A Comparison of Fabric Arc Ratings and the Performance of Arc Rated Clothing Exposed to Arc Flashes Generated Using AC and DC Energy Sources

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Agenda

- Background and Objectives
- Materials and Methods – Experimental Design
- Results
- Discussion and Conclusions
- Path Forward

Background and Objectives

Background and Objectives

- Labeled ratings currently in all arc-rated clothing was generated with an AC energy source
- A growing trend of increasing use of DC power means more workers are potentially exposed to a DC arc
- Lack of knowledge surrounding the level of protection that existing arc-rated clothing provides against a DC-generated arc

Potential Outcomes

- Different Arc Ratings AC vs DC, with consistent and predictable differences
  - The industry/market can manage this with a “DC Correction factor”
- Different Arc Ratings AC vs DC, but with unpredictable differences
  - This would require all new Standard Test Methods
  - Re-testing of any product wishing to determine the DC Arc Rating
  - Re-labeling of any product wishing to add a DC Arc Rating
  - New requirements for risk-assessments to differentiate
- No difference in Arc Ratings AC vs DC
  - Least disruptive to the industry
  - Existing Arc Ratings and garment labels still apply to both hazards

Materials and Methods

Materials

- 5 Arc-Rated fabrics were selected for the study
  - All Single-Layer and all Navy in color
  - 4 are woven fabrics
  - 1 is a tri-laminate
- Selected for their market significance and frequency of use for arc protection
- 4 woven fabrics were selected for having an anticipated arc rating of at least 8 cal/cm^2 (Cat 2)
- Tri-laminate was selected as having a higher arc rating (Cat 3) as single-layer
- All samples taken from single rolls of fabric to limit variability

Description of Materials Tested

Sample ID	Composition	Nominal Weight (oz/yd^2)	Fabric Construction	Color	Anticipated Arc Rating (cal/cm^2)
Fabric A	Multi-fiber FR blend	5.3	Twill	Navy	8-12
Fabric B	Multi-fiber FR blend	6.1	Ripstop	Navy	8-12
Fabric C	Cotton/Nylon blend	7.0	Twill	Navy	8-12
Fabric D	Cotton	9.0	Twill	Navy	8-12
Fabric E	Polyester/PTFE	9.0	Trilaminate	Navy	25+

Testing Schedule

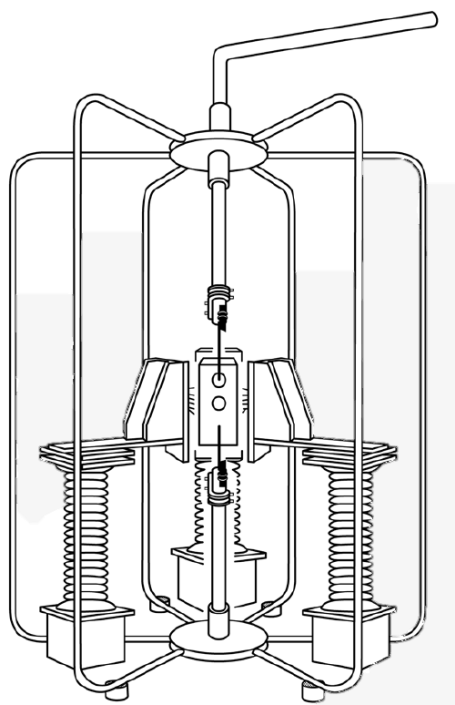
- Specimens of each of the 5 test fabrics were tested on each of 6 consecutive days to minimize variation
- Testing days have some alternation of the energy source from AC to DC – while still trying to minimize inefficiency of switching between systems
- Within each single day, the specific order of testing was selected randomly and alternated from day to day

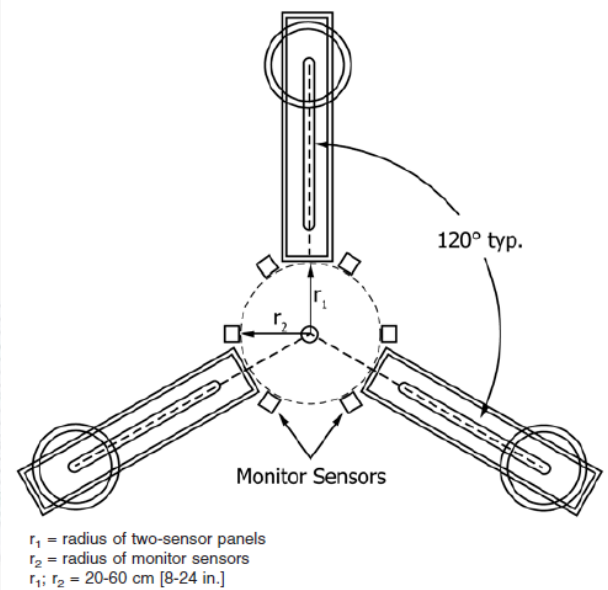
TEST DAY 1	DC Arc Ratings
TEST DAY 2	AC Arc Ratings
TEST DAY 3	AC Arc Ratings
TEST DAY 4	DC Arc Ratings
TEST DAY 5	DC Arc Ratings
TEST DAY 6	AC Arc Ratings

Sample Preparation

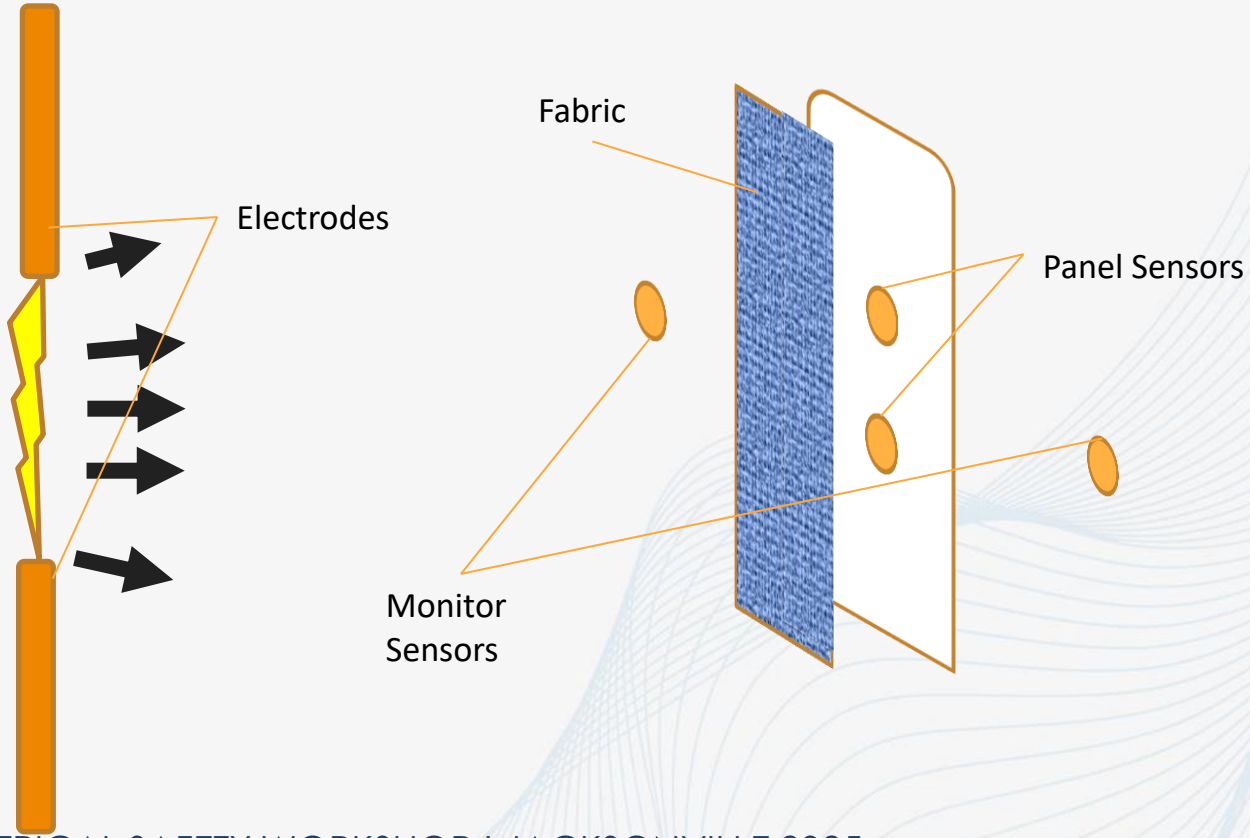
- Samples were pre-conditioned as prescribed in ASTM F1959/F1959M-24b
  - 3 cycles of home laundering and 1 cycle of tumble drying according to AATCC LP1, Wash Cycle 3, Wash Temperature IV, and Drying Procedure Aiii
  - Specimens were not restored by pressing
- Pre-conditioned samples were cut into 26” x 12”
- Specimens were conditioned in controlled laboratory conditions prior to testing
- Fabric weights were measured and recorded in accordance with ASTM F1959/F1959M-24b

Test Apparatus as specified in ASTM F1959/F1959M-24b

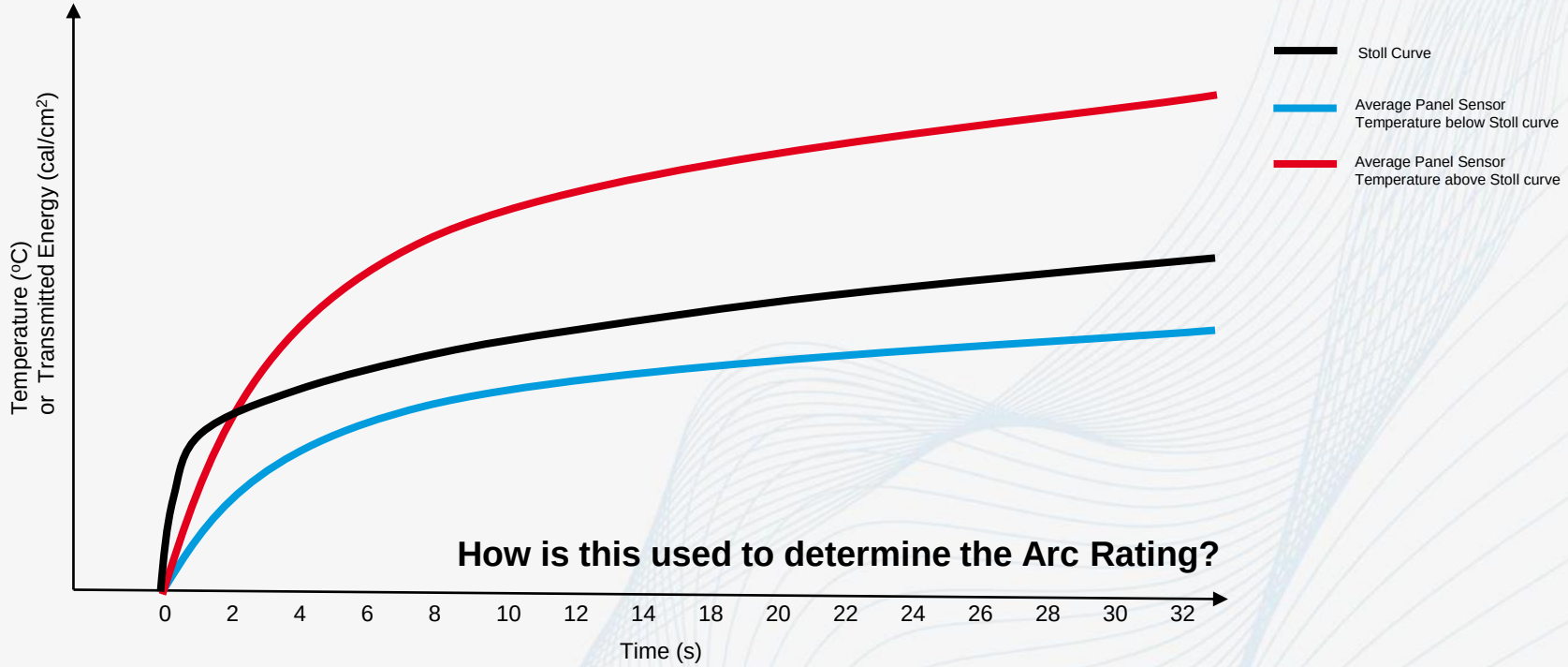




Test Apparatus as specified in ASTM F1959/F1959M-24b



Data Analysis as specified in ASTM F1959/F1959M-24b



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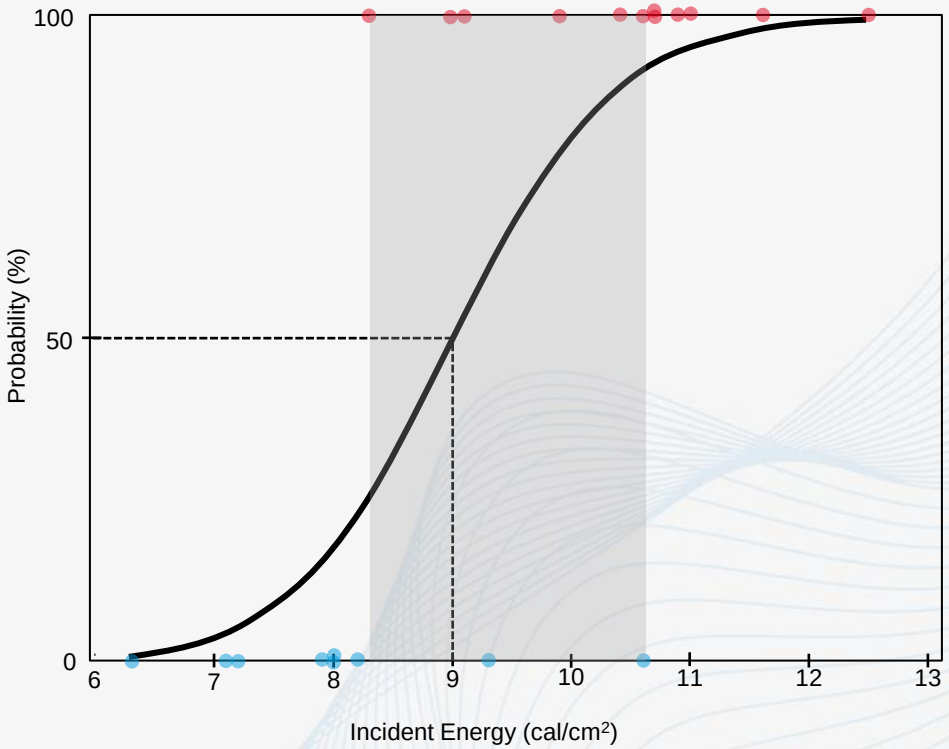
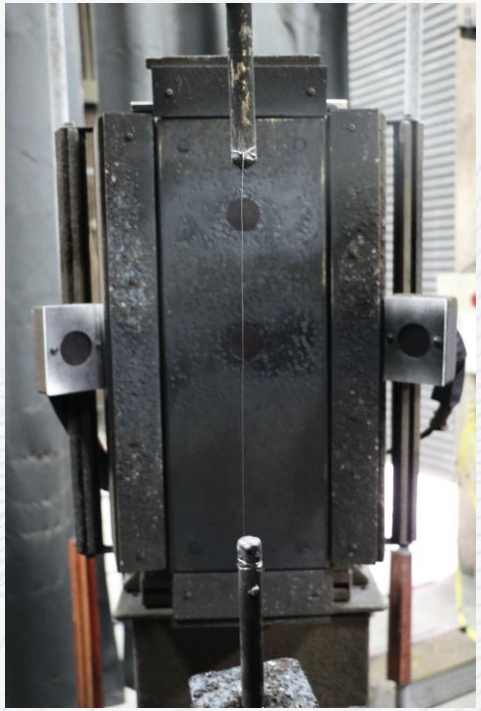
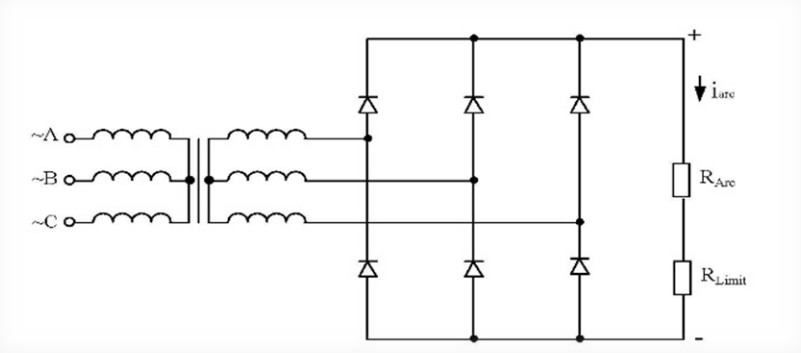


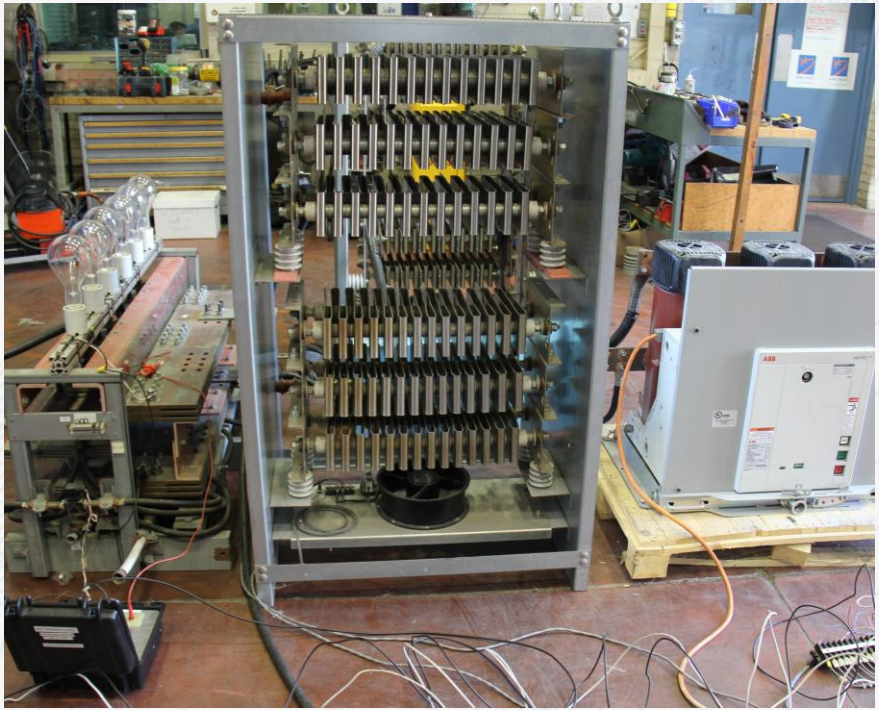
Test Apparatus as specified in ASTM F1959/F1959M-24b



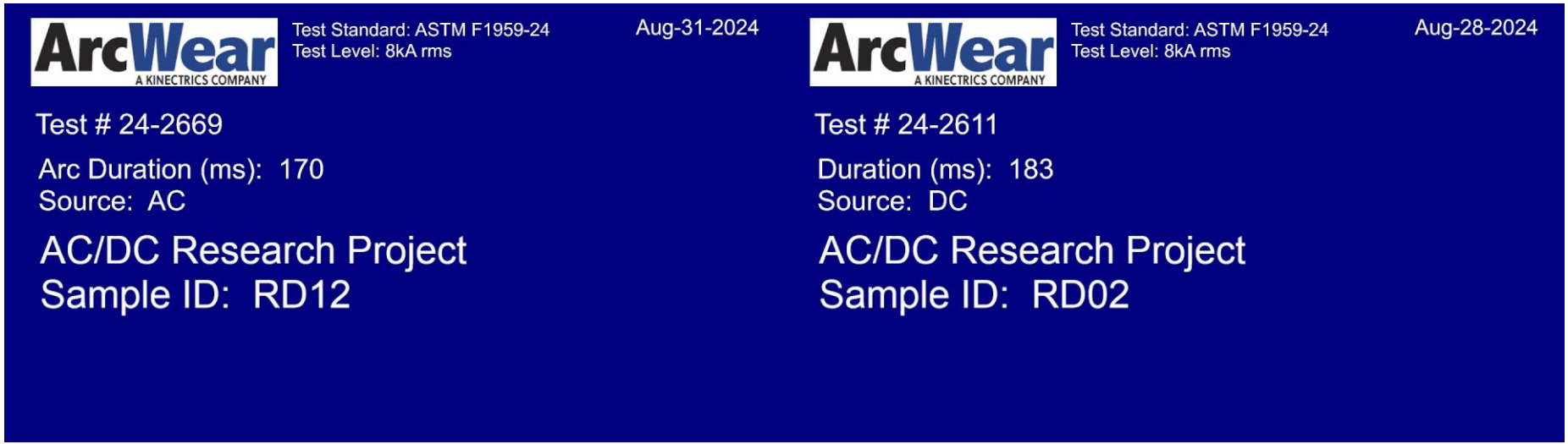
Apparatus Modification for DC Tests



- 3-Phase full-wave rectifier used to replace the AC source with a DC source of equal capacity
- R_{limit} Resistor was adjusted to provide nominal 8000A DC arcing current to match that of the AC tests

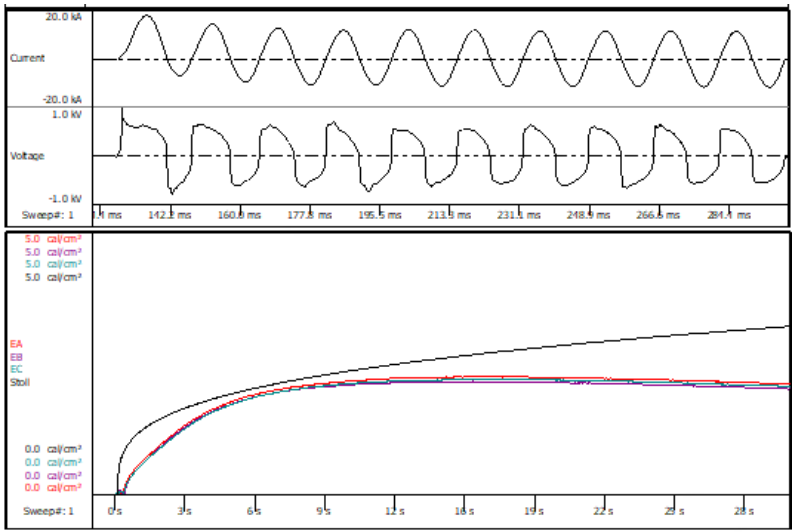


Comparison of AC vs DC arc flash – similar duration

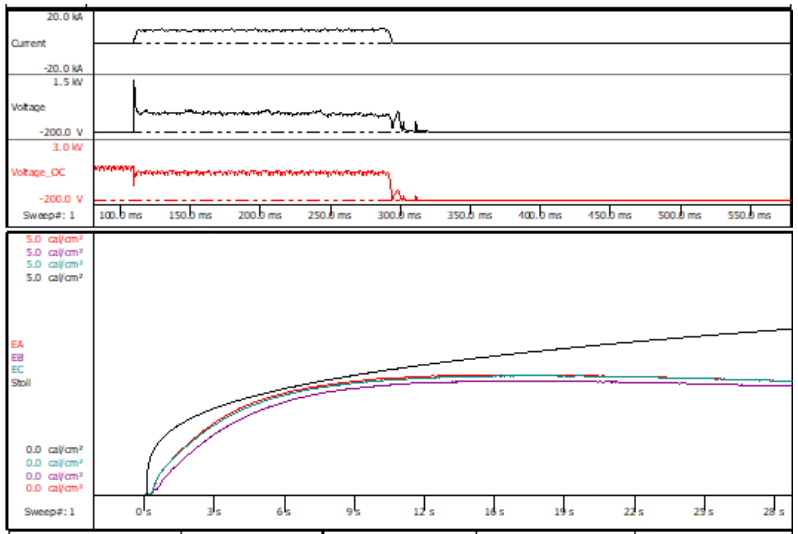


Can you Spot the difference?!?

Comparison of AC vs DC arc forms – similar duration



Current Total RMS	8.569 k A	Panel A:	Panel B:	Panel C:
Current Peak	18.26 k A	Ei = 8.87 cal/cm²	Ei = 8.32 cal/cm²	Ei = 9.06 cal/cm²
Arc Voltage	497.6 V	SCD = -0.113	SCD = -0.162 cal/cm²	SCD = -0.162 cal/cm²
Duration (cycles)	10.18 cycles	HAF = 74.6 %	HAF = 74.1 %	HAF = 75.8 %
Duration (time)	169.6 m s			
Arc Energy	657.1 k J	Test Date	8/31/2024	



Current Total RMS	8.059 k A	Panel A:	Panel B:	Panel C:
Current Peak	9.063 k A	Ei = 10.2 cal/cm²	Ei = 8.05 cal/cm²	Ei = 8.18 cal/cm²
Arc Voltage	494.2 V	SCD = -0.077	SCD = -0.229 cal/cm²	SCD = -0.11 cal/cm²
Duration (cycles)	11.00 cycles	HAF = 77.5 %	HAF = 72.9 %	HAF = 72.2 %
Duration (time)	183.3 m s			
Arc Energy	728.1 k J	Test Date	8/28/2024	

Experimental Design

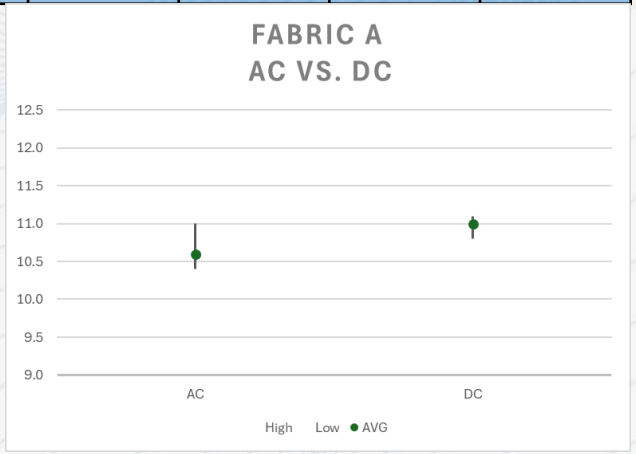
Study Design Element	Rationale

Results

Results – Individual Arc Ratings

	AC Arc Ratings					DC Arc Ratings				
Sample ID	**Rep 1**	**Rep 2**	**Rep 3**	**AVG**	**StdDev**	**Rep 1**	**Rep 2**	**Rep3**	**AVG**	**StdDev**
Fabric A	10.4	10.4	11.0	10.6	0.346	11.1	10.8	11.1	11.0	0.173

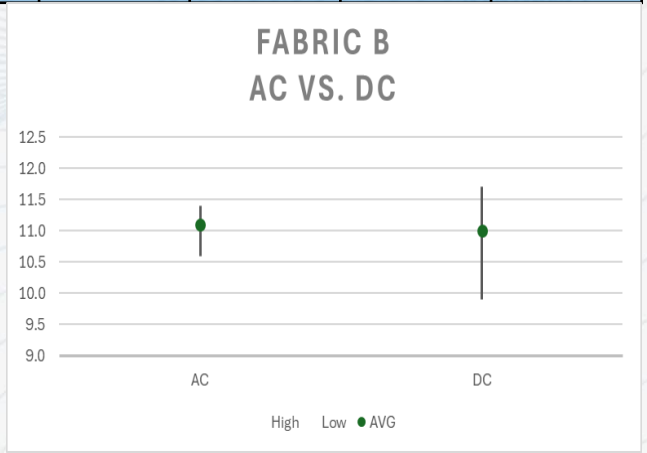
- Fabric A
  - Multi-fiber FR Blend
  - 5.3 oz/yd^2
  - Twill



Results – Individual Arc Ratings

	AC Arc Ratings					DC Arc Ratings				
Sample ID	**Rep 1**	**Rep 2**	**Rep 3**	**AVG**	**StdDev**	**Rep 1**	**Rep 2**	**Rep3**	**AVG**	**StdDev**
Fabric B	10.6	11.4	11.4	11.1	0.462	9.9	11.7	11.4	11.0	0.964

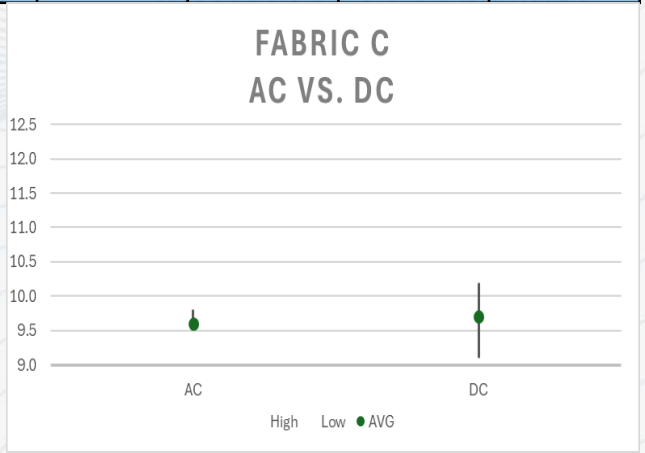
- Fabric B
  - Multi-fiber FR Blend
  - 6.1 oz/yd^2
  - Ripstop



Results – Individual Arc Ratings

	AC Arc Ratings					DC Arc Ratings				
Sample ID	**Rep 1**	**Rep 2**	**Rep 3**	**AVG**	**StdDev**	**Rep 1**	**Rep 2**	**Rep3**	**AVG**	**StdDev**
Fabric C	9.5	9.5	9.6	9.6	0.153	9.1	9.8	10.2	9.7	0.361

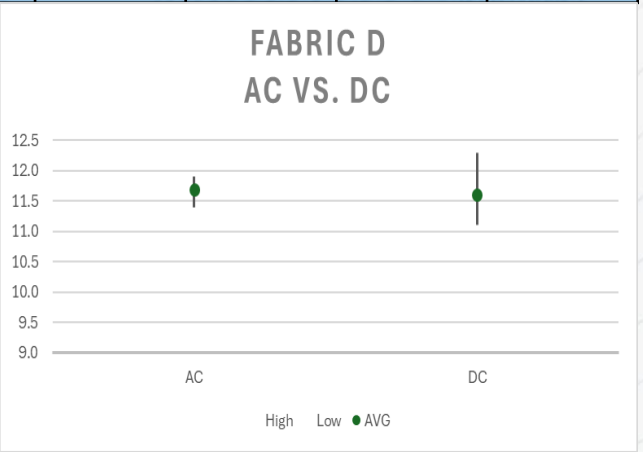
- Fabric C
  - Cotton/Nylon Blend
  - 7.0 oz/yd^2
  - Twill



Results – Individual Arc Ratings

	AC Arc Ratings					DC Arc Ratings				
Sample ID	**Rep 1**	**Rep 2**	**Rep 3**	**AVG**	**StdDev**	**Rep 1**	**Rep 2**	**Rep3**	**AVG**	**StdDev**
Fabric D	11.7	11.9	11.4	11.7	0.252	11.5	11.1	12.3	11.6	0.208

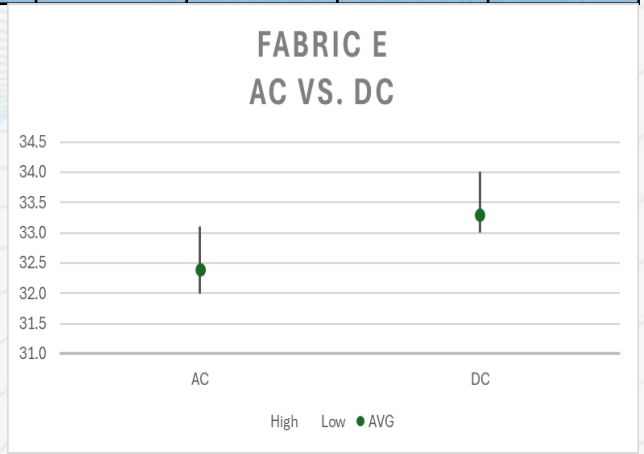
- Fabric D
  - 100% Cotton
  - 9.0 oz/yd^2
  - Twill



Results – Individual Arc Ratings

	AC Arc Ratings					DC Arc Ratings				
Sample ID	**Rep 1**	**Rep 2**	**Rep 3**	**AVG**	**StdDev**	**Rep 1**	**Rep 2**	**Rep3**	**AVG**	**StdDev**
Fabric E	32.0	32.2	33.1	32.4	0.586	34.0	33.0	33.0	33.3	0.551

- Fabric E
  - Polyester/PTFE
  - 9.0 oz/yd^2
  - Trilaminate



Results Summary

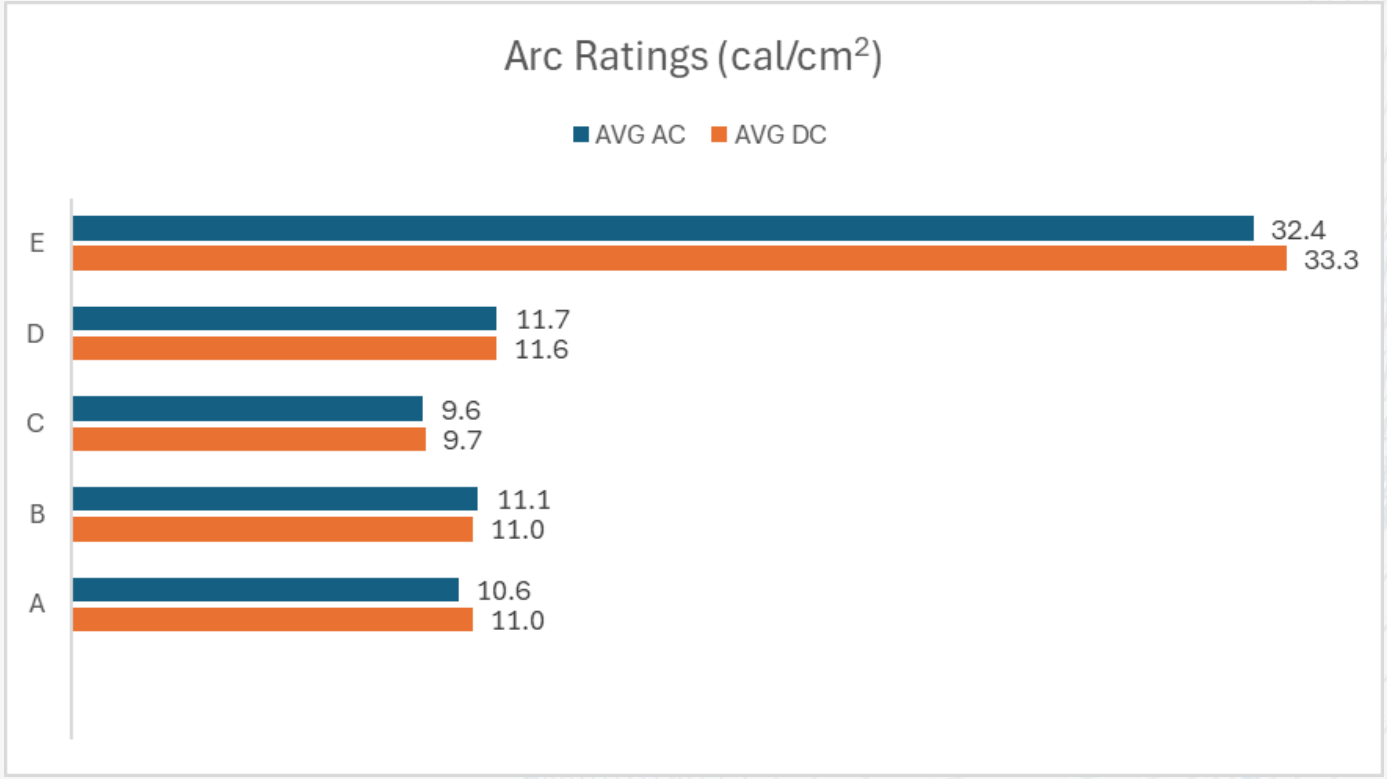
Average Arc Rating

Sample ID	AC Arc Rating	DC Arc Rating	Difference
Fabric A	**10.6**	**11.0**	+0.4
Fabric B	**11.1**	**11.0**	-0.1
Fabric C	**9.6**	**9.7**	+0.1
Fabric D	**11.7**	**11.6**	-0.1
Fabric E	**32.4**	**33.3**	+0.9

Rounded per ASTM F1959

Sample ID	AC Arc Rating	DC Arc Rating
Fabric A	**11**	**11**
Fabric B	**11**	**11**
Fabric C	**9.6**	**9.7**
Fabric D	**12**	**12**
Fabric E	**32**	**33**

Average arc rating comparison of AC and DC for Fabrics A-E



Discussion and Conclusions

Conclusion and Discussion

General Conclusion

The data very clearly suggests that there is **no significant difference** between arc ratings generated using AC energy and those generated using DC energy.

Discussion Points

Previous studies have shown double-digit percent variation in arc ratings over a series of months or years, and from lot-to-lot. To eliminate as many variables as possible, it was important for this study to use the same production lots and keep a tight testing timeline when switching from AC to DC power supply.

Discussion

Discussion Points

- Studying each fabric individually, we confirm that our efforts to reduce inherent variability were successful. There was no clear trend of an arc rating (either AC or DC) of a given fabric increasing or decreasing consistently over successive testing dates.

- When comparing the ASTM F1959 arc ratings for this study, it is evident that the variation between AC and DC is well within the anticipated variation of the test. Three of the five test fabrics (Fabric A, B, and D) averaged exactly the same reported arc rating, and a fourth was only different (by 0.1 cal/cm^2) because it does not round per the standard convention. These fabrics show very good precision and indicate no difference in arc ratings generated using AC and DC energy sources.

Conclusions

- Our research studied the relative arc ratings of fabrics when those ratings were determined using either AC energy or DC energy in order to shed light on an unknown area of mitigating risk with the use of arc rated clothing.

- Results show that for single layer arc rated fabrics, at least the five fabrics evaluated in this study, there is no significant difference between arc ratings when exposed to AC arcs vs DC arcs.

Path Forward

Path Forward

- Test Single-Layer fabric systems with EBT arc ratings

- Test Multi-Layer fabric systems

- Study other types of PPE
- Face Protection – as the light spectrum could play a vital role in differences
- Hand Protection
- Fall Protection

Thank you

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