Material Change Similarity

Microscale Combustion Calorimetry - Providing the Flammability Properties of Materials; a Key to Managing Fire Safety

IAMFTWG

March 6-7, 2018

Savannah, GA

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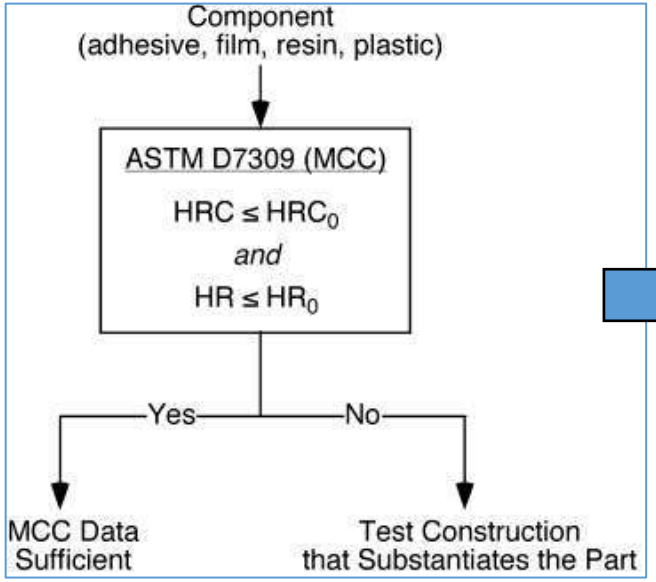
FAA International Aircraft Materials Fire Test Working Group
Material Change Similarity Task Group

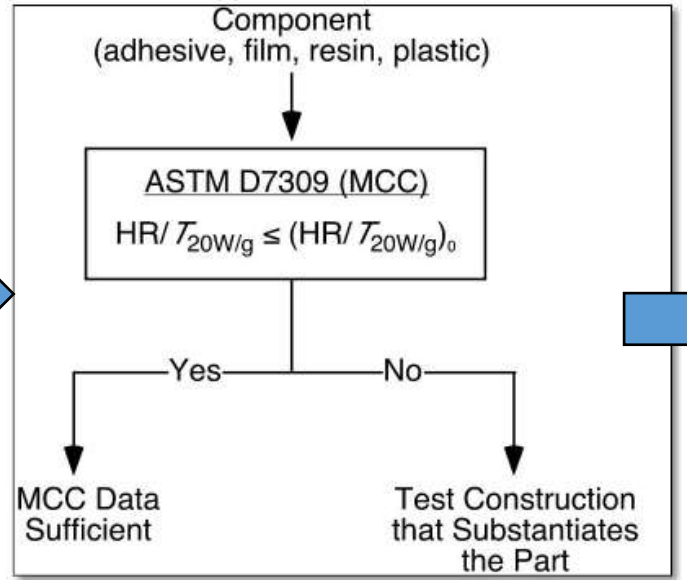
Task Group Goal:

- MCC is a molecular level material property and determines flammability properties.
- Develop test procedure and process to determine if a material change can be considered a “minor change” using Microscale Combustion Calorimetry (ASTM D7309).
- Proposed draft guidance developed was published in June 2016. https://www.fire.tc.faa.gov/pdf/materials/MCC_Guidance_June_2016.pdf

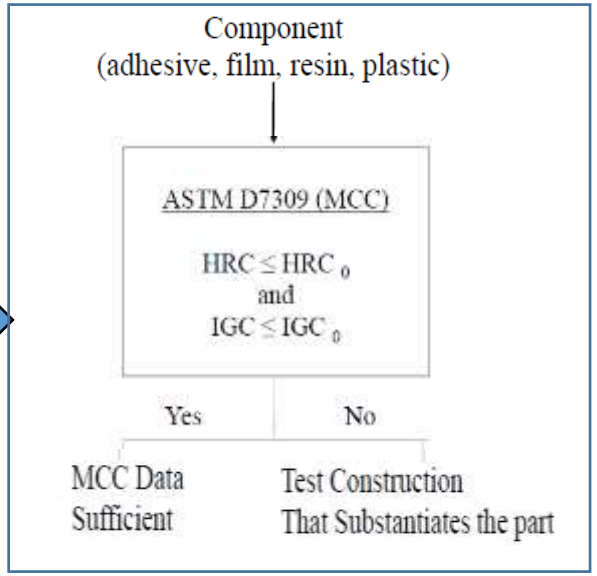
MCC Criteria Development Timeline:



2016: HRC and HRR



1Q 2017: IGC



4Q 2017: IGC & HRC

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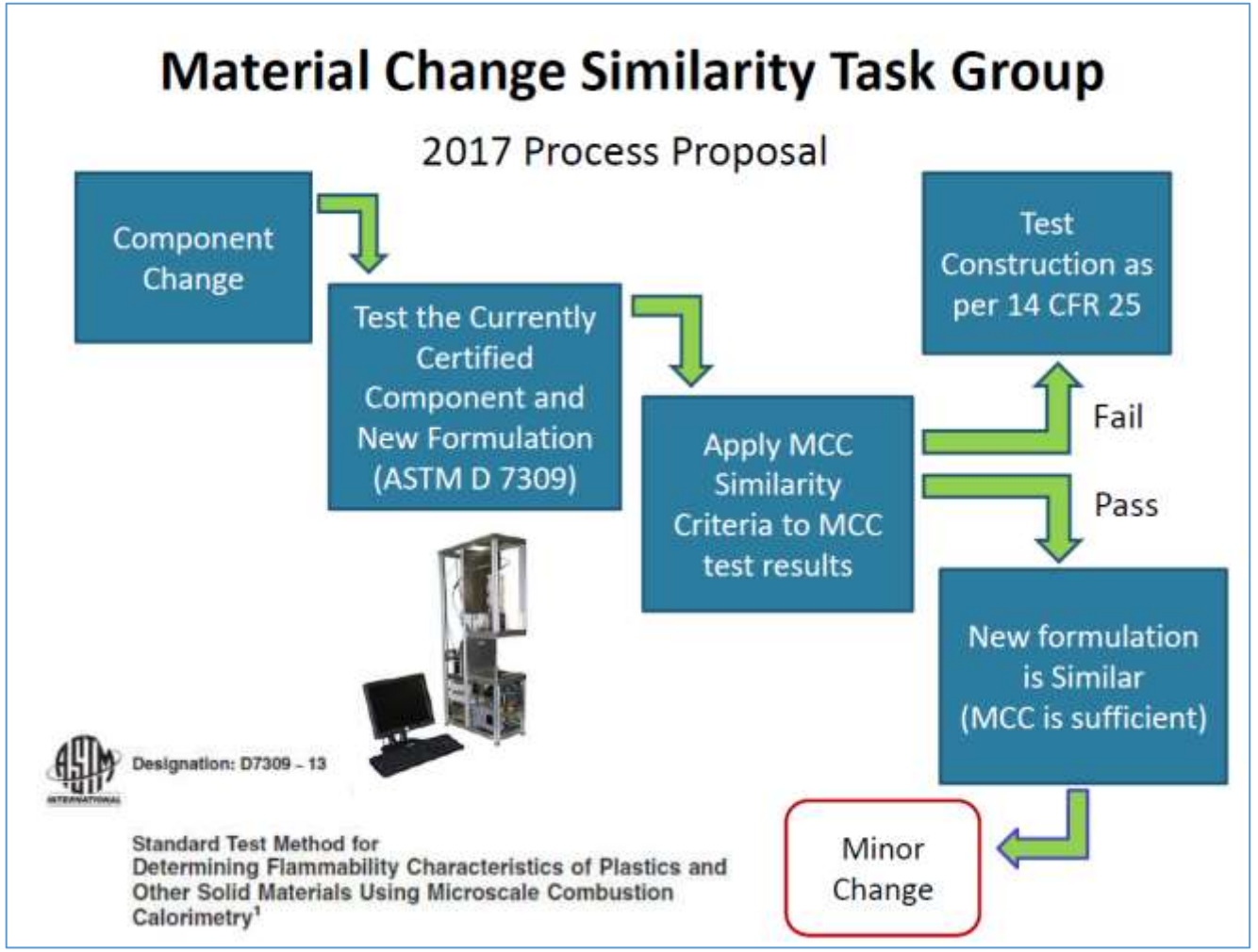
MCC Similarity Comparison:

- Compare material changes to current certified materials
- Equivalent or better MCC performance confirms minor change



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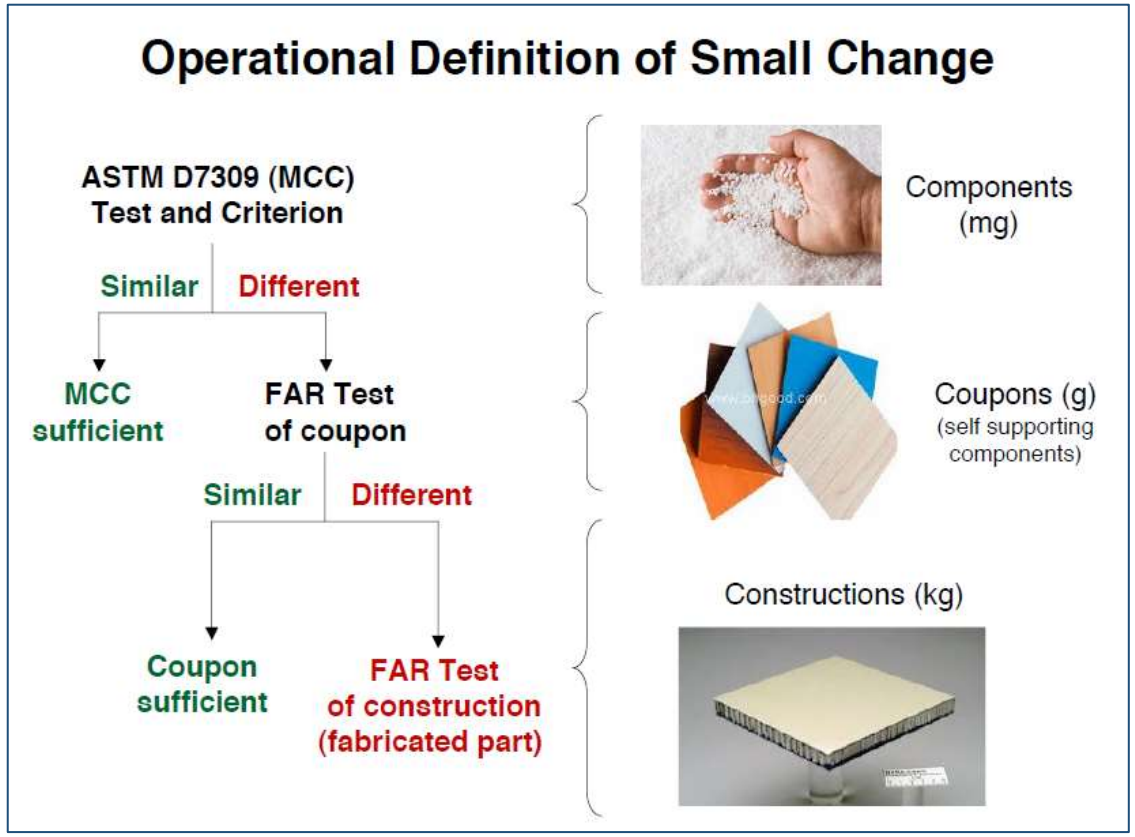
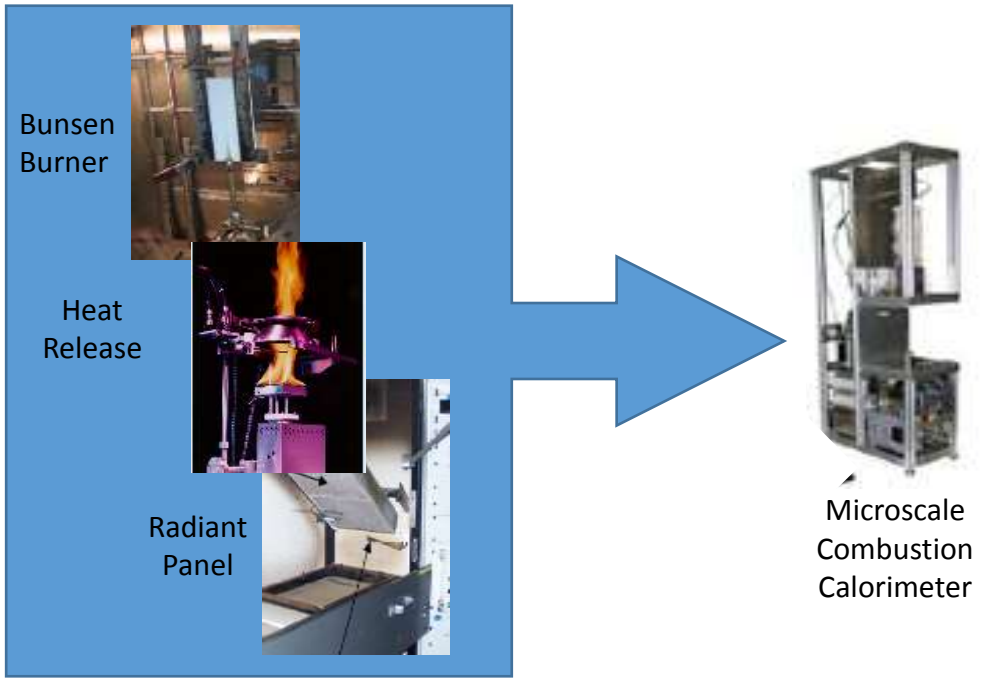
MCC Similarity Comparison:





Determine boundary conditions for utilizing MCC

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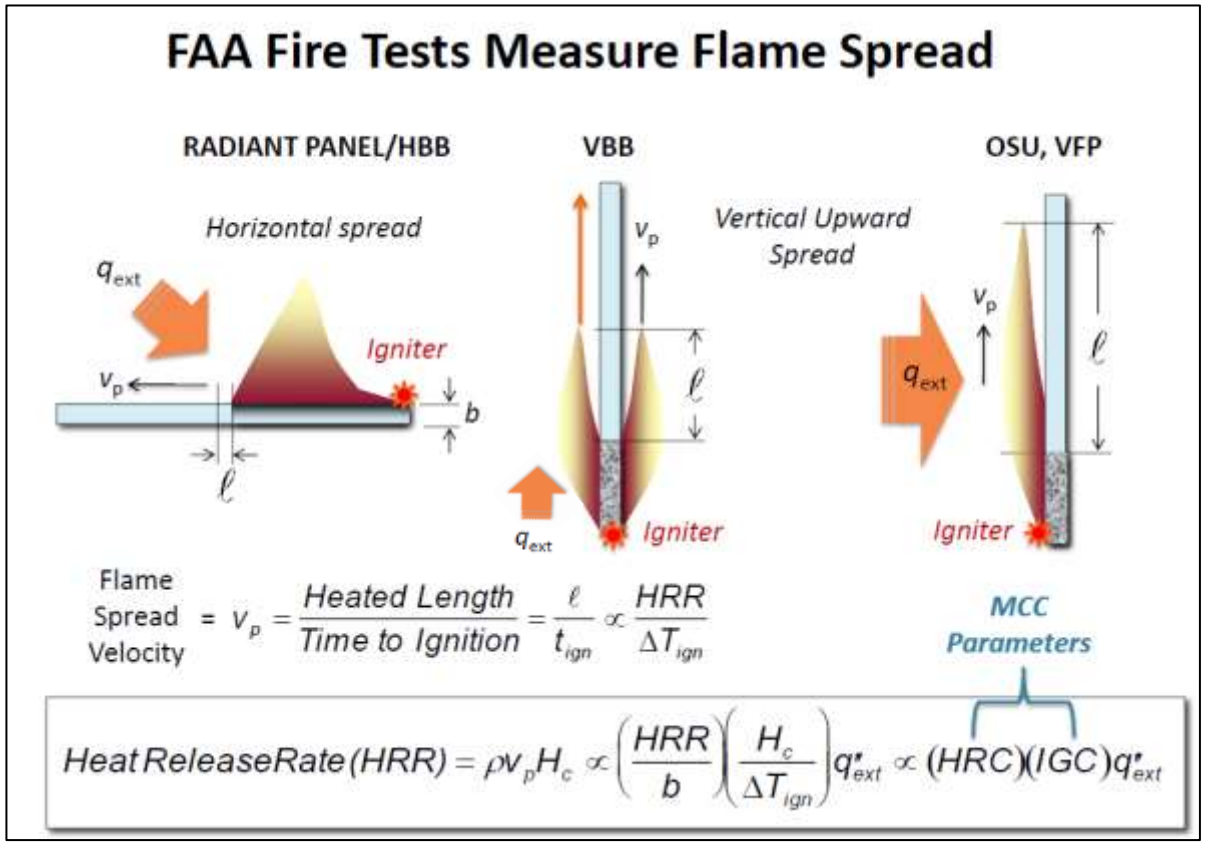
Test Criteria: Heat Release Capacity (HRC) and Ignition Capacity (IGC)

- Together, these two criteria define the overall combustion properties of materials which can lead to propagation.



https://www.fire.tc.faa.gov/pdf/materials/Oct17Meeting/Lyon-1017-MaterialChange.pdf

A materials flammability properties define how parts ignite, burn, & propagate

Ignition Capacity + Heat Release Capacity → Flame Spread & Fire Growth Rate

FRC

New Term: FRC (Fire Resistance Capacity)

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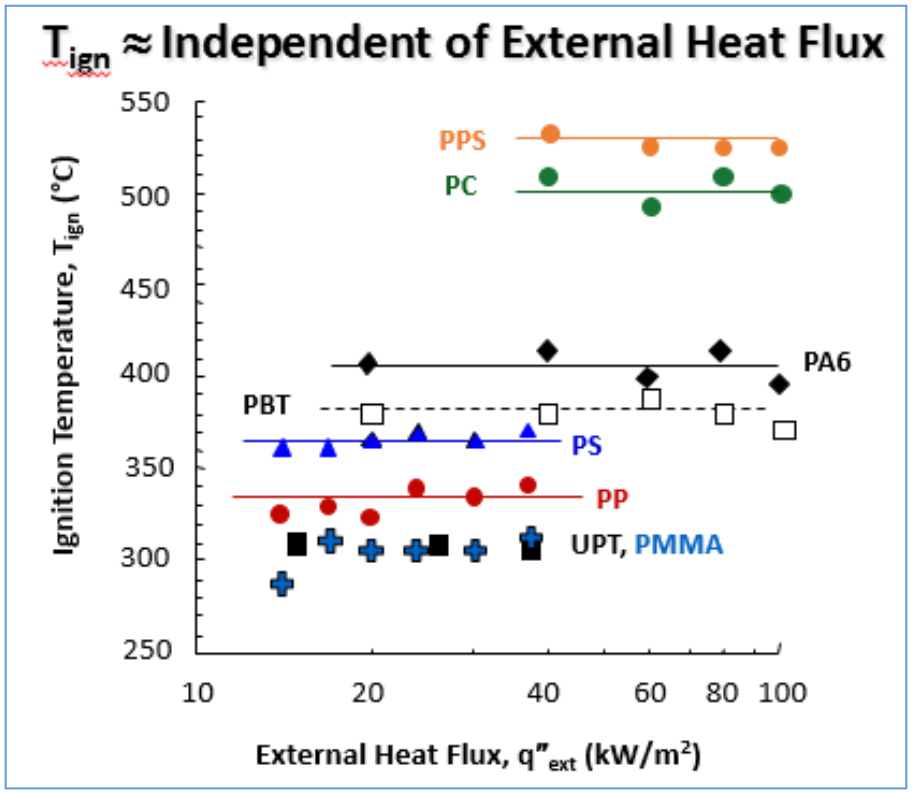
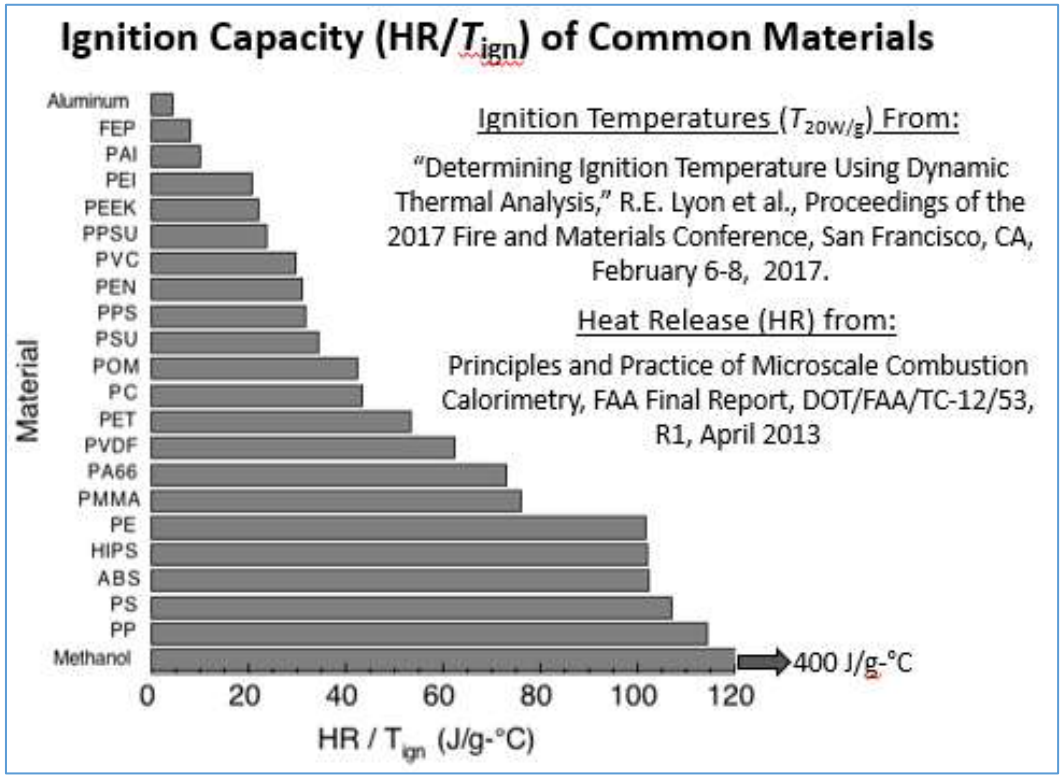
Test Criteria: Ignition Temperature of a material

- Independent of External Heat Flux and correlates with the thermal stability of polymers.





https://www.fire.tc.faa.gov/pdf/materials/March17Meeting/Boeing-0317-MCC_SIMILARITY.pdf

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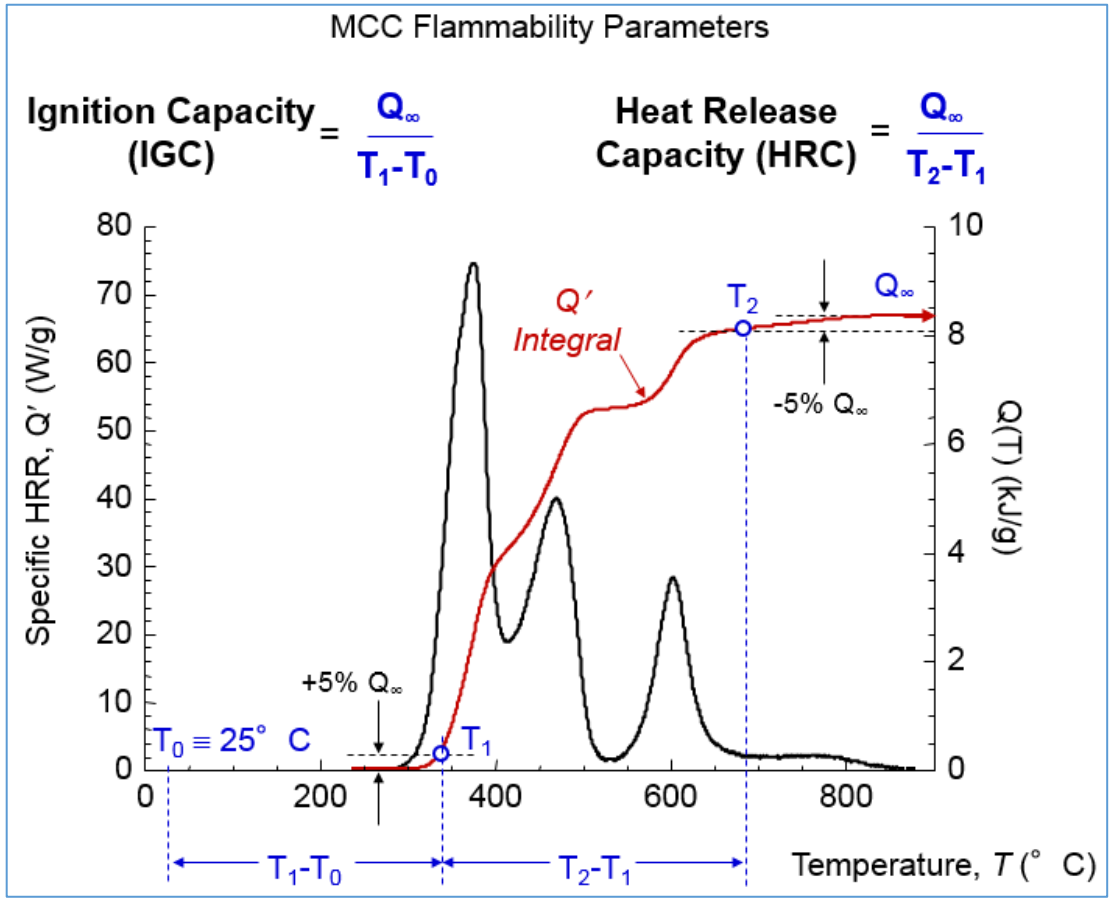
Test Criteria: MCC Component Procedure (Updated)



COMPONENT PROCEDURE

1. Measure specific heat release rate Q′ versus temperature *T* as per ASTM D7309 (5 replicates)
2. Integrate Q′/β versus *T* to obtain Q versus *T*, i.e., Q(*T*).
3. Obtain total heat release $Q(T_\infty) = Q_\infty = h_c$(J/g)
4. Obtain T_1 at 5% deflection from Q(T) baseline, i.e., at $0.05Q_\infty$
5. Obtain T_2 at $Q_\infty-(0.05Q_\infty)$, i.e., $0.95Q_\infty$.
6. Calculate 2 Flammability Parameters
   - HRC (J/g-K) = $h_c/(T_2-T_1)$
   - IGC (J/g-K) = $h_c/(T_1-T_0)$

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Test Criteria: MCC Similarity Comparison (Updated)

COMPONENT SIMILARITY PROCESS

1) Test 5 samples in MCC (ASTM D7309)

2) Determine 3 combustion properties

- h_c = 8.33 kJ/g
- T_1 = 343° C at 5% of h_c
- T_2 = 637° C at 95% of h_c

3) Compute 2 flammability parameters: HRC & IGC

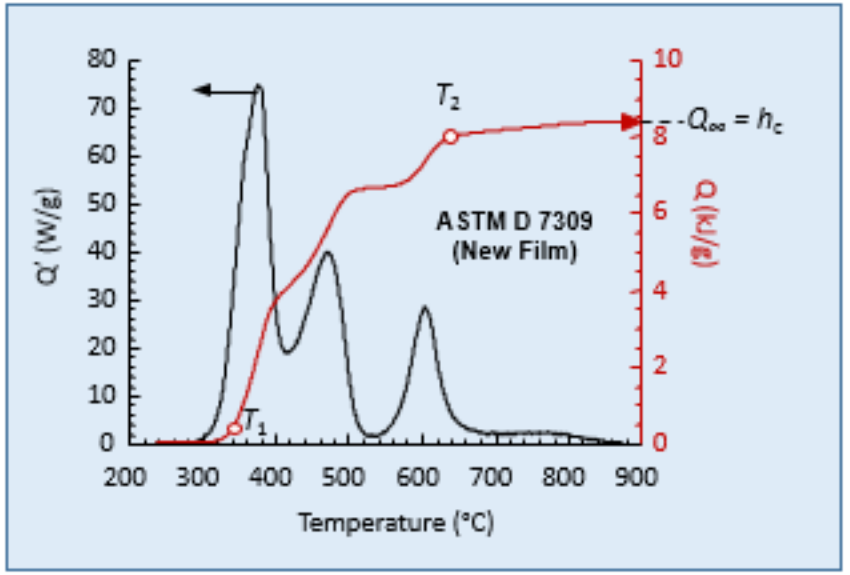
- **HRC = $h_c/(T_2-T_1)$ = 28 J/g-K**
- **IGC = $h_c/(T_1-T_o)$ = 26 J/g-K**

- **HRC = ...**
- **IGC = ...**

Data from certified construction

?

4) Calculate Fire Resistance Capacity (FRC)
HRC + IGC = FRC



4) Apply statistical criteria (TBD) to determine whether FRC = HRC + IGC of new component is similar to certified component

FAR Tests of Coupons — *Different* | *Similar* — *Small Change*

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TASK GROUP BREAK-OUT TOPICS:

Guidance Document Updates:

- New definitions and updated reference material
- Calculation of MCC criteria
- Statistical analysis approach

Statistical Analysis Methodology: (Details provided in Appendix)

- Testing Methodology
- T-test

Case Studies:

- Primer & Topcoats
- Phenolic Resins
- Thermoplastics
- Adhesives

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Next Steps:

- Material Change case studies (2Q 2018)
- Update Guidance as required (3Q 2018)
- Submit to FAA for new Advisor Circular or Policy Memo (4Q 2018)

Future Opportunities:

?

Future Opportunities:

- Leverage knowledge of material fire properties
  - Material based MOCs – E.g. phenolic panels, thermoplastics
  - Standard material test configurations
- Utilize MCC in certification testing and future regulatory development
  - Incorporate MCC into current guidance/regulations
  - Full scale tests – performance is controlled by material properties.
- Assessment of Fleet Performance - Post-crash and in-flight fire scenarios
  - What can we learn about cabin fire safety performance relative to materials flammability?
  - What can we learn about the state-of-art material performance relative to the regulations?

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Interior Materials & Requirements

	737-200 (Manchester) [Cert Basis 1967]		737-500 (Denver) [Cert Basis 1990]		State-of-Art [2005+]	
FEATURE	**Materials**	**Test Method**	**Materials**	**Test Method**	**Materials**	**Test Method**
Floor Panels	Fiberglass/epoxy/nomex (Lightweight)	Horiz BB, 12sec VBB	Fiberglass/epoxy/nomex (Lightweight & medium weight)	Cargo Liner Burnthrough	Carbon/epoxy/nomex	Cargo Liner Burnthrough
Sidewall Panels	Vinyl aluminum laminate	Horiz BB, 12sec VBB	Fiberglass/nomex honeycomb/phenolic with tedlar laminate	Heat Release	Fiberglass & carbon/nomex honeycomb/phenolic with tedlar laminate	Heat Release
Sidewall Panel Air Grills	Polycarbonate/aluminum screen	Horiz BB, 12sec VBB	High Temperature thermoplastic W/Tedlar foil laminate noise/airflow baffle	Heat Release	High Temperature thermoplastic W/Tedlar foil laminate noise/airflow baffle	Heat Release
Stowbins	Fiberglass/epoxy/nomex with vinly/tedlar laminate	Horiz BB, 12sec VBB	Fiberglass/carbon/nomex honeycomb/phenolic with tedlar laminate	Heat Release	Fiberglass/carbon/nomex honeycomb/phenolic with tedlar laminate	Heat Release
Ceilings	Epoxy/polyester compression molded fiberglass & vinyl aluminum laminate	Horiz BB, 12sec VBB	Fiberglass/carbon/nomex honeycomb/phenolic with tedlar laminate	Heat Release	Fiberglass/carbon/nomex honeycomb/phenolic with tedlar laminate	Heat Release
Cargo Liners	Fiberglass/epoxy/polyester sheet	Horiz BB, 12sec VBB	Fiberglass/phenolic sheet	Cargo liner oil burner	Fiberglass/phenolic sheet	Cargo liner oil burner
Seat Cushions	Non-fire blocked polyurethane foam	Horiz BB, 12sec VBB	Fire-blocked polyurethane foam	Seat Oil Burner	Fire-blocked polyurethane foam	Seat Oil Burner
Fuselage Insulation	PET Film/Fiberglass Batting	Horiz BB, 12sec VBB	PET Film/Fiberglass Batting & fire stop below window	12 sec VBB	PEEK/PVF/PEEK Film/Fiberglass Batting & fire stop below window	Radiant Panel

Material Flammability Performance During Post-crash Fire

1985: 737-200, Manchester (AAIB Aircraft Accident Report, August 1988)

External Fire Damage: Left side aft of wing

Interior Fire Damage: Passenger Aisle looking forward

Material Flammability Performance During Post-crash Fire

2008: 737-500, Denver

AAR-10-04; 737-500 Accident Report; Continental Flight 1404, Denver, CO on December 20, 2008
https://www.ntsb.gov/investigations/AccidentReports/Pages/AAR1004.aspx

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Material Flammability Performance During Post-crash Fire

2008: 737-500, Denver

Material Flammability Performance During Post-crash Fire

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Material Flammability Performance During Post-crash Fire

2016: 767-300, Chicago

NTSB Airworthiness Group Chairman's Factual Report, American Airlines Flight 383, 767-300, Chicago, IL on October 28, 2016
https://dms.ntsb.gov/pubdms/search/hitlist.cfm?docketID=60058&CFID=1162339&CFTOKEN=3b2ad8e5a9b13897-F1C836F4-F78C-90A7-555B28897F98613

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Material Flammability Performance During Post-crash Fire

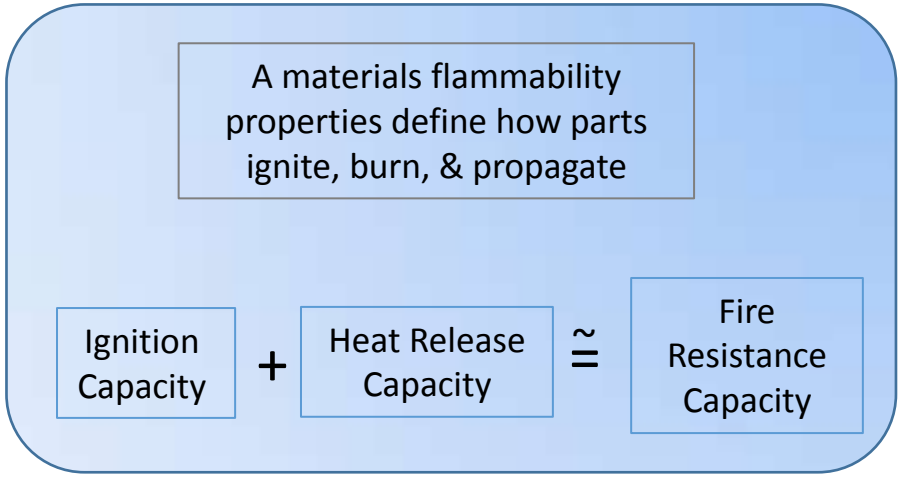
2016: 767-300, Chicago


Figure 57 Seat 34 charred seat cushion

NTSB Airworthiness Group Chairman's Factual Report, American Airlines Flight 383, 767-300, Chicago, IL on October 28, 2016
https://dms.ntsb.gov/pubdms/search/hitlist.cfm?docketID=60058&CFID=1162339&CFTOKEN=3b2ad8e5a9b13897-F1C836F4-F78C-90A7-555B28897F98613

Summary - Future Opportunities:

- Continue to leverage knowledge of materials fire properties, incorporate MCC into guidance/regulation
- Include MCC in testing and regulation development activities
- Assessment of current system of flammability requirements – move toward materials based certification



Thank You!

Note: The following slides provide a summary of the Statistical Analysis approach for use with the Material Change Similarity process.

Statistical Methodology for Material Change Similarity using MCC

International Aircraft Materials Fire Test Working Group
Material Change Similarity Task Group
Savannah, GA
06-07 March 2018

Thomas W. Little, Ph.D.
Boeing Commercial Airplanes

Acknowledgements
FAA Tech Center: Richard E. Lyon, Ph.D., Natallia Safronava
Boeing: Dan Slaton

Material Change Similarity

- **Background**
  - Material Change Similarity Task Group is developing a process to quantitatively determine the impact of material composition changes on flammability properties
  - Fundamental process
    - Measure fundamental material flammability properties using Microscale Combustion Calorimetry (MCC)
      - Examples: Heat release capacity (HRC), flame spread capacity (FSC), total heat release (THR), ….
    - Statistically compare properties of the “new” and “old” materials -> “after compositional change” vs. “before compositional change” (“original material” vs. “reformulated material”)
    - If results are not significantly different, consider the new and old materials interchangeable from perspective of flammability performance

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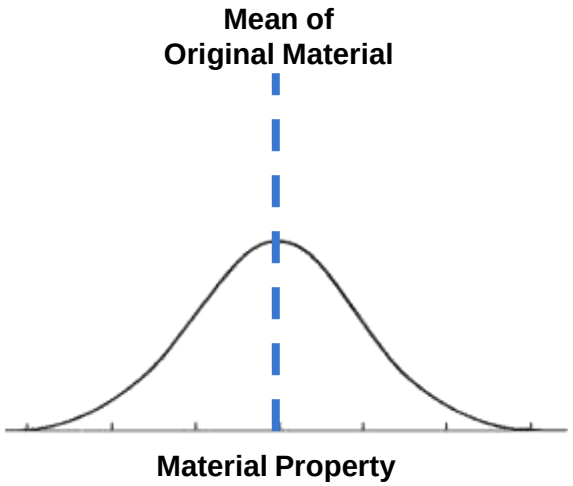

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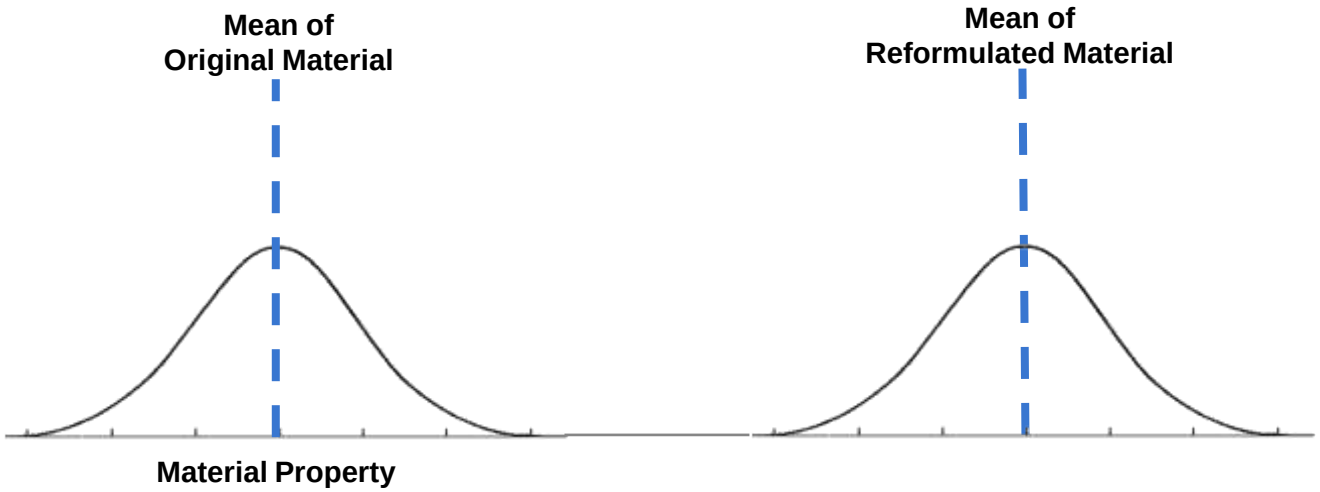

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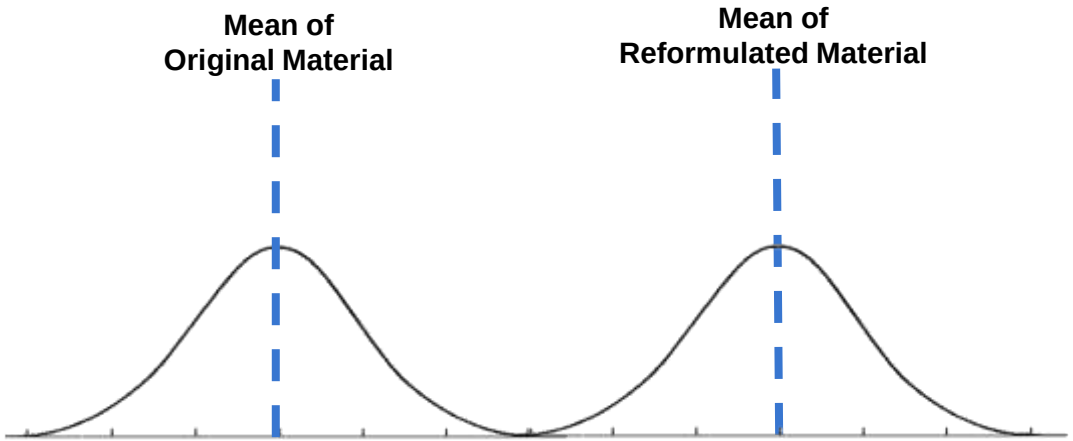

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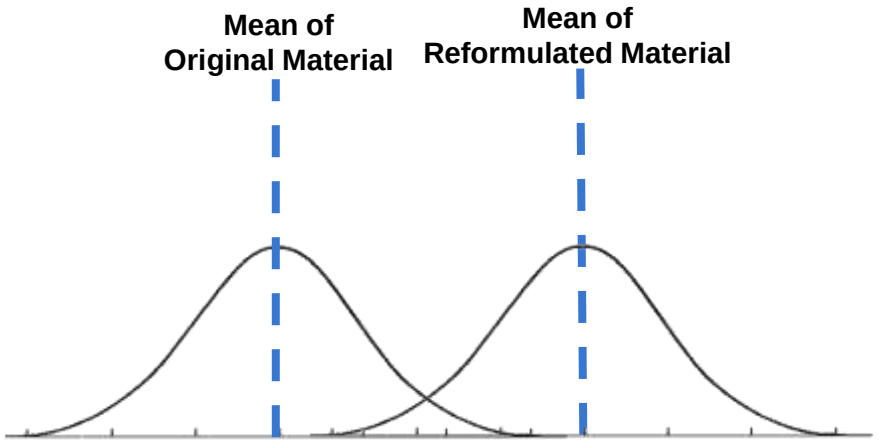

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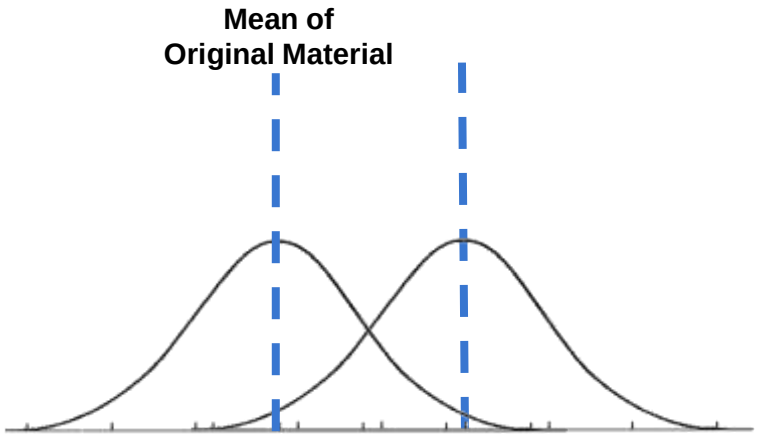

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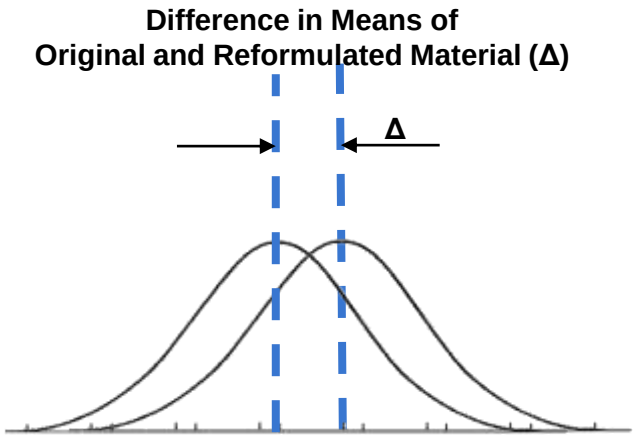

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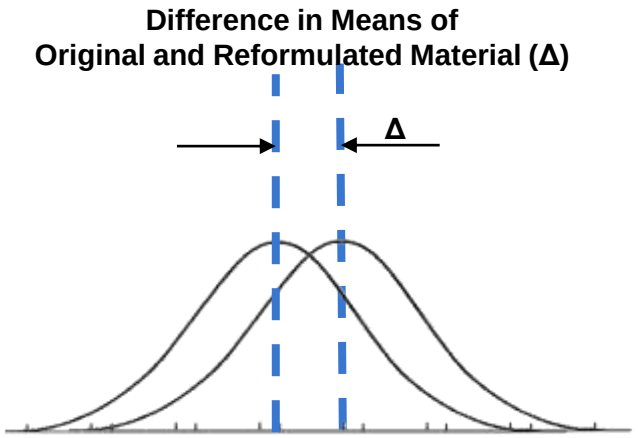


Problem Statement

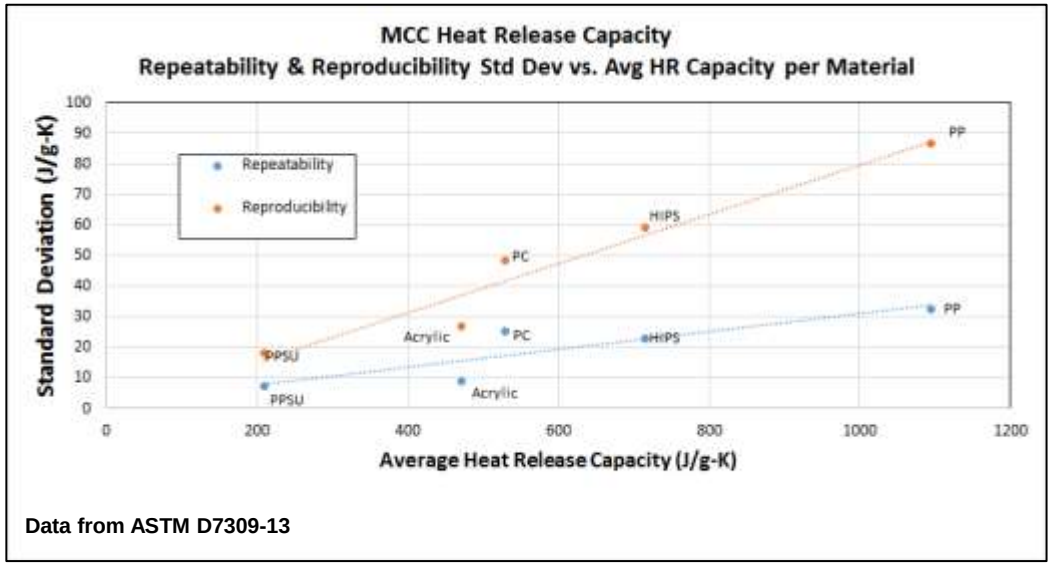
Need suitable statistical data analysis procedures and evaluation criteria to determine when “old” and “new” materials may be considered interchangeable, i.e.

-> “How small does Δ need to be for interchangeability?”

Material Change Similarity

- **ASTM MCC Statistical Methodology?**
  - ASTM D7309 “Standard Test Method for Determining Flammability Characteristics of Plastics and Other Solid Materials Using Microscale Combustion Calorimetry” (Section 14)
  - References
    - ASTM E177 “Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods”
    - ASTM E691 “Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method”

- Key Points
  - Objective: Determine MCC *precision statistics*: repeatability (r) & reproducibility (R) limits
  - Calculated from “Interlaboratory Study,” aka “round-robin” (RR) (*2010-2011*)
  - Based on “repeatability standard deviation” (s_r) and “reproducibility standard deviation” (s_R)
    - Calculated from *all labs* in the RR
    - s_r and s_R are a f(measurement value)
  - s_r and $s_R \neq$ “typical” (within-laboratory) standard deviation
  - s_r and s_R do not cover entire range or latest MCC parameters (e.g. FSC)
- **Conclusion**: ASTM D7309 statistical methodology not optimal for material change comparisons



Data from ASTM D7309-13

Material Change Similarity

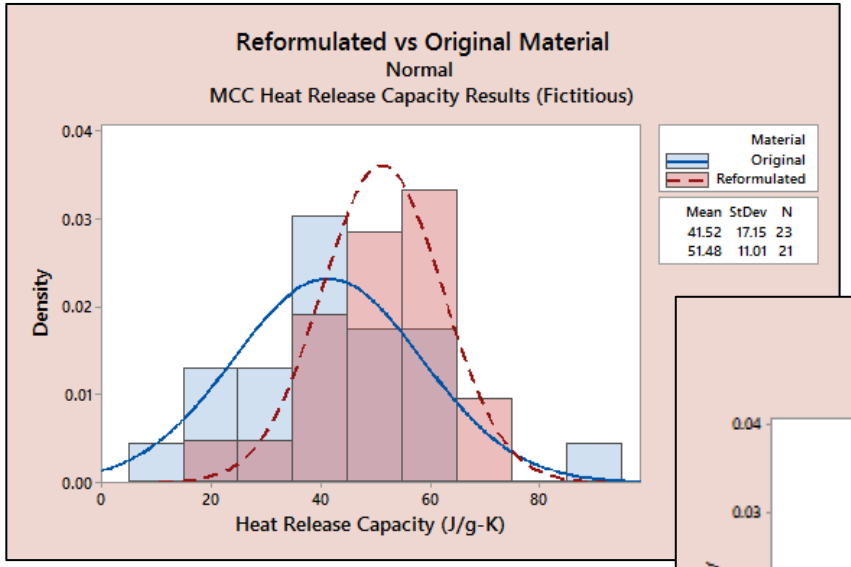
- **Proposed Statistical Methodology**
  - Traditional “null hypothesis significance testing”
    - Widely used for comparison of 2 (or more) data sets
    - “Null hypothesis”: the means for the material property for the original and reformulated material are identical
    - “Significance testing”: collection & analysis of data -> assessed against the null hypothesis at a given level of statistical “significance”
    - If there is sufficient statistical evidence, the null hypothesis is rejected; and the 2 materials are not considered interchangeable in terms of flammability properties.
  - Fundamental procedure
    - Collect MCC data (HRC, FSC, …) for original & reformulated materials simultaneously (head-to-head comparison)
      - Notation: Let original material = “material 1” and reformulated material = “material 2”
      - Number of specimens = n_1 and n_2 (ideally, $n_1 = n_2$)
    - Calculate means and standard deviations for both materials ($<x>_1$, s_1; $<x>_2$, s_2) and “pooled standard deviation” s_p
      - $s_p{}^2 = \frac{(n_1-1)s_1{}^2+(n_2-1)s_2{}^2}{n_1+n_2-2}$

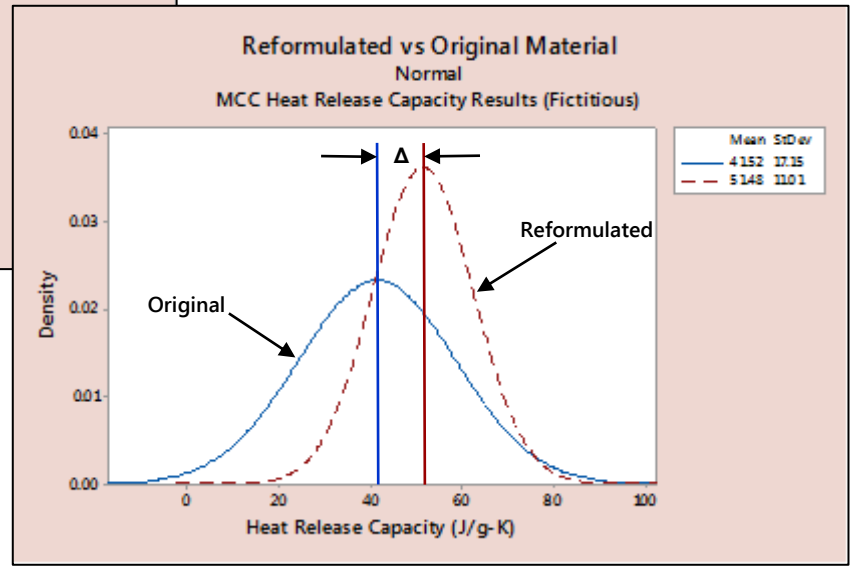
Material Change Similarity

- **Proposed Statistical Methodology**
  - Fundamental procedure (continued)
    - Calculate the test statistic
      - Assumption: Comparing only 2 data sets (“original” vs. “reformulated”) -> Use “t-test” -> test statistic = “t”
      - $t = \frac{<X>_1 - <X>_2}{s_p \sqrt{\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$
    - Determine the corresponding “p-value” and compare to the “significance level,” often 0.05 (i.e. 5%).
      - p-value: probability, assuming the null hypothesis is true, the t statistic will be at least as extreme as the calculated value
    - If p-value < “significance level,” reject the null hypothesis -> original material and reformulated material are *not* interchangeable.

Material Change Similarity

- **Proposed Statistical Methodology--EXAMPLE**
  - Example: *Fictitious* Heat Release Capacity (HRC) results from “original” and “reformulated” material
  - Intended to demonstrate statistical procedure only….not intended to be representative of any true material HRC





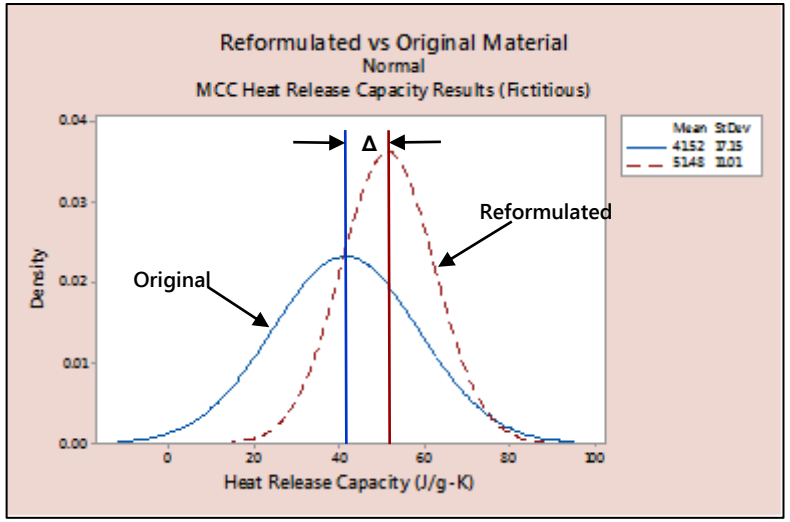
- **Δ = (41.52 – 51.48) = -9.9545 J/g-K**
- **Pooled std dev (s_p) = 14.5512 J/g-K**
- **t-statistic = -2.27**
- **p-value = 0.014**
- **Significance level = 0.050**
- **-> Reject hypothesis that “reformulated” = “original”**

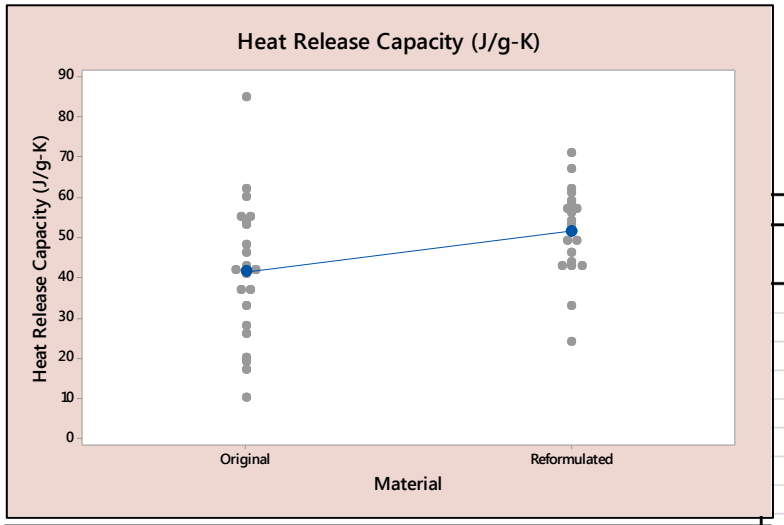
Original Data

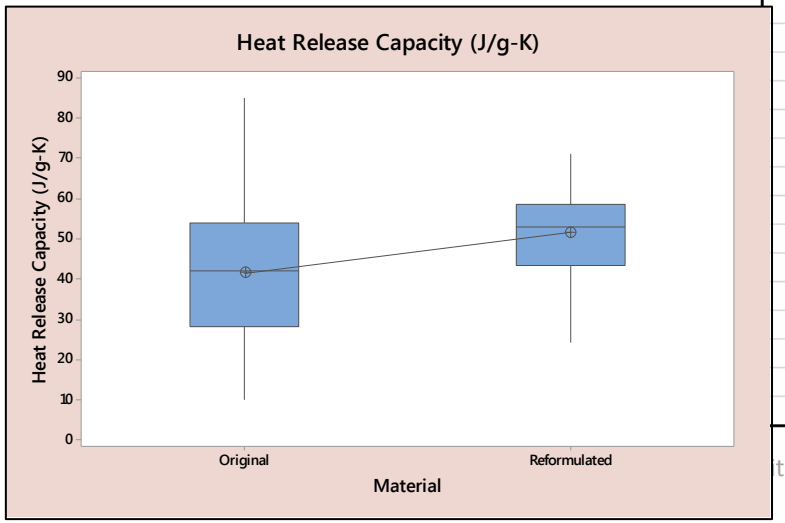
Heat Release Capacity (J/g-K)	
Original Material	Reformulated Material
42	24
43	43
55	58
26	71
62	43
37	49
33	61
41	44
19	67
54	49
20	53
85	56
46	59
10	52
17	62
60	54
53	57
42	33
37	46
42	43
55	57
28	
48	

Material Change Similarity

- **Proposed Statistical Methodology--EXAMPLE**
  - Example: *Fictitious* Heat Release Capacity (HRC) results from “original” and “reformulated” material







- **Δ = (41.52 – 51.48) = -9.9545 J/g-K**
- **Pooled std dev (s_p) = 14.5512 J/g-K**
- **t-statistic = -2.27**
- **p-value = 0.014**
- **Significance level = 0.050**
- **-> Reject hypothesis that “reformulated” = “original”**

NOTE: Merely knowing 2 distributions overlap is *not* sufficient for determining statistical “equivalence.”

Original Data

Heat Release Capacity (J/g-K)	
Original Material	Reformulated Material
42	24
43	43
55	58
26	71
62	43
37	49
33	61
41	44
19	67
54	49
20	53
85	56
46	59
10	52
17	62
60	54
53	57
42	33
37	46
42	43
55	57
28	
48	

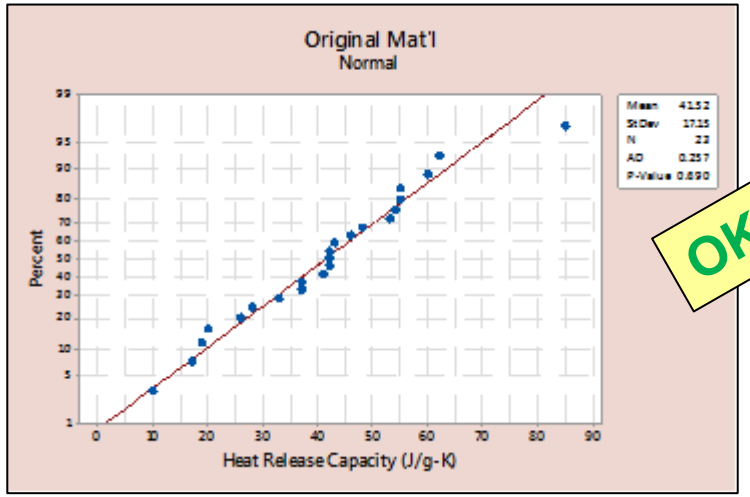
Material Change Similarity

- **Proposed Statistical Methodology**
  - Additional Information and Considerations -> “The devil is in the details.”
    - Test Procedures
      - Must have sufficient number of test samples
      - Samples should be tested in a randomized order -> do *not* sequentially test all Mat’l 1, then all Mat’l 2
    - Analysis
      - Assumes measurement results are normally distributed (i.e. follow a Gaussian distribution)
      - Assumes mat’l 1 & 2 std dev values sufficiently close to warrant use of “pooled standard deviation” for t-test
      - Based on 1-sided t-test -> actually testing for “reformulated mat’l not statistically worse than original mat’l”
        - In English….
          - If population mean of Mat’l 2 **≤** Mat’l 1 -> materials are “interchangeable”
          - If population mean of Mat’l 2 **>** Mat’l 1 -> materials are not “interchangeable”
        - In language of statistics….
          - Null hypothesis: $\mu_1 = \mu_2$ or $\mu_1 - \mu_2 = 0$
          - Alternative hypothesis: $\mu_1 - \mu_2 < 0$
      - Provisionally assume significance level = 5% -> may want to change value in the future

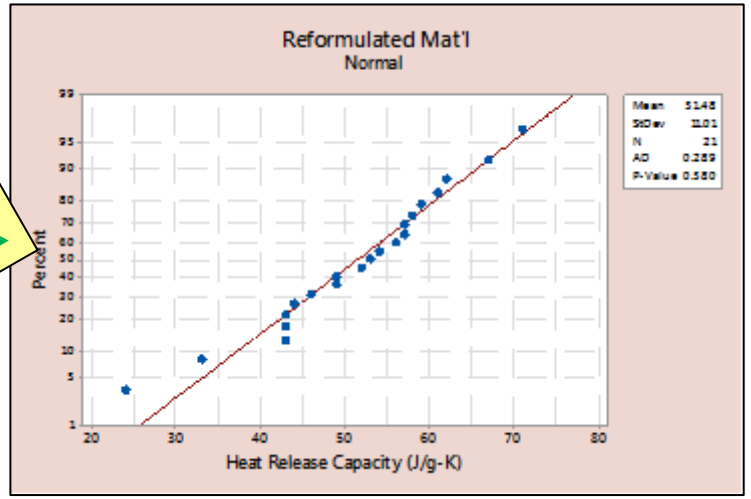
Backup

Material Change Similarity

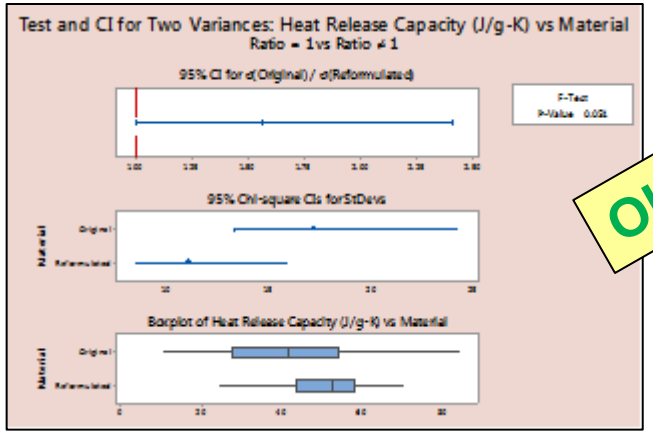
- **Proposed Statistical Methodology**
  - Example: *Fictitious* Heat Release Capacity (HRC) results from “original” and “reformulated” material
  - Check of normality (Gaussian distribution)



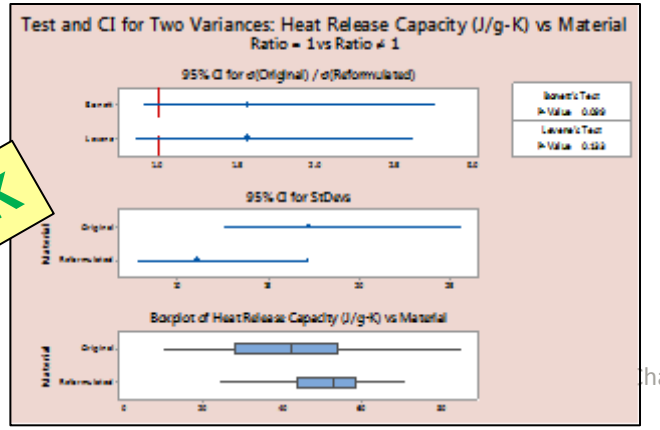
OK



  - Check of equal variance (to validate use of “pooled standard deviation”)



OK



Original Data

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60	54
53	57
42	33
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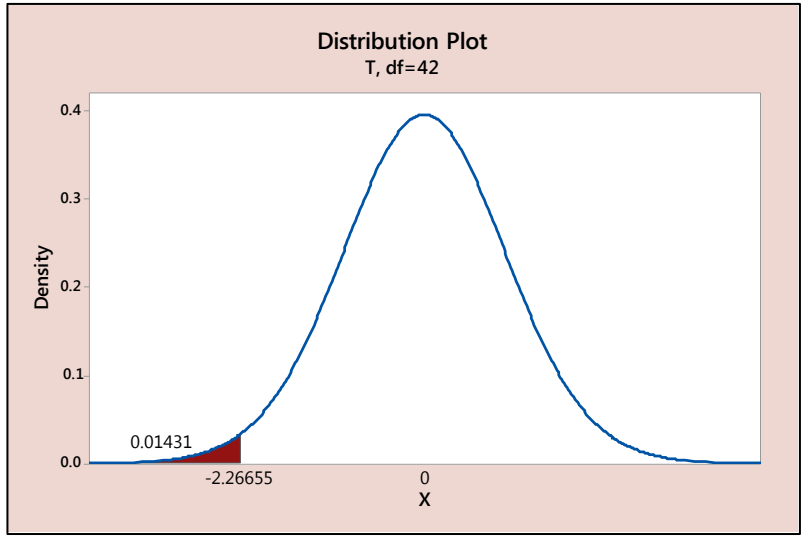
55	57
28	
48	

Material Change Similarity

- **Proposed Statistical Methodology**
  - Example: *Fictitious* Heat Release Capacity (HRC) results from “original” and “reformulated” material
  - T-statistic and p-value
    - t-statistic: -2.26655 -> p-value: 0.01431



    - P-values can be obtained from…
      - Statistical software packages (Minitab, JMP, SAS, R…)
      - Excel (TDIST, T.DIST.RT functions)
      - Online conversion web sites
      - Some calculators (ex. TI-83 graphing calculator)
      - Estimation/interpolation of t-tables

- Estimate p-value from interpolation
- NOTE: Degrees of freedom = (n_1 + n_2 – 2)

t-distribution critical values		
	95% conf	98% conf
Deg of freedom	p = 0.025	p = 0.010
40	2.021	2.423
42	2.018	2.418
50	2.009	2.403

Material Change Similarity

- **Proposed Statistical Methodology**
  - Sample size (REFERENCE ONLY)