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Microscale Flammability Criterion for Constituents of Aircraft Cabin Materials

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16. Abstract

A method and criterion are described to assess the no-effect level of a constituent change on the fire performance of aircraft cabin material or construction. A constituent may be a thermosetting resin, coating, composite, adhesive, potting compound, film, fabric, elastomer, rubber, or thermoplastic. This can be used in the construction of a cabin material whose heat of combustion can be reliably measured using a 1-10 milligram sample in American Society for Testing and Materials (ASTM) D7309-21, Standard Test Method for Determining Flammability Characteristics of Plastics and Other Solid Materials Using an MCC. Bench-scale fire testing as per 14 Code of Federal Regulations (CFR) § 25.853 (Compartment Interiors, 2020) was conducted on several dozen cabin materials with changed constituents. Results showed that the relative difference in the microscale Fire Growth Capacity (FGC) of the certified and changed constituent in ASTM D7309-21 must be less than 0.3 (30%) to have no significant effect on the fire performance of the cabin material.

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Acronyms

Acronym	Definition
ASTM	American Society for Testing and Materials
CFR	Code of Federal Regulations
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FGC	Fire Growth Capacity
HR	Heat Release
HRR	Heat Release Rate
MCC	Microscale Combustion Calorimetry
OSU	Ohio State University
PHRR	Peak Heat Release Rate
THR	Total Heat Released
VBB	Vertical Bunsen Burner

Executive summary

Flammability regulations of airplane cabin materials include prescriptive tests for fire performance. These regulations form the basis for certification of the airplane type design. When a single constituent such as a resin, coating, composite, adhesive, potting compound, film, fabric, or thermoplastic used in the construction of cabin materials must be changed, current flammability regulations require re-certification of all constructions in the aircraft cabin that contain the constituent, even when a fire safety improvement is made. This is a costly and time consuming process.

The invention, patenting, licensing, and codification of the Federal Aviation Administration (FAA)'s MCC enabled the measurement of combustion properties using milligram-size samples and prompted the creation of a Material Change Similarity Task Group within the FAA-industry Materials Fire Test Forum. The objective of the task group was to evaluate the MCC as an alternate means of complying with federal aviation flammability regulations when a constituent of a certified cabin material or construction was changed due to cost, availability, performance, or environmental concerns. A constituent was defined as any material whose specific heat release rate history Q (W/g) can be reliably measured using a 10 milligram sample in ASTM D7309-21, Standard Test Method for Determining Flammability Characteristics of Plastics and Other Solid Materials Using a Microscale Combustion Calorimeter. In practice, constituents are thermosetting resins, coatings, composites, adhesives, potting compounds, films, elastomers/rubber, fabrics, or thermoplastics used in the construction of a cabin material.

The FGC is a microscale combustion parameter measured in the MCC for ignitability and heat release rate that correlates the diverse Federal Aviation Regulation (FAR) fire behaviors measured in 14 CFR 25 bench-scale fire tests. An FAA-industry study conducted by the Material Change Similarity Task Group tested several dozen certified and substitute constituents at milligram scale for FGC as per ASTM D7309-21 and at bench-scale for FAR results as per 14 CFR 25. The FAA-industry study showed that there was no significant difference in 14 CFR 25 fire test results of cabin materials if the relative change in FGC of the constituent was less than 0.3 (30%).

1 Introduction

At the request of aircraft industry participants in the International Aircraft Materials Fire Test Forum, a Material Change Similarity Task Group was formed to evaluate the FAA's MCC as a method to determine equivalent flammability or similarity of substitute constituents in aircraft cabin materials. The motivation was to explore alternative means of complying with flammability regulations when a single constituent used in the construction of a certified cabin material is changed due to cost, availability, performance, or environmental concerns. At the time, federal aviation regulations required costly re-certification of all cabin materials and constructions containing the new constituent (Compartment Interiors, 2020)

The FAA's MCC was patented and licensed to two manufacturers in 2005 and was codified the following year as ASTM D7309-06, Standard Test Method for Determining Flammability Characteristics of Plastics and Other Solid Materials Using a Microscale Combustion Calorimeter (ASTM, 2013). Since that time, FAA research (Walters & Lyon, 2012; Lyon, Walters, Stoliarov, & Safronava, 2014; Lyon, Walters, & Stoliavor, 2006; Lyon, et al., 2014; Lyon & Safronnava, 2013; Safronava & Lyon, 2012) showed that an MCC combustion property called the heat release capacity (HRC) was a reasonably good predictor of pass/fail test results in the 14 CFR 25 fire test for heat release rate (Horner, 2000), but HRC was an unreliable predictor of pass/fail results for ignitability in vertical Bunsen burner tests (Safronava & Lyon, 2012; Horner, 2000)

Based on these considerations, the Material Change Similarity Task Group decided that a microscale combustion parameter should be identified that included ignitability and heat release to better correlate all FAA fire tests. ASTM D7309 could be used as an alternate means of complying with federal aviation regulations when a single constituent of an aircraft cabin material or construction is changed. A microscale combustion parameter or FGC was derived from the temperature dependence of the chemical processes responsible for ignition and burning of combustible solids. The FGC was found to correlate time-to-flashover in full-scale fire tests (Lyon, Safronava, Walters, & Crowley, 2020; Safronava, Lyon, & Walters, 2000; Lyon, Walters, & Safronava, 2021) and the wide range of fire behavior measured in 14 CFR 25 flammability tests. Some examples include heat release in forced flaming combustion at Ohio State University (OSU), unforced upward flame propagation from Vertical Bunsen Burner(VBB), and forced horizontal flame spread (radiant panel) (Horner, 2000). In 2021, the FGC was included in the latest revision of ASTM 2013.

Once the method (ASTM D7309-21) and metric (FGC) for combustibility at micro-scale were in place, software to automatically calculate FGC was developed at the FAA and distributed to licensed vendors of the MCC. An extensive validation study by the FAA and aircraft industry was initiated to compare differences in FGC of constituents to differences in bench-scale fire test results of cabin materials containing these constituents. This report provides a criterion for FGC of substitute constituents derived from the FAA-industry micro- and bench-scale studies supporting a determination of similar flammability of aircraft cabin materials when a single constituent is changed.

2 Sampling of constituents

Test specimens of constituents having mass of 1-10 mg should be homogeneous but must be representative of the combustion properties of the constituent being tested.

- Specimens may be a thermosetting resin, coating, composite, rubber / elastomeric compound, adhesive, potting compound, film, fabric, or thermoplastic used in the construction of a cabin material.
- Specimens may be solids of any form (chunk, shavings, film, powder, fiber) if they can be contained in the MCC specimen cup, which is approximately 6 mm in diameter and 3 mm in height (85 mm^3).
- Specimens of filled or fiber reinforced plastics may have non-uniform composition (heterogeneous) at the 10 mg scale due to poor dispersion of the additive. At least five tests of heterogeneous specimens should be performed to obtain a consistent and representative FGC for the constituent.

3 Microscale combustion calorimetry

The FGC defined in ASTM D7309-21 is a parameter derived from the temperature dependence of the chemical processes responsible for ignition and burning of combustible materials. The FGC unit is J/g-K and is calculated from three properties of combustible components measured in the standard test:

- h_c = Specific heat release of sample (J/g).
- $T_{5\%}$, = Temperature at 5% of h_c measured at a heating rate when measured at 1 K/s, which approximates the ignition temperature of the sample (K).

- $T_{95\%}$, = Temperature at 95% of h_c measured at 1 K/s, which approximates the burning temperature of the sample (K).

Volatile components at or near the start temperature of the test can make the reference value of the specific heat release rate Q_0 and the ignition temperature $T_{5\%}$ uncertain when calculating FGC and should be removed by delaying the test for a suitable period.

Specimens that decompose to carbonaceous char can release a small amount of heat in a high temperature process that may make determination of the final reference value of the specific heat release rate Q_0 and the burning temperature $T_{95\%}$ uncertain when calculating FGC. In these cases, at least five tests of FGC should be conducted until a consistent and representative value of FGC for the constituent is obtained. All MCC tests of constituents were conducted at the FAA's William J. Hughes Technical Center in New Jersey and at an industry participant laboratory on microscale combustion calorimeters that was constructed, calibrated, and operated according to ASTM D7309-21.

Figure 1 shows MCC data for an adhesive, plotted as the specific heat release rate Q (W/g) normalized for the heating rate β (K/s) in the test, i.e., Q/β (J/g-K), versus the sample temperature on the left hand ordinate (*y*-axis). The integral of this curve is the heat *h* released at temperature *T* and is plotted on the right hand ordinate. The total heat released (THR) by complete combustion of the adhesive pyrolysis products at the highest temperature of the test is h_c = 24.2 kJ/g. The ignition and burning temperatures at 5% and 95% of h_c, respectively, are $T_{5\%}$ = 710K (437°C) and $T_{95\%}$ = 843K (570°C). These three MCC test parameters and a standard room temperature T_0 = 298K (25°C) are used to calculate the fire growth capacity in ASTM D7309-21:

$$FGC = \left(\frac{h_c}{T_{95\%}-T_{5\%}}\right)\left(\frac{T_{95\%}-T_0}{T_{5\%}-T_0}\right) = 241\ \frac{J}{g-K} \quad (1)$$

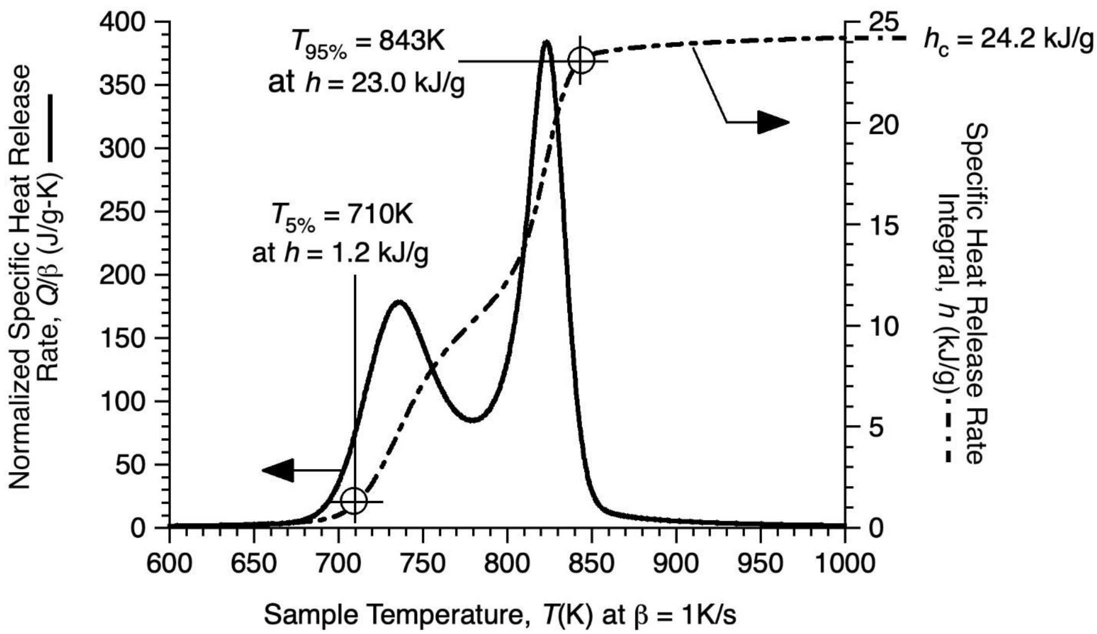

Figure 1. Schematic calculation of FGC using h_c, $T_{5\%}$ and $T_{95\%}$.

4 Bench scale fire tests

Several dozen bench scale fire tests were conducted according to 14 CFR 25 (Compartment Interiors, 2020) by the aircraft industry to determine the acceptance criterion for FGC of changed constituents measured at the FAA Technical Center. Fire tests in the FAA-industry study are the rate of heat release measured in the OSU apparatus, and the propensity for upward vertical flame propagation after 12- and 60-second ignition by a VBB. This includes the flame spread rate measured in the radiant panel test for thermal acoustic insulation. These tests were conducted by industry participants of the Material Change Similarity Task Group in accordance with 14 CFR 25 (Compartment Interiors, 2020) as described in the FAA Fire Test Handbook (Horner, 2000). The acceptance criteria for these tests are given in Table 1, Table 2, and Table 3.

Table 1. Acceptance (pass/fail) criteria for 14 CFR 25 VBB test (FAR)

Test	Flame Extinguish Time (seconds)	Burn Length (inches)	Drip Extinguish Time (seconds)
60 s VBB	≤ 15	≤ 6	≤ 3
12 s VBB	≤ 15	≤ 8	≤ 5

Table 2. Acceptance (pass/fail) criteria for 14 CFR 25 heat release rate test (FAR)

Peak Heat Release Rate (PHRR) (kW/m^2)	2-minute THR ($kW\text{-}min/m^2$)
≤ 65	≤ 65

Table 3. Acceptance (Pass/Fail) Criteria for 14 CFR 25 Radiant Panel Test (FAR)

Flame propagation distance (inches)	After flame time (seconds)
< 2	< 3

Twelve validation studies were conducted that produced 69 comparisons of microscale FGC and 14 CFR 25 bench-scale FAR fire test results for substitute and certified constituents. The results of these microscale/bench-scale comparisons are listed in Appendix A, Table A-1.

5 Microscale criterion for flammability of substitute cabin material constituents

The change in FGC of the substitute constituent (A) relative to FGC of the certified constituent (B) was less than 30% in all cases. Only constituents with intrinsic flammability FGC like the certified constituent, due to changes in flame retardant additive, suppliers, color, etc., were considered for substitution.

Figure 2 is a plot of the relative difference of microscale versus bench-scale fire test results for substitute and certified constituents of aircraft cabin materials. In this plot, the absolute value of the relative difference in FGC of the certified and changed constituent with respect to the certified constituent, $\Delta FGC/FGC_B$ from Column 4 of Table A-1 (Appendix A), is shown on the ordinate (*y*-axis). The absolute value of the relative difference in 14 CFR 25 fire test results of the cabin materials containing these different constituents with respect to the cabin material with the certified constituent, $\Delta FAR/FAR_B$, in Column 6 of Table A-1 (Appendix A), is shown on the abscissa (*x*-axis). Figure 2 shows that there is no correlation between relative changes in FGC of constituents and relative changes in FAR of substituted cabin materials for $\Delta FGC/FGC_B < 0.3$, but there is a 97% chance (67/69) that a cabin material containing the changed constituent will pass the requisite 14 CFR 25 fire tests. The empirical criterion for the no-effect level of constituent changes from the data of the FAA-industry case studies (Table A-1 in Appendix A,) is:

$$\frac{|FGC_A - FGC_B|}{FGC_B} \equiv \frac{\Delta FGC}{FGC_B} \leq 0.3 \qquad (2)$$

The last row of Table A-1 gives the average coefficient of variation of the 69 certified *FAR* tests of cabin materials, $COV_B = \sigma_B / FAR_B = 0.16$, so the criterion based on *FAR* uncertainty is:

$$\frac{\Delta FGC}{FGC_B} \leq 2\frac{\sigma_B}{FAR_B} = 2\,COV_B = (2)(0.16) \approx 0.3 \qquad (3)$$

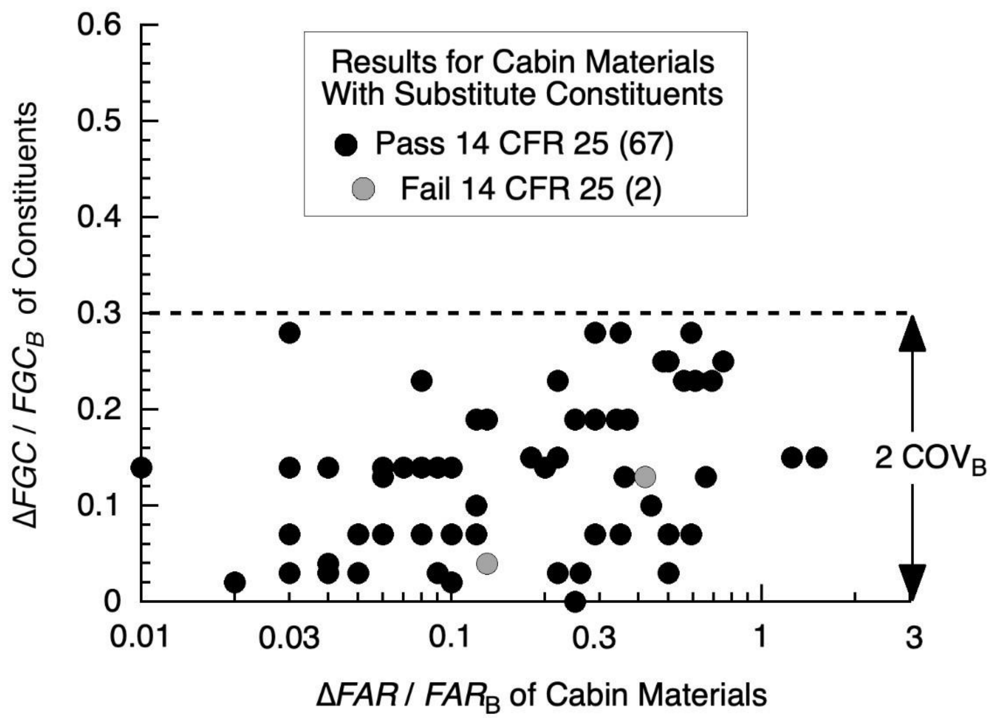

Figure 2. Summary of FAA-industry similarity studies of cabin material substituents

The no-effect level of a constituent change is therefore equivalent to constraining the relative change in FGC to less than the uncertainty of the FAR fire test results at the 95% confidence level.

6 Conclusions

This report describes a microscale test method and criterion for demonstrating equivalent fire performance of cabin materials when a single constituent is changed for reasons of cost, performance, availability, or environmental concerns. Constituents of cabin materials include adhesives, potting compounds, coatings, films, thermoplastics, thermosetting resins, elastomeric compounds/rubber, and textile fibers used in different design configurations whose fire growth capacity (FGC) can be represented by a 1-10 mg sample in a microscale combustion calorimeter according to ASTM D7309-21. Extensive studies were conducted by the FAA and aircraft industry to determine how the microscale FGC of constituents correlated with bench-scale FAR tests of cabin materials.

It was found that 97% of cabin materials with changed constituents passed the FAR requirements for heat release, upward flame propagation and horizontal flame spread when the relative change in FGC of the constituent was less than the uncertainty in the FAR fire test result of the certified cabin material at the 95% confidence level, i.e.:

$$\frac{\Delta FGC}{FGC_B} \leq 2\frac{\sigma_B}{FAR_B} = 0.3 \tag{4}$$

It is expected that quality control testing of changed cabin materials in production will validate this criterion for changed constituents.

7 Acknowledgements

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A Case study reference information

Column 1 of Table A-1 is the reference information for the case study (Safronava, Lyon, & Walters, 2000). Seven upward flame propagation tests of cabin materials containing A/B constituents were conducted by exposing vertical samples to a Bunsen burner for 12s or 60s as per 14 CFR 25. Only the burn length was reported for these tests, so FAR = burn length for these VBB tests of constituent A and B. Twenty-nine cabin materials with A/B constituents were tested in the OSU for peak (P) and total (T) heat release rate (HRR) for a total of 2 x 29 = 58 OSU results. So, FAR = OSU PHRR (OSU, P) and FAR = OSU THR at 2-min (OSU, T). Two (2) radiant panel tests (RP) of A/B constituents were conducted and after-flame time (t) and flame propagation distance (D) were reported for a total of 2 x 2 = 4 measurements, so FAR = after flame time (RP, t) and FAR = flame propagation distance (RP, D).

- Column 2 indicates whether the changed constituent (A) or the certified constituent (B) corresponds to the test results in that row for ASTM D7309 (FGC) and 14 CFR 25 (FAR) in Columns 3-7.
- Column 3 contains average values of FGC and standard deviations σ_{FGC} for 3-5 replicate tests of the fire growth capacity for the changed (A) and certified (B) constituent.
- Column 4 contains the absolute value of the difference in FGC of the substitute constituent (A) and certified constituent (B) with respect to the fire growth capacity of the certified constituent, i.e., $|FGC_A-FGC_B|/FGC_B \equiv \Delta FGC/FGC_B$.
- Column 5 contains average values of the FAR test of Column 1 and standard deviations σ_{FAR} for 3-5 replicate bench scale fire-tests for the changed (A) and certified (B) constituent.
- Column 6 contains the absolute value of the relative difference in the results of the FAR fire test of Column 1 with respect to the fire test result of the certified constituent, i.e.,
- $|FAR_A-FAR_B|/FAR_B \equiv \Delta FAR/FAR_B$.
- Column 7 is the coefficient of variation of the certified constituent in the FAR fire test of Column 1, i.e., $COV_B = \sigma_B/FAR_B$.

Table A-1: Case study reference information

Case ID [11] (FAR)	*Constituent*	ASTM D7309-21b		14 CFR 25		
		FGC ± σ_{FGC}	ΔFGC/ FGC_B	FAR ± σ_{FAR}	ΔFAR/ FAR_B	COV_B = σ_B/FAR_B
1.1 (VBB, 60s)	A B	38.7 ± 1.0 41.8 ± 1.4	0.07	4.0 ±0.1 3.7 ± 0.3	0.08	0.08
1.2 (VBB, 60s)	A B	38.7 ± 1.0 41.8 ± 1.4	0.07	3.2 ± 0.3 3.4 ± 0.1	0.06	0.03
2.1 (VBB, 60s)	A B	69.1 ± 2.8 60.5 ± 2.0	0.14	1.3 ± 0.1 1.2 ± 0.2	0.08	0.17
2.2 (VBB, 60s)	A B	69.1 ± 2.8 60.5 ± 2.0	0.14	1.5 ± 0.1 1.6 ± 0.1	0.06	0.06
2.3 (VBB, 60s)	A B	69.1 ± 2.8 60.5 ± 2.0	0.14	1.2 ± 0.1 1.1 ± 0.1	0.09	0.09
2.4 (VBB, 60s)	A B	69.1 ± 2.8 60.5 ± 2.0	0.14	1.1 ± 0.1 1.0 ± 0.0	0.10	0.00
5 (VBB, 12s)	A B	464.0 ± 3.0 499.0 ± 8.0	0.07	0.1 ± 0.0 0.2 ± 0.0	0.50	0.00
1.1 (OSU, P)	A B	38.7 ± 1.0 41.8 ± 1.4	0.07	31.4 ± 1.2 35.8 ± 1.8	0.12	0.05
1.2 (OSU, P)	A B	38.7 ± 1.0 41.8 ± 1.4	0.07	31.4 ± 1.2 34.8 ± 3.5	0.10	0.10
2.1 (OSU, P)	A B	69.1 ± 2.8 60.5 ± 2.0	0.14	43.6 ± 4.8 41.8 ± 3.1	0.04	0.07
2.2 (OSU, P)	A B	69.1 ± 2.8 60.5 ± 2.0	0.14	56.0 ± 4.5 51.7 ± 2.4	0.08	0.05
2.3 (OSU, P)	A B	69.1 ± 2.8 60.5 ± 2.0	0.14	50.8 ± 3.4 49.0 ± 3.0	0.04	0.06

Case ID [11] (FAR)	*Constituent*	ASTM D7309-21b		14 CFR 25		
		FGC ± σ_{FGC}	ΔFGC/ FGC_B	FAR ± σ_{FAR}	ΔFAR/ FAR_B	$COV_B = \sigma_B/FAR_B$
2.4 (OSU, P)	A B	69.1 ± 2.8 60.5 ± 2.0	0.14	58.0 ± 4.2 59.5 ± 8.1	0.03	0.14
3.1 (OSU, P)	A B	102.0 ± 3.0 104.0 ± 2.0	0.02	44.4 ± 1.6 45.5 ± 3.7	0.02	0.08
3.2 (OSU, P)	A B	101.0 ± 7.0 104.0 ± 2.0	0.03	41.3 ± 1.6 45.5 ± 3.7	0.09	0.08
4 (OSU, P)	A B	82.0 ± 2.0 80.0 ± 2.0	0.03	47.9 ± 1.6 50.3 ± 3.2	0.05	0.06
6.1.1 (OSU, P)	A B	43.6 ± 0.6 40.6 ± 0.6	0.07	28.0 ± 10.6 39.3 ± 10.2	0.29	0.26
6.1.2 (OSU, P)	A B	43.6 ± 0.6 40.6 ± 0.6	0.07	33.5 ± 6.3 32.5 ± 4.7	0.03	0.14
6.2.1 (OSU, P)	A B	17.4 ± 0.9 24.0 ± 0.6	0.28	28.0 ± 10.6 39.3 ± 10.2	0.29	0.26
6.2.2 (OSU, P)	A B	17.4 ± 0.9 24.0 ± 0.6	0.28	33.5 ± 6.3 32.5 ± 4.7	0.03	0.14
7 (OSU, P)	A B	44.0 ± 1.0 49.0 ± 1.0	0.10	14.3 ± 8.7 12.8 ± 0.5	0.18	0.04
8 (OSU, P)	A B	109.0 ± 1.0 113.0 ± 1.0	0.04	54.0 ± 2.0 52.0 ± 2.0	0.04	0.04
9.1.a (OSU, P)	A B	57.0 ± 1.0 59.0 ± 2.0	0.03	28.0 ± 8.0 23.0 ± 6.0	0.22	0.26
9.2.a (OSU, P)	A B	50.0 ± 1.0 59.0 ± 2.0	0.15	28.0 ± 6.0 23.0 ± 6.0	0.22	0.26
9.3.a (OSU,P)	A B	44.0 ± 1.0 59.0 ± 2.0	0.25	23.0 ± 9.0 23.0 ± 6.0	0.00	0.26

Case ID [11] (FAR)	*Constituent*	ASTM D7309-21b		14 CFR 25		
		FGC ± σ_{FGC}	ΔFGC/ FGC_B	FAR ± σ_{FAR}	ΔFAR/ FAR_B	COV_B = σ_B/FAR_B
9.1.b (OSU, P)	A	57.0 ± 1.0		43.0 ± 14.0		
	B	59.0 ± 2.0	0.03	34.0 ± 3.0	0.26	0.09
9.2.b (OSU, P)	A	50.0 ± 1.0		40.0 ± 6.0		
	B	59.0 ± 2.0	0.15	34.0 ± 3.0	0.18	0.09
9.3.b (OSU, P)	A	44.0 ± 1.0		34.0 ± 3.0		
	B	59.0 ± 2.0	0.25	23.0 ± 6.0	0.49	0.09
10.a(*) (OSU, P)	A	26.0 ± 2.0		<u>75.0</u> ± 6.0		
	B	23.0 ± 2.0	0.13	53.0 ± 15.0	0.42	0.28
10.b (OSU,P)	A	26.0 ± 2.0		72.0 ± 3.0		
	B	23.0 ± 2.0	0.13	68.0 ± 6.0	0.06	0.09
12.1.a (OSU, P)	A	76.0 ± 1.0		44.7 ± 3.0		
	B	64.0 ± 1.0	0.19	39.5 ± 3.6	0.13	0.09
12.2.a (OSU, P)	A	79.0 ± 3.0		30.7 ± 2.5		
	B	64.0 ± 1.0	0.23	39.5 ± 3.6	0.22	0.09
12.1.b (OSU, P)	A	76.0 ± 1.0		64.5 ± 3.9		
	B	64.0 ± 1.0	0.19	48.2 ± 3.6	0.34	0.07
12.2.b (OSU, P)	A	79.0 ± 3.0		37.7 ± 3.9		
	B	64.0 ± 1.0	0.23	48.2 ± 3.6	0.22	0.07
12.1.c (OSU, P)	A	76.0 ± 1.0		65.2 ± 4.0		
	B	64.0 ± 1.0	0.19	50.4 ± 8.6	0.29	0.17
12.2.c (OSU, P)	A	79.0 ± 3.0		46.3 ± 5.7		
	B	64.0 ± 1.0	0.23	50.4 ± 8.6	0.08	0.17
1.1 (OSU, T)	A	38.7 ± 1.0		26.1 ± 2.4		
	B	41.8 ± 1.4	0.07	27.8 ± 3.0	0.05	0.11
1.2 (OSU, T)	A	38.7 ± 1.0		37.1 ± 4.2		
	B	41.8 ± 1.4	0.07	39.3 ± 4.5	0.06	0.11

Case ID [11] (FAR)	*Constituent*	ASTM D7309-21b		14 CFR 25		
		FGC ± σ_{FGC}	ΔFGC/ FGC_B	FAR ± σ_{FAR}	ΔFAR/ FAR_B	COV_B = σ_B/FAR_B
2.1	A	69.1 ± 2.8		45.4 ± 4.0		
(OSU, T)	B	60.5 ± 2.0	0.14	45.4 ± 5.6	0.00	0.12
2.2	A	69.1 ± 2.8		58.9 ± 4.2		
(OSU, T)	B	60.5 ± 2.0	0.14	55.0 ± 2.9	0.07	0.05
2.3	A	69.1 ± 2.8		57.8 ± 4.1		
(OSU, T)	B	60.5 ± 2.0	0.14	58.5 ± 3.5	0.01	0.06
2.4	A	69.1 ± 2.8		68.4 ± 3.5		
(OSU, T)	B	60.5 ± 2.0	0.14	70.9 ± 3.9	0.04	0.06
3.1	A	102.0 ± 3.0		39.7 ± 1.1		
(OSU, T)	B	104.0 ± 2.0	0.02	44.1 ± 1.1	0.10	0.02
3.2	A	101.0 ± 7.0		42.4 ± 1.0		
(OSU, T)	B	104.0 ± 2.0	0.03	44.1 ± 1.1	0.04	0.02
4	A	82.0 ± 2.0		35.6 ± 1.3		
(OSU, T)	B	80.0 ± 2.0	0.03	34.5 ± 3.5	0.03	0.10
6.1.1	A	43.6 ± 0.6		20.0 ± 7.2		
(OSU, T)	B	40.6 ± 0.6	0.07	30.7 ± 5.7	0.35	0.19
6.1.2	A	43.6 ± 0.6		9.9 ± 4.9		
(OSU, T)	B	40.6 ± 0.6	0.07	24.3 ± 6.8	0.59	0.28
6.2.1	A	17.4 ± 0.9		20.0 ± 7.2		
(OSU, T)	B	24.0 ± 0.6	0.28	30.7 ± 5.7	0.35	0.19
6.2.2	A	17.4 ± 0.9		9.9 ± 4.9		
(OSU, T)	B	24.0 ± 0.6	0.28	24.3 ± 6.8	0.59	0.28
7	A	44.0 ± 1.0		8.4 ± 4.7		
(OSU, T)	B	49.0 ± 1.0	0.10	15.1 ± 2.6	0.44	0.17
8(*)	A	109.0 ± 1.0		72.0 ± 3.0		
(OSU, T)	B	113.0 ± 1.0	0.04	64.0 ± 4.0	0.13	0.06

Case ID [11] (FAR)	*Constituent*	ASTM D7309-21b		14 CFR 25		
		FGC ± σ_{FGC}	ΔFGC/ FGC_B	FAR ± σ_{FAR}	ΔFAR/ FAR_B	COV_B = σ_B/FAR_B
9.1.a (OSU, T)	A B	57.0 ± 1.0 59.0 ± 2.0	0.03	3.0 ± 2.0 2.0 ± 2.0	0.50	1.00
9.2.a (OSU, T)	A B	50.0 ± 1.0 59.0 ± 2.0	0.15	5.0 ± 2.0 2.0 ± 2.0	1.50	1.00
9.3.a (OSU, T)	A B	44.0 ± 1.0 59.0 ± 2.0	0.25	3.0 ± 3.0 2.0 ± 2.0	0.50	1.00
9.1.b (OSU, T)	A B	57.0 ± 1.0 59.0 ± 2.0	0.03	4.0 ± 1.0 4.0 ± 2.0	0.00	0.50
9.2.b (OSU, T)	A B	50.0 ± 1.0 59.0 ± 2.0	0.15	9.0 ± 5.0 4.0 ± 2.0	1.25	0.50
9.3.b (OSU, T)	A B	44.0 ± 1.0 59.0 ± 2.0	0.25	7.0 ± 3.0 4.0 ± 2.0	0.75	0.50
10.a (OSU, T)	A B	26.0 ± 2.0 23.0 ± 2.0	0.13	53.0 ± 6.0 32.0 ± 7.0	0.65	0.22
10.b (OSU, T)	A B	26.0 ± 2.0 23.0 ± 2.0	0.13	60.0 ± .0 44.0 ± 6.0	0.36	0.14
12.1.a (OSU, T)	A B	76.0 ± 1.0 64.0 ± 1.0	0.19	34.2 ± 3.1 38.7 ± 5.0	0.12	0.13
12.2.a (OSU, T)	A B	76.0 ± 1.0 64.0 ± 1.0	0.23	11.9 ± 3.2 38.7 ± 5.0	0.69	0.13
12.1.b (OSU, T)	A B	76.0 ± 1.0 64.0 ± 1.0	0.19	48.2 ± 1.7 38.6 ± 1.8	0.25	0.05
12.2.b (OSU, T)	A B	76.0 ± 1.0 64.0 ± 1.0	0.23	16.9 ± 1.6 38.6 ± 1.8	0.56	0.05
12.1.c (OSU, T)	A B	76.0 ± 1.0 64.0 ± 1.0	0.19	52.1 ± 4.4 37.9 ± 4.3	0.37	0.11

Case ID [11] (FAR)	*Constituent*	ASTM D7309-21b		14 CFR 25		
		FGC ± σ_{FGC}	ΔFGC/ FGC_B	FAR ± σ_{FAR}	ΔFAR/ FAR_B	COV_B = σ_B/FAR_B
12.2.c (OSU, T)	A B	76.0 ± 1.0 64.0 ± 1.0	0.23	14.8 ± 2.3 37.9 ± 4.3	0.61	0.11
11.1 (RP, D)	A B	10.0 ± 1.0 10.0 ± 1.0	0.00	1.0 ± 0.1 0.8 ± 0.0	0.25	0.00
11.2 (RP, D)	A B	10.0 ± 1.0 10.0 ± 1.0	0.00	0.8 ± 0.2 0.8 ± 0.0	0.00	0.00
11.1 (RP, t)	A B	10.0 ± 1.0 10.0 ± 1.0	0.00	0.0 ± 0.0 0.0 ± 0.0	0.00	0.00
11.1 (RP, t)	A B	10.0 ± 1.0 10.0 ± 1.0	0.00	0.0 ± 0.0 0.0 ± 0.0	0.00	0.0
					Average COV_B =	0.16