratories. The second phase of this round-robin (interlaboratory CTS evaluation) is designed to specifically address this issue and will be reported in a future paper.
4. The participating laboratories, the NFRC Testing Task Group, the NFRC Accreditation Policy Committee, other technical experts, and test professionals should work together to address some of the recognized weaknesses in current test protocols and methods. Specific recommendations should be forwarded by these parties to ASTM to improve both the efficiency and accuracy of the test method. Some areas identified for better standardization and quality control include baffle temperature measurement and control, sample surface temperature measurements, wind speed measurement and calibration, and test chamber calibration.
5. Better defined calibration procedures and calculation guidelines will assist all participating laboratories providing fenestration energy performance ratings. Such a standardized approach will help ensure uniformity of test method application, as well as equipment calibration and personnel training needs. The NFRC is developing detailed inspection checklists and other tools to assist this process.

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Architectural Testing, Inc.—York, Pa.
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Fenestration Testing Laboratory, Inc.—Ontario, Calif.
Huntingdon Engineering and Environmental, Inc.—St. Paul, Minn.
NRC Canada—Ottawa, Ont.
Performance Testing, Inc.—Redmond, Wash.
Quality Testing, Inc.—Everett, Wash.
Warnock Hersey, Inc.—Middleton, Wisc.

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