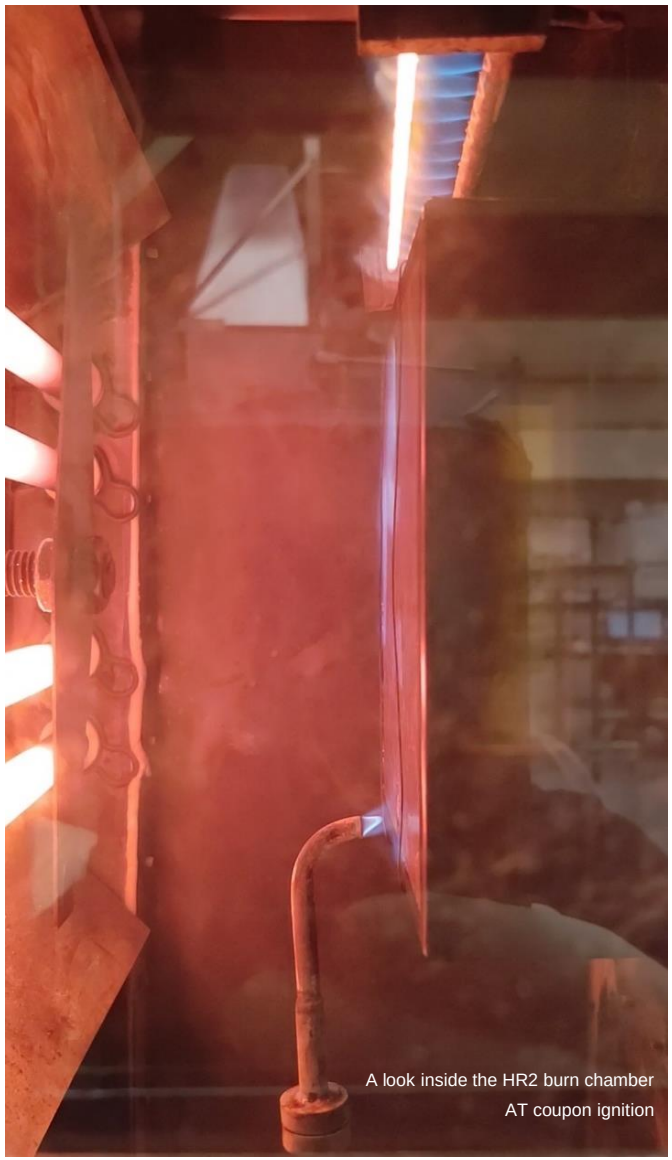
HR2 Development – TRL 6 Testing and Planning



A look inside the HR2 burn chamber
AT coupon ignition

Presented by: Brian Johnson, BCA Flammability

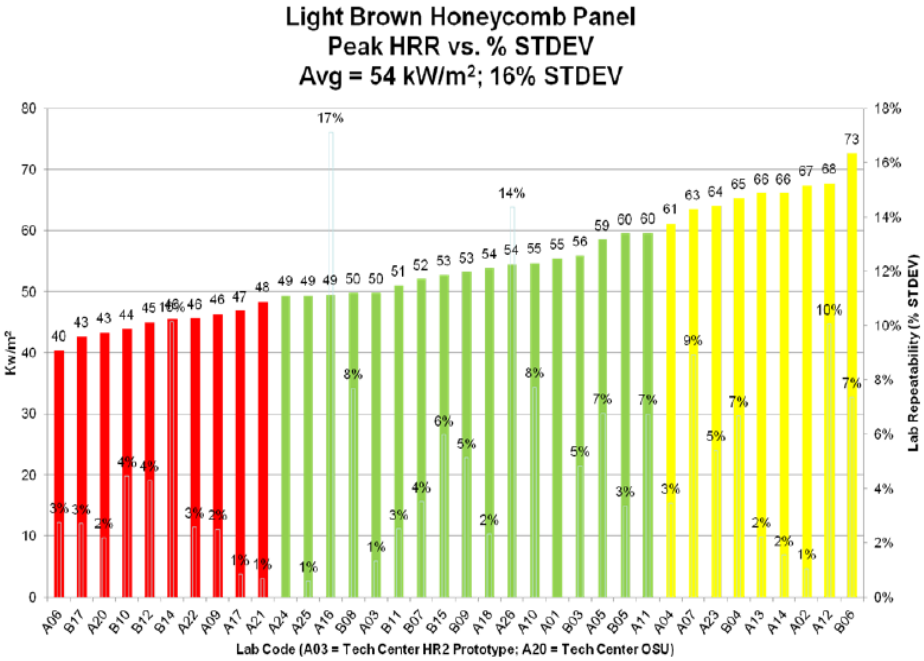
Prepared by: Yaw Agyei, BR&T
Yonas Behboud, BR&T
Genya Shimada, BR&T
Brian Johnson, BCA Flammability

OSU Test Method

14CFR25.853(d)

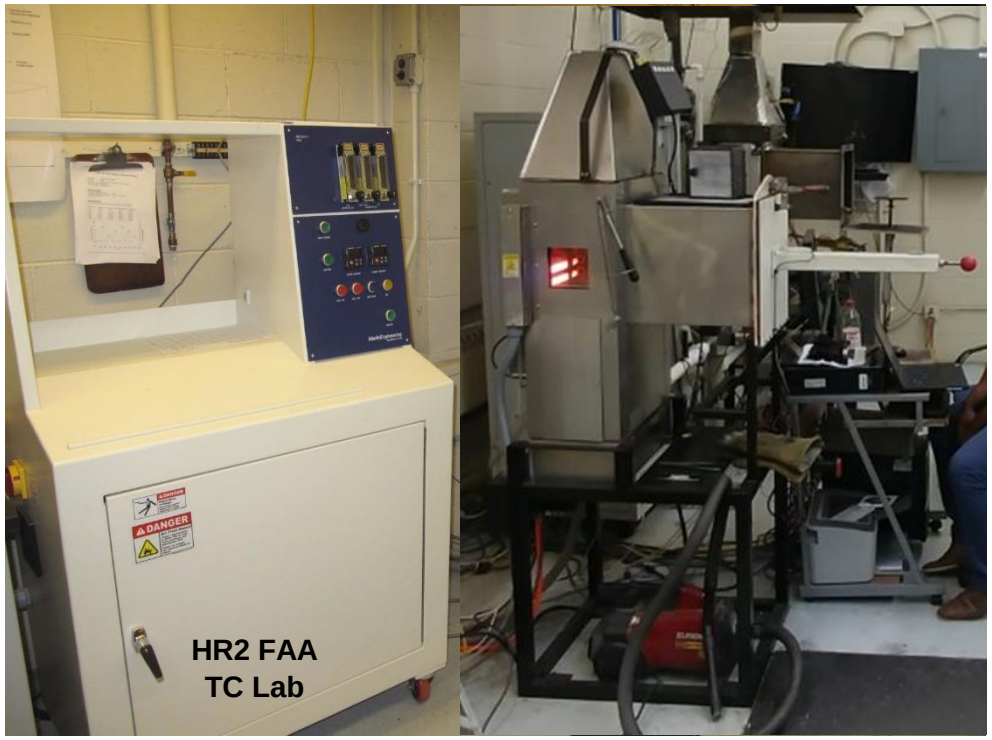
- Added in 1986
- Current FAR - Appendix F Part IV
- Applicable to interior exposed surfaces greater than 144 square inches
- Measures heat release as a function of time
- Test code: HR

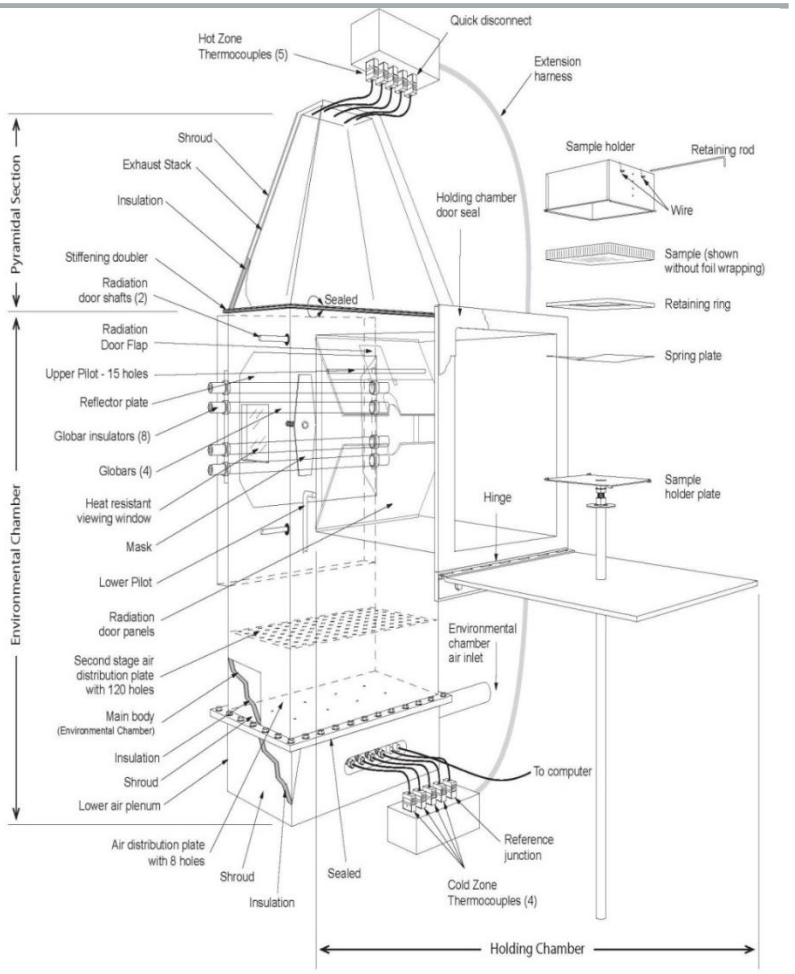
- Reproducibility challenges persist
- Specification does not tightly control some key parameters
- Decades of certification data in use



**Presented June 2012*

HR2 - Next Generation OSU





**Presented October 2016*

Design and Other Changes

- Elimination of cooling flow / inner chimney
- Insulation / metal wall specification changes
- Coupon location in chamber specified
- Air and methane flows controlled via MFCs
- Single lower Tcouple - DAQ correction
- HFG calibration / limit changes (3.65 W/cm^2)
- Methane calibration and cal factor correction
- Multiple additional procedural changes

Anticipated Improvements

- Repeatability driven by design and cal changes
- Reproducibility increased via spec controls
- Cross industry variation greatly reduced

Developmental Project Technical Readiness

Flammability Test Method/Equipment TRLs (Derived from NASA TRL)

MATURITY LEVEL

Discovery

Feasibility

Practicality

Applicability

Production Readiness

TRL 1	Basic principles/concept of test equipment and procedure defined.
TRL 2	Test method concept formulated and defined by draft standards.
TRL 3	Analytical and experimental critical function and/or characteristic proof-of concept (e.g. by modifying old/existing equipment)
TRL 4	New prototype equipment validation in laboratory environment (robustness)
TRL 5	Updated prototype equipment validation in relevant production environment (repeatability). Documented test guidance framework.
TRL 6	Multiple prototypes validation in relevant environment (reproducibility)
TRL 7	Finalized prototype equipment demonstation on range of production configurations. Documented test guidance defined.
TRL 8	Final test equipment drawigns released, equipment built to the standards, and “qualified” through test and demonstration. Documented test guidance finalized.
TRL 9	Multiple production units verified by successful round robin testing.

**Presented in October 2014*

HR2 Tailored TRL Development Model

TRL 4 - *Robustness* - apparatus, calibration method, equipment, procedures. Evaluate calibration factor variation using methane only / no coupons.

➡ Gate 4 / Enter **TRL 5**: Calibration factor variation (< 5%)

TRL 5 - *Repeatability* - variation in measurements taken on the same item under the same conditions. Homogenous coupon tested multiple times using one unit.

➡ Gate 5 / Enter **TRL 6**: Coefficient of Variation (CoV) improvement vs. OSU

TRL 6 - *Reproducibility* - variation in measurements taken on the same items under the same conditions using different machines.

➡ Gate 6 / Enter **TRL 7**: Individual coupon type CoV and ANOVA evaluation

TRL 7 - *Range* - demonstrated ability to test a range of coupon materials and configurations. Establish pass/fail criteria for HR2 total and peak heat release.

➡ Gate 7 / Enter **TRL 8**: Results over a range of sample types that are consistent with OSU empirical results.

HR2 Development Goal and Status

- HR2 Goal: Define a robust method to determine peak and total heat release that improves repeatability and reproducibility when compared with OSU

History / Status

- NASA Technical Readiness Level (TRL) model adopted
- TRL 4 - Robustness completed - calibration factor variation < 5%
- TRL 5 - Repeatability completed - CoV improvement demonstrated
- HR2 development is in **TRL 6 -** Reproducibility
  - Individual coupon type CoV and ANOVA evaluation
  - Success criteria will be determined by the OSU / HR2 task group*

* Key members: Mike Burns (FAATC), Martin Spencer (MarlinEngineering), Mike Schall (Deatak), Jan Christian Thomas (Airbus), Yaw Agyei (Boeing BR&T), Kent Wenderoth (Herb Curry)

TRL 6 Test Plan - Presented March 2020

Approach

- Phase 1 - Evaluate units to ensure parameters fall within set ranges
- Phase 2 - Test 40 specimens and compare variation to reproducibility criteria
  - Revised to 24 specimens per sample type to accommodate instruments coming online

Instruments

Tested

- Marlin Engineering HR2 - FAA TC, Egg Harbor Township, New Jersey
- Deatak HR2 - FAA TC, Egg Harbor Township, New Jersey

Future Implementation

- Marlin Engineering HR2 - Boeing Test Laboratory, Seattle, Washington
- Marlin Engineering HR2 - Airbus Fire Test Laboratory, Bremen, Germany

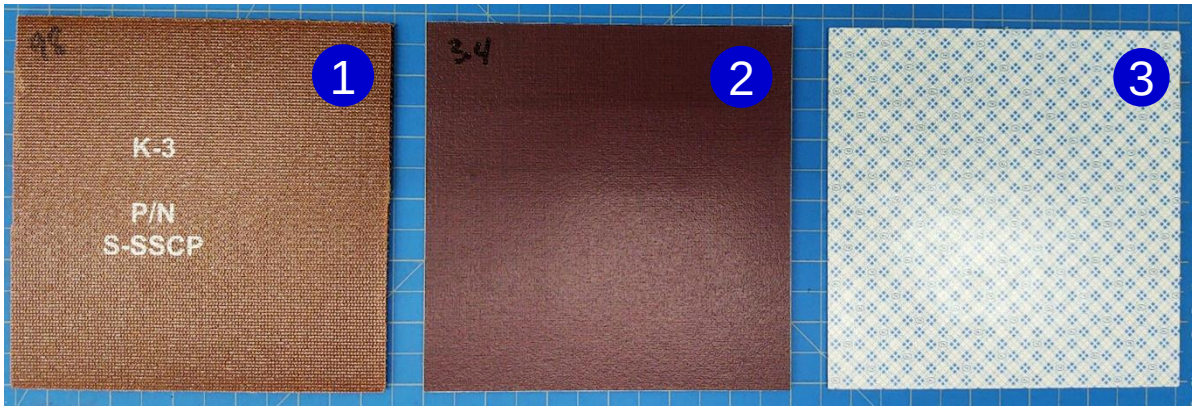
TRL 6 Test Plan – Part 1 – Presented April 2021

Test Coupons

- Coupons fabricated at Airbus (AT), Boeing (BPD), and Schneller (SPD)
- Panels shipped to Boeing for randomization and distribution
- Coupons stored in conditioning chamber (70ºF, 50% RH) prior to test
- Develop plan to statistically evaluate variation due to storage effects*

40 randomized samples each of 3 homogenous coupon types per unit

1. Standard laminate panel (SPD) - provided by the FAA / Schneller
2. Boeing standard panel with decorative (BPD) - provided by Boeing
3. Aluminum panel with transfer tape (AT) - provided by Airbus



* Boeing panels exhibit very little additional variation when similarly stored

TRL 6 Test Plan – Part 1

Post Testing Actions – Presented April 2021

- ME Schneller panel mean results are 3 - 4 points lower than expected
  - Deatak Schneller panel results are very close to TRL 5 results
    - ~ 1 point difference in mean peak and mean 2-min total HR
  - ➢ Indicates lower air flow or heat loss during TRL 6 testing
- Suspected issue with ME unit due to this and BPD upper pilot extinguishing
  - ME unit had not had major maintenance since installation (7 years)
  - Pressure and flow measurements were taken after testing
    - Lower plenum pressure was low (11” WC vs 13” WC in DE)
    - No leaks discovered in the lower plenum area
    - Hardware joining lower plenum, main air distribution plate and main body were loose enough to be turned by hand

Post Testing Actions (continued) – Presented April 2021

- ME unit was completely torn down in the weeks after testing
  - Insulation was significantly deteriorated (left, right, & rear of unit)
    - All unit insulation was replaced
  - Upper, inner door mechanism bushings were burned out
    - Mechanisms were replaced
  - Gaskets / seals worn out - replaced with high temp 1/8” graphite
    - Exhaust stack
    - Viewing window
    - Rear globar pan
    - Holding chamber
- Currently calibrating heat flux and preparing to assess operating parameters
- Spare Schneller and BPD coupons will be tested to asses performance

- Due to these issues, it was decided that TRL 6 Phase 2 was needed

TRL 6 Test Plan – Part 2

Approach

- Phase 1 – Collect 100 operating parameter sets to ensure units fall within set ranges
- Phase 2 - Test 30 specimens of 2 coupon types and evaluate reproducibility
  - Aluminum panel with transfer tape (AT) were not tested due to late peak time

Instruments Tested

- Marlin Engineering HR2 (ME) - FAA TC, Egg Harbor Township, New Jersey
- Deatak HR2 (DE) - FAA TC, Egg Harbor Township, New Jersey

Future Implementation

- Marlin Engineering HR2 - Boeing Test Laboratory, Seattle, Washington
- Marlin Engineering HR2 - Airbus Fire Test Laboratory, Bremen, Germany

Note: Final TRL 6 Decision Requires Data from More Instruments

TRL 6 Test Plan – Part 2

Test Coupons

- Coupons fabricated at Boeing (BPD) and Schneller (SPD)
- Panels shipped to Boeing for randomization and distribution
- Coupons stored in conditioning chamber (70ºF, 50% RH) prior to test

Test 30 randomized samples each of 2 homogenous coupon types per unit

1. Standard laminate panel (SPD) - provided by the FAA / Schneller

   Thank you to Perry Riggenbach for your assistance with these!

2. Boeing standard panel with decorative (BPD) - provided by Boeing

TRL 6 Test - Part 2 - Calibration and Test Data Log

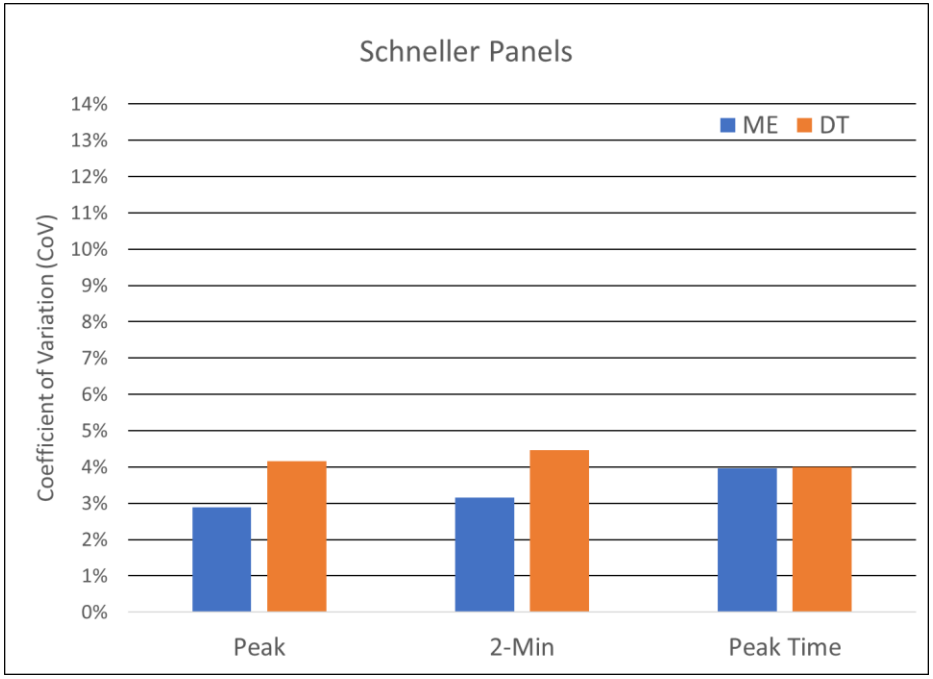
CF	Random Factor								Control Factors							Response Factors				
Unit	Day	Set	File Name	Order	Sample Holder #	Specimen Type	Specimen #	Specimen ID	Specimen Mass (Pre-test, g)	Room Temp (°F)	Room Humidity (% RH)	Outside Temp (°F)	Outside Humidity (% RH)	Supply Air Temp (°C)	Supply Air Pressure (mmHg)	Tpile Baseline (°C)	Peak Heat Release Rate (kW/m²)	Peak Time (sec)	2-Min Total HR (kW-min/m²)	Eliminated
FAA-ME	1	1	FAA-ME-Day1-Set1	5	2	SPD	67	SPD-67	25	72.5	20	54.7	24	22.7	20.02	342.10	47.37	42	35.58	
FAA-ME	1	1	FAA-ME-Day1-Set1	7	1	SPD	15	SPD-15	25	72.1	20	54	24	22.7	20	343.30	46.64	45	35.61	
FAA-ME	1	1	FAA-ME-Day1-Set1	9	3	SPD	16	SPD-16	25	72.0	20	53.2	24	22.7	20	343.30	48.46	46	36.44	
FAA-ME	1	2	FAA-ME-Day1-Set2	11	2	SPD	28	SPD-28	25	72.1	20	53.4	25	22.8	20	343.80	48.54	45	34.87	
FAA-ME	1	2	FAA-ME-Day1-Set2	12	3	SPD	80	SPD-80	25	72.5	20	53.2	25	22.9	19.99	344.10	48.46	45	35.47	
FAA-ME	1	2	FAA-ME-Day1-Set2	13	1	SPD	60	SPD-60	25	72.5	20	54.3	25	22.8	19.99	343.50	48.17	45	37.64	
FAA-ME	1	2	FAA-ME-Day1-Set2	17	2	SPD	25	SPD-25	25	72.1	20	54.7	25	22.5	20.02	343.30	51.30	44	34.75	
FAA-ME	1	2	FAA-ME-Day1-Set2	18	3	SPD	78	SPD-78	25	72.5	20	54	25	22.4	20.02	346.90	48.75	50	33.90	
FAA-ME	1	3	FAA-ME-Day1-Set3	21	3	SPD	3	SPD-3	25	72.9	22	53.6	26	22.4	20.02	345.00	47.30	47	34.12	
FAA-ME	1	3	FAA-ME-Day1-Set3	23	2	SPD	100	SPD-100	25	73.4	21	53.2	25	22.4	20.01	343.60	48.90	45	36.72	
FAA-ME	1	3	FAA-ME-Day1-Set3	24	3	SPD	85	SPD-85	25	73.2	21	53.2	25	22.2	20.01	346.00	48.17	43	35.72	
FAA-ME	1	3	FAA-ME-Day1-Set3	28	1	SPD	70	SPD-70	25	72.3	21	53.1	26	22.5	20	342.50	48.32	44	37.68	
FAA-ME	1	3	FAA-ME-Day1-Set3	30	3	SPD	36	SPD-36	25	72.5	21	53.6	27	22.5	20	342.70	49.77	45	36.35	
FAA-ME	2	1	FAA-ME-Day2-Set1	32	1	SPD	63	SPD-63	25	73.0	23	50.7	29	22.9	20.02	340.60	46.30	45	33.90	
FAA-ME	2	1	FAA-ME-Day2-Set1	36	3	SPD	6	SPD-6	25	73.6	23	53.6	29	22.6	20.03	340.30	50.43	45	35.70	
FAA-ME	2	1	FAA-ME-Day2-Set1	38	2	SPD	41	SPD-41	25	73.9	22	54	29	22.6	20.02	340.50	47.44	43	34.43	
FAA-ME	2	1	FAA-ME-Day2-Set1	39	3	SPD	33	SPD-33	25	72.7	21	55	28	22.6	20.03	341.50	48.83	46	35.56	
FAA-ME	2	2	FAA-ME-Day2-Set2	41	2	SPD	86	SPD-86	25	73.9	21	61	28	22.6	20.04	341.40	46.06	44	34.27	
FAA-ME	2	2	FAA-ME-Day2-Set2	42	3	SPD	1	SPD-1	25	74.1	21	64.9	27	22.7	20.02	342.80	45.84	41	33.49	
FAA-ME	2	2	FAA-ME-Day2-Set2	43	1	SPD	94	SPD-94	25	73.9	21	67.5	26	22.8	20.02	343.10	47.59	47	35.81	
FAA-ME	2	2	FAA-ME-Day2-Set2	44	2	SPD	17	SPD-17	25	74.3	21	64.9	25	22.9	20.02	342.60	47.52	43	35.11	
FAA-ME	2	2	FAA-ME-Day2-Set2	46	1	SPD	69	SPD-69	25	73.2	21	59.70	26.00	22.4	20.03	340.70	46.94	44	36.16	
FAA-ME	2	2	FAA-ME-Day2-Set2	47	2	SPD	47	SPD-47	25	73.6	21	57	26	22.4	20.03	342.40	48.03	44	35.81	
FAA-ME	2	2	FAA-ME-Day2-Set2	48	3	SPD	75	SPD-75	25	73.8	20	59.2	25	22.3	20.05	342.50	49.26	45	36.90	
FAA-ME	2	2	FAA-ME-Day2-Set2	49	1	SPD	30	SPD-30	25	73.6	20	60.4	25	22.3	20.03	343.60	50.65	45	35.56	
FAA-DT	3	1	FAA-DT-Day3-Set1	5	2	SPD	48	SPD-48	27	74.1	20	55.8	21	22.6	20.02	334.23	50.00	47	38.00	
FAA-DT	3	1	FAA-DT-Day3-Set1	7	1	SPD	98	SPD-98	26	73.6	20	58.1	21	22.4	20.02	335.67	46.70	44	37.00	
FAA-DT	3	1	FAA-DT-Day3-Set1	9	3	SPD	9	SPD-9	27	73.8	20	59.7	21	22.4	20.02	336.22	47.10	46	37.70	
FAA-DT	3	2	FAA-DT-Day3-Set2	11	2	SPD	2	SPD-2	26.5	74.1	20	65.8	21	22.7	20.02	335.57	46.80	47	38.50	
FAA-DT	3	2	FAA-DT-Day3-Set2	12	3	SPD	24	SPD-24	26.5	74.3	20	65.8	21	22.6	20.02	335.19	51.30	46	43.60	
FAA-DT	3	2	FAA-DT-Day3-Set2	13	1	SPD	89	SPD-89	26.5	73.9	20	60.1	21	22.5	20.02	336.97	47.40	44	39.10	
FAA-DT	3	2	FAA-DT-Day3-Set2	17	2	SPD	93	SPD-93	26.5	73.2	20	91	21	22.1	20.02	334.72	48.90	46	37.50	
FAA-DT	3	2	FAA-DT-Day3-Set2	18	3	SPD	99	SPD-99	26	73.0	20	92.1	21	22.2	20.02	336.78	48.90	43	38.40	
FAA-DT	3	3	FAA-DT-Day3-Set3	21	3	SPD	37	SPD-37	26	75.2	20	65.3	21	23.2	19.98	336.25	49.50	45	37.50	
FAA-DT	3	3	FAA-DT-Day3-Set3	23	2	SPD	84	SPD-84	26	75.0	20	64	21	23.1	19.99	337.36	45.10	42	37.30	
FAA-DT	3	3	FAA-DT-Day3-Set3	24	3	SPD	35	SPD-35	25.5	75.0	20	63.3	21	23.1	19.99	335.74	49.60	43	40.80	
FAA-DT	3	3	FAA-DT-Day3-Set3	28	1	SPD	73	SPD-73	26	75.6	20	61.5	21	22.8	20	333.61	51.20	42	41.30	
FAA-DT	3	3	FAA-DT-Day3-Set3	30	3	SPD	43	SPD-43	26.5	75.7	20	61.5	20	22.9	20	331.90	52.20	44	41.70	
FAA-DT	4	1	FAA-DT-Day4-Set1	32	2	SPD	20	SPD-20	26.5	75.9	22	60.6	28	22.7	20.06	332.94	48.40	44	39.10	
FAA-DT	4	1	FAA-DT-Day4-Set1	36	3	SPD	64	SPD-64	26.5	75.8	21	62.2	26	22	20.06	333.30	48.20	44	39.20	
FAA-DT	4	1	FAA-DT-Day4-Set1	38	2	SPD	44	SPD-44	26.5	74.7	20	63.9	25	22.2	20.06	336.04	44.30	46	35.70	
FAA-DT	4	1	FAA-DT-Day4-Set1	39	3	SPD	18	SPD-18	26	74.7	20	63.1	25	22.2	20.07	335.06	49.40	43	39.80	
FAA-DT	4	2	FAA-DT-Day4-Set2	41	2	SPD	11	SPD-11	26.5	74.5	20	67.5	25	22.2	20.07	333.92	45.80	48	37.90	
FAA-DT	4	2	FAA-DT-Day4-Set2	42	3	SPD	57	SPD-57	26.5	74.3	20	66.7	24	22.2	20.06	336.44	48.50	45	38.20	
FAA-DT	4	2	FAA-DT-Day4-Set2	43	1	SPD	12	SPD-12	26.5	74.3	20	66.7	24	22.2	20.06	336.82	46.90	44	38.10	
FAA-DT	4	2	FAA-DT-Day4-Set2	44	2	SPD	27	SPD-27	26	74.1	20	70.2	24	22.2	20.06	336.51	45.30	42	37.40	
FAA-DT	4	2	FAA-DT-Day4-Set2	46	1	SPD	50	SPD-50	27	74.1	20	67.1	24	22.1	20.06	334.30	46.90	45	37.60	

- Marlin Unit (ME): 25 SPDs tested, 30 BPDs tested
- Deatak Unit (DT): 25 SPDs tested, 30 BPDs tested
- Calibration factor determined on test day 1 only for each unit (ME, DT)
- Heat flux was measured, calibrated each day prior to testing (center, corners)

TRL 6 Test – Part 2 – Schneller Panels - Results

Peak HR, 2-Minute Total HR, and Peak Time

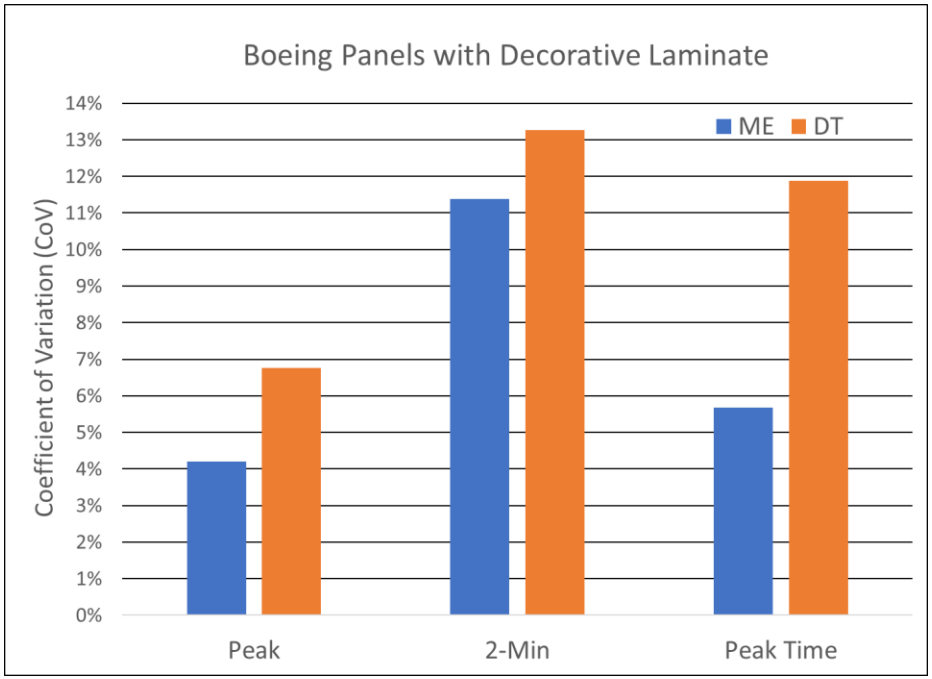
		ME	DT
Peak Heat Release	Mean	48.20	48.16
(kW/m^2)	Std Dev	1.39	2.00
	CoV	2.88%	4.15%
2-Min Total Heat Release	Mean	35.50	38.70
($kW*min/m^2$)	Std Dev	1.12	1.73
	CoV	3.15%	4.47%
Peak Time (sec)	Mean	44.72	44.76
	Std Dev	1.77	1.79
	CoV	3.95%	3.99%



TRL 6 Test – Part 2 – Boeing Panel w/Dec Analysis

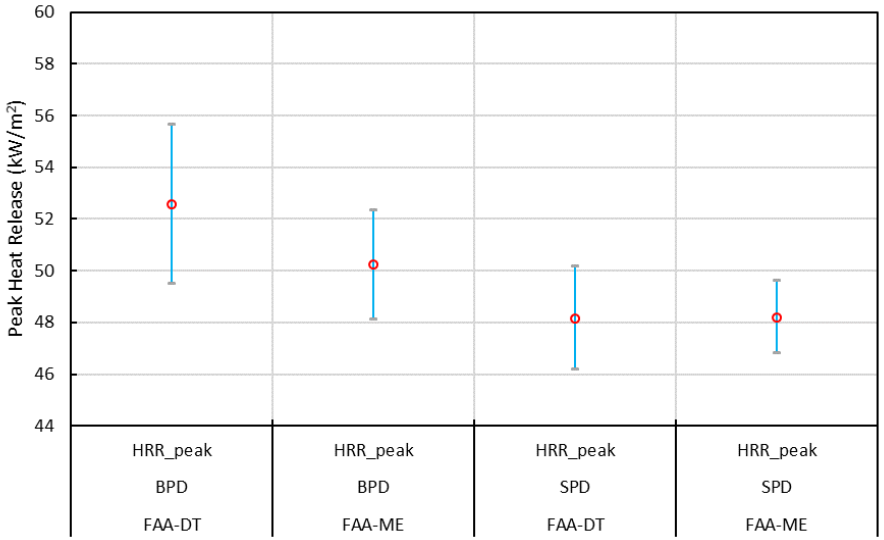
Peak HR, 2-Minute Total HR, and Peak Time

		ME	DT
Peak Heat Release	Mean	50.23	52.92
(kW/m^2)	Std Dev	2.11	3.58
	CoV	4.20%	6.77%
2-Min Total Heat Release	Mean	38.95	42.94
($kW*min/m^2$)	Std Dev	4.43	5.70
	CoV	11.38%	13.26%
Peak Time (sec)	Mean	17.96	18.67
	Std Dev	1.02	2.22
	CoV	5.67%	11.88%

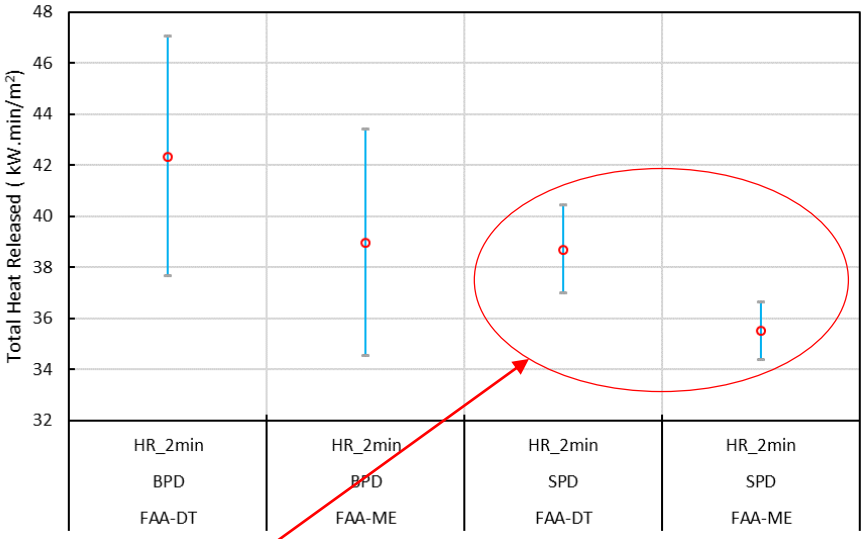


TRL 6 Test – Part 2 – Results

Peak Heat Release



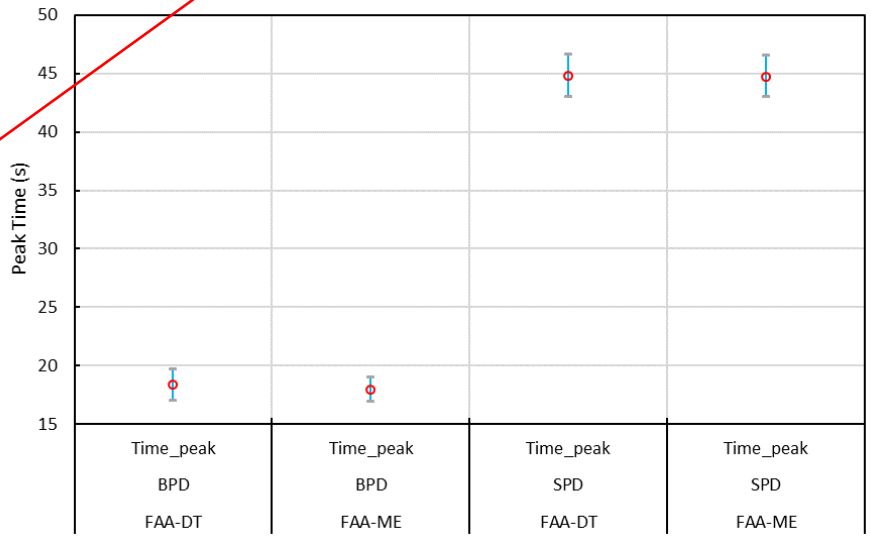
2-Min Total Heat Release



- Plots indicate average (mean) values
- Error bars are +/- 1 standard deviation (σ)
- Means are within 1 std dev of each other with 1 exception:

  2-Min Total HR – Schneller panel

Peak Time



Note: Thanks to Christian Thomas of Airbus for charts and data analysis.

TRL 6 Test – Part 2 – Takeaways

- Peak HRR
  - SPD means are very similar with very low deviation
  - BPD means differ by 2.7 points, but fall within the deviation of the machines
- Peak Time
  - SPD sample deviation for both machines is 3-4%
  - BPD sample deviation for both machines is 4-5%
- 2-Min Total HRR
  - Highest deviation came from the BPD sample – expected due to decorative
  - BPD means differ by 3 points, but fall within the deviation of the machines
  - SPD means lie outside the deviation of the machines (+/-1σ) – the reason is unclear and should be investigated
  - DT machine produced larger 2-Min Total HR means for both materials – this may indicate that more energy is stored in the DT machine structure

TRL 6 Test – Part 2 – Takeaways (cont.)

The uncertainties in the data presented can be considered reasonable given the complexities in the:

- Combustion processes
- Test environment
- Measurement processes

<u>Discussion topics</u>

- Peak HR is most influenced by the material burning behavior
- 2-Min Total HR is most influenced by the instrument construction, materials and environment

➢ This led to a discovery that the insulation was not the same for both instruments

TRL 6 Test – Part 2 – Post-Analysis Actions

Instrument insulation during TRL 6 Part 2:

- Deatak FAATC unit used ROXUL AFB (w/aluminum foil), density 10 lb/ft^3
- Marlin FAATC unit used ROXUL (no foil backing), density 8 lb/ft^3

Action: Current specification, which includes insulation density and R-value, will be updated to include the moisture barrier (aluminum foil backing) and 3” tape

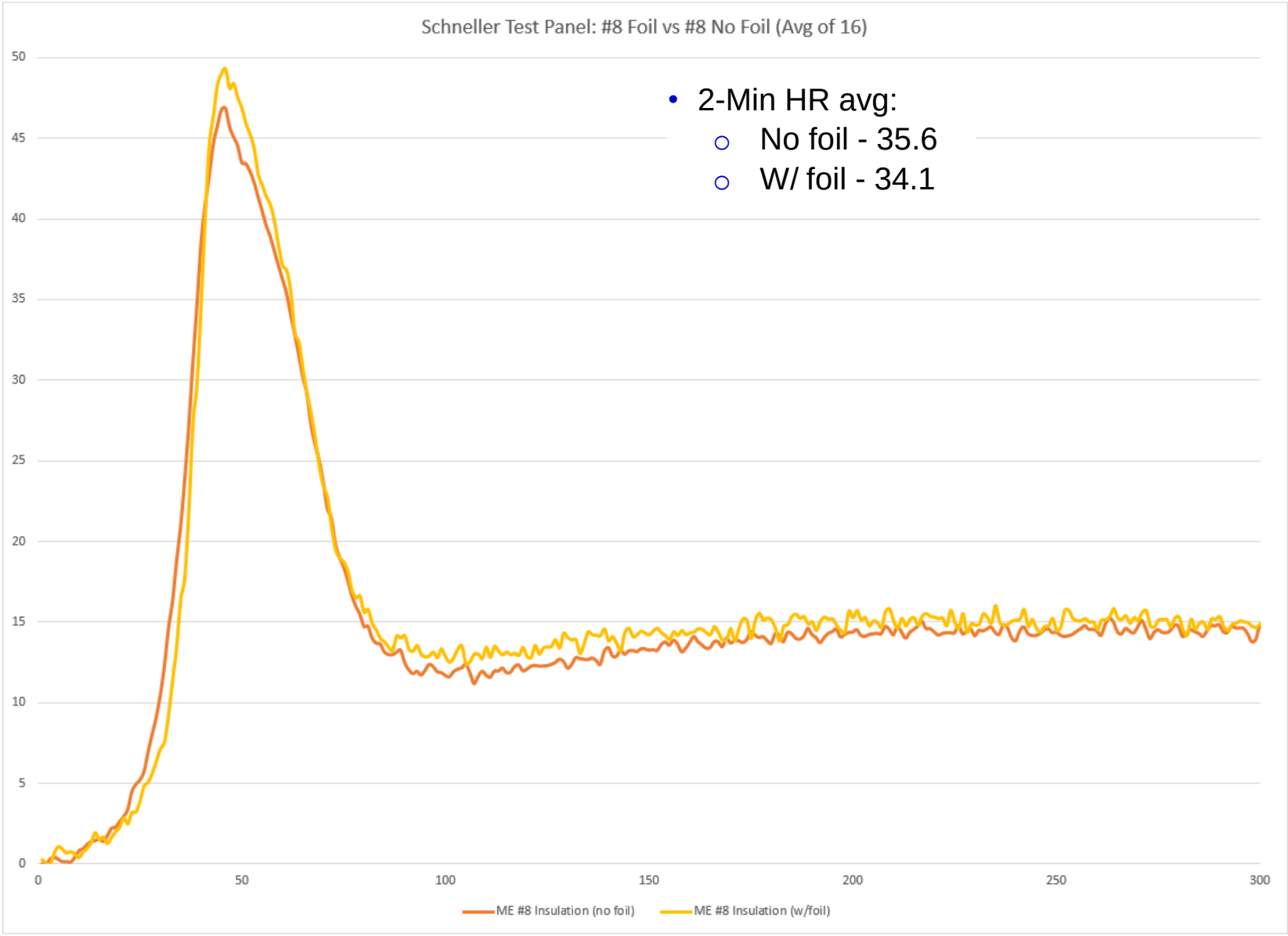
- Mineral wool/foil backing (Rockwool)
  - R-value = 4, K-value = 0.23 BTU*in +/-10%
  - Density 8 lb/ft^3
  - Moisture vapor barrier (foil) installed facing away from metallic skin
- Insulation tape, 3 in width, silver aluminum

Action: Both instruments torn down and insulation completely removed

- New insulation (ROXUL 19NE81) ordered and fitted into both units
- 16 Schneller coupons were tested on each rebuilt instrument

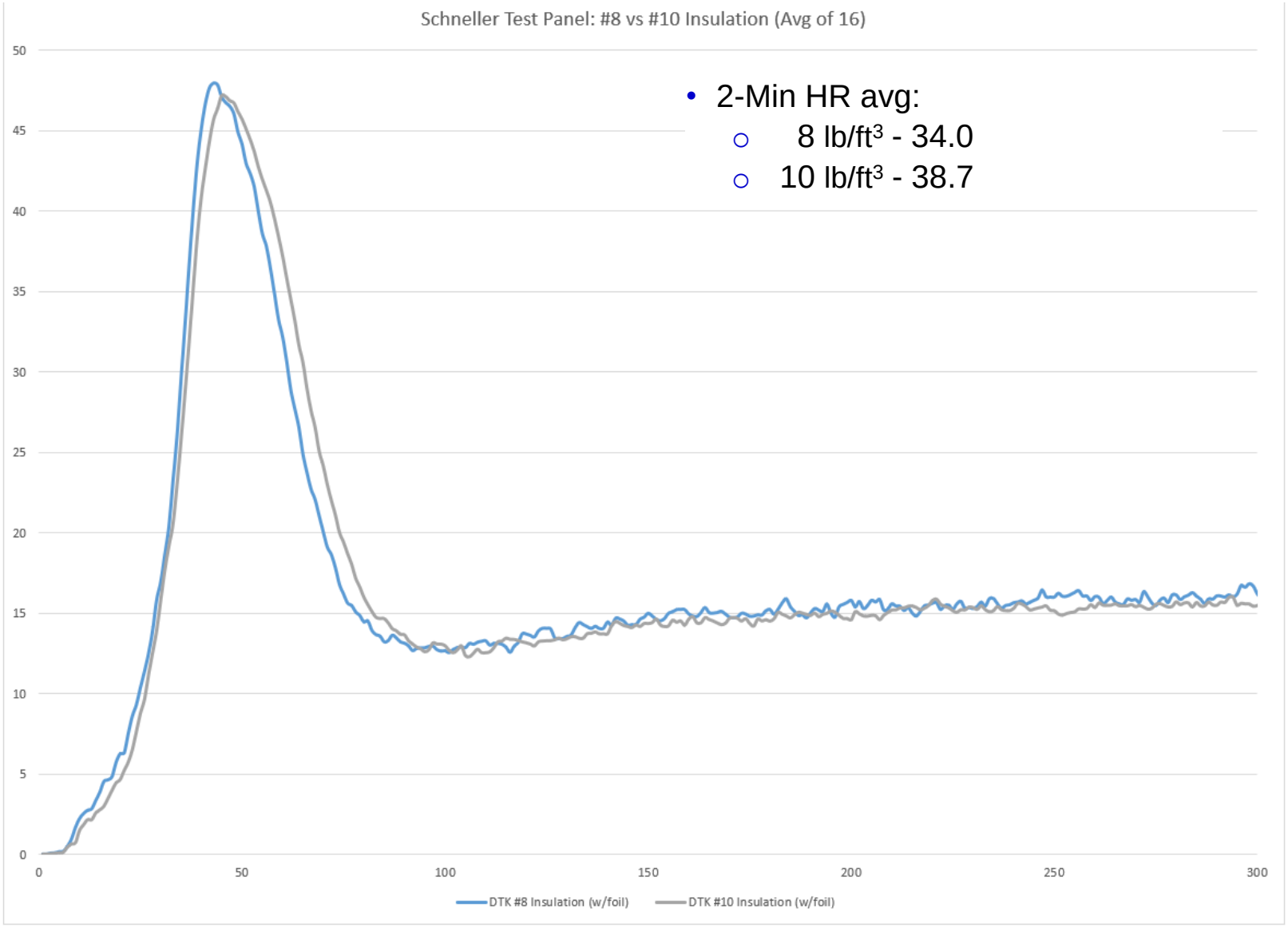
  Note: these coupons were not from the same lot as those used in TRL 6

TRL 6 Test – Part 2 – Post-Analysis – Marlin Test



- 2-Min HR avg:
  - No foil - 35.6
  - W/ foil - 34.1

TRL 6 Test – Part 2 – Post-Analysis – Deatak Test



- 2-Min HR avg:
  - 8 lb/ft^3 - 34.0
  - 10 lb/ft^3 - 38.7

TRL 6 Test – Part 2 – Post-Analysis Actions

- 2-Min Total HR Data Comparison – New Insulation & Tape (ME & DE)

		2-Min Total HR (W/m^2)		
		Mean	**Std Dev**	**CoV**
TRL 6 Part 2 Data	**ME 8# no foil**	35.6	1.12	3.15%
	DE 10# w/foil	38.7	1.73	4.47%
New 16 Coupons	**ME 8# w/foil**	34.1	1.19	3.50%
	DE 8# w/foil	34.0	1.71	5.00%

  - ➢ Average values very close and within 1 standard deviation

Questions for the HR2 Breakout Session

- Should TRL 6 testing be repeated on the FAA TC units (Schneller only)?
- How many instruments and locations are required to complete TRL 6?
  - Two in the same location is not sufficient

Next Steps

Anticipated Schedule

Boeing HR2 delivery and installation	Complete
Boeing HR2 unit response experiment	In Progress*
Boeing HR2 TRL 6 testing and data analysis complete	Nov 2022
FAA TC HR2 TRL 6 Schneller retest	TBD
FAA TC data analysis complete	TBD
Airbus HR2 upgrades	TBD
Airbus HR2 unit response experiment	TBD
Airbus testing and data analysis complete	TBD

* Attend HR2 Breakout Session for more details

Questions?