

# Color Change in Accelerated Weathering Testing of PVC Plastics

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# Introduction

- Inorganic color additives in plastics like PVC are increasingly being replaced by organic additives
  - Organic pigments are often better from a safety perspective
  - However, they often have decreased lightfastness performance
- Colorfastness performance of materials in outdoor environments can be studied with weathering testing
- Sunlight can cause different weathering phenomena (yellowing, color fade) depending on photon wavelength (short/longwave UV, visible)

# Weathering Testing Programs

# What is Weathering?

**Weathering** is changes in material properties resulting from exposure to the radiant energy present in **sunlight** in combination with **heat** (including temperature cycling) and **water** in its various states, predominately as humidity, dew, and rain.

# Forces of Weathering

## Know Your Enemy!

- Sunlight
- Heat
- Water



# Conduct both Outdoor and Accelerated Lab Testing

**Natural Outdoor** weathering in Florida, Arizona, or both



+

**Accelerated** weathering in xenon, UV fluorescent, condensation, metal halide, solar concentrator, or some combination

+





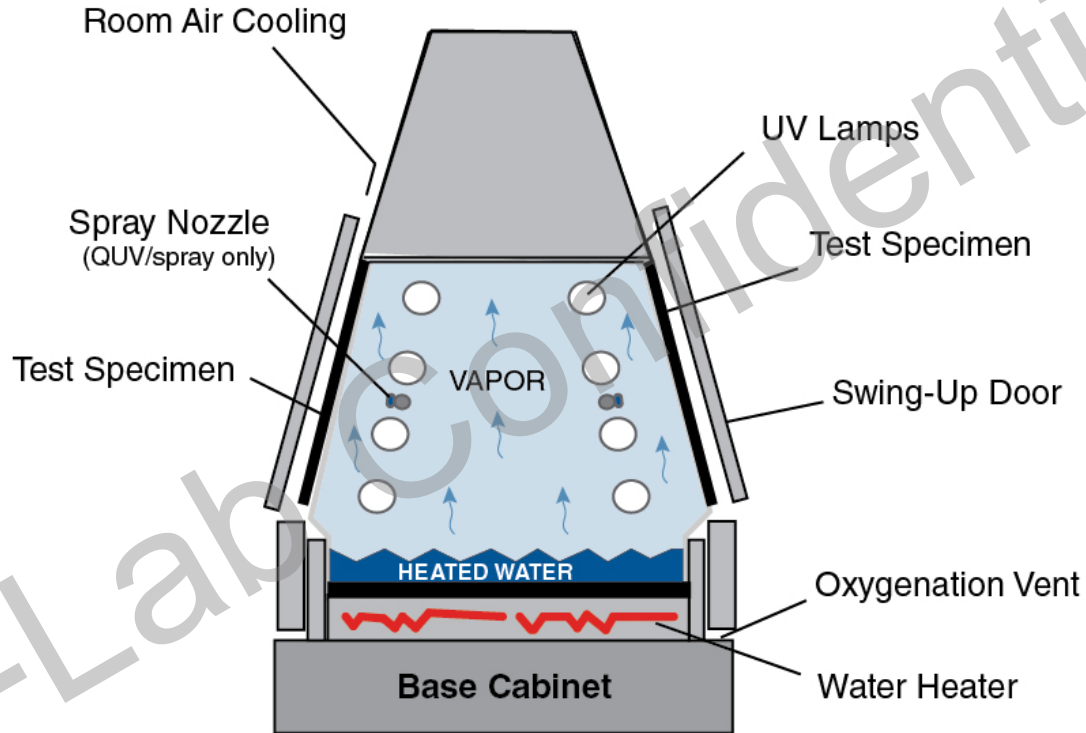
# Natural Outdoor Testing: Florida

- High UV irradiance
- High temperatures
- High time of wetness (TOW)
- High humidity





# Accelerated Lab Testing: Fluorescent UV



# Accelerated Lab Testing: Xenon Arc (Flat Array)

- 1) User interface
- 2) USB port for data transfer
- 3) Xenon lamps with irradiance control
- 4) Optical filters
- 5) Water spray
- 6) Onboard irradiance sensors
- 7) Black Panel Temp sensor
- 8) Specimen holders
- 9) Relative Humidity/CAT sensor



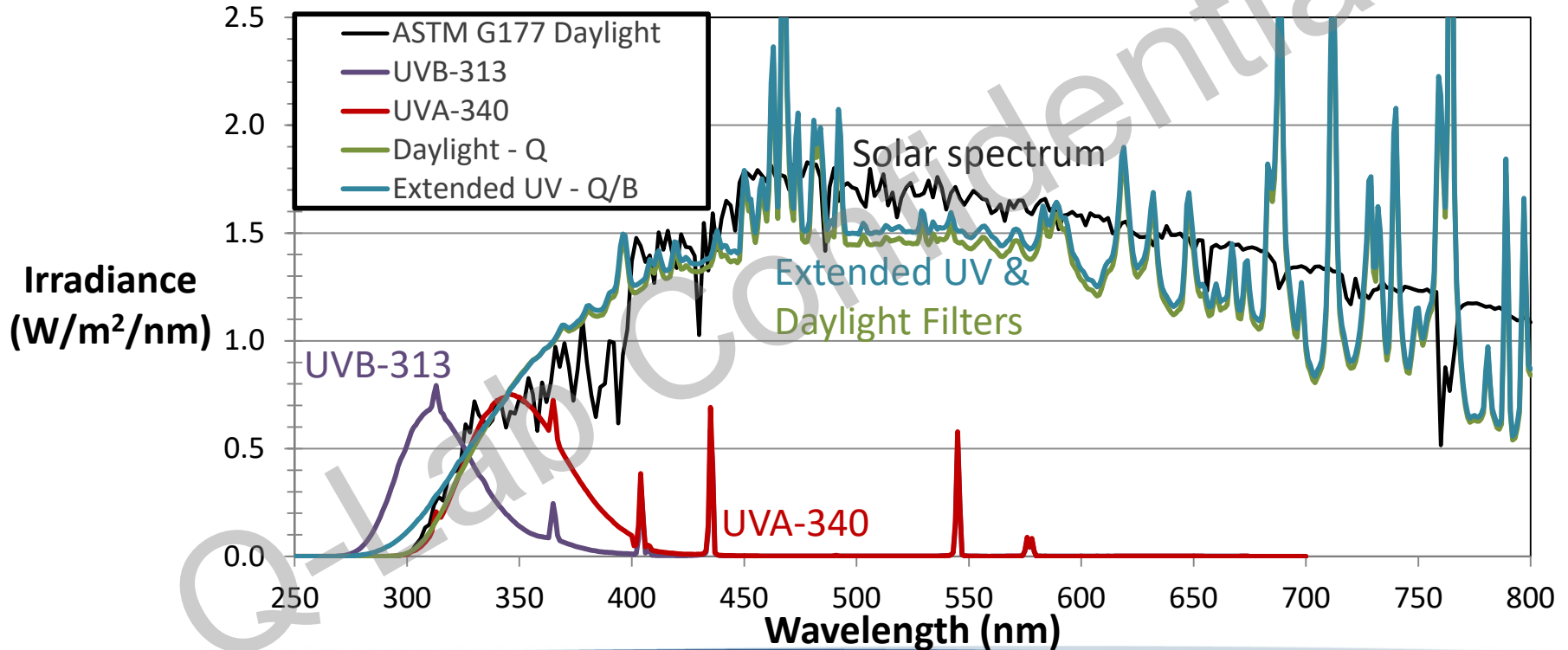
# Accelerated Lab Testing: Xenon Arc (Rotating Rack)

- 1) User interface
- 2) USB port for data transfer
- 3) Xenon lamps with irradiance control
- 4) Optical filters
- 5) Water spray
- 6) Onboard irradiance sensors
- 7) Black Panel Temp sensor
- 8) Specimen holders
- 9) Relative Humidity/CAT sensor



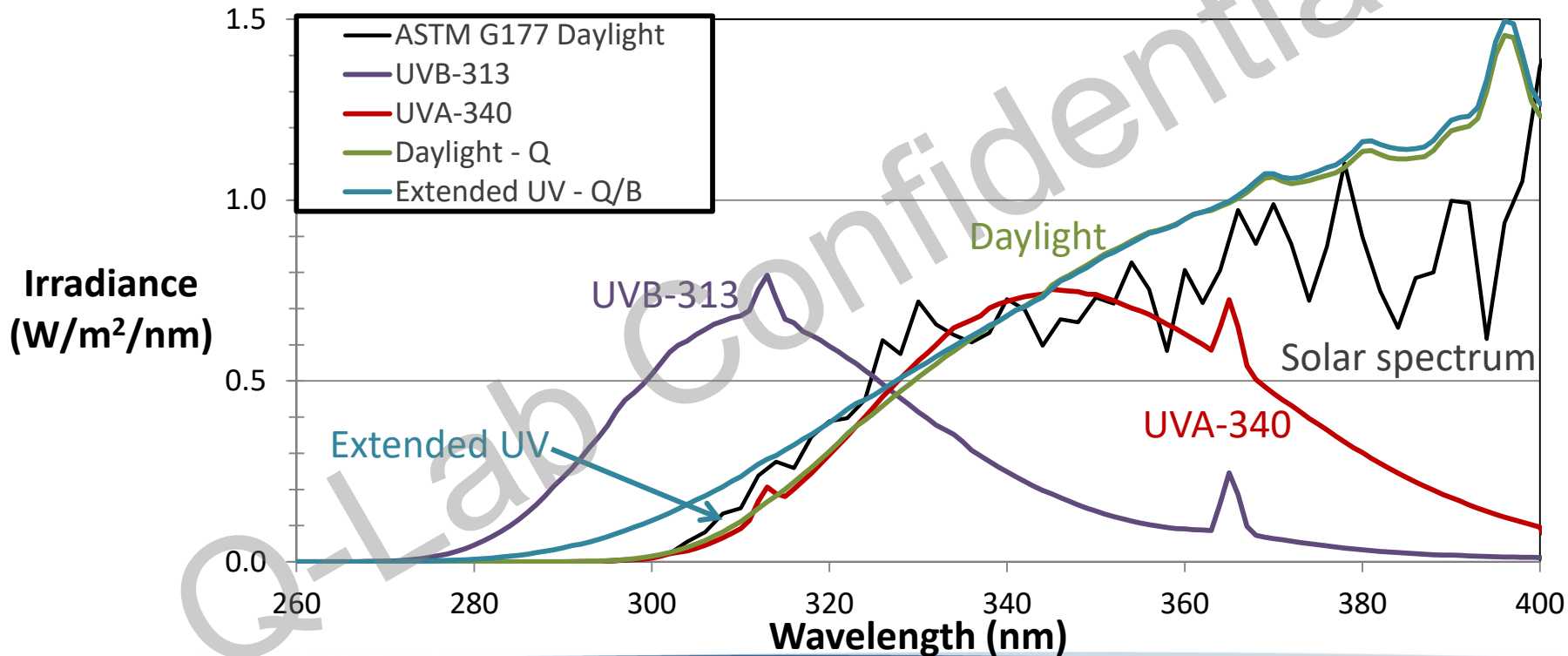
# Light Spectrum Comparison

## UV and Visible Region



# Light Spectrum Comparison

## UV Region



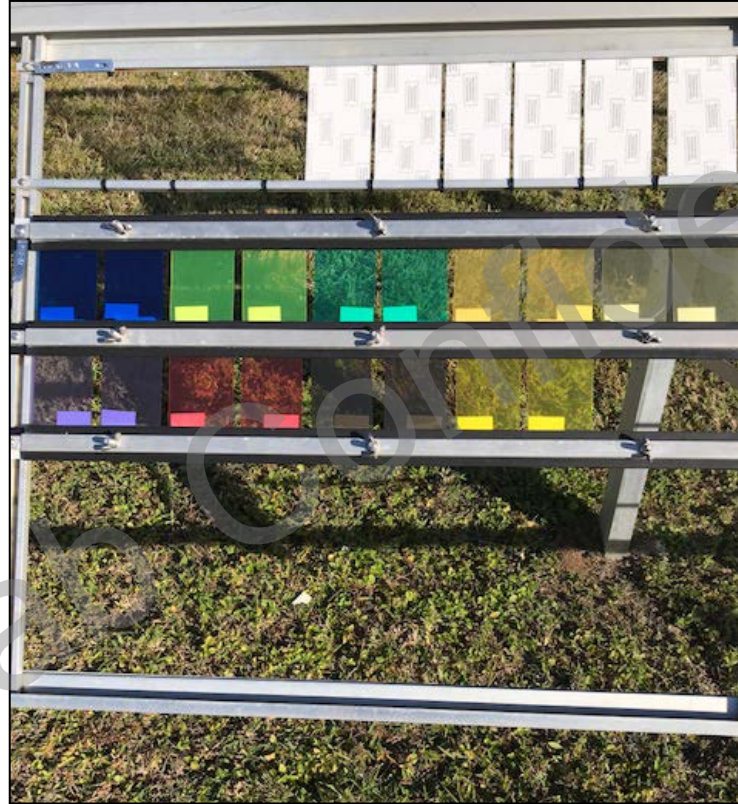
# PVC Weathering Test Program

- Outdoor Exposures
  - Florida
  - Unbacked specimens, 45° south facing
  - 57 days
- Fluorescent UV
  - UVA-340 and UVB-313 lamps
  - 4h light, 0.72 W/m<sup>2</sup>/nm, 45 °C
  - 4h condensation, 40 °C
  - 200 hours
- Xenon arc
  - Daylight-Q and Extended UV-Q/B filters
  - 5h light, 0.68 W/m<sup>2</sup>/nm, 35-45 °C
  - 20 min spray, 40 °C
  - 200 hours





# Outdoor Exposure: Florida

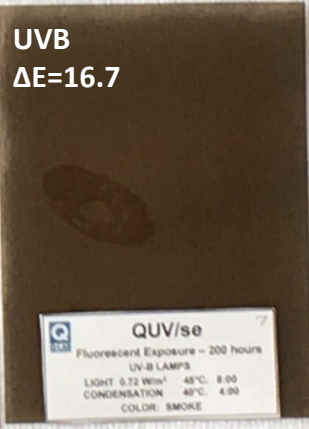
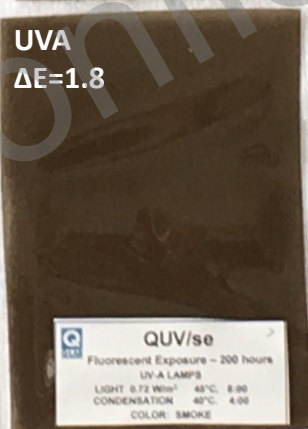
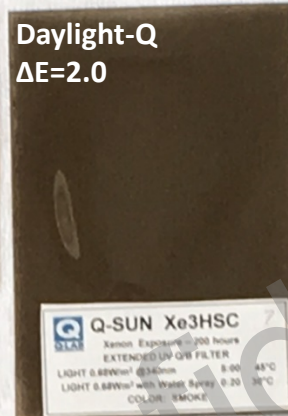
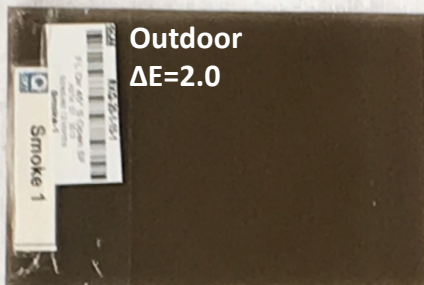




# Outdoor Exposure: Cleveland



# Color Change of PVC Plastics: Test Results



Smoke





Outdoor  
 $\Delta E=2.5$

Daylight-Q  
 $\Delta E=5.0$

Ext UV-Q/B  
 $\Delta E=6.3$

Unexposed

**Q-SUN Xe3HSC**  
Xenon Exposure - 200 hours  
DAYLIGHT Q FILTER  
LIGHT 0.89W/m<sup>2</sup> @340nm 8:00 45°C  
LIGHT 0.89W/m<sup>2</sup> with Water Spray 9:20 30°C  
COLOR: YELLOW

**Q-SUN Xe1BC**  
Xenon Exposure - 200 hours  
EXTENDED UV Q/B FILTER  
LIGHT 0.72W/m<sup>2</sup> TUV 8:00 35°C  
DARK with Water Spray 9:20 30°C  
COLOR: YELLOW

UVA  
 $\Delta E=4.7$

UVB  
 $\Delta E=43.0$

**QUV/se**  
Fluorescent Exposure - 200 hours  
UV-A LAMPS  
LIGHT 0.72 W/m<sup>2</sup> 45°C 8:00  
CONDENSATION 40°C 4:00  
COLOR: YELLOW

**QUV/se**  
Fluorescent Exposure - 200 hours  
UV-B LAMPS  
LIGHT 0.72 W/m<sup>2</sup> 45°C 8:00  
CONDENSATION 40°C 4:00  
COLOR: YELLOW

**Yellow**



**Yellow**



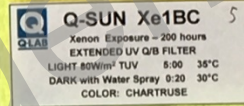
Outdoor  
 $\Delta E=5.6$



Daylight-Q  
 $\Delta E=7.7$

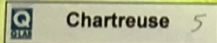
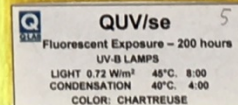
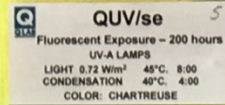
Ext UV-Q/B  
 $\Delta E=11.0$

Unexposed



UVA  
 $\Delta E=11.9$

UVB  
 $\Delta E=25.5$



Chartreuse



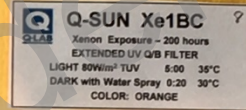
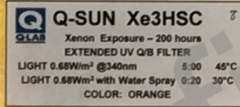
Outdoor  
 $\Delta E=8.6$



Daylight-Q  
 $\Delta E=11.2$

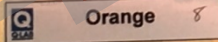
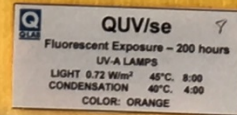
Ext UV-Q/B  
 $\Delta E=11.4$

Unexposed



UVA  
 $\Delta E=10.2$

UVB  
 $\Delta E=17.7$



Orange

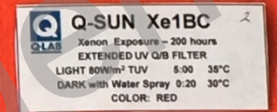
Outdoor  
 $\Delta E=14.0$



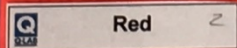
Daylight-Q  
 $\Delta E=35.0$



Ext UV-Q/B  
 $\Delta E=11.8$



Unexposed



UVA  
 $\Delta E=16.8$



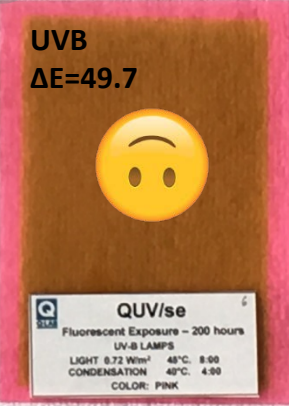
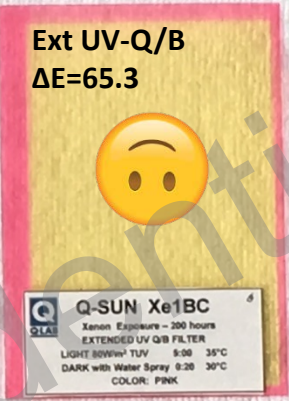
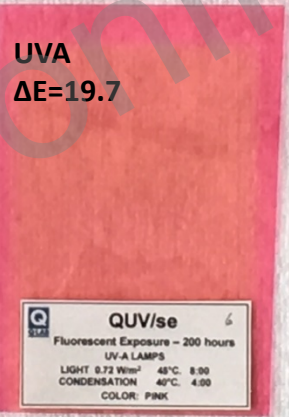
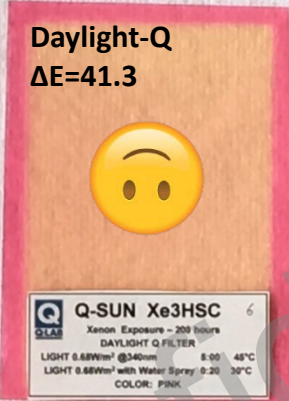
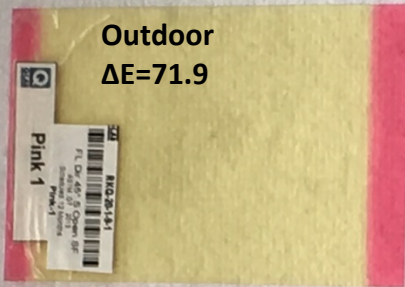
UVB  
 $\Delta E=14.3$



Red







Pink

*Those **red** and **pink** results  
were a bit unusual, right?*



# Variety in Color Change Modes

## UVB-313



*UV light*

PVC polymer degradation

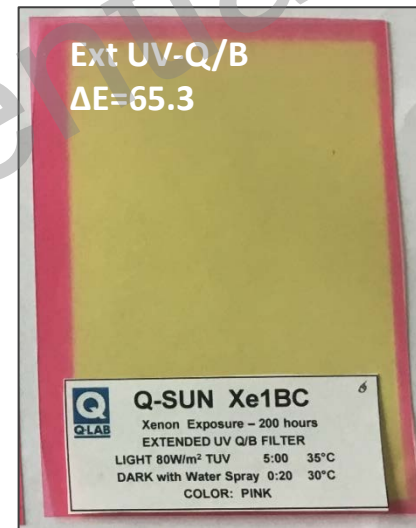
## Xenon Daylight



*Visible light*

Pigment degradation

## Xenon Extended UV

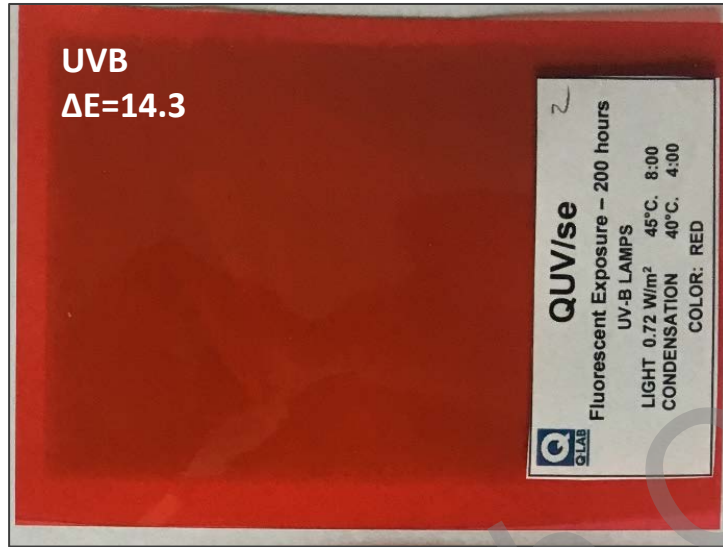


*UV + Visible light*

PVC polymer degradation  
and Pigment degradation



# Color Change and Red Specimens



- No visible light
- Darkening from PVC polymer breakdown
- Visible light
- Color fade from pigment degradation

***Red and Pink specimens illustrate the limitations of using total color change as a single metric!***





# Color Change of PVC Plastics: Correlation and Conclusions

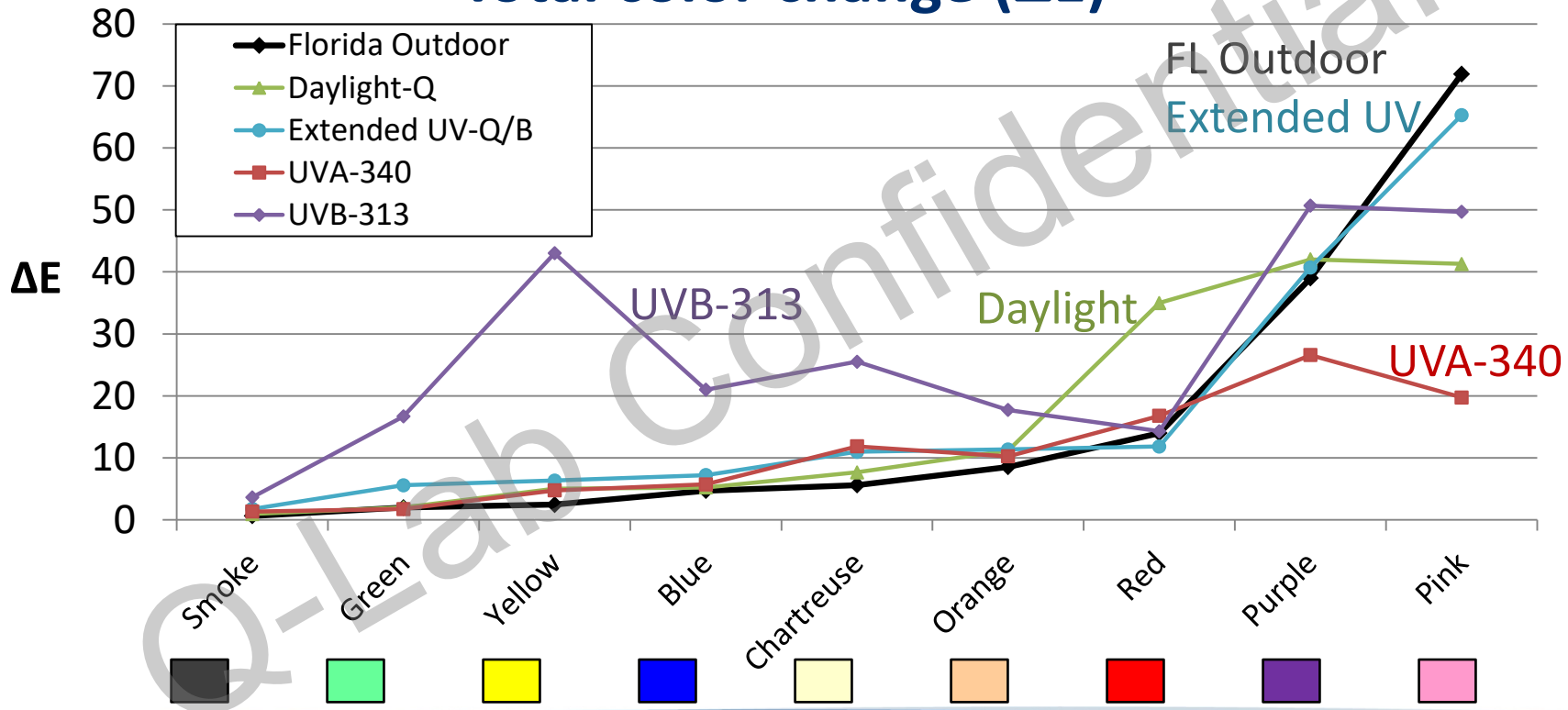
# Correlation: Accelerated vs Outdoor

Color	Florida Outdoor		Daylight		Extended UV		UVA-340		UVB-313	
	$\Delta E$	Rank	$\Delta E$	Rank	$\Delta E$	Rank	$\Delta E$	Rank	$\Delta E$	Rank
Smoke	0.6	1	1.0	1	1.8	1	1.3	1	3.6	1
Green	2.0	2.5	2.0	2	5.6	2	1.8	1	16.7	3.5
Yellow	2.5	2.5	5.0	3.5	6.3	3	4.7	3	43.0	7
Blue	4.7	4	5.2	3.5	7.2	4	5.7	4	21.0	5
Chartreuse	5.6	5	7.7	5	11.0	6	11.9	6	25.5	6
Orange	8.6	6	11.2	6	11.4	6	10.2	5	17.7	3.5
Red	14.0	7	35.0	7	11.8	6	16.8	7	14.3	2
Purple	39.0	8	42.0	8.5	40.7	8	26.6	9	50.7	8.5
Pink	71.9	9	41.3	8.5	65.3	9	19.7	8	49.7	8.5
Rank order correlation with Outdoors --->			<b>0.98</b>		<b>0.96</b>		<b>0.95</b>		<b>0.54</b>	

*Excellent color change correlation between FL outdoors and accelerated (except UVB-313)*

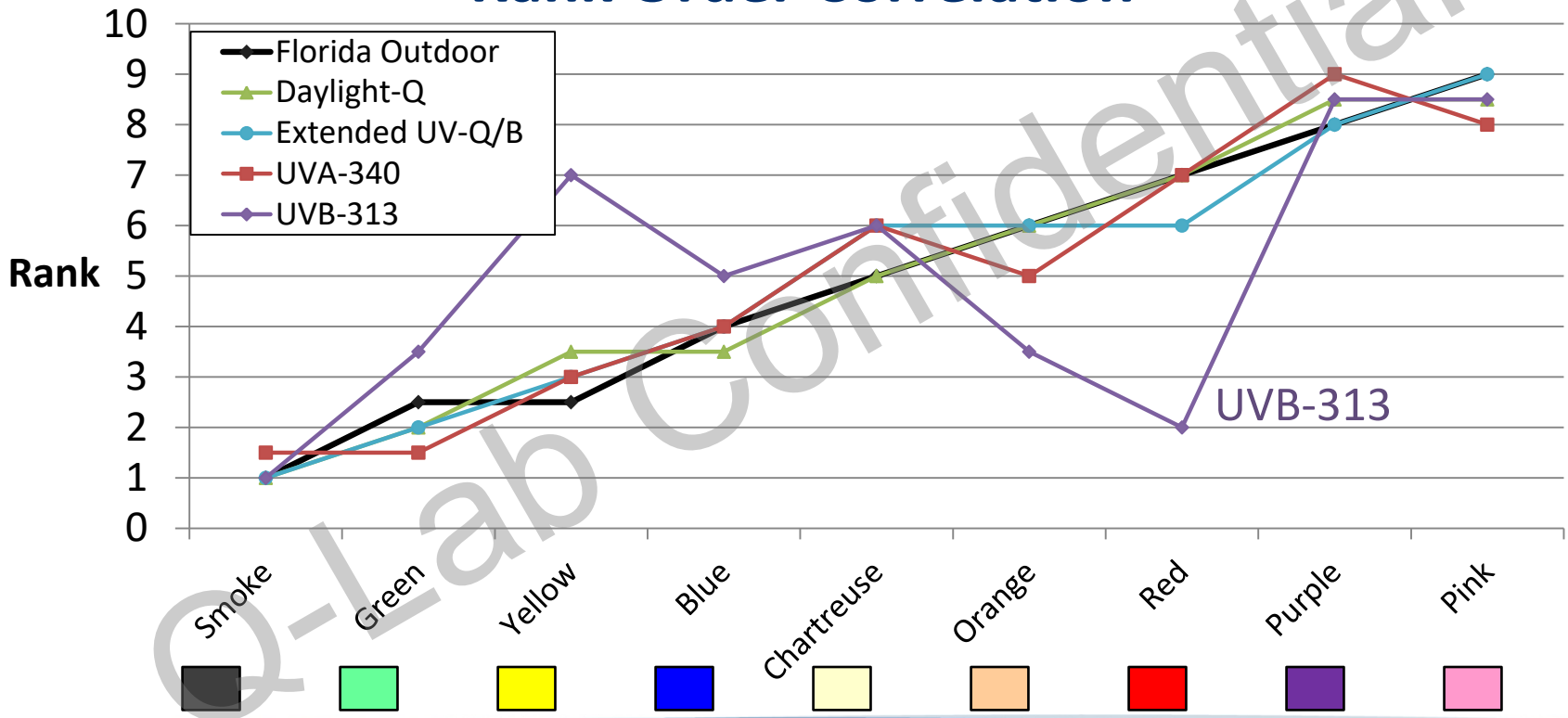
# Correlation: Accelerated vs Outdoor

## Total color change ( $\Delta E$ )



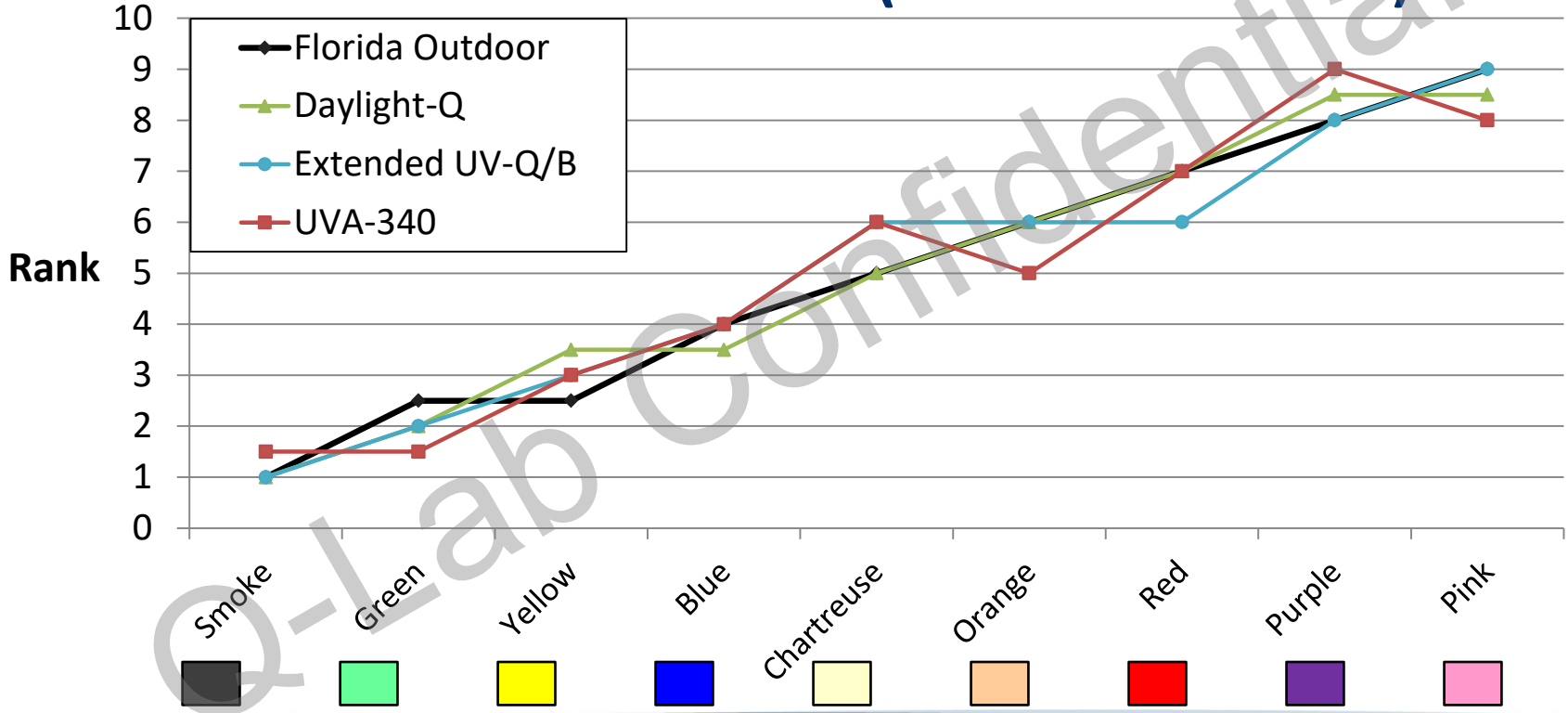
# Correlation: Accelerated vs Outdoor

## Rank Order Correlation



# Correlation: Accelerated vs Outdoor

## Rank Order Correlation (without UVB-313)



# Summary

- Accelerated weathering testing of colored PVC plastics performed, color change ( $\Delta E$ ) measured
  - Outdoor exposures for 2 months (Florida)
  - Accelerated lab for 200 hours (UV fluorescent and xenon arc)
- Significant differences in extent of color change observed among 9 different colors

# Conclusions

- Correlation for color change between accelerated and outdoor tests
  - Excellent rank order correlation for xenon (Daylight or Extended UV filter) and UV fluorescent (UVA-340 lamps)
  - Poor correlation for UV fluorescent UVB-313 lamps
- Different degradation observed for pigments and base plastics
  - Darkening from plastic yellowing from shortwave UV
  - Fade from breakdown of pigments from visible light
  - Differences most pronounced for pink and red specimens
  - Illustrates the need for thorough color characterization beyond  $\Delta E$



# Thoughts on Accelerated Weathering

- There is no “magic number” for accelerated testing - weathering testing is strongly material-dependent
- Good correlation for color change does not necessarily mean good correlation for physical properties. Understanding failure mode is key.
- Retesting must be done any time materials chemistry is modified
- Outdoor weathering data is critical for correlation and to validate accelerated tests - “Test the Test”!

# Thank you for your attention!



*Special thanks to Richard Kish for devising and carrying out the comparative study in this presentation*

**Questions?**  
**[info@q-lab.com](mailto:info@q-lab.com)**