Registration No. 27809

-Technical Report-

Effect of Transitioning from Standard Reference Material 2806a to Standard Reference Material 2806b for Light Obscuration Particle Countering

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April 2016

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Development, and Engineering Center
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Warren, Michigan 48397-5000

UNCLASSIFIED

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
04-5-2016	Technical	18-21 January 2016

4. TITLE AND SUBTITLE
Effect of Transitioning from Standard Reference Material 2806a to Standard Reference Material 2806b for Light Obscuration Particle Countering

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Joel Schmitigal

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army TARDEC RDTA SIE-ES-FPT-PSD
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Warren, MI 48397-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
27809

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army TARDEC RDTA SIE-ES-FPT-PSD
6501 E. 11 Mile Road
Mail Stop 110
Warren, MI 48397-5000

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
DISTRIBUTION A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The change from Standard Reference Material (SRM) 2806a to SRM 2806b has produced a noticeable shift in particle size distribution of the reference materials used to calibrate ISO 11171 particle counters. There are three viable options to address the particle counter limits published in MIL-DTL-83133J when utilizing instruments calirbated with SRM 2806b rather than SRM 2806a.

15. SUBJECT TERMS
fuel, JP-8, diesel, contamination, particulate, particle counting, ISO 11171

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	none	38	Joel Schmitigal
					19b. TELEPONE NUMBER (*Include area code*) 586-282-4235

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Joel Schmitigal
Force Projection Technology

Standard Form 298 (Rev. 8/98)

Prescribed by ANSI Std. Z3

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Appendix A

Introduction

MIL-DTL-83133J, Detail Specification for Turbine Fuel, Aviation, Kerosene Type, JP-8 (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37) allows for the use of light obscuration particle counting for the detection of incidental contaminants (1). The use of light obscuration particle counting will increase in prominence across the Army with the introduction of high pressure common rail fuel injection systems, as fuel system component suppliers have stated that particulate size and distribution is more important than particulate mass. These engines, with increased injection pressures, are not as tolerant to the large number of small particles that are currently allowed under gravimetric mass limits. The light obscuration particle counters utilized to perform this testing are calibrated to ISO 11171, Hydraulic fluid power – Calibration of automatic particle counters for liquids (2) and operated according to the following test methods:

- IP 564: Determination of the level of cleanliness of aviation turbine fuel - Laboratory automatic particle counter method (3)
- IP 565: Determination of the level of cleanliness of aviation turbine fuel - Portable automatic particle counter method (4)
- IP 577: Determination of the level of cleanliness of aviation turbine fuel - Automatic particle counter method using light extinction (5)
- ASTM D7619-12b Standard Test Method for Sizing and Counting Particles in Light and Middle Distillate Fuels, by Automatic Particle Counter (6)

In 2014, the National Institute of Standards & Technology (NIST) introduced Standard Reference Material® 2806b (SRM 2806b) to replace SRM 2806a whose supply had been depleted in 2010. The change from SRM 2806a to SRM 2806b has produced a noticeable shift in particle size distribution of the reference materials. The variation in the quantity and distribution of particles between the two reference materials is attributed to improvements in the Scanning Electron Microscope technology and the image processing technology used to measure particulate size and distribution.

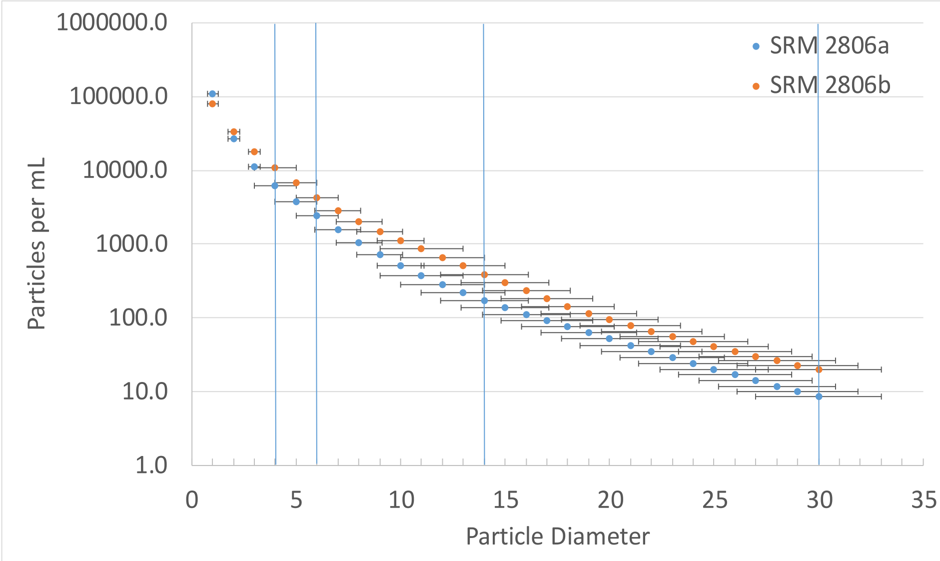

Figure 1. Shift in particulate distribution from SRM 2806a to SRM 2806b.

To account for the shift in particle size distribution when using SRM 2806b compared to SRM 2806a, ISO/TC 131/SC 6/WG 1 has recommended a revision to ISO 11171. This recommendation states that test results obtained using instruments calibrated with SRM 2806b shall be reported either: 1) in units of µm(c) using conversion factor of 0.898 for particle sizes less than or equal to 38 µm(b) to account for the difference in calibration using SRM 2806b rather than SRM 2806a or 2) in units of µm(b) to indicate calibration using SRM 2806b (7).

The µm(c) designation is used to identify an instrument having been calibrated with SRM 2806a while µm(b) is used for instruments calibrated with SRM 2806b. These ISO committees recommendations came about from data obtained during a round robin conducted in 15 laboratories measuring 6 samples each using instruments calibrated with SRM 2806(a) and SRM 2806(b). The slope of the line (m) of best fit for the 15 laboratories ranged from 0.844-0.987 with the mean slope being 0.898 (7).

Limits for incidental contamination limits found MIL-DTL-89133J which were established by for instruments calibrated with SRM 2806a. To determine the effect that the use of particle counters calibrated with SRM 2806b will have on these limits instrumentation calibrated with both reference materials were evaluated online at the EI 1581 Test Facility at Southwest Research Institute through The US Army TARDEC Fuels and Lubricants Research Facility. An ACM20 calibrated with SRM 2806b was obtained from Parker Hannifin to compare against an ACM20 instrument calibrated with SRM 2806a. Stanhope Seta provided an AvCount 2 particle counter and AvCount Lite instrument calibrated with SRM 2806b for comparison purposes against an AvCount instrument calibrated with SRM 2806a.

The AvCount 2 and AvCount Lite instruments both calibrated with SRM 2806b vary by 1.06% for particles ≥4µm (b), well within the tolerance allowed in Table C.2 of ISO-11171. Therefore for this report only, AvCount 2 data will be compared to AvCount, calibrated with SRM 2806a.

Evaluation

The test protocol, conducted by TARDEC, for comparing the light obscuration particle counters calibrated with SRM 2806a to SRM 2806b was modified from the concepts found in Energy Institute (EI) 1598 – Design, functional requirements and laboratory testing protocols for electronic sensors to monitor free water and/or particulate matter in aviation fuel (8). The evaluation looked to determine the degree of variation between the instruments calibrated with the two different standard reference materials. The water distribution was generated using the centrifugal pump specified in EI 1581, Specification and qualification procedures for aviation jet fuel filter/separators (9). The testing was performed with no filtration devices placed between the contaminant injection and the detection system. The test protocol is provided below:

1. Operate the system at approximately 105.7 gallons per minute (400 liters per minute) in a single pass flow loop as specified in EI 1598. (contaminant is removed after electronic sensors)

2. Prior to each test ensure that Jet A fuel is clean and dry, obtaining baseline data for 30 minutes.

3. Upon completion of baseline, obtain data when injecting ISO 12103-1 A1 ultrafine test dust at approximately 0.25 mg/L, 0.5 mg/L, 1.0 mg/L, 2.0 mg/L, and 2.5 mg/L.

4. Upon completion of baseline, perform analysis using ISO 12103-1 A2 fine test dust at approximately 0.25 mg/L, 0.5 mg/L, 1.0 mg/L, 2.0 mg/L, and 2.5 mg/L.

5. Upon completion of baseline, perform analysis using ISO 12103-1 A3 medium test dust at approximately 0.25 mg/L, 0.5 mg/L, 1.0 mg/L, 2.0 mg/L, and 2.5 mg/L. At the time of test, three additional data points were taken at two higher injection rates.

6. Upon completion of baseline, perform same analysis using a mixture of 90% A1 Ultrafine test dust and 10% Red Iron Oxide (RIO) at approximately 0.25 mg/L, 0.5 mg/L, 1.0 mg/L, 2.0 mg/L. At the time of test, three additional data points were taken at two higher injection rates.

7. Upon completion of baseline, obtain electronic sensor data using water contamination at approximately 5, 10, 20, and 40 ppm. Verify water contamination levels via ASTM D3240-15 (10).

The particle size distribution for ISO 12103-1 test dusts as provided Powder Technology Incorporated is provided in Table 1.

	A3 Medium Test Dust	A2 Fine Test Dust	A1 Ultrafine Test Dust	Red Iron Oxide
micron	% Less Than	% Less Than	% Less Than	
1	1.0 – 3.0	2.5 – 3.5	1.0 – 3.0	96.0
2	4.0 – 5.5	10.5 – 12.5	9.0 – 13.0	
3	7.5 – 9.5	18.5 – 22.0	21.0 – 27.0	
4	10.5 – 13.0	25.5 – 29.5	36.0 – 44.0	
5	15.0 – 19.0	31.0 – 36.0	56.0 – 64.0	
7	28.0 – 33.0	41.0 – 46.0	83.0 – 88.0	
10	40.0 – 45.0	50.0 – 54.0	97.0 – 100	
20	65.0 – 69.0	70.0 – 74.0	100	
40	84.0 – 88.0	88.0 – 91.0		
80	99.0 – 100	99.5 – 100		
120	100	100		

Table 1. Test dust particle size distribution as determined by sieving, Powder Technology, Inc.

Analysis

Light obscuration particle counters are unable to differentiate between free water and solid particulates, so for this report the term particles will include free water droplets. Based on the round robin conducted by ISO/TC 131/SC 6/WG 1 the slope of the line of best fit has been proposed as a multiplication factor to convert data from SRM 2806b calibrated instruments to SRM 2806a calibrated instruments. The following analysis contains the data collected by TARDEC to validate the findings of ISO/TC 131/SC 6/WG 1. All figures presented contain slope and coefficient of determination for the best fit line when the y-intercept is set at zero. The ISO/TC 131/SC 6/WG 1 data calculations used to develop the 0.898 conversion factor were processed in this way.

Particle count shift caused by change in standard reference material Parker ACM20

The ACM20 instruments saw an increase of 22% for instruments calibrated with SRM 2806b over instruments calibrated SRM 2806a for all particles ≥4µm (Figure 2). When the high leverage samples, that fall outside the 0.0 - 2.5 mg/L particulate and 10 ppm free water operational range, further improves the correlations (Figure 3). Counts for particles ≥6µm increased by an average of 33%, (Figure 4) removing the high leverage samples had little to no effect on the correlation (Figure 5). An average increase of 31% in counts was observed for particles ≥14µm, (Figure 6), removing the high leverage samples decreased the correlation of determination (Figure 7). An average increase of 131% was observed for particles ≥30µm (Figure 8 - Figure 9). Table 2 details the changes in the slope of the best fit line for each channel by setting the y-intercept at zero, and removing and high leverage samples.

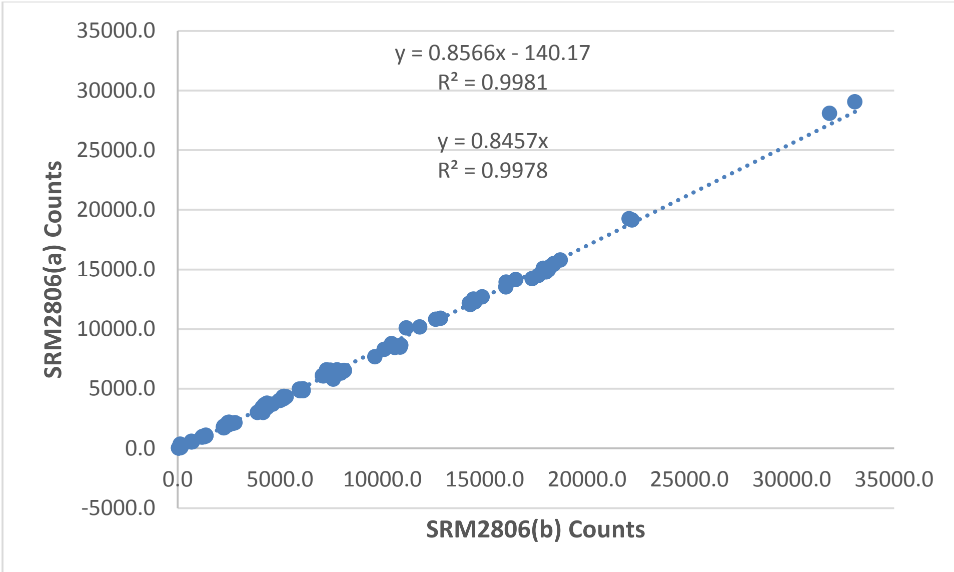

Figure 2. All particles ≥4μm counted by Parker ACM20 instruments calibrated with SRM 2806b vs Parker ACM20 instrument calibrated with SRM 2806a

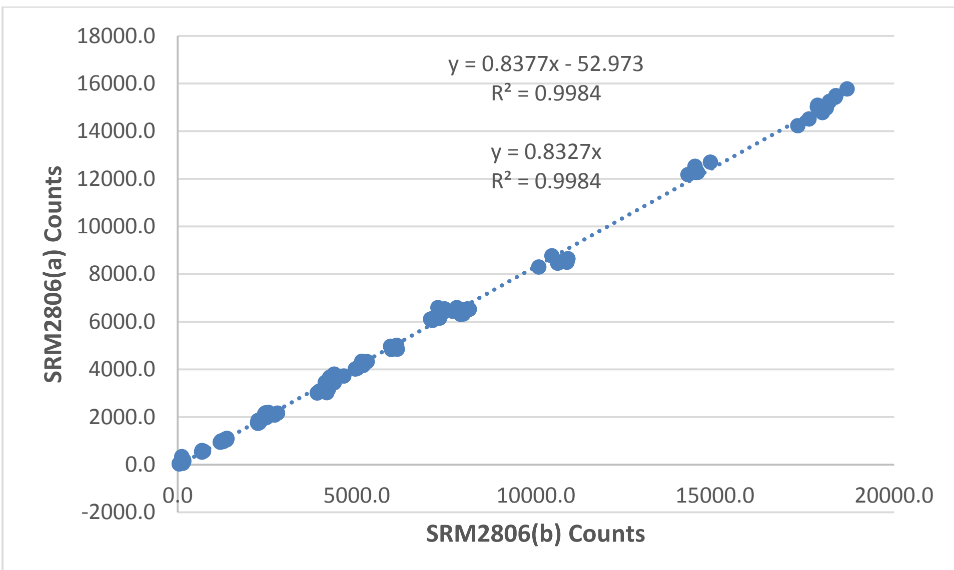

Figure 3. All particles ≥4μm counted by Parker ACM20 instruments calibrated with SRM 2806b vs Parker ACM20 instrument calibrated with SRM 2806a, high leverage samples removed

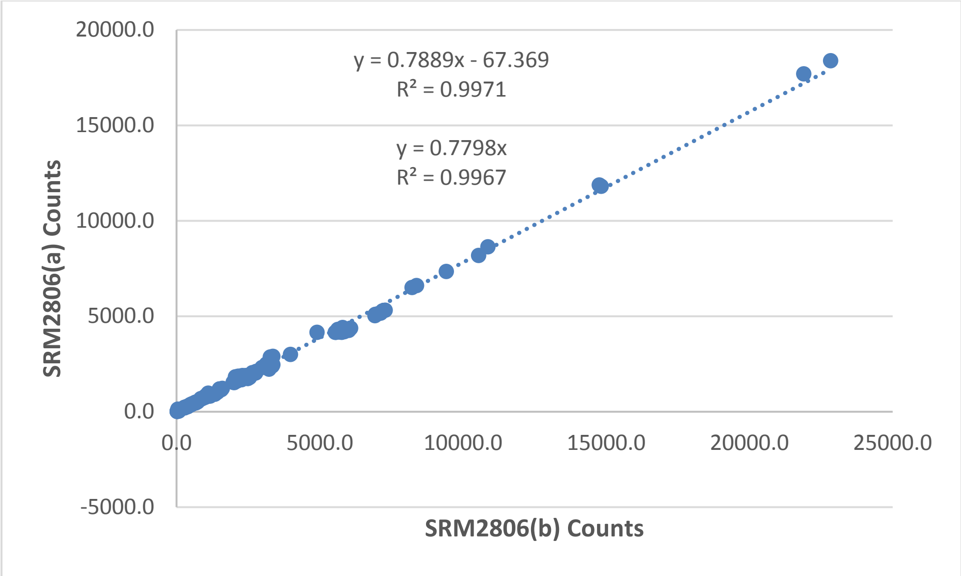

Figure 4. All particles ≥6μm counted by Parker ACM20 instruments calibrated with SRM 2806b vs Parker ACM20 instrument calibrated with SRM 2806a

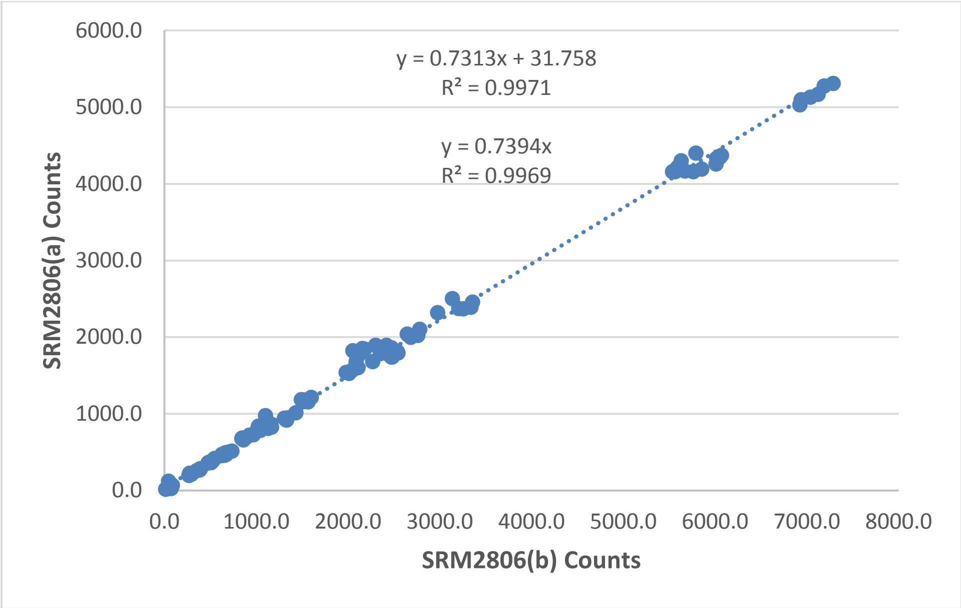

Figure 5. All particles ≥6μm counted by Parker ACM20 instruments calibrated with SRM 2806b vs Parker ACM20 instrument calibrated with SRM 2806a, high leverage samples removed

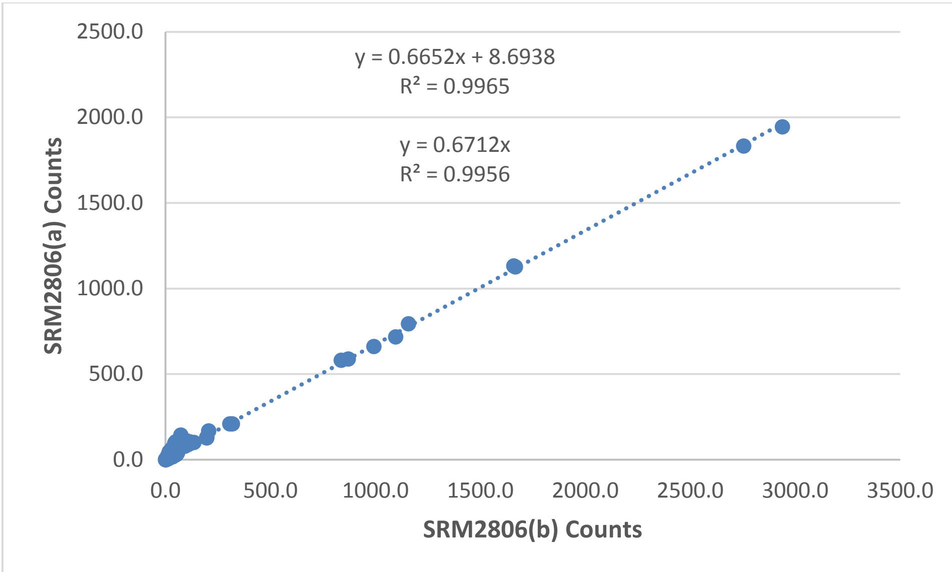

Figure 6. All particles ≥14µm counted by Parker ACM20 instruments calibrated with SRM 2806b vs Parker ACM20 instrument calibrated with SRM 2806a

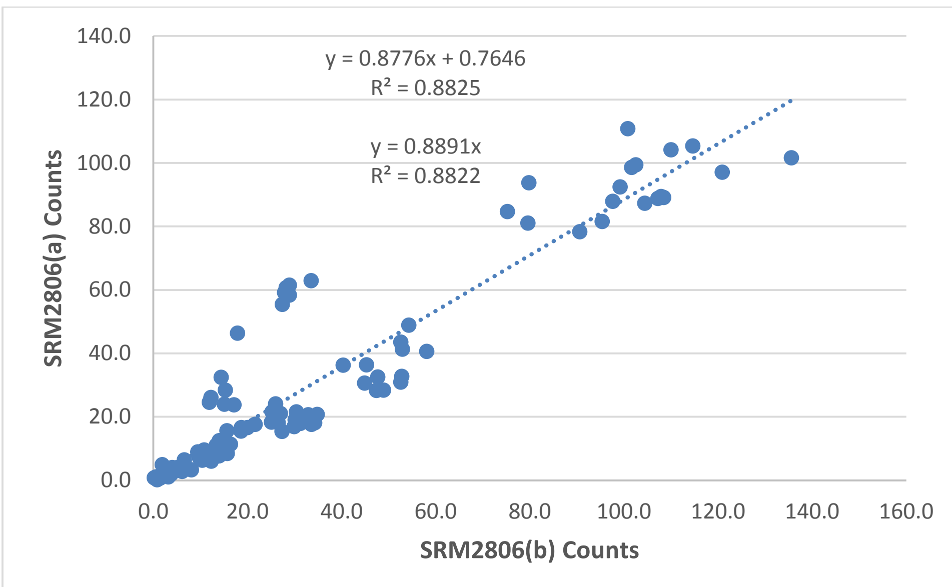

Figure 7. All particles ≥14µm counted by Parker ACM20 instruments calibrated with SRM 2806b vs Parker ACM20 instrument calibrated with SRM 2806a, high leverage samples removed

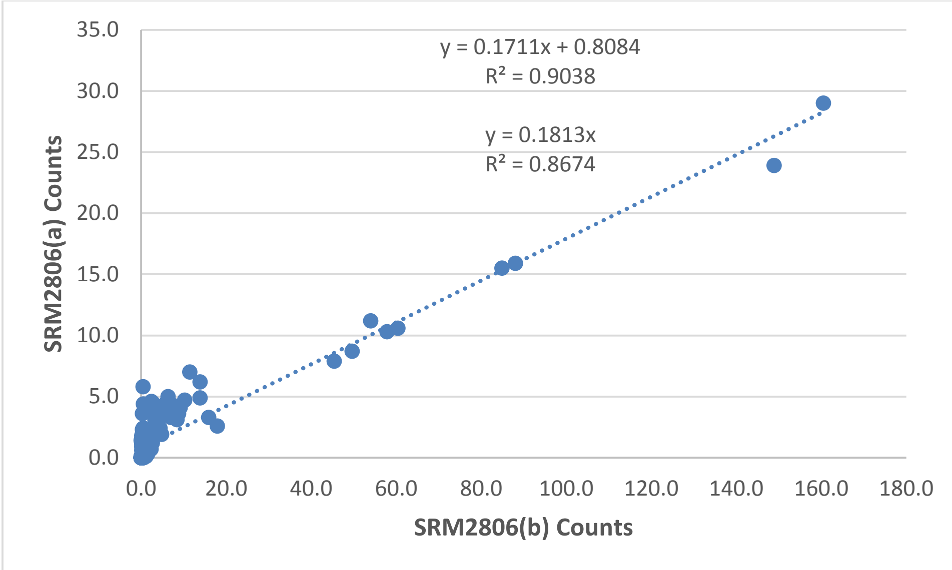

Figure 8. All particles ≥30µm counted by Parker ACM20 instruments calibrated with SRM 2806b vs Parker ACM20 instrument calibrated with SRM 2806a

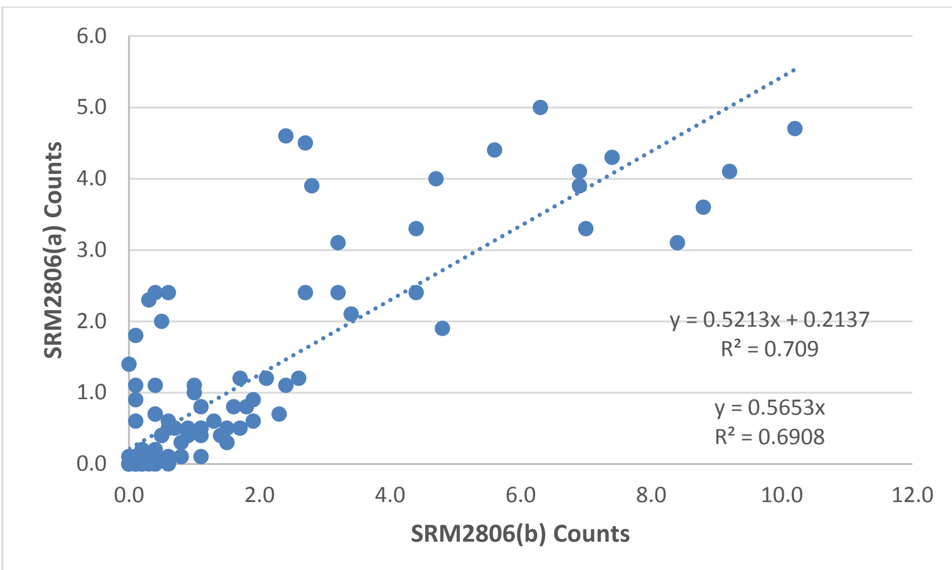

Figure 9. All particles ≥30µm counted by Parker ACM20 instruments calibrated with SRM 2806b vs Parker ACM20 instrument calibrated with SRM 2806a, high leverage samples removed

		All samples		High leverage samples removed	
	x̄ change from (c) to (b)	slope	slope with y=0	slope	slope with y=0
≥4µm	22%	0.8566	0.8457	0.8377	0.8327
≥6µm	33%	0.7889	0.7798	0.7313	0.7394
≥14µm	31%	0.6652	0.6712	0.8776	0.8891
≥30µm	131%	0.1711	0.1813	0.5213	0.5653

Table 2. Percentage difference between SRM 2806a (c) and SRM 2806b (b) measurements, and slope of best fit line for data for Parker instrumentation.

Particle count shift caused by change in standard reference material AvCount instruments

The AvCount 2 instrument calibrated with SRM 2806b demonstrated an average increase of 8% for all particles ≥4µm over the AvCount instrument calibrated with SRM 2806a (Figure 10) with an improved coefficient of determination, R^2, when the high leverage samples were removed from the sample set (Figure 11). The AvCount instruments averages decrease of 2% for particles ≥6µm (Figure 12), again the R^2 increased when the high leverage samples were removed (Figure 13). Particulate counts increased by 4% for particles ≥14µm, (Figure 14), the coefficient of determination decreased with the removal of the high leverage samples (Figure 15). An average decrease of 9% for particles ≥30µm was observed (Figure 16). There is a significant decrease in R^2 when the high leverage samples were removed, but the change in slope is also significant and may reflect a more accurate conversion factor (Figure 17). Table 3 details the changes in the slope of the best fit line for each channel for the AvCount instruments caused by setting the y-intercept at zero, and removing and high leverage samples.

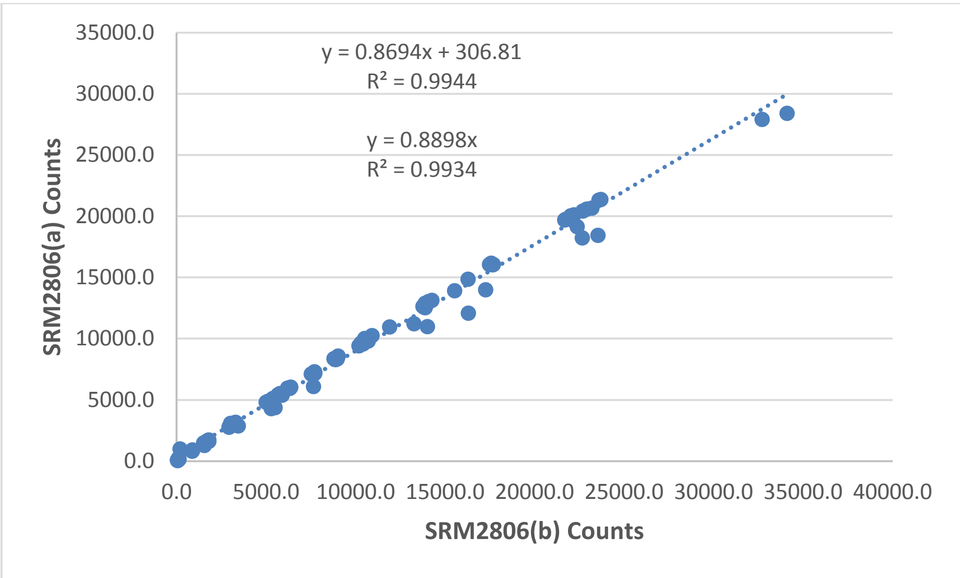

Figure 10. All particles ≥4µm counted by AvCount 2 calibrated with SRM 2806b vs AvCount instrument calibrated with SRM 2806a

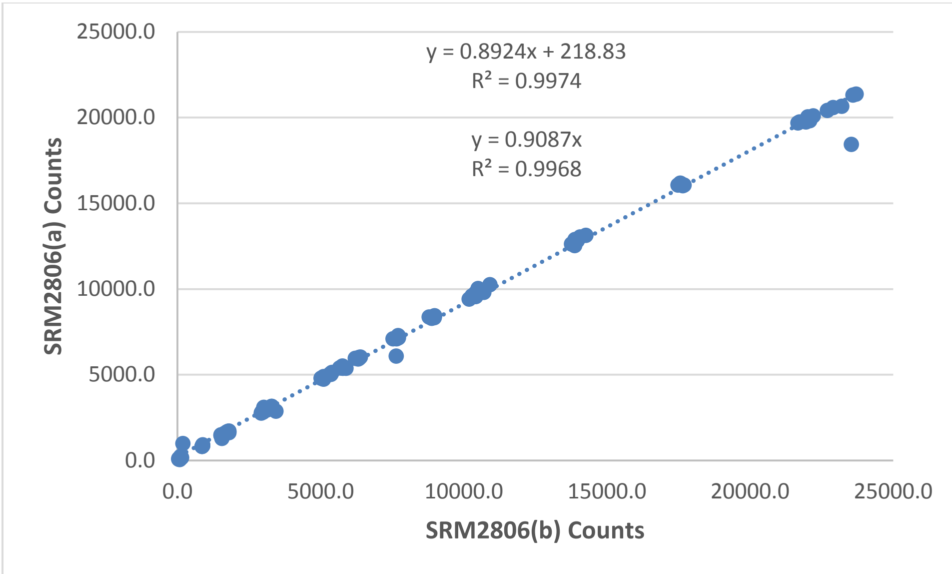

Figure 11. All particles ≥4µm counted by AvCount 2 instruments calibrated with SRM 2806b vs AvCount instrument calibrated with SRM 2806a, high leverage samples removed

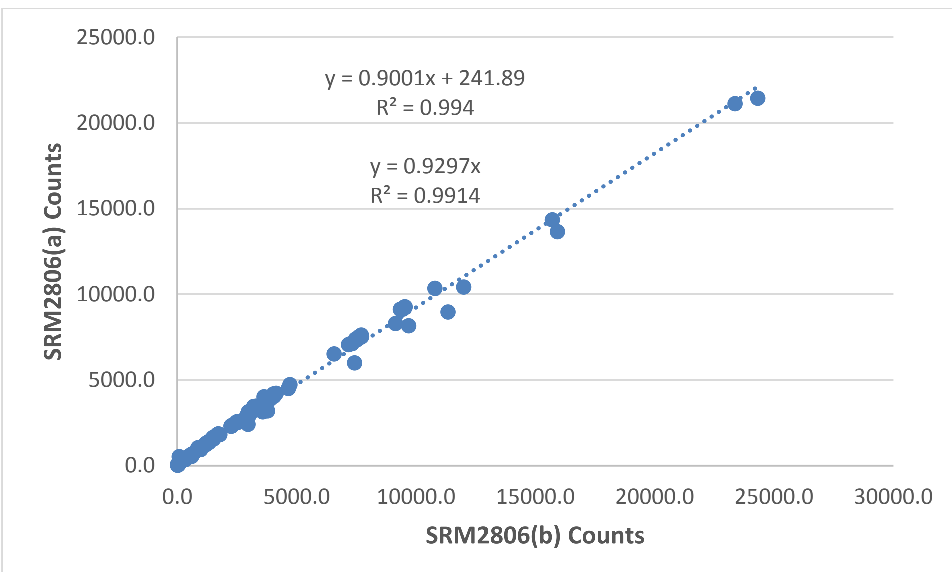

Figure 12. All particles ≥6µm counted by Stanhope Seta AvCount 2 instrument calibrated with SRM 2806b vs AvCount instrument calibrated with SRM 2806a

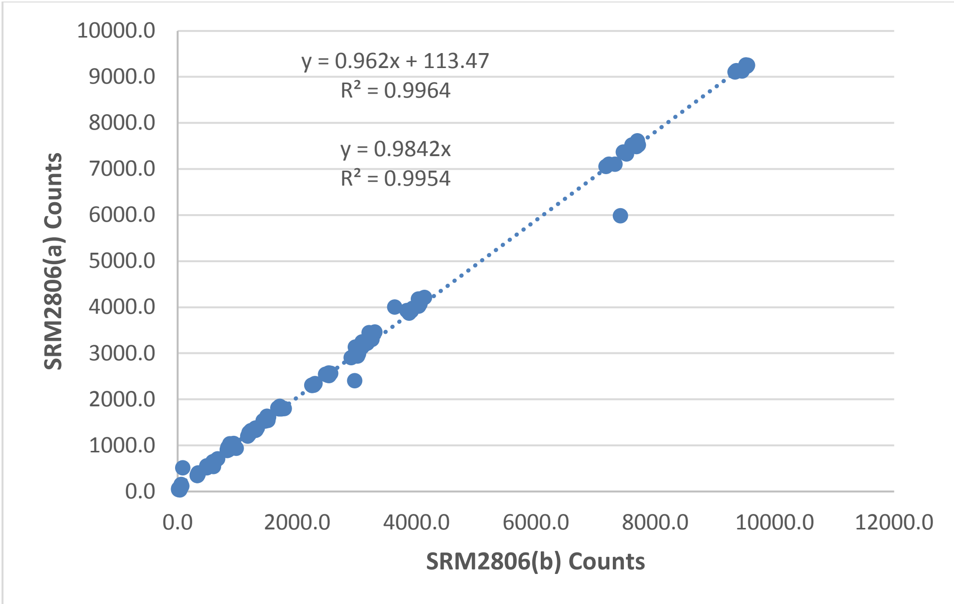

Figure 13. All particles ≥6µm counted by Stanhope Seta AvCount 2 instruments calibrated with SRM 2806b vs AvCount instrument calibrated with SRM 2806a, high leverage samples removed

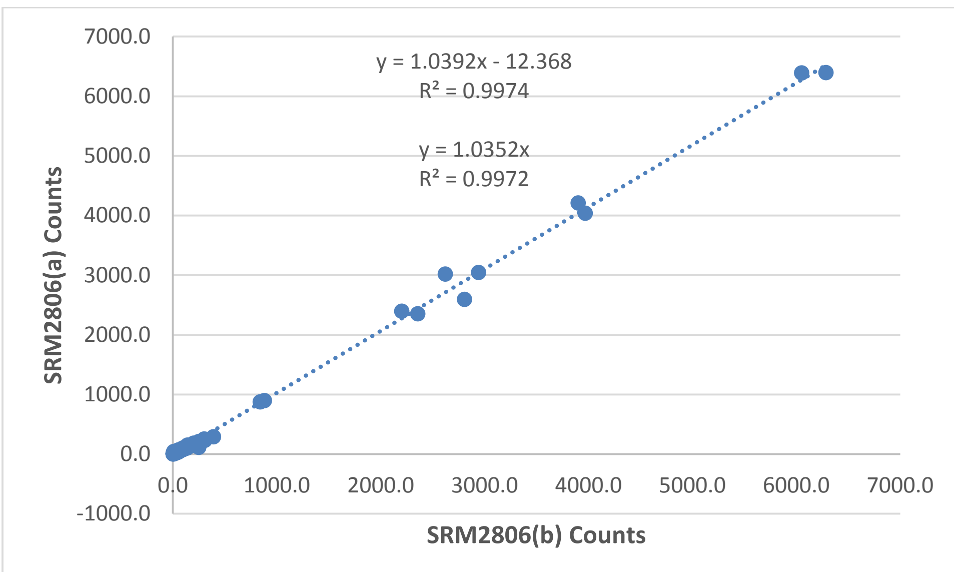

Figure 14. All particles ≥14µm counted by Stanhope Seta AvCount 2 instruments calibrated with SRM 2806b vs AvCount instrument calibrated with SRM 2806a

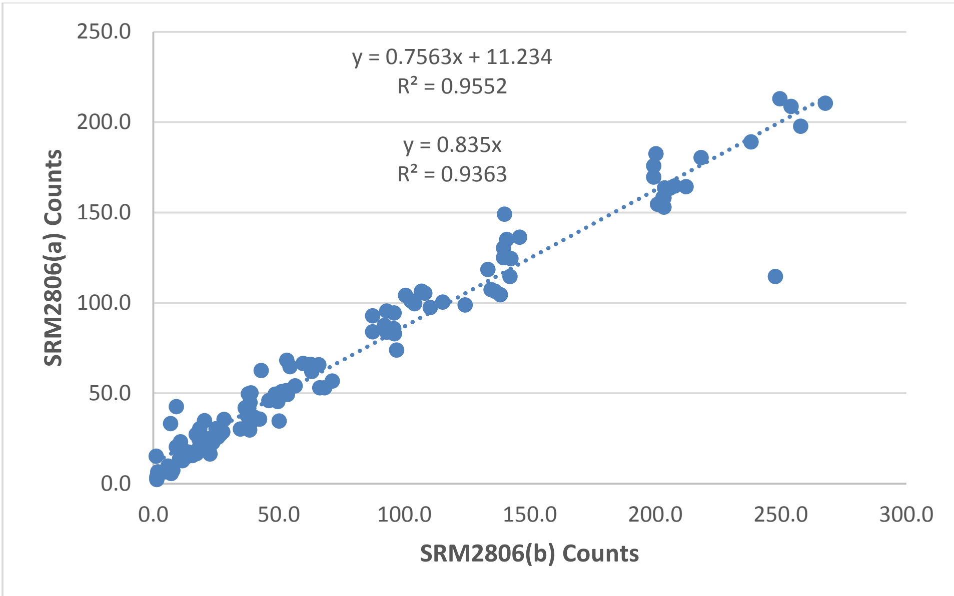

Figure 15. All particles ≥14µm counted by Stanhope Seta instruments calibrated with SRM 2806b vs AvCount instrument calibrated with SRM 2806a, high leverage samples removed

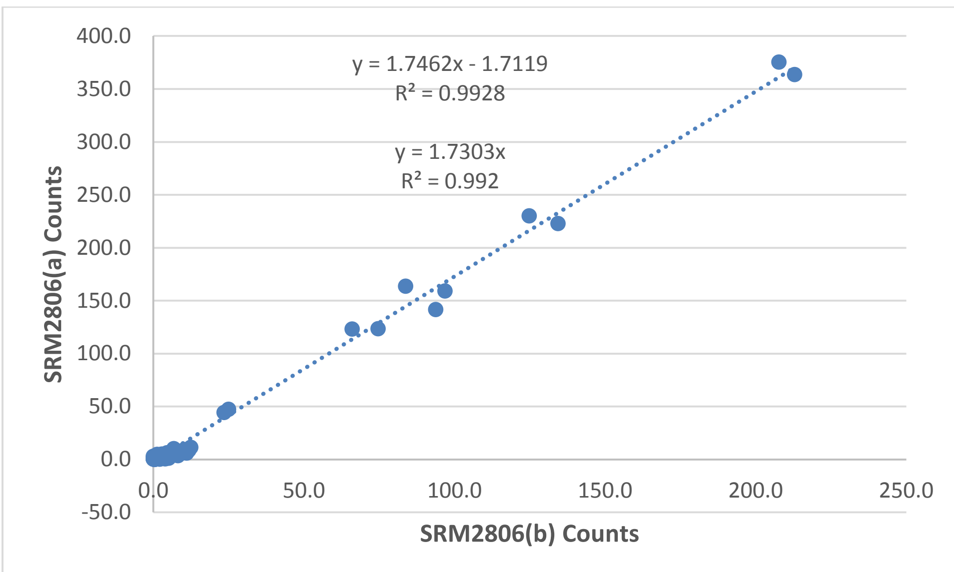

Figure 16. All particles ≥30µm counted by Stanhope Seta AvCount 2 instruments calibrated with SRM 2806b vs AvCount instrument calibrated with SRM 2806a

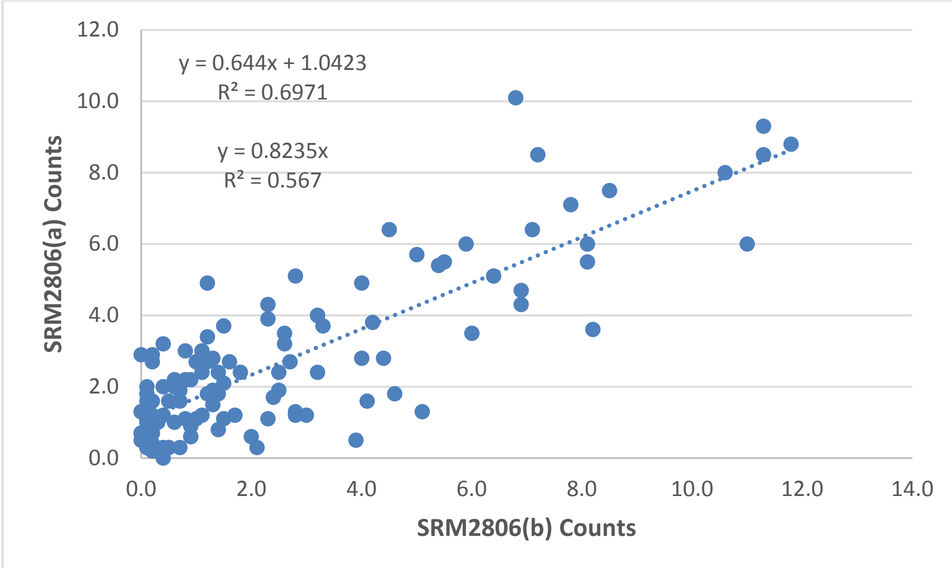

Figure 17. All particles ≥30µm counted by Stanhope Seta AvCount 2 instruments calibrated with SRM 2806b vs AvCount instrument calibrated with SRM 2806a, high leverage samples removed

		All samples		High leverage samples removed	
	x̄ change from (c) to (b)	slope	slope with y=0	slope	slope with y=0
≥4µm	8%	0.8694	0.8898	0.8924	0.9087
≥6µm	-2%	0.9001	0.9297	0.9620	0.9842
≥14µm	4%	1.0392	1.0352	0.7563	0.8350
≥30µm	-9%	1.7462	1.7303	0.6440	0.8235

Table 3. Percentage difference between SRM 2806a (c) and SRM 2806b (b) instrument measurements, and slope of best fit line for data for Stanhope Seta instruments.

Comparison of results by manufacturer

All instruments used in the evaluation were calibrated to ISO 11171, and exhibited a high level of precision. However the accuracy of the measurements could be disputed. The manufacturer to manufacturer variation for the instruments calibrated with SRM 2806a exhibited a 42% difference for all 131 samples tested for particles ≥4µm, this dropped to 26% when comparing the data obtained from the instruments calibrated with SRM 2806b. Particles counts for particulate ≥6µm were 75% higher for the Stanhope Seta AvCount than the Parker Hannifin ACM20 instrument calibrated with SRM 2806a. The percentage dropped to 29% for the manufacturer to manufacturer comparison for instruments calibrated with SRM 2806b. Particle counts for particles ≥14µm were an average of 330% higher on the AvCount instrument than the ACM20 instrument both calibrated with SRM 2806a. The ≥14µm variation dropped to 214% between the AvCount 2 instrument than the ACM20 instrument calibrated with SRM 2806b, these numbers are high due to the low density of particulates present in this size range. The 30µm channel displayed particle counts an average of 631% higher on the AvCount instrument than the ACM20 instrument for the instruments calibrated with SRM 2806a. This 30µm differential dropped to 402% for the instruments from both manufactures calibrated with SRM 2806b, again these numbers are high due to the relatively low number of particles present. The decrease in manufacturer to manufacturer variation seen with SRM 2806b calibrated instruments is attributable to the increased precision and accuracy used to measure the standard reference material.

The variation between instruments and manufacturers can be partially attributed to the accuracy, or lack thereof, in the measurement and quantification of particulates within the standard reference material. The variation is also an artifact of the instrument manufacturers' calibration procedures but is allowed for within the tolerance allocation found in Table C.2 of ISO 11171. Other causes of variation include the sample measurement technology and sample handling variations within each manufacturer's instrumentation.

Development of Conversion Factor

ISO/TC 131/SC 6/WG 1 has proposed a generic conversion factor of 0.898 for particulate channels from 4.0 – 38.0µm to convert data obtained on an instrument calibrated with SRM 2806b to back to comparable data what would have been expected from an instrument calibrated with SRM 2806a. Particle counts from 15 laboratories taken on instruments calibrated with SRM 2806a and SRM 2806b were taken for 6 samples. The best fit line slope (m) for the data from each of these 15 laboratories was then averaged to give the 0.898 conversion factor.

Using the data from this evaluation and plotting the data from each channel of the Parker ACM20 instruments gives a line of best fit with a slope of 0.8363, Figure 18. The slope of the line of best fit for the Stanhope Seta AvCount instruments is 0.8889, Figure 19, giving an average for the two manufacturers of 0.8626. The line of best fit when all the data from both instruments is combined has a slope of 0.8696 as shown in Figure 20.

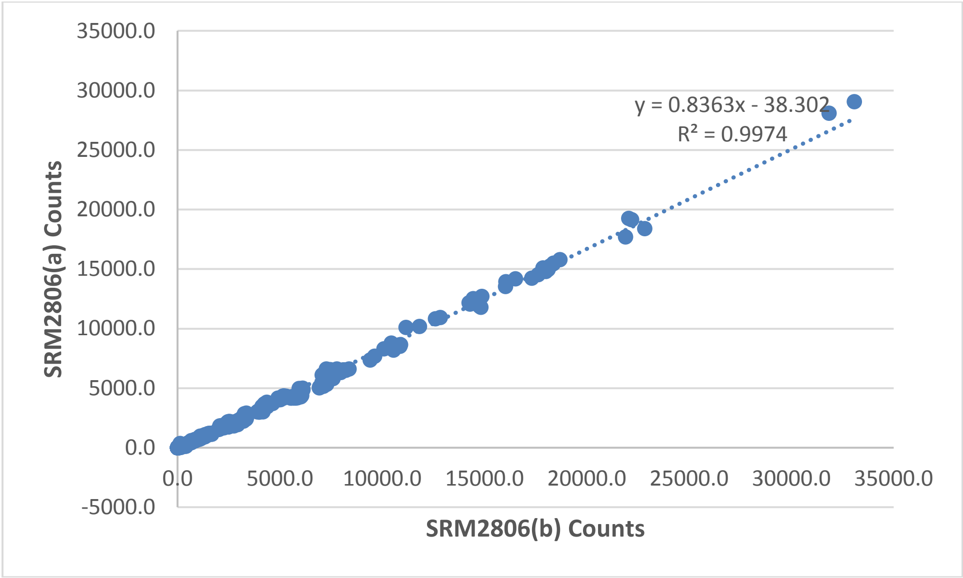

Figure 18. All particles counted by Parker ACM20 instrument calibrated with SRM 2806b vs Parker ACM20 instrument calibrated with SRM 2806a

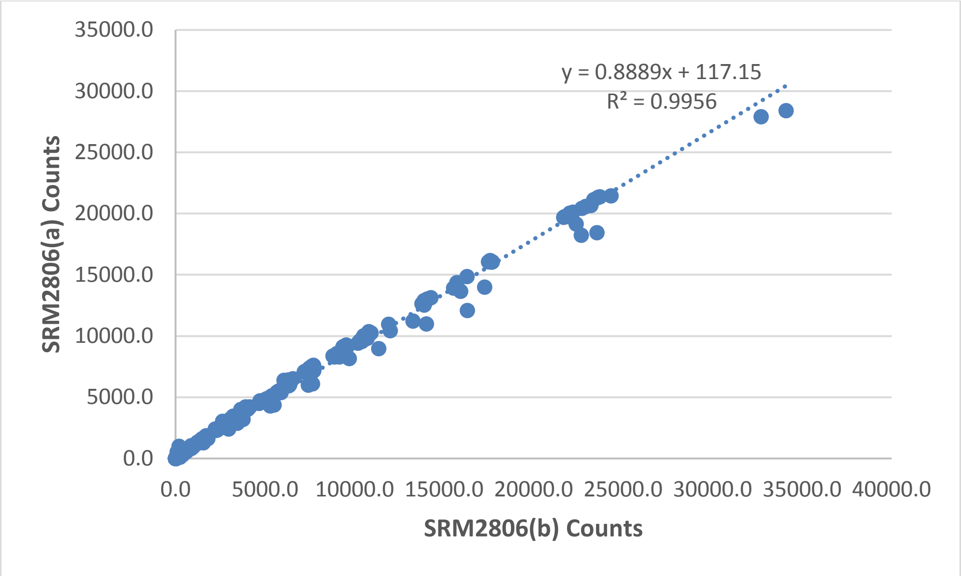

Figure 19. All particles counted by AvCount 2 instrument calibrated with SRM 2806b vs Stanhope Seta AvCount 2 instrument calibrated with SRM 2806a

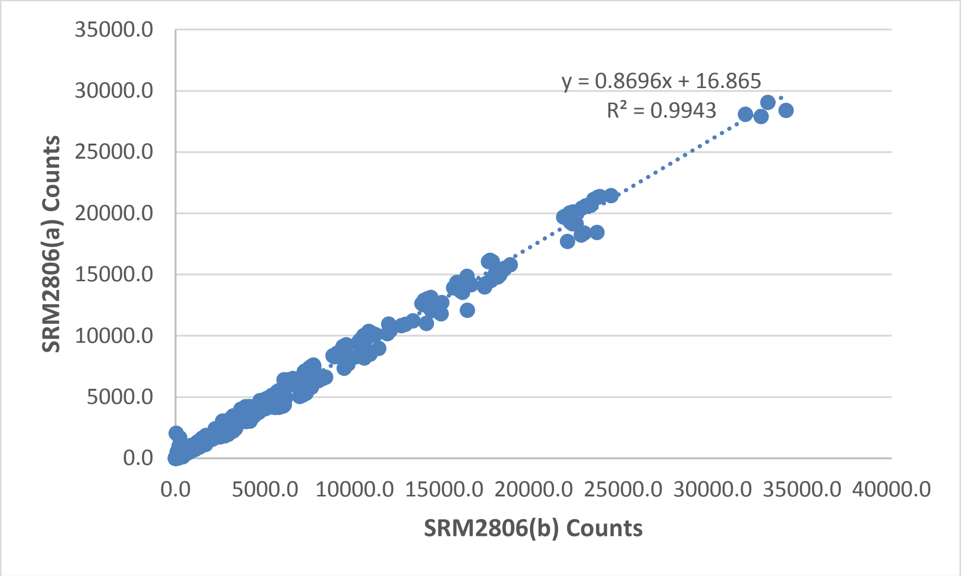

Figure 20. All particles counted by both particle counters calibrated with SRM 2806b vs both instruments calibrated with SRM 2806a

Removing high removing high leverage samples that are not within the operational range of usable fuels further improves the correlations, the best fit line for this Parker ACM20 data has a slope of 0.8247, Figure 21, while the slope of the line of best fit for the Stanhope Seta AvCount instruments is 0.9103, Figure 22, giving an average for the two manufactures of 0.8675. The line of best fit when all the data from both instruments is combined has a slope of 0.8823 as shown in Figure 23.

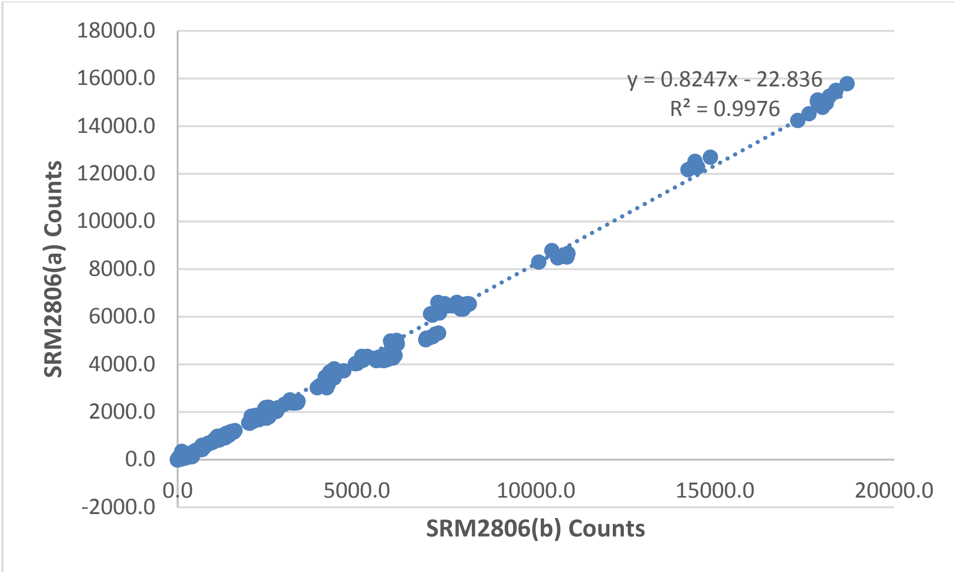

Figure 21. All particles counted by Parker ACM20 instrument calibrated with SRM 2806b vs Parker ACM20 instrument calibrated with SRM 2806a, high leverage samples removed

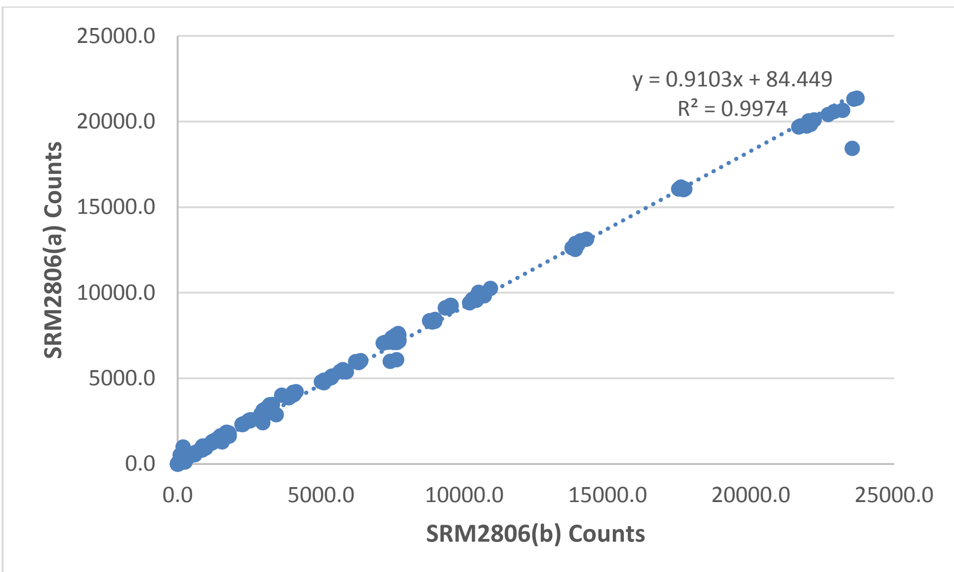

Figure 22. All particles counted by AvCount 2 instrument calibrated with SRM 2806b vs Stanhope Seta AvCount 2 instrument calibrated with SRM 2806a, high leverage samples removed

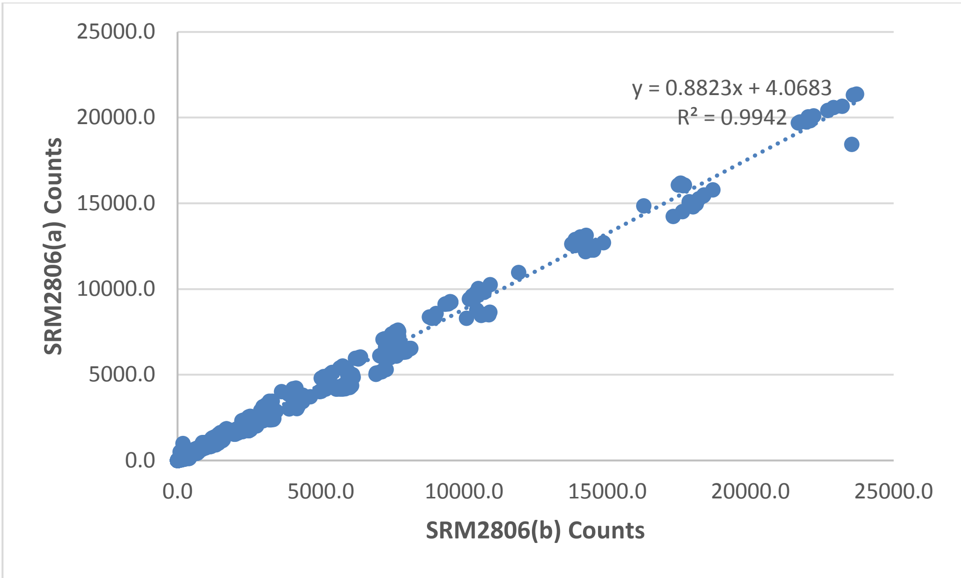

Figure 23. All particles counted by both particle counters calibrated with SRM 2806b vs both instruments calibrated with SRM 2806a, high leverage samples removed

Forcing the y-intercept to zero, which was utilized by ISO/TC 131/SC 6/WG 1, gives the best fit line for the Parker ACM20 data a slope of 0.8328, Figure 24. The slope of the line of best fit for the Stanhope Seta AvCount instruments is 0.8981, Figure 25, giving an average for the two manufacturers of 0.8655. The line of best fit when all the data from both instruments is combined has a slope of 0.8710 as shown in Figure 26.

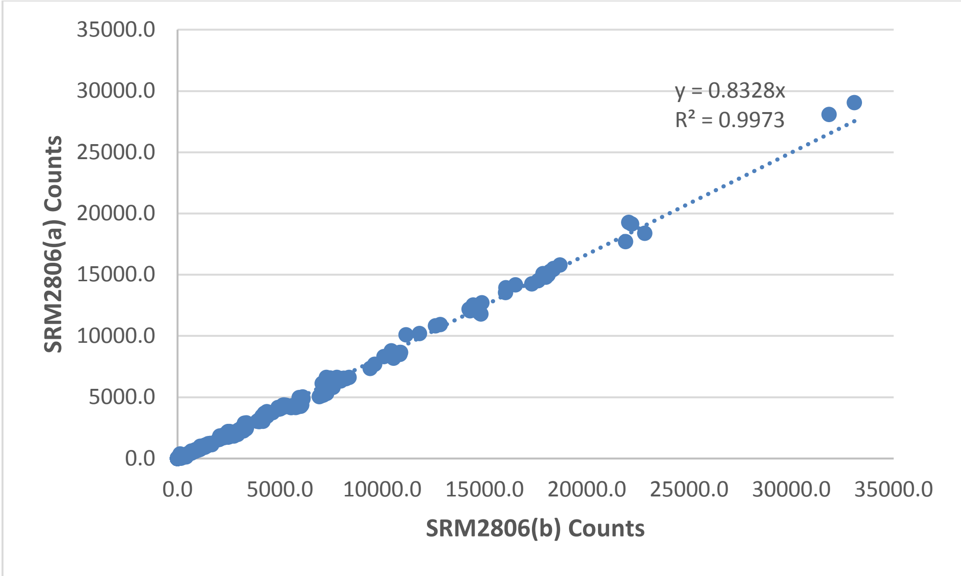

Figure 24. All particles counted by Parker ACM20 instrument calibrated with SRM 2806b vs Parker ACM20 instrument calibrated with SRM 2806a, y-intercept forced to zero

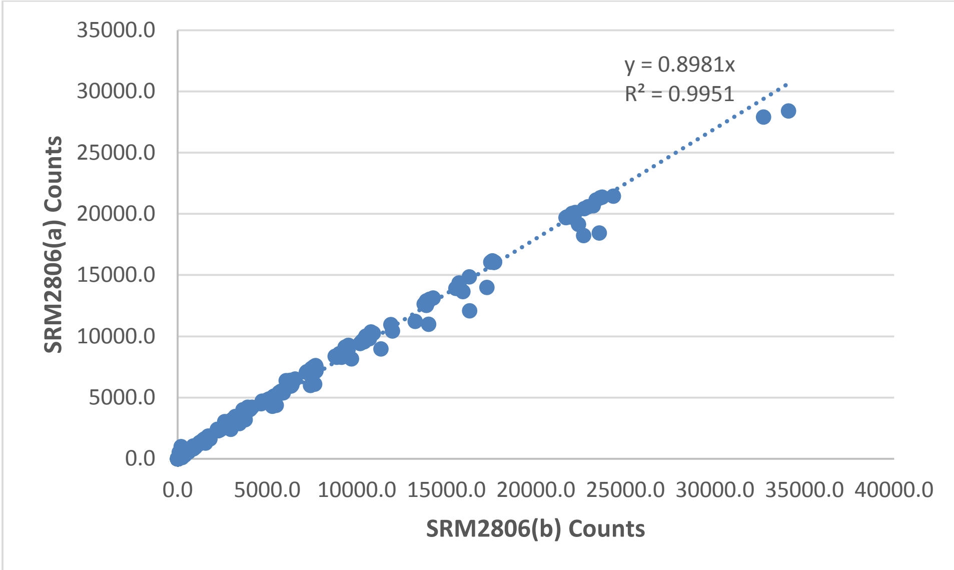

Figure 25. All particles counted by AvCount 2 instrument calibrated with SRM 2806b vs Stanhope Seta AvCount 2 instrument calibrated with SRM 2806a, y-intercept forced to zero

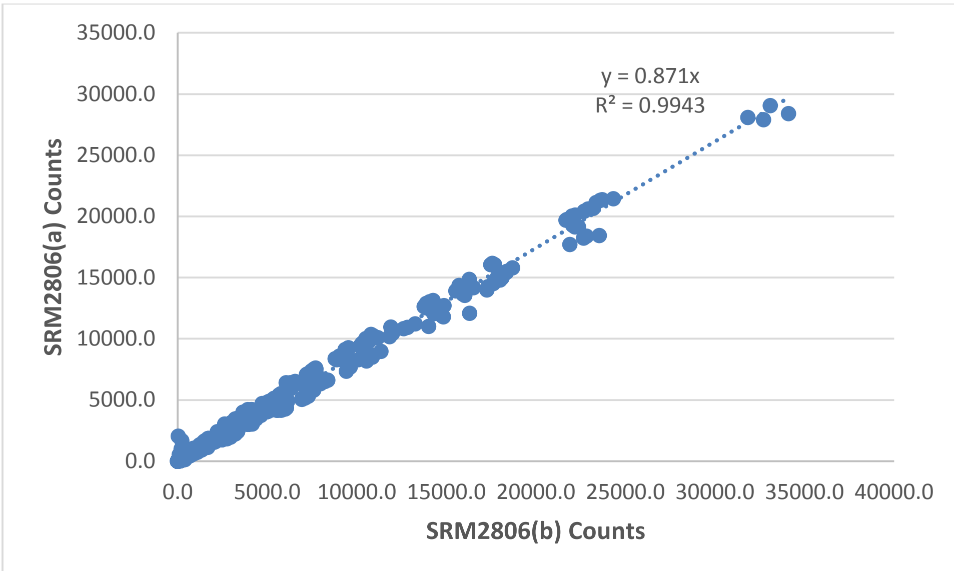

Figure 26. All particles counted by both particle counters calibrated with SRM 2806b vs both instruments calibrated with SRM 2806a, y-intercept forced to zero

These conversion factors can be further refined by removing the high leverage samples which may give a more accurate line of best fit slope for the data range of interest as displayed in Figure 27 thru Figure 29. Setting the y-intercept to zero with the high leverage samples removed gives a slope of 0.8221 for the Parker ACM20 data and 0.9179 for the Stanhope Seta AvCount and AvCount 2 instruments giving an average of 0.8700. Combining the data from both instruments gives a slope of 0.8827.

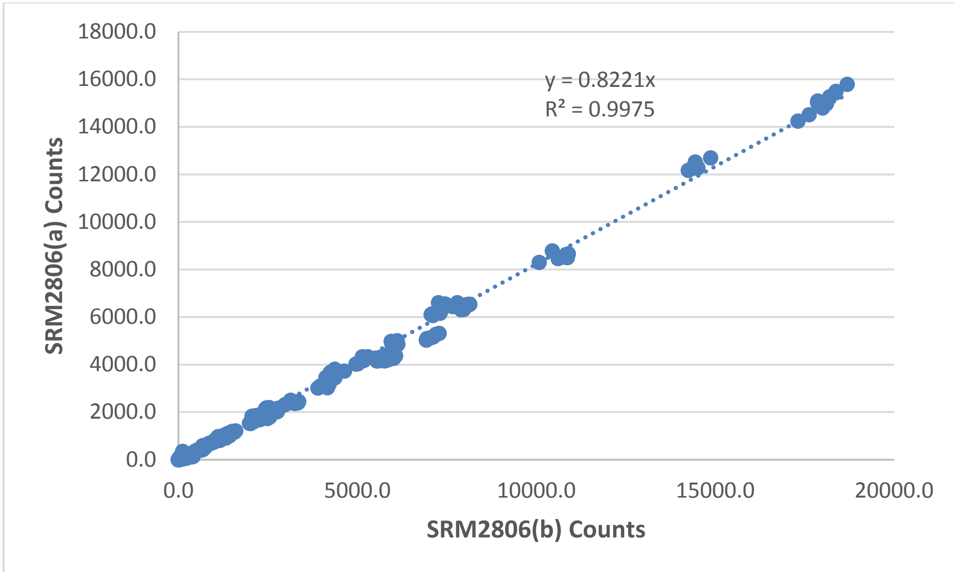

Figure 27. All particles counted by Parker ACM20 instrument calibrated with SRM 2806b vs Parker ACM20 instrument calibrated with SRM 2806a, y-intercept set to zero, high leverage samples removed

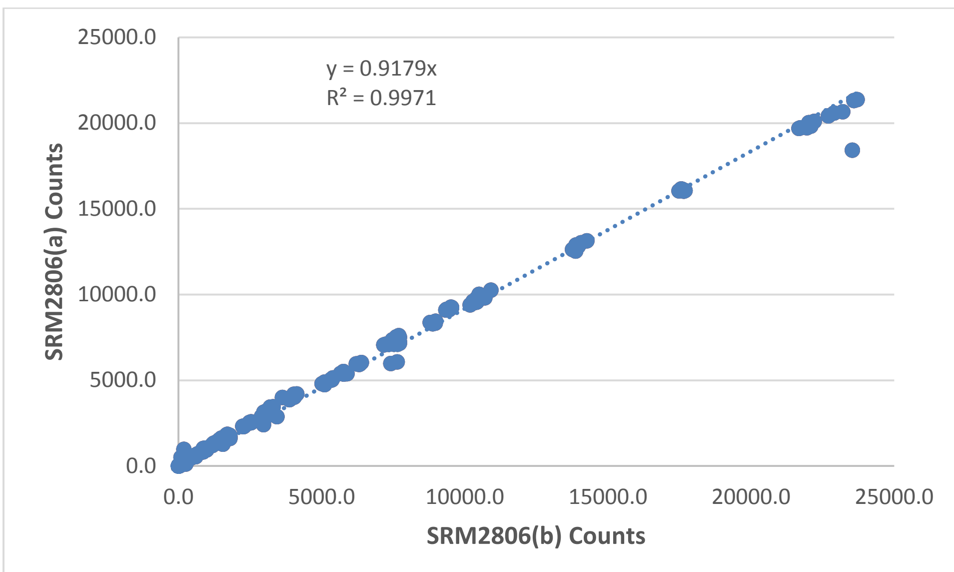

Figure 28. All particles counted by AvCount 2 instrument calibrated with SRM 2806b vs Stanhope Seta AvCount 2 instrument calibrated with SRM 2806a, y-intercept forced to zero, high leverage samples removed

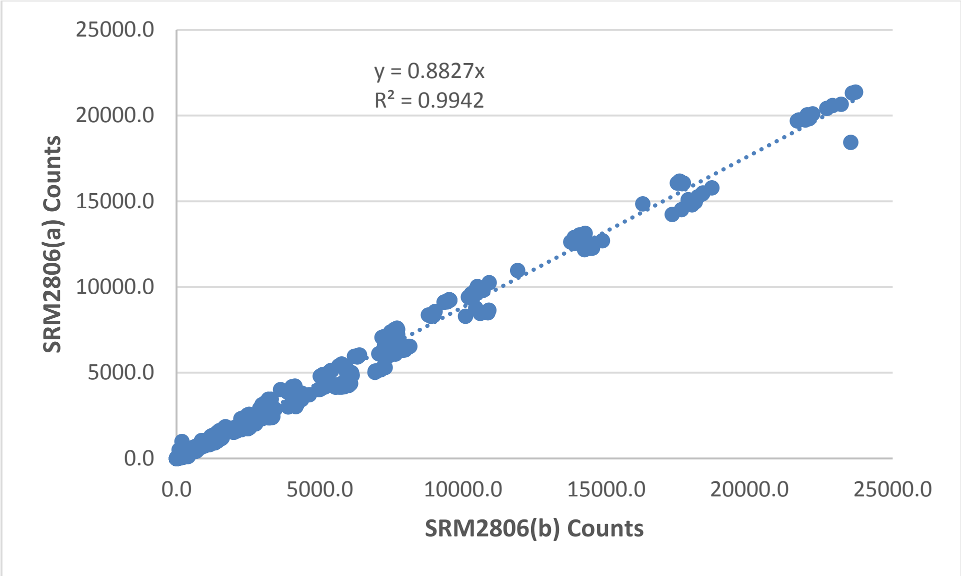

Figure 29. All particles counted by both particle counters calibrated with SRM 2806b vs both instruments calibrated with SRM 2806a, y-intercept forced to zero, high leverage samples removed

This data confirms that using the 0.898 conversion factor will provide an acceptable approximation when a conversion is required between particle counters calibrated with SRM 2806b to SRM2806a. This conversion factor could be more precise if: 1) individual conversion factors where develop for each manufacturer and 2) conversion factors were developed for each particle size channel.

Effect on Established limits

In 2015, the Department of Defense established ISO code particle counter limits of 19/17/14/13 in MIL-DTL-83133. These limits equate to 5000, 1300, 160, and 80 particles respectively for the ≥4μm (c), ≥6μm (c), ≥14μm (c), and ≥30μm (c) particle counting channels respectively utilizing particle counters calibrated with SRM 2806a.

Table 4 details the number of micron (b) particles that would be allowable for instruments calibrated with SRM 2806b under the existing 5000/1300/160/80 particle counter limits. Using the 0.898 conversion factor, limits would need to be raised to 5568/1448/178/89. The effects of instrument specific and particulate channel size specific conversion factors found in Table 4, almost all counts would move up an ISO code. Instrument and channels specific conversion formulas are provided within Table 5. Values provided in Table 6 provides the same (b) to (c) conversion, utilizing the conversion factors obtained by setting the line of best fit through a y-intercept of 0, provided in Table 7, again almost all counts would move up an ISO code.

	≥4µm	≥6µm	≥14µm	≥30µm
19/17/14/13 limit (c)	5000	1300	160	80
(c) to (b) using 0.898 factor	5568	1448	178	89
Parker ACM 20				
(b) = ((c) + 38.302)/0.8363	6025	1600	237	141
(c) to (b) using channel specific formulas	6001	1733	227	463
Parker ACM 20 high leverage counts removed				
(b) = ((c) + 22.836)/0.8247	6091	1604	222	125
(c) to (b) using channel specific formulas	5602	1734	181	46
Stanhope Seta AvCount				
(b) = ((c) - 117.15)/0.8889	5493	1331	48	-42
(c) to (b) using channel specific formulas	5848	1176	166	127
Stanhope Seta AvCount high leverage counts removed				
(b) = ((c) - 84.449)/0.9103	5400	1335	83	-5
(c) to (b) using channel specific formulas	5848	1233	197	123
Both Instruments data combined				
(b) = ((c) - 16.865)/0.8696	5730	1476	165	73
(c) to (b) using channel specific formulas	5704	1422	177	66
Both Instruments data combined high leverage counts removed				
(b) = ((c) -4.40683)/0.8823	5662	1468	176	86
(c) to (b) using channel specific formulas	5663	1457	194	123

Table 4. Calculated particle limits for instruments calibrated with SRM 2806b based on current limits and calculated conversion factors.

≥4µm	≥6µm	≥14µm	≥30µm
Parker ACM 20			
c=0.8566b-140.17	c=0.7889b-67.369	c=0.6652b+8.6938	c=0.1711b+0.8084
Parker icount high leverage counts removed			
c=0.8377b-52.973	c=0.7313b+31.758	c=0.8776b+0.7646	c=0.5213b+0.2137
Stanhope Seta AvCount			
c=0.8694b+306.81	c=0.9001b+241.89	c=1.0392b-12.368	c=1.7462b-1.7119
Stanhope Seta AvCount high leverage counts removed			
c=0.8924b-218.83	c=0.962b+113.47	c=0.7563b+11.234	c=0.644b+1.0423
Both Instruments data combined			
c=0.8681b+48.526	c=0.8557b+83.313	c=0.9826b-13.939	c=1.2337b-1.4636
Both Instruments data combined high leverage counts removed			
c=0.8798b+17.895	c=0.8955b-5.1887	c=0.7969b+5.6271	c=0.6439b+0.5357

Table 5. Instrument and particle channel specific conversion formulas.

	≥4µm	≥6µm	≥14µm	≥30µm
19/17/14/13 limit (c)	5000	1300	160	80
(c) to (b) using 0.898 factor	5568	1448	178	89
Parker ACM 20				
(b) = (c)/0.8328	6004	1561	192	96
(c) to (b) using channel specific formulas	5912	1667	238	441
Parker ACM 20 high leverage counts removed				
(b) = (c)/0.8221	6082	1581	195	97
(c) to (b) using channel specific formulas	6005	1758	180	142
Stanhope Seta AvCount				
(b) = (c)/0.8981	5567	1448	178	89
(c) to (b) using channel specific formulas	5619	1398	155	46
Stanhope Seta AvCount high leverage counts removed				
(b) = (c)/0.9179	5437	1414	174	87
(c) to (b) using channel specific formulas	5502	1321	192	97
Both Instruments data combined				
(b) = (c)/0.8710	5741	1493	184	92
(c) to (b) using channel specific formulas	5737	1501	164	66
Both Instruments data combined high leverage counts removed				
(b) = (c)/0.8827	5664	1473	181	91
(c) to (b) using channel specific formulas	5673	1453	190	108

Table 6. Calculated particle limits for instruments calibrated with SRM 2806b based on current limits and calculated conversion factors, intercept forced to zero.

≥4µm	≥6µm	≥14µm	≥30µm
Parker icount			
0.8457	0.7798	0.6712	0.1813
Parker icount high leverage counts removed			
0.8327	0.7394	0.8891	0.5653
Stanhope Seta AvCount			
0.8898	0.9297	1.0352	1.7303
Stanhope Seta AvCount high leverage counts removed			
0.9087	0.9842	0.835	0.8235
Both Instruments data combined			
0.8715	0.8663	0.9773	1.2185
Both Instruments data combined high leverage counts removed			
0.8813	0.8944	0.8432	0.7417

Table 7. Instrument and particle channel specific conversion factors (m).

Table 8 gives an indication of comparative data between SRM 2806a and SRM 2806b calibrated instruments if the ISO code limits as established for SRM 2806a instruments are kept and directly applied to SRM 2806b calibrated instruments. This would effectively lower the cleanliness limit, using the 0.898 conversion factor, for SRM 2806b instruments to what would be the equivalent of 4490/1167/144/72 on a SRM 2806a calibrated instrument. Additional instrument and channel specific conversions are provided within Table 8 utilizing the conversion formulas provided in Table 5. The values provided in Table 9 details the same (b) to (c) conversion but uses factors developed by setting the line of best fit y-intercept at 0, provided in Table 7. Almost all the data points would still fall within the ISO code published within MIL-DTL-83133J.

	≥4µm	≥6µm	≥14µm	≥30µm
19/17/14/13 limit (b)	5000	1300	160	80
(b) to (c) using 0.898 factor	4490	1167	144	72
Parker ACM 20				
(c) = 0.8363(b) - 38.302	4143	1049	96	29
(b) to (c) using channel specific formulas	4143	958	115	14
Parker ACM 20 high leverage counts removed				
(c) = 0.8247(b) - 22.836	4101	1049	109	43
(b) to (c) using channel specific formulas	4136	982	141	42
Stanhope Seta AvCount				
(c) = 0.8889(b) + 117.15	4562	1273	259	188
(b) to (c) using channel specific formulas	4654	1412	154	138
Stanhope Seta AvCount high leverage counts removed				
(c) = 0.9103(b) + 84.449	4636	1268	230	157
(b) to (c) using channel specific formulas	4243	1364	132	53
Both Instruments data combined				
(c) = 0.8696(b) + 16.865	4365	1147	156	86
(b) to (c) using channel specific formulas	4389	1196	143	97
Both Instruments data combined high leverage counts removed				
(c) = 0.8823(b) + 4.40683	4416	1151	146	75
(b) to (c) using channel specific formulas	4417	1159	133	52

Table 8. Perceived effect of applying the established ISO code to SRM 2806b calibrated instruments without conversion, expressed as SRM 2806a equivalent measurements.

	≥4µm	≥6µm	≥14µm	≥30µm
19/17/14/13 limit (b)	5000	1300	160	80
(b) to (c) using 0.898 factor	4490	1167	144	72
Parker ACM 20				
(c) = 0.8328(b)	4164	1083	133	67
(b) to (c) using channel specific formulas	4229	1014	107	15
Parker ACM 20 high leverage counts removed				
(c) = 0.8221(b)	4111	1069	132	66
(b) to (c) using channel specific formulas	4164	961	142	45
Stanhope Seta AvCount				
(c) = 0.8981(b)	4491	1168	144	72
(b) to (c) using channel specific formulas	4449	1209	166	138
Stanhope Seta AvCount high leverage counts removed				
(c) = 0.9179(b)	4590	1193	147	73
(b) to (c) using channel specific formulas	4544	1279	134	66
Both Instruments data combined				
(c) = 0.8710(b)	4355	1132	139	70
(b) to (c) using channel specific formulas	4358	1126	156	97
Both Instruments data combined high leverage counts removed				
(c) = 0.8827(b)	4414	1148	141	71
(b) to (c) using channel specific formulas	4407	1163	135	59

Table 9. Perceived effect of applying the established ISO code to SRM 2806b calibrated instruments without conversion, expressed as SRM 2806a equivalent measurements, intercept forced to zero.

Conclusions

The Scanning Electron Microscope (SEM) technology and the image processing technology used to measure particulate size and distribution of particles in SRM2806b have improved since the introduction of SRM2806a. The SEM provides for more accurate and precise measurements and an overall better defined standard reference material. The better defined SRM 2806b will improve both the accuracy and precision of automatic particle counters, and bring about less variation between manufacturers.

Moving forward, it is best to manage results from SRM 2806b instruments as reported from the instrument designated with µm (b). Appling any conversion factor introduce error into the measurements while trying to duplicate a less precise and accurate measurements associated with SRM 2806a calibrated instruments. Additionally, based on the samples and instruments tested it does not appear that the conversion factor has a linear relationship to particulates ≥30µm, this may be attributable to the low density of particulates in this size range.

There are three viable options to address the particle counter limits published in MIL-DTL-83133J for instruments calibrated with SRM 2806b: 1) keep ISO code limits as established for SRM 2806a particle counters and convert micron (b) measurements to micron (c) utilizing one of the conversion factors; 2) abandon the use of ISO 4406 ISO codes and adjust limits to allow for more particles for instruments calibrated to SRM 2806b; 3) keep ISO code limits as established for SRM 2806a instruments and apply them SRM 2806b calibrated instruments.

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List of Symbols, Abbreviations, and Acronyms

µm	Micrometer
ASTM	ASTM International
DTL	Detail
EI	Energy Institute
ISO	International Organization for Standardization
JP	Jet Propellant
mg/L	Milligrams per Liter
MIL	Military
NATO	North Atlantic Treaty Organization
ppm	Parts Per Million
SRM	Standard Reference Material

Appendix A

Test Dust	Concentra tion	Time	STM D3240	ASTM D2276	ACM 20 - old calibration				ACM 20 - new calibration				SETA AvCount - old calibration				SETA AvCount - new calibration				ETA AvCount Lite - new calibration			
		min	ppm	mg/L	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm
ISO 12103-1 A1 ultrafine test dust	2.50	0	0.0	0.000	95.3	50.6	4.9	0.1	75.2	37.3	1.9	0.0	54.7	34.2	6.6	0.7	73.2	35.9	4.4	0.0	71.2	39.3	5.6	0.0
		5		2.060	15783.3	5308.5	32.8	0.1	18685.1	7284.0	52.8	1.1	20098.1	9253.7	118.6	1.9	22204.6	9541.8	133.3	0.7	22485.4	9611.3	112.6	0.4
		10			15432.2	5167.1	32.5	0.5	18352.1	7121.2	47.7	0.7	19735.6	9127.5	136.4	3.2	21952.5	9450.7	145.9	0.4	22235.3	9528.2	112.2	0.6
		15	0.0		15091.1	5097.1	28.4	0.1	17861.6	6938.4	48.9	0.6	19738.3	9132.6	130.3	2.7	21733.0	9358.4	139.5	1.0	21931.5	9415.3	117.5	0.8
		20		2.040	15258.9	5129.3	30.6	0.1	18198.1	7037.6	44.9	0.6	20036.5	9259.9	135.2	3.4	22017.4	9520.1	140.8	1.2	22187.9	9508.9	112.6	0.6
		25			15493.6	5276.9	30.9	0.4	18373.2	7189.1	52.6	0.9	19827.2	9229.9	149.1	4.9	22085.2	9533.1	139.9	1.2	22469.1	9662.1	117.2	1.4
		30			15030.6	5029.6	28.3	0.1	17858.8	6921.7	47.4	0.8	19685.6	9106.9	125.1	2.8	21675.4	9336.0	139.5	4.0	21888.8	9394.1	109.4	0.9
	2.00	0	0.0	0.000	189.6	69.5	0.9	0.0	164.4	67.1	1.2	0.0	982.1	512.8	33.2	2.7	182.4	82.2	6.8	1.0	231.7	120.2	18.7	1.0
		5		0.560	12698.1	4401.9	18.1	0.1	14867.1	5791.5	34.3	0.1	16032.2	7487.6	97.5	1.3	17654.2	7682.0	110.3	2.8	17729.9	7686.1	92.9	0.7
		10			12275.0	4165.9	19.0	0.1	14516.8	5672.4	30.1	0.4	16062.7	7520.7	106.5	2.8	17693.0	7714.1	106.9	1.3	17724.8	7680.8	95.0	0.9
		15	0.0		12269.8	4157.6	17.6	0.0	14446.2	5563.1	33.6	0.4	16135.7	7525.0	101.2	2.1	17583.1	7665.2	102.7	1.5	17693.1	7697.7	89.1	0.3
		20		0.300	12304.6	4215.3	21.6	0.1	14384.9	5590.4	30.4	0.4	16137.3	7529.2	99.5	1.8	17593.3	7670.8	104.0	1.2	17744.2	7711.4	96.0	2.2
		25			12524.2	4300.3	20.8	0.2	14440.8	5629.5	34.8	0.4	16168.3	7610.9	106.1	2.4	17563.0	7699.4	106.7	1.1	17706.9	7695.2	102.8	2.8
		30			12174.9	4159.6	17.9	0.1	14246.6	5534.9	33.4	0.1	16055.3	7525.5	105.5	2.4	17478.6	7609.4	108.1	3.2	17652.2	7667.1	95.2	1.2
	1.00	5		0.800	6158.4	2020.9	7.7	0.1	7304.7	2760.4	13.9	0.1	8439.8	4007.6	68.3	2.7	8983.1	3631.9	53.1	1.2	9111.3	3988.0	67.5	2.2
		10			6278.0	2102.2	8.4	0.1	7291.1	2782.4	15.7	0.1	8402.4	3974.1	64.8	1.9	8940.3	3932.9	54.4	1.3	9065.3	3980.8	60.9	1.8
		15	0.0		6210.1	2042.3	7.7	0.0	7249.9	2751.6	14.0	0.1	8332.2	3919.6	51.4	1.1	8966.4	3912.7	52.9	2.3	9043.9	3938.6	51.8	1.1
		20		0.760	6064.1	1998.6	8.4	0.2	7108.3	2682.6	14.3	0.2	8376.0	3925.0	49.3	0.6	8896.8	3898.8	53.4	2.0	8980.8	3911.6	57.6	1.4
		25			6132.4	2029.5	7.6	0.1	7085.8	2653.0	13.6	0.1	8296.6	3870.5	49.5	0.9	8874.7	3873.0	48.6	0.9	8939.0	3870.0	57.1	1.7
		30			6109.7	2038.9	9.3	0.0	7056.9	2644.4	13.3	0.1	8364.8	3927.2	66.5	3.2	8793.0	3840.6	59.7	2.6	8756.7	3759.2	48.6	0.6
	0.50	0	0.0	0.000	109.1	37.2	0.2	0.0	103.1	44.3	0.8	0.0	166.7	91.9	5.7	0.3	106.6	49.9	7.1	2.1	132.6	68.8	10.0	0.3
		5		0.200	3628.9	1154.6	3.8	0.0	4315.9	1562.8	5.9	0.1	5017.2	2310.9	28.2	0.6	5322.8	2246.6	27.1	0.9	5355.9	2255.5	28.4	0.3
		10			3650.0	1178.1	3.4	0.0	4232.1	1508.3	4.9	0.0	5107.7	2324.5	27.8	0.3	5370.1	2274.8	25.6	0.5	5426.3	2228.6	25.3	0.5
		15	0.0		3804.4	1214.6	6.4	0.0	4364.5	1597.6	6.6	0.1	5132.6	2345.5	34.6	1.3	5392.8	2299.6	50.1	5.1	5425.8	2279.6	28.5	0.4
		20		0.380	3704.6	1179.2	3.9	0.0	4297.0	1519.9	4.8	0.0	5088.1	2319.0	29.8	0.5	5372.9	2279.4	38.3	3.9	5440.9	2286.2	34.6	0.3
		25			3672.6	1152.7	4.0	0.0	4247.3	1506.1	4.0	0.0	5031.0	2305.0	37.9	1.2	5360.3	2274.8	37.3	3.0	5380.3	2246.2	25.3	0.5
		30			3670.0	1182.1	3.9	0.0	4246.3	1490.2	5.2	0.0	5047.3	2300.0	30.2	1.2	5324.0	2252.3	34.6	2.8	5373.6	2252.7	33.7	0.5
	0.25	5		0.300	2178.9	683.1	1.9	0.0	2458.4	844.9	2.6	0.0	3021.5	1360.4	20.8	0.8	3112.5	1296.1	18.5	1.4	3147.9	1304.4	19.5	0.4
		10			2182.7	684.6	2.3	0.0	2518.1	879.9	3.5	0.0	2976.9	1334.3	16.6	0.3	3163.1	1314.1	17.2	0.5	3204.4	1314.4	16.1	0.2
		15	0.0		2197.7	686.5	2.1	0.0	2533.4	882.1	3.5	0.1	3032.8	1371.4	17.5	0.7	3146.5	1308.1	13.8	0.1	3214.1	1324.5	15.1	0.2
		20		0.120	2106.0	657.2	1.9	0.1	2456.9	858.4	3.7	0.1	3046.6	1378.5	16.2	0.2	3136.2	1302.1	14.0	0.3	3172.1	1314.8	15.5	0.3
		25			2135.0	672.9	2.1	0.0	2431.1	843.9	3.2	0.0	2969.3	1330.5	15.6	0.3	3132.9	1299.0	15.5	0.7	3154.5	1306.4	17.4	0.1
		30			2134.4	666.2	3.1	0.1	2466.6	857.4	3.8	0.0	2930.7	1316.0	17.4	0.3	3045.6	1251.5	13.8	0.1	3109.5	1284.5	18.3	0.4

Table A1. ISO 12103-1 A1 ultrafine test dust evaluation data

Test Dust	Concentra tion	Time	STM D3240	ASTM D2276	ACM 20 - old calibration				ACM 20 - new calibration				SETA AvCount - old calibration				SETA AvCount - new calibration				ETA AvCount Lite - new calibration			
		min	ppm	mg/L	≥4μm	≥6μm	≥14μm	≥30μm	≥4μm	≥6μm	≥14μm	≥30μm	≥4μm	≥6μm	≥14μm	≥30μm	≥4μm	≥6μm	≥14μm	≥30μm	≥4μm	≥6μm	≥14μm	≥30μm
ISO 12103-1 A2 fine test dust	2.50	0	0.0	0.020	72.3	25.7	0.6	0.0	88.4	34.9	0.7	0.0	159.1	80.2	7.5	1.0	124.6	51.7	7.7	0.2	138.6	60.0	9.3	0.8
		5		2.300	8296.9	2317.6	84.7	3.1	10080.9	2977.1	75.2	3.2	12623.5	4025.6	153.0	6.4	13762.6	4036.9	203.4	7.1	13957	4071	178	2.8
		10			8513.6	2370.0	81.6	3.3	10707.0	3256.3	95.4	7.0	13029.8	4192.2	154.6	6.0	14065.8	4101.7	200.9	11.0	14252	4168	178	3.5
		15	0.0	1.700	8461.2	2374.3	87.9	4.3	10603.0	3207.4	97.6	7.4	12532.4	4072.4	163.5	8.8	13875.3	4059.1	205.7	11.8	14034	4108	180	3.3
		20			8776.6	2501.4	93.8	4.5	10446.9	3135.7	79.8	2.7	12884.9	4180.7	158.3	8.0	13881.4	4030.1	203.1	10.6	13958	4059	171	2.6
		25			8502.7	2390.0	89.1	3.6	10862.7	3340.1	108.4	8.8	12818.8	4161.7	169.6	8.5	13964.7	4046.6	199.3	7.2	14134	4117	178	3.2
		30			8655.2	2454.2	89.4	3.1	10895.6	3356.6	107.9	8.4	13132.8	4214.2	158.1	7.5	14262.2	4133.7	203.4	8.5	14419	4196	176	2.4
	2.00	0			346.0	119.7	0.7	0.0	115.6	43.5	0.5	0.0	106.3	52.2	2.3	0.0	93.2	33.5	1.3	0.4	106.8	47.1	3.9	0.2
		5		0.120	6596.8	1822.8	59.2	2.4	7263.9	2052.9	27.9	0.4	9405.5	3037.1	98.9	2.7	10182.2	2974.2	124.2	1.6	10272.5	3026.9	120.3	1.1
		10			6291.8	1761.8	55.4	1.8	7346.7	2113.6	27.4	0.1	9582.1	3134.4	107.3	4.0	10354.6	3075.1	134.5	3.2	10489.6	3120.1	126.0	2.3
		15			6548.2	1849.5	61.5	1.4	7450.7	2156.2	28.9	0.0	9671.5	3172.3	104.5	3.5	10434.3	3108.3	138.3	6.0	10595.4	3155.1	123.8	2.7
		20		1.320	6599.4	1892.8	62.9	2.3	7791.0	2299.1	33.5	0.3	9555.2	3131.5	106.4	3.8	10386.1	3083.7	136.1	4.2	10515.3	3111.8	122.7	1.3
		25			6446.6	1809.4	58.4	2.4	7668.5	2155.6	28.9	0.6	9669.4	3166.6	114.6	5.1	10422.2	3096.3	142.1	6.4	10605.4	3134.2	116.9	1.4
		30			6512.1	1842.5	60.7	2.0	7919.8	2180.1	28.2	0.5	9768.0	3244.3	124.6	5.7	10413.9	3088.9	142.4	5.0	10616.6	3118.2	119.9	0.9
	1.00	5		0.680	3176.8	867.8	23.8	0.7	4203.2	1156.6	17.1	0.4	4824.6	1610.0	65.8	3.7	5080.5	1519.2	65.9	3.3	5126.8	1519.9	58.7	0.6
		10			3098.6	836.6	26.1	0.6	3954.1	1022.9	12.2	0.1	4746.7	1545.9	56.7	1.8	5097.9	1512.8	71.3	4.6	5147.4	1511.8	54.6	0.3
		15			3146.0	859.6	28.4	0.7	4049.4	1107.6	15.3	0.4	4894.7	1631.1	65.9	3.9	5102.3	1496.9	62.7	2.3	5174.2	1501.2	53.7	0.4
		20		0.100	3019.4	811.6	24.6	0.9	4166.0	1080.6	11.9	0.1	4788.5	1545.8	53.0	2.8	5055.0	1464.6	68.2	4.4	5100.5	1469.2	53.0	0.4
		25			3013.9	813.4	24.0	1.1	3890.4	1047.2	15.1	0.4	4771.6	1531.6	53.1	1.6	5084.1	1464.5	66.3	4.1	5073.9	1469.3	53.9	0.3
		30			3455.3	973.6	32.4	1.1	4119.8	1101.0	14.4	0.1	4804.0	1536.5	62.1	4.0	5007.2	1430.6	63.1	3.2	5019.7	1428.9	52.8	0.8
	0.50	0			83.4	24.8	1.0	0.1	90.1	31.4	0.8	0.0	155.6	81.9	9.7	1.2	104.9	41.7	5.8	1.1	106.9	47.5	9.6	0.9
		5		0.380	1767.4	457.1	15.5	0.8	2277.7	653.8	18.6	1.1	2826.1	914.2	34.9	1.7	2986.0	842.8	39.4	2.4	2997.0	864.0	46.0	2.3
		10			1812.7	471.0	16.6	1.0	2282.3	646.9	18.7	1.0	2890.0	961.5	41.7	3.0	2985.5	841.3	38.0	0.8	3020.3	860.6	38.1	1.2
		15			1752.0	451.7	15.6	0.5	2227.4	621.6	15.6	1.1	2878.3	923.4	35.8	1.2	3009.4	858.8	39.3	1.7	3020.5	867.3	39.1	1.6
		20		0.060	1734.1	460.9	16.6	0.6	2244.4	643.2	20.0	1.3	2834.9	905.5	33.1	1.9	2978.5	849.9	38.0	2.5	2985.0	851.3	37.0	1.1
		25			1783.5	474.4	17.6	1.2	2268.4	657.9	21.6	2.1	2795.4	911.2	36.7	2.2	2934.8	831.8	40.1	0.8	2994.3	834.5	33.4	0.9
		30			1774.4	468.6	46.4	1.1	2235.2	625.4	17.9	1.0	2761.3	890.9	35.8	2.4	2927.9	828.2	42.3	2.5	2944.0	383.9	36.8	0.9
	0.25	5		0.260	1046.5	267.9	7.9	0.1	1366.6	382.4	11.3	0.8	1693.5	555.6	24.1	1.8	1760.7	487.6	22.6	1.4	1774.9	506.3	19.5	0.8
		10			1063.8	280.8	9.6	0.3	1364.3	392.6	10.8	0.8	1714.2	553.2	24.5	1.1	1795.9	506.2	24.3	1.5	1826.7	521.8	24.5	0.9
		15			1010.1	271.0	9.0	0.5	1301.6	376.7	10.9	0.6	1615.4	518.4	16.4	0.6	1791.7	492.9	22.5	0.9	1780.4	505.5	20.0	0.5
		20		0.200	986.5	258.8	9.0	0.4	1265.2	350.6	9.4	0.9	1662.8	527.9	19.5	1.0	1739.8	487.1	20.9	0.9	1725.2	483.8	21.1	0.7
		25			1063.8	281.4	11.1	0.4	1365.4	390.4	13.6	1.4	1638.0	516.9	18.8	1.1	1732.0	488.2	22.2	0.8	1727.1	483.0	21.9	0.6
		30			1040.9	270.3	7.1	0.4	1351.6	377.4	9.8	0.5	1704.8	558.6	22.9	1.5	1771.9	499.7	23.7	1.3	1786.1	501.3	19.6	0.3
	?? (inc. inj. 4.2)	0			10091.8	2860.8	104.1	4.4	11165.2	3268.1	48.6	0.5	14851.7	4713.9	165.8	5.1	16274.4	4713.4	221.8	6.6	16507.9	4789.9	196.4	1.1
		5			10179.1	2891.3	96.9	3.6	11819.7	3363.6	43.3	0.3												
	?? (inc. inj. 8.0)	0			13935.3	4152.1	143.0	5.8	16042.4	4906.3	72.6	0.4	19999.3	6514.6	231.8	8.1	22041.2	6563.2	306.6	9.9	22314.7	6651.8	268.8	1.9

Table A2. ISO 12103-1 A2 fine test dust evaluation data

Test Dust	Concentra tion	Time	STM D3240	ASTM D2276	ACM 20 - old calibration				ACM 20 - new calibration				SETA AvCount - old calibration				SETA AvCount - new calibration				ETA AvCount Lite - new calibration			
		min	ppm	mg/L	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm
ISO 12103-1 A3 medium test dust	2.50	0	0.0		64.0	25.9	3.3	0.5	142.7	73.1	8.1	1.5	75.4	38.2	6.5	1.0	43.9	13.7	1.8	0.6	52.0	20.0	2.6	0.2
		5		1.620	4850.3	1858.1	101.6	4.7	6125.2	2473.1	135.6	10.2	7098.0	2905.3	189.1	4.9	7524.3	2903.2	238.1	4.0	7562.7	2905.8	223.4	2.0
		10			4893.0	1876.5	104.1	4.4	6057.1	2398.7	110.0	5.6	6080.4	2408.1	114.6	4.7	7642.5	2964.0	247.9	6.9	7688.2	2957.5	218.7	1.8
		15			4911.9	1851.5	105.4	4.0	6080.4	2408.1	114.6	4.7	7163.2	2942.9	197.8	5.5	7718.5	3012.1	257.9	8.1	7780.7	2995.3	223.9	2.9
		20		0.520	5006.9	1893.1	110.8	4.6	6110.7	2418.9	100.8	2.4	7243.9	2991.8	210.5	9.3	7718.5	3026.9	267.8	11.3	7758.6	2962.2	214.7	1.8
		25			4973.6	1861.1	99.4	3.3	5939.4	2339.1	102.5	4.4	7095.4	2947.0	213.0	10.1	7644.8	2950.5	249.6	6.8	7732.5	2954.1	210.6	1.4
		30			4839.7	1782.7	92.4	3.9	5969.4	2351.9	99.2	2.8	7280.7	3019.4	208.8	8.5	7701.4	2978.1	254.1	11.3	7759.2	2982.0	213.7	2.0
	2.00	0			45.1	15.1	1.1	0.0	41.7	13.8	0.6	0.0	241.6	150.9	28.7	3.6	103.0	59.6	27.7	8.2	86	45	11.5	1.5
		5		1.520	4040.9	1566.1	87.3	5.0	5011.9	2045.8	104.4	6.3	5965.6	2542.3	175.8	6.0	6205.5	2473.5	199.3	5.9	6233	2474	180	1.8
		10			4065.4	1536.9	81.1	2.4	5012.5	1978.9	79.6	2.7	5955.3	2534.2	164.6	5.4	6315.5	2521.7	207.6	5.4	6406	2539	179	1.3
		15			4337.1	1675.9	98.6	4.1	5138.6	2088.1	101.6	6.9	6030.0	2567.6	180.4	7.1	6381.6	2559.2	218.3	7.8	6422	2540	179	1.4
		20		1.720	4164.7	1602.1	88.8	3.9	5173.9	2108.7	107.2	6.9	5964.2	2519.1	164.3	6.0	6343.9	2532.4	212.3	8.1	6384	2506	173	1.2
		25			4021.9	1526.1	78.3	2.4	4953.7	2009.3	90.6	3.2	6005.9	2575.1	182.6	6.4	6336.7	2529.4	200.2	4.5	6373	2511	176	0.8
		30			4332.8	1679.1	97.1	4.1	5291.3	2267.0	120.9	9.2	5924.6	2520.2	163.6	5.5	6310.3	2515.0	203.7	5.5	6345	2504	174	1.0
	1.00	5		0.900	2167.7	823.8	41.3	0.7	2789.3	1166.4	52.9	2.3	3165.4	1383.1	100.4	4.3	3294.4	1333.5	115.3	6.9	3264	1307	86	0.7
		10			2092.4	808.5	40.6	2.1	2707.3	1129.0	58.1	3.4	2933.6	1321.7	104.1	5.1	3040.7	1225.9	100.5	2.8	3077	1250	84	0.4
		15			2004.6	784.2	43.5	1.9	2492.5	1045.3	52.6	4.8	2911.2	1256.3	87.5	3.7	2985.1	1201.1	92.1	1.5	2980	1182	76	0.6
		20		0.120	1918.2	726.0	36.4	1.2	2354.4	967.7	45.3	2.6	2849.9	1234.0	83.8	2.7	2959.0	1195.5	93.0	2.7	3001	1198	81	0.3
		25			2098.1	808.6	48.9	2.4	2435.9	1017.5	54.3	4.4	2942.1	1280.5	95.6	4.3	3012.9	1194.3	92.9	2.3	3029	1206	79	0.2
		30			1904.1	719.7	36.3	1.1	2320.9	926.4	40.3	2.4	2831.8	1204.9	84.1	3.5	2964.4	1174.8	87.3	2.6	2937	1155	76	0.1
	0.50	0	0.0	0.000	37.8	13.9	0.8	0.1	39.4	15.0	0.2	0.1	103.8	64.6	15.2	1.6	40.4	14.3	1.1	0.2	35.2	13.7	1.6	0.2
		5		0.440	1103.1	415.7	24.1	0.8	1376.6	547.8	26.0	1.8	1667.0	709.2	54.2	2.2	1719.5	670.3	56.5	0.6	1734.0	674.1	48.9	0.4
		10			1067.1	396.6	21.6	0.8	1319.4	532.6	25.2	1.6	1567.0	671.5	51.0	2.4	1621.7	635.0	51.1	1.4	1641.4	638.6	47.1	0.3
		15			975.4	361.4	20.1	0.6	1268.9	509.1	25.6	1.9	1279.5	544.3	45.5	3.0	1545.7	597.2	49.6	1.1	1545.1	596.6	42.8	0.5
		20		0.120	948.8	357.9	18.3	0.9	1185.6	474.7	25.1	1.9	1485.9	645.5	48.6	2.4	1518.7	587.7	48.4	1.8	1519.4	583.9	41.5	0.1
		25			963.4	360.1	19.6	1.2	1200.6	478.1	26.3	1.7	1461.4	619.8	46.0	2.0	1512.0	588.8	46.0	0.6	1541.0	600.0	41.9	0.4
		30			992.6	370.3	21.1	0.5	1214.6	489.7	27.0	1.7	1485.4	628.8	49.4	2.2	1524.0	591.4	48.5	0.9	1540.7	590.5	42.4	0.4
	0.25	5		0.200	567.9	209.3	11.4	0.5	694.4	276.6	16.4	1.1	913.2	399.7	35.5	2.0	881.5	339.7	28.1	0.4	896.8	344.8	25.4	0.0
		10			567.1	219.5	10.0	0.3	706.2	285.6	14.4	1.5	858.7	371.3	30.4	1.6	867.0	328.5	24.9	0.7	881.4	333.2	23.9	0.1
		15			572.6	213.1	10.9	0.4	720.5	293.6	14.3	0.5	817.5	347.8	25.7	1.2	861.3	332.5	25.5	0.4	866.2	332.9	24.6	0.1
		20		0.220	593.2	225.1	12.5	0.5	673.6	275.4	14.0	0.9	864.5	365.0	25.9	1.0	882.7	332.8	25.7	0.3	882.9	341.6	23.7	0.3
		25			537.6	200.5	11.1	0.6	666.1	266.8	12.4	0.6	876.0	372.4	27.8	1.1	877.8	340.0	25.9	1.0	876.3	339.4	24.1	0.5
		30			534.6	196.0	11.1	0.4	676.0	265.9	13.4	1.1	826.2	350.2	27.5	1.6	851.4	325.7	26.8	0.5	842.0	323.0	22.0	0.3
	?? (inc. inj. 4.4)	0			5979.6	2289.1	130.6	4.9	7592.4	3219.6	196.3	13.8	8451.6	3481.5	251.8	11.3	8983.8	3462.0	300.0	12.4	9059.8	3455.8	251.0	1.6
		5			5797.1	2229.8	126.6	6.2	7592.4	3219.6	196.3	13.8	8569.1	3533.0	243.0	9.3	9018.5	3489.2	295.2	10.3	9064.4	3458.7	248.8	1.7
	?? (inc. inj. 8.0)	0			7692.1	2996.1	168.2	7.0	9636.9	3976.2	205.8	11.4	10956.4	4500.9	293.2	7.9	11908.4	4651.3	389.0	6.8	11934.0	4627.0	333.0	1.6

Table A3. ISO 12103-1 A3 medium test dust evaluation data

Test Dust	Concentra tion	Time	STM D3240	ASTM D2276	ACM 20 - old calibration				ACM 20 - new calibration				SETA AvCount - old calibration				SETA AvCount - new calibration				ETA AvCount Lite - new calibration			
		min	ppm	mg/L	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm
90% ISO 12103-1 A3 medium test dust/10% Red Iron Oxide	2.00	0			129.6	64.7	2.6	0.1	163.4	85.1	4.2	0.2	164.3	117.1	42.7	2.9	136.4	70.3	9.1	0.2	128.0	68.0	6.8	0.0
		5		1.660	14841.2	4259.5	16.9	0.1	17999.1	6009.0	29.9	0.3	21310.6	7331.0	83.0	1.3	23596.2	7517.5	96.0	0.1	24077.0	7681.0	76.2	0.0
		10			14966.4	4369.9	17.9	0.0	18105.3	6069.1	31.2	0.6	21368.0	7370.0	94.5	1.1	23703.7	7465.9	95.9	0.1	24116.0	7664.0	76.0	0.0
		15			14982.9	4342.1	19.8	0.0	18099.2	6047.1	32.1	0.4	18431.0	5987.7	74.0	1.1	23535.0	7417.2	96.9	0.1	23999.0	7626.0	77.9	0.1
		20		1.180	14790.1	4331.5	20.6	0.1	17995.0	6016.4	32.9	0.2	20659.5	7107.8	85.8	0.7	23198.1	7321.8	95.8	0.2	23780.0	7591.0	81.0	0.2
		25			14516.6	4192.5	15.4	0.1	17625.5	5854.1	27.3	0.2	20589.5	7102.5	84.1	1.0	22905.6	7224.6	93.2	0.1	23365.0	7386.0	70.5	0.0
		30			14241.0	4157.2	18.1	0.1	17308.5	5763.1	26.5	0.2	20411.9	7057.5	92.8	1.8	22698.2	7174.6	87.3	0.1	23099.0	7343.0	72.0	0.0
	1.00	5		0.120	6533.7	1792.2	6.3	0.0	8136.6	2544.9	10.4	0.1	10253.0	3462.9	50.3	1.3	10907.6	3304.1	38.9	0.0	11094.0	3386.0	33.4	0.0
		10			6347.4	1754.4	6.0	0.1	7885.8	2461.8	12.3	0.1	10022.7	3448.1	62.7	2.7	10503.7	3204.2	42.9	0.2	10602.0	3232.0	27.7	0.1
		15			6540.1	1816.5	6.6	0.0	8085.6	2530.6	10.4	0.1	9560.7	3220.5	44.9	1.3	10419.2	3171.9	38.5	0.0	10639.0	3219.0	32.6	0.1
		20		0.360	6519.4	1809.9	7.9	0.0	8124.3	2538.4	12.3	0.1	9814.5	3299.0	40.2	0.7	10700.3	3254.8	37.3	0.0	10882.0	3323.0	22.8	0.0
		25			6323.3	1740.9	7.7	0.0	7969.4	2486.0	11.3	0.2	9921.4	3373.4	49.7	2.0	10583.7	3215.8	37.8	0.1	10773.0	330.0	37.1	0.0
		30			6314.3	1739.9	7.0	0.0	7894.5	2475.4	11.9	0.0	9607.6	3243.5	41.9	1.4	10285.6	3102.8	36.6	0.1	10452.0	3164.0	26.8	0.1
	0.50	0			101.7	33.7	0.7	0.0	104.1	40.0	1.4	0.1	123.9	53.8	3.7	0.2	104.4	30.0	1.4	0.2	109.1	33.9	0.5	0.0
		5		0.380	3721.6	1012.6	3.3	0.0	4633.0	1430.1	6.2	0.2	5382.4	1801.4	20.5	0.4	5884.9	1783.1	20.8	0.1	5961.8	1800.5	164.0	0.1
		10			3436.2	915.5	4.1	0.1	4367.6	1331.4	6.1	0.1	5510.2	1847.3	27.3	0.6	5764.7	1709.3	17.1	0.1	5900.9	1756.2	18.6	0.0
		15			3445.1	940.6	2.8	0.0	4307.6	1307.6	6.1	0.1	5455.3	1840.3	30.4	1.0	5728.1	1706.3	18.5	0.1	5773.0	1712.0	15.4	0.0
		20		0.420	3468.1	933.5	3.9	0.1	4341.9	1318.1	4.9	0.1	5391.6	1795.4	24.4	0.6	5735.5	1697.1	18.7	0.1	5797.2	1713.2	15.0	0.0
		25			3477.1	945.4	4.3	0.0	4368.9	1336.3	5.8	0.3	5401.8	1813.9	34.9	2.9	5661.5	1674.9	20.4	0.0	5775.9	1717.6	15.3	0.0
		30			3486.9	922.6	3.8	0.0	4349.9	1324.4	6.0	0.4	5370.9	1796.6	25.1	0.7	5768.2	1734.8	20.7	0.2	5870.8	1745.8	18.5	0.0
	0.25	5		0.260	1984.6	512.7	1.1	0.0	2471.6	734.9	3.2	0.0	3149.3	1045.5	23.1	1.6	3280.2	937.5	10.8	0.1	3397.0	973.6	9.6	0.0
		10			1911.9	498.9	2.4	0.0	2368.7	700.6	3.4	0.0	3082.8	996.2	13.8	0.3	3231.0	929.9	10.4	0.4	3292.0	959.0	9.7	0.0
		15			1792.8	470.6	1.9	0.1	2252.4	673.8	2.6	0.1	2992.5	978.8	15.5	0.3	3119.4	899.3	11.3	0.1	3189.0	931.0	11.7	0.0
		20		0.160	1820.8	473.9	1.8	0.0	2253.1	663.9	2.4	0.1	2926.6	953.5	12.7	0.5	3091.6	899.6	11.6	0.0	3090.0	874.0	7.4	0.0
		25			1864.9	489.6	2.6	0.0	2240.3	665.6	3.4	0.2	3093.1	1037.2	20.4	1.2	3014.3	872.6	9.2	0.2	3042.0	872.0	8.2	0.0
		30			1882.8	493.9	2.1	0.0	2338.6	685.7	2.4	0.0	2876.6	937.8	14.2	0.4	3437.6	978.8	12.4	0.2	3439.0	986.0	8.6	0.0

Table A4. 90% ISO 12103-1 A1 ultrafine test dust + 10% Red Iron Oxide evaluation data

Contaminant	Concentra tion	Time	STM D3240	ASTM D2276	ACM 20 - old calibration				ACM 20 - new calibration				SETA AvCount - old calibration				SETA AvCount - new calibration				ETA AvCount Lite - new calibration			
		min	ppm	mg/L	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm	≥4µm	≥6µm	≥14µm	≥30µm
H_20		0	0.0		31.7	11.5	0.5	0.0	37.2	12.8	0.7	0.0	46.1	23.8	3.7	0.3	40.5	14.2	2.1	0.4	48.0	20.0	2.6	0.0
		5	3.2		4236.1	2519.3	210.1	3.3	5156.0	3324.1	317.7	15.9	4372.4	3199.3	897.9	44.4	5500.2	3774.1	881.4	23.5	5561.0	3760.0	879.0	19.5
		10	3.0		4354.6	2582.9	209.1	2.6	5186.4	3305.8	305.4	17.9	4283.7	3129.1	875.7	47.4	5285.0	3580.7	839.7	24.9	5729.0	3834.0	884.0	20.0
		15	11.4		12060.9	7346.9	662.1	11.2	14296.1	9411.3	993.1	54.0	12082.5	8969.1	2592.6	141.5	16305.2	11343.0	2806.1	93.7	14956.0	10269.0	2492.0	55.3
		20	9.7		10822.6	6500.6	580.2	7.9	12606.0	8215.9	836.6	45.4	11207.0	8297.2	2394.7	123.1	13257.9	9142.0	2202.8	66.0	13348.0	9116.0	2173.0	46.5
		25	9.6		10918.6	6612.6	587.8	8.7	12835.7	8375.3	870.0	49.6	10992.5	8153.0	2351.6	123.5	14017.7	9692.1	2357.2	74.6	13688.0	9361.0	2236.0	51.3
		30	12.8		13528.9	8188.3	716.9	10.3	16028.0	10548.4	1096.2	57.8	13899.4	10346.4	3020.8	163.6	15522.3	10786.6	2622.6	83.7	16849.0	11599.0	2822.0	63.8
		35	13.5		14165.5	8636.8	794.2	10.6	16519.9	10871.0	1156.9	60.4	13997.6	10424.9	3044.8	159.1	17264.3	11988.7	2942.4	96.8	17953.0	12381.0	3013.0	72.5
		40	21.7		19256.2	11865.4	1131.9	15.5	22047.8	14753.6	1659.3	84.9	18225.9	13655.2	4037.3	222.9	22665.8	15926.6	3968.6	134.3	23563.0	16466.0	4158.0	100.2
		45	22.8		19146.6	11798.0	1126.1	15.9	22187.5	14824.1	1667.2	88.0	19141.0	14344.3	4208.7	230.2	22374.9	15705.7	3900.1	124.8	23364.0	16263.0	4054.0	93.1
		50	33.9		28078.2	17688.7	1832.4	23.9	31835.0	21893.2	2753.7	148.9	27907.0	21118.5	6391.1	375.3	32704.1	23358.3	6052.5	207.7	34419.0	24601.0	6538.0	166.2
		55	37.5		29046.1	18388.4	1944.4	29.0	33083.9	22829.9	2939.6	160.5	28406.0	21436.6	6396.0	363.5	34099.9	24317.1	6286.1	212.9	34242.0	24367.0	6408.0	157.0

Table A5. Free water evaluation data