

# 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
- Performance of these colored materials in outdoor environments can be studied with weathering testing
- Sunlight can cause different weathering phenomena (yellowing, color fade) depending on photon wavelength (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 FL, AZ, or both



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



# Natural Outdoor Testing: Florida

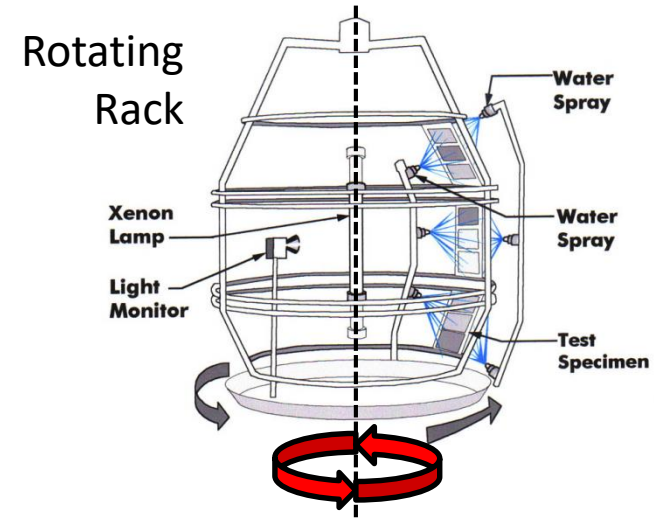
- High UV irradiance
- High temperatures
- High time of wetness (TOW)
- High humidity



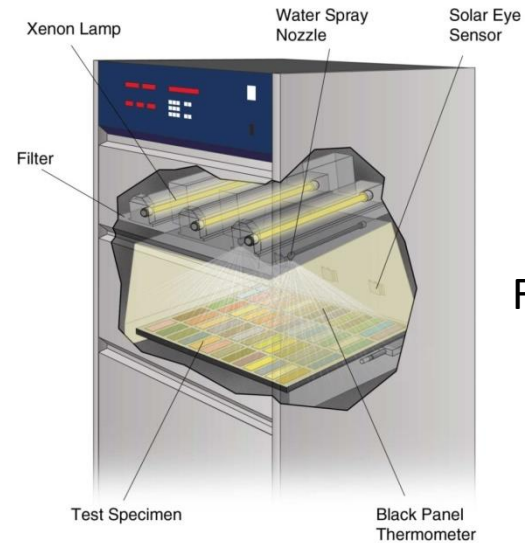
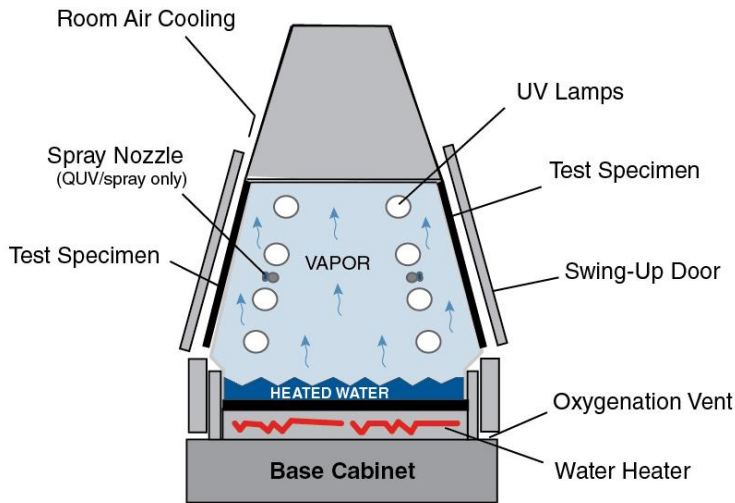


# Accelerated Laboratory Weathering Testing

## Xenon Arc



## Fluorescent UV



## Flat Array

# Accelerated Weathering Testing

## Fluorescent UV and Xenon Arc are Complementary Technologies

### Fluorescent UV

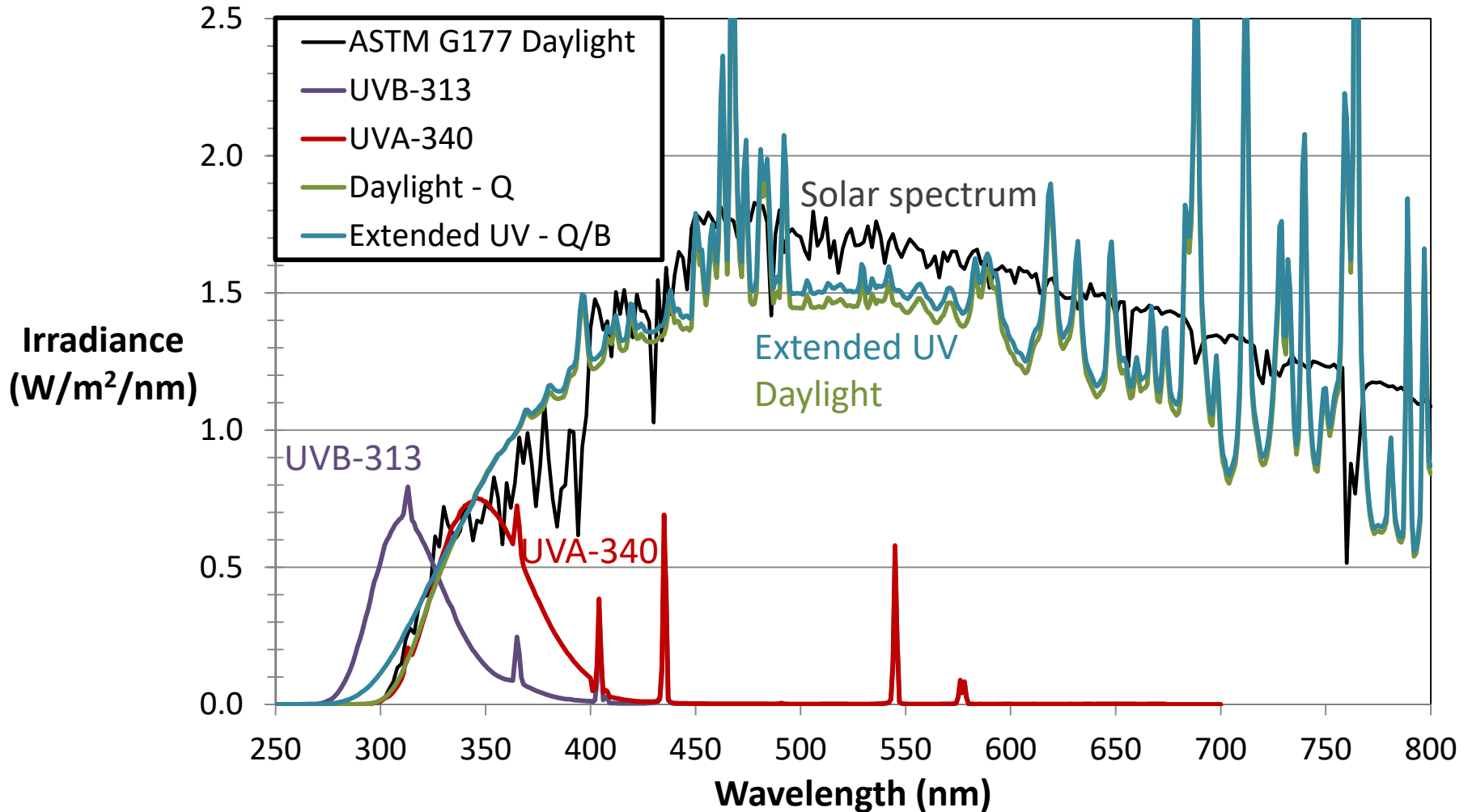
- UVA-340 best simulation of shortwave UV
- No visible light
- UVB-313 is a harsh spectrum
- Stable spectrum over time
- No RH control necessary
- Condensation or water spray
- Relatively inexpensive and simple

### Xenon Arc

- Best simulation of full spectrum sunlight (UV-Vis-IR)
- Daylight filter matches solar spectrum – Extended UV is harsher
- Spectrum changes
- RH control
- Water spray
- More expensive and complex

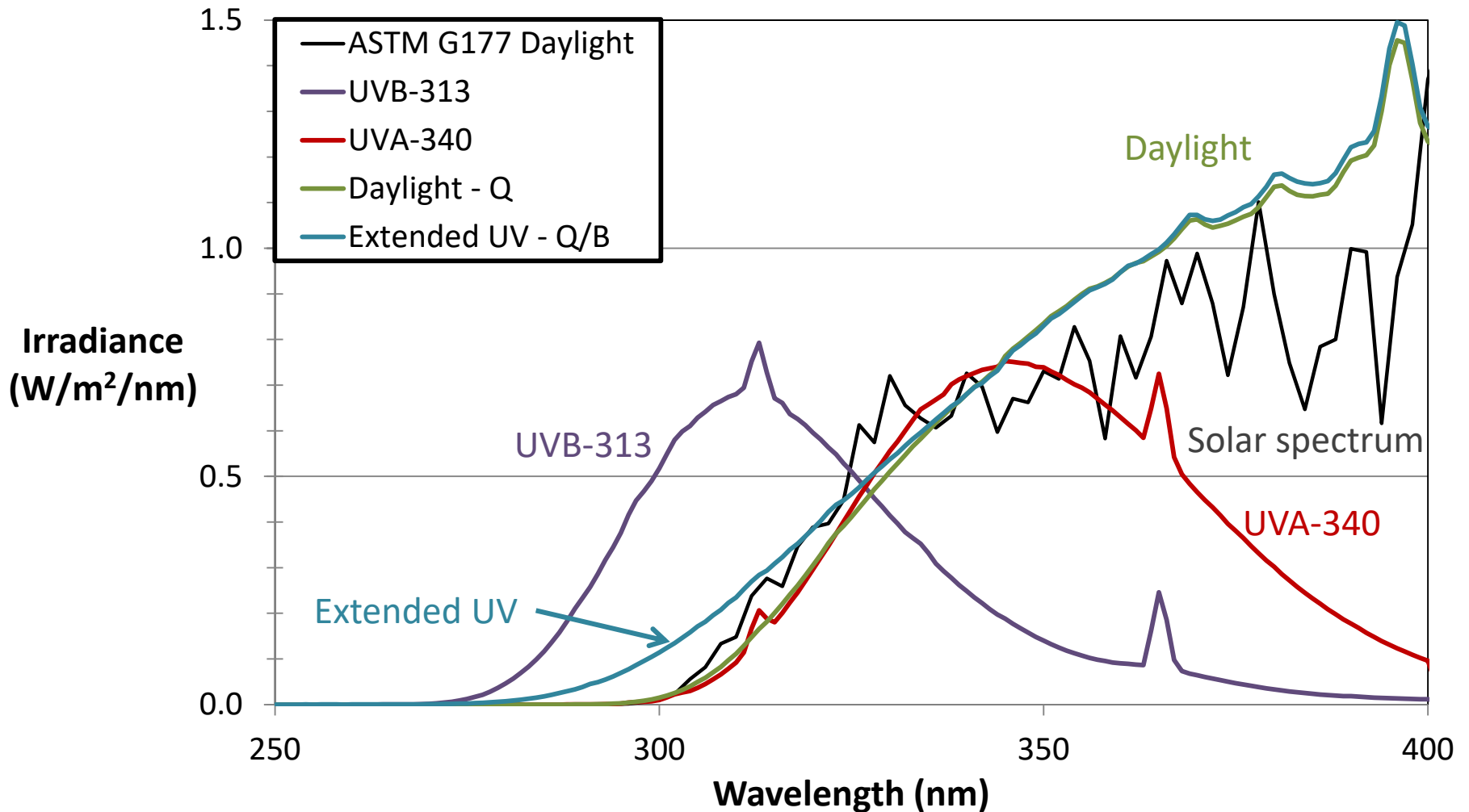
# Light Spectrum Comparison

## UV and Visible Region



# Light Spectrum Comparison

## UV Region



# PVC Weathering Test Program

- Outdoor Exposures
  - Florida
  - Unbacked specimens, 45° south facing
  - 57 days



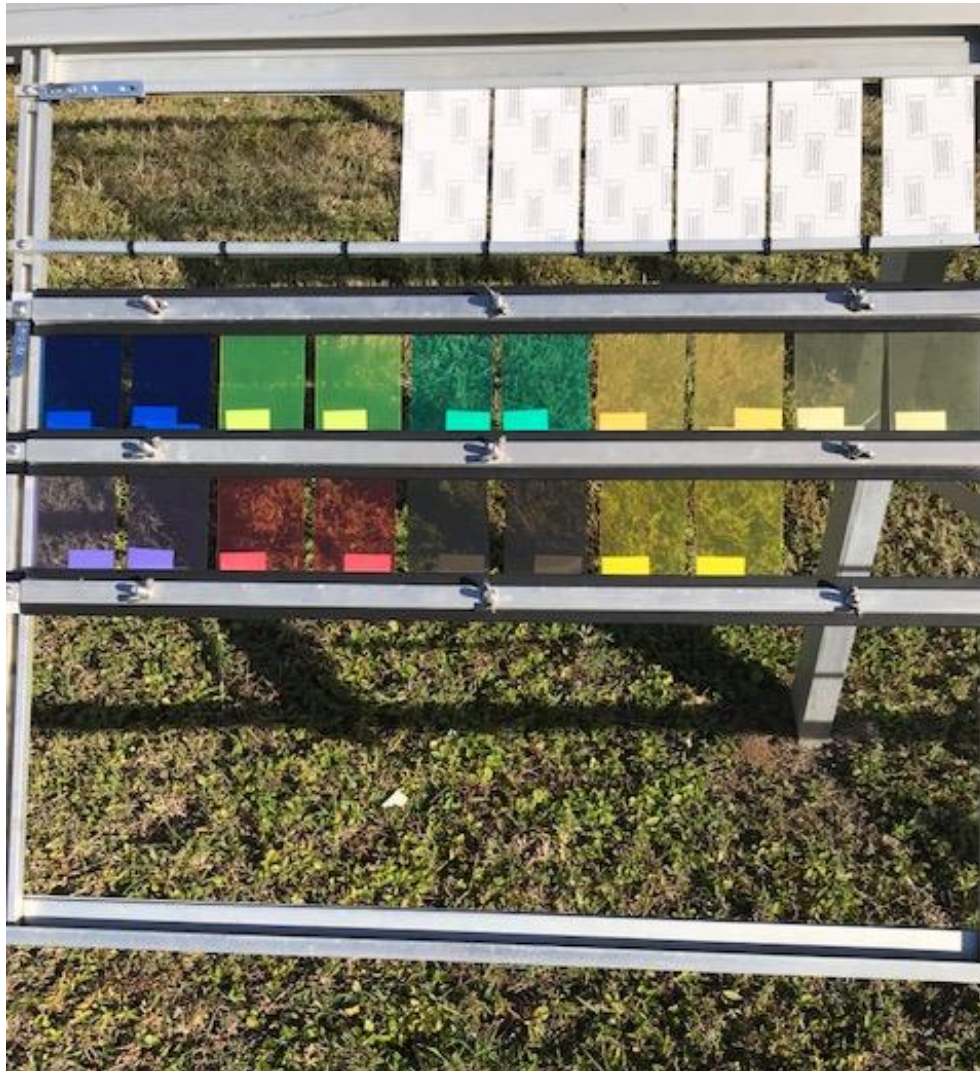
- Fluorescent UV
  - UVA-340 and UVB-313 lamps
  - 4h light, 0.72 W/m<sup>2</sup>/nm, 45 °C
  - 4h condensation, 40 °C
  - 200 hours total



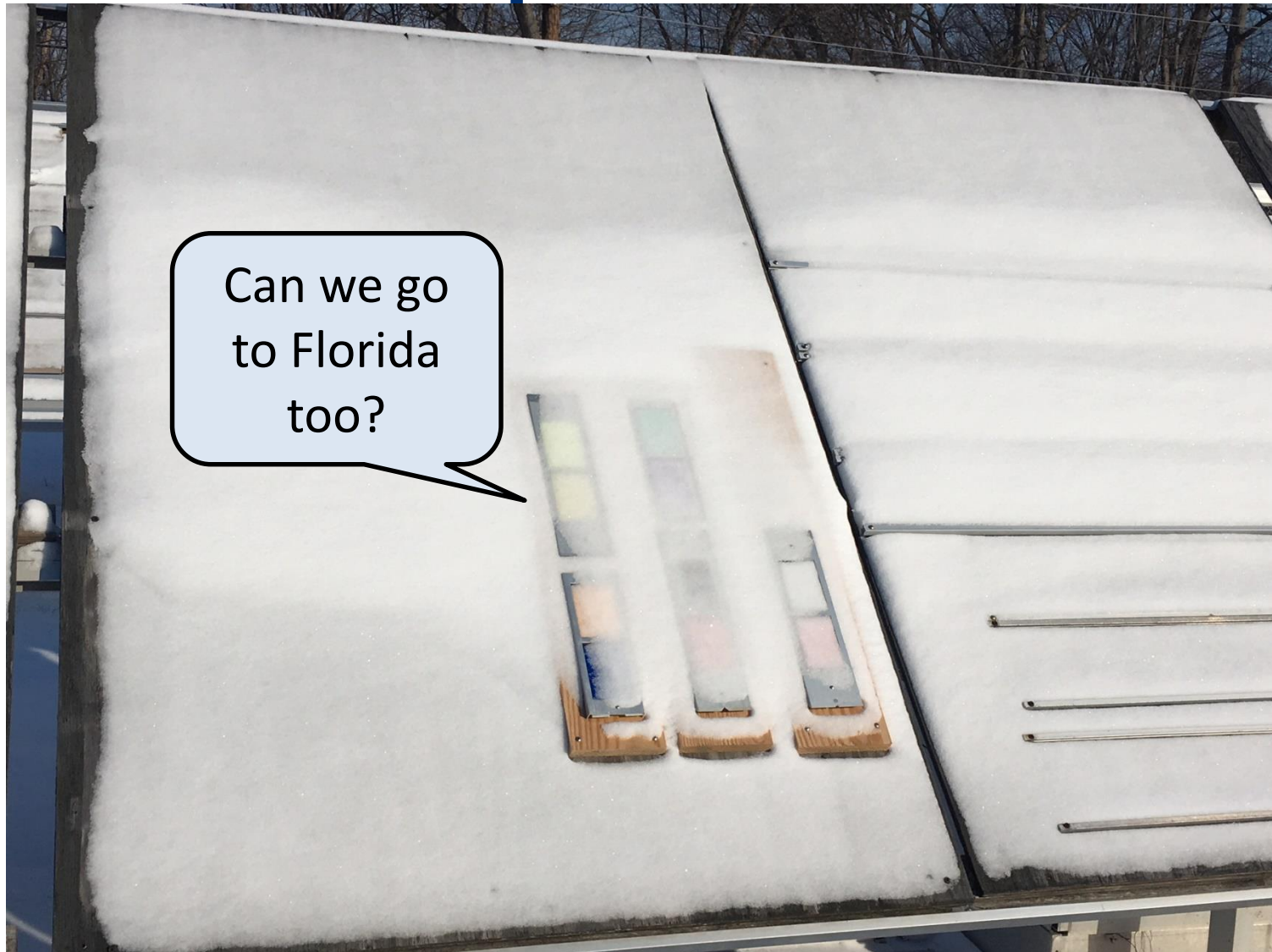
- Xenon arc
  - Daylight-Q and Extended UV-Q/B filters
  - 5h light, 0.68 W/m<sup>2</sup>/nm, 35-45 °C
  - 20 min spray, 40 °C
  - 200 hours total



# Outdoor Exposure: Florida



# Outdoor Exposure: Cleveland





# Color Change of PVC Plastics: Test Results



# Smoke

Daylight Q

$\Delta E=1.0$



Q-SUN Xe3HSC 7

Xenon Exposure - 200 hours

EXTENDED UV Q/B FILTER

LIGHT 0.68W/m<sup>2</sup> @340nm 5:00 45°C

LIGHT 0.68W/m<sup>2</sup> with Water Spray 0:20 30°C

COLOR: SMOKE

Ext UV-Q/B

$\Delta E=1.8$



Q-SUN Xe1BC 7

Xenon Exposure - 200 hours

EXTENDED UV Q/B FILTER

LIGHT 80W/m<sup>2</sup> TUV 5:00 35°C

DARK with Water Spray 0:20 30°C

COLOR: SMOKE

UVA

$\Delta E=1.3$



QUV/se 7

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: SMOKE

UVB

$\Delta E=3.6$



QUV/se 7

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: SMOKE



Smoke 7

# Green

Daylight Q

$\Delta E=2.0$

Ext UV-Q/B

$\Delta E=5.6$



**Q-SUN Xe3HSC** 4

Xenon Exposure – 200 hours  
DAYLIGHT Q FILTER

LIGHT 0.68W/m<sup>2</sup> @340nm 5:00 45°C  
LIGHT 0.68W/m<sup>2</sup> with Water Spray 0:20 30°C  
COLOR: GREEN



**Q-SUN Xe1BC** 4

Xenon Exposure – 200 hours  
EXTENDED UV Q/B FILTER

LIGHT 80W/m<sup>2</sup> TUV 5:00 35°C  
DARK with Water Spray 0:20 30°C  
COLOR: GREEN

UVA

$\Delta E=1.8$

UVB

$\Delta E=16.7$



Green 4



**QUV/se** 4

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: GREEN



**QUV/se** 4

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: GREEN

# Yellow


Daylight Q  $\Delta E=5.0$

 **Q-SUN Xe3HSC** 3  
Xenon Exposure – 200 hours  
DAYLIGHT Q FILTER  
LIGHT 0.68W/m<sup>2</sup> @340nm 5:00 45°C  
LIGHT 0.68W/m<sup>2</sup> with Water Spray 0:20 30°C  
COLOR: YELLOW

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


 **Q-SUN Xe1BC** 3  
Xenon Exposure – 200 hours  
EXTENDED UV Q/B FILTER  
LIGHT 80W/m<sup>2</sup> TUV 5:00 35°C  
DARK with Water Spray 0:20 30°C  
COLOR: YELLOW

UVA  $\Delta E=4.7$

 **QUV/se** 3  
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

UVB  $\Delta E=43.0$

 **QUV/se** 3  
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 3

# Blue



Daylight Q

$\Delta E=5.2$



**Q-SUN Xe3HSC**

Xenon Exposure – 200 hours  
DAYLIGHT Q FILTER  
LIGHT 0.68W/m<sup>2</sup> @340nm 5:00 45°C  
LIGHT 0.68W/m<sup>2</sup> with Water Spray 0:20 30°C  
COLOR: BLUE

Ext UV-Q/B

$\Delta E=7.2$



**Q-SUN Xe1BC**

Xenon Exposure – 200 hours  
EXTENDED UV Q/B FILTER  
LIGHT 80W/m<sup>2</sup> TUV 5:00 35°C  
DARK with Water Spray 0:20 30°C  
COLOR: BLUE

UVA

$\Delta E=5.7$



**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: BLUE

UVB

$\Delta E=21.0$



**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: BLUE

# Chartreuse

Daylight Q  $\Delta E=7.7$

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

 **Q-SUN Xe3HSC** 5  
Xenon Exposure – 200 hours  
DAYLIGHT Q FILTER  
LIGHT 0.68W/m<sup>2</sup> @340nm 5:00 45°C  
LIGHT 0.68W/m<sup>2</sup> with Water Spray 0:20 30°C  
COLOR: CHARTREUSE

 **Q-SUN Xe1BC** 5  
Xenon Exposure – 200 hours  
EXTENDED UV Q/B FILTER  
LIGHT 80W/m<sup>2</sup> TUV 5:00 35°C  
DARK with Water Spray 0:20 30°C  
COLOR: CHARTREUSE


UVA  $\Delta E=11.9$

UVB  $\Delta E=25.5$



Chartreuse 5

 **QUV/se** 5  
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: CHARTREUSE

 **QUV/se** 5  
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: CHARTREUSE

# Orange

Daylight Q  $\Delta E=11.2$

 **Q-SUN Xe3HSC** 8  
Xenon Exposure – 200 hours  
EXTENDED UV Q/B FILTER  
LIGHT 0.68W/m<sup>2</sup> @340nm 5:00 45°C  
LIGHT 0.68W/m<sup>2</sup> with Water Spray 0:20 30°C  
COLOR: ORANGE

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

 **Q-SUN Xe1BC** 8  
Xenon Exposure – 200 hours  
EXTENDED UV Q/B FILTER  
LIGHT 80W/m<sup>2</sup> TUV 5:00 35°C  
DARK with Water Spray 0:20 30°C  
COLOR: ORANGE

UVA  $\Delta E=10.2$

 **QUV/se** 8  
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: ORANGE

UVB  $\Delta E=17.7$

 **QUV/se** 8  
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: ORANGE

 Orange 8

# Red

Daylight Q  $\Delta E=35.0$



**Q-LAB** Q-SUN Xe3HSC 2  
Xenon Exposure - 200 hours  
DAYLIGHT Q FILTER  
LIGHT 0.68W/m<sup>2</sup> @340nm 5:00 45°C  
LIGHT 0.68W/m<sup>2</sup> with Water Spray 0:20 30°C  
COLOR: RED

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

**Q-LAB** Q-SUN Xe1BC 2  
Xenon Exposure - 200 hours  
EXTENDED UV Q/B FILTER  
LIGHT 80W/m<sup>2</sup> TUV 5:00 35°C  
DARK with Water Spray 0:20 30°C  
COLOR: RED

UVA  $\Delta E=16.8$

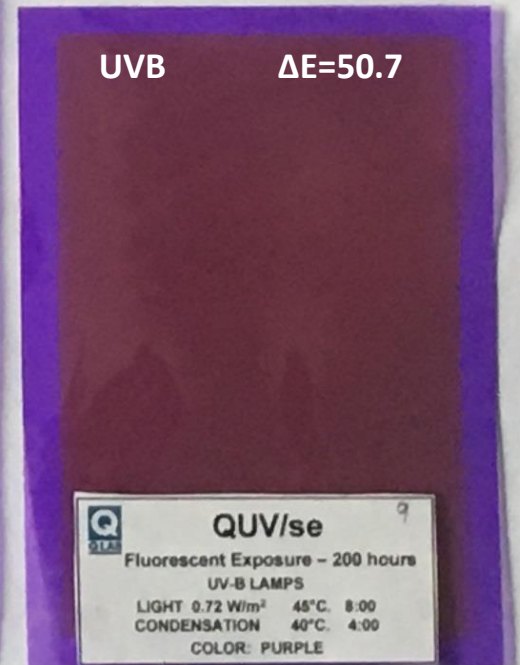
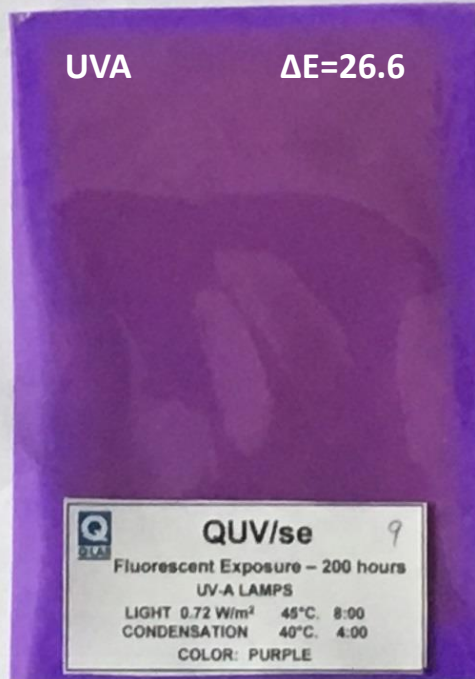
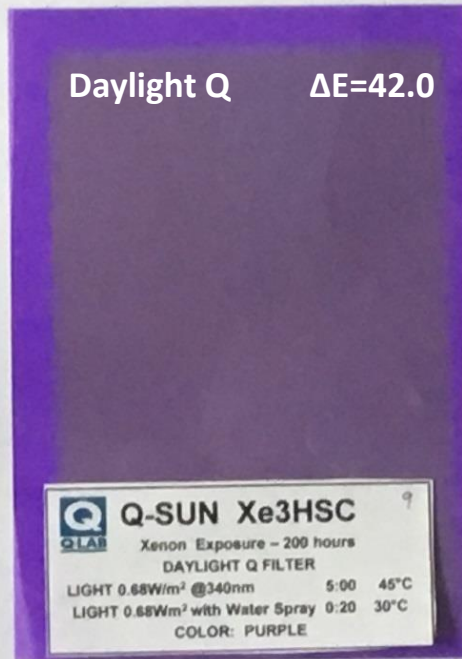
**Q-LAB** QUV/se 2  
Fluorescent Exposure - 200 hours  
UV-A LAMPS  
LIGHT 0.72 W/m<sup>2</sup> 45°C. 8:00  
CONDENSATION 40°C. 4:00  
COLOR: RED

UVB  $\Delta E=14.3$

**Q-LAB** QUV/se 2  
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: RED

**Q-LAB** Red 2

# Purple





# Pink


Daylight Q  $\Delta E=41.3$



 **Q-SUN Xe3HSC** 6  
Xenon Exposure – 200 hours  
DAYLIGHT Q FILTER  
LIGHT 0.68W/m<sup>2</sup> @340nm 5:00 45°C  
LIGHT 0.68W/m<sup>2</sup> with Water Spray 0:20 30°C  
COLOR: PINK

Ext UV-Q/B  $\Delta E=65.3$





 **Q-SUN Xe1BC** 6  
Xenon Exposure – 200 hours  
EXTENDED UV Q/B FILTER  
LIGHT 80W/m<sup>2</sup> TUV 5:00 35°C  
DARK with Water Spray 0:20 30°C  
COLOR: PINK

UVA  $\Delta E=19.7$

UVB  $\Delta E=49.7$



 **QUV/se** 6  
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: PINK

 **QUV/se** 6  
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: PINK

Pink 6



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



# Variety in Color Change Modes

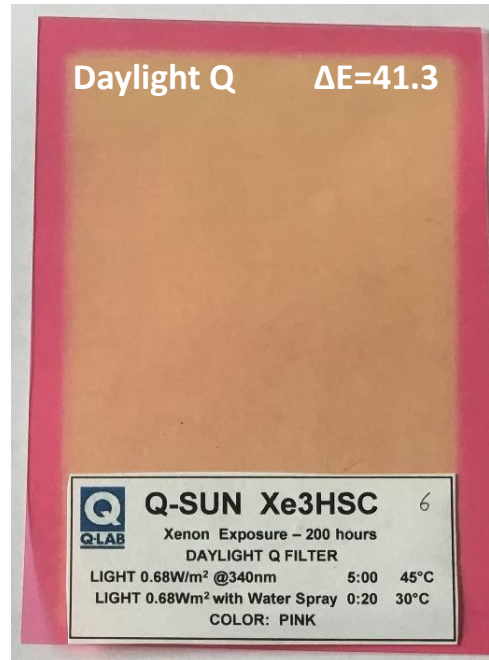
## UVB-313



*UV light*

PVC polymer degradation

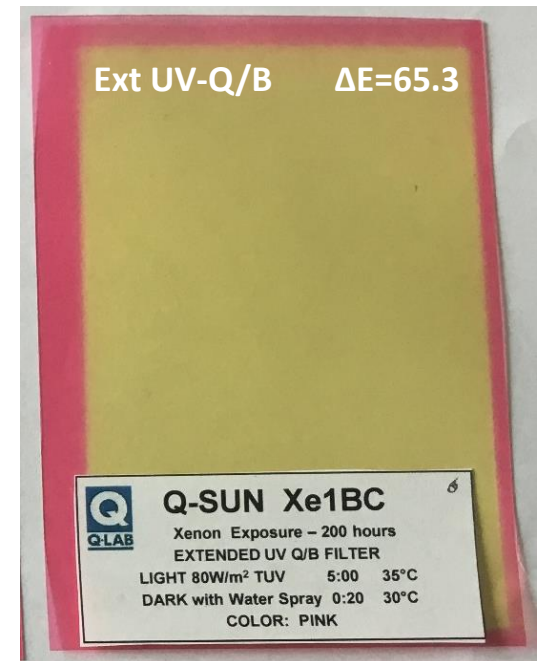
## Xenon Daylight



*Visible light*

Pigment degradation

## Xenon Extended UV

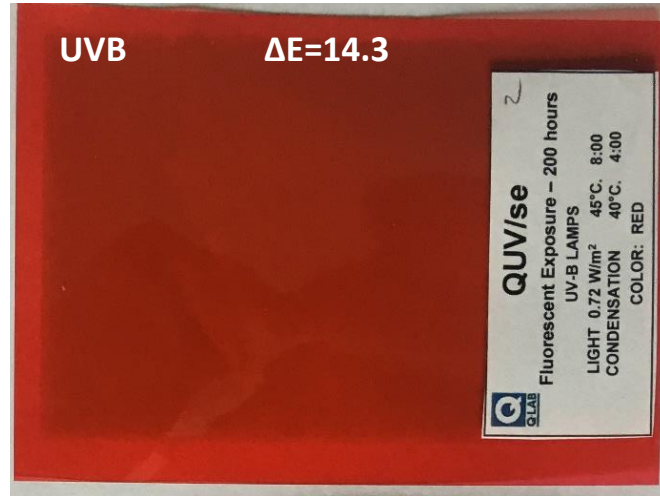


*UV + Visible light*

PVC polymer degradation  
and Pigment degradation

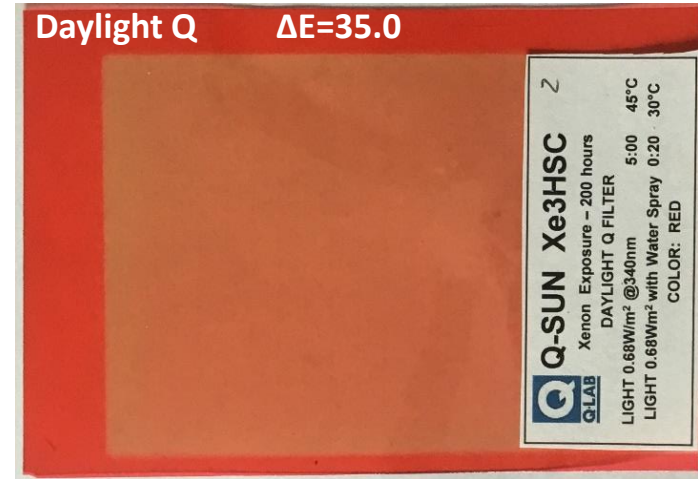
# Color Change and Red Specimens

## UVB-313



- No visible light
- Darkening from PVC polymer breakdown

## Xenon Daylight



- Visible light
- Color fade from loss of 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**

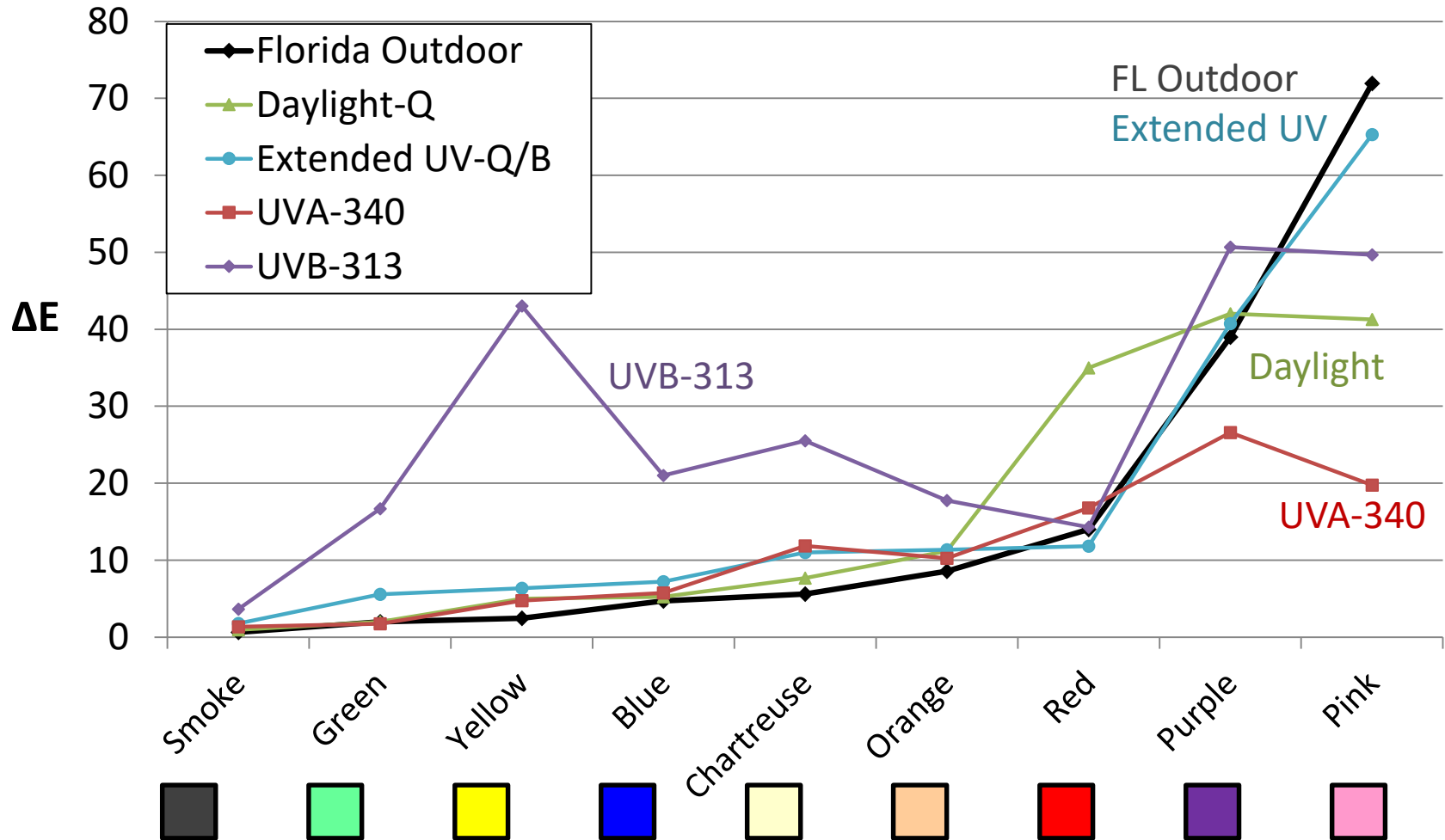
# Correlation: Accelerated vs Outdoor

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*

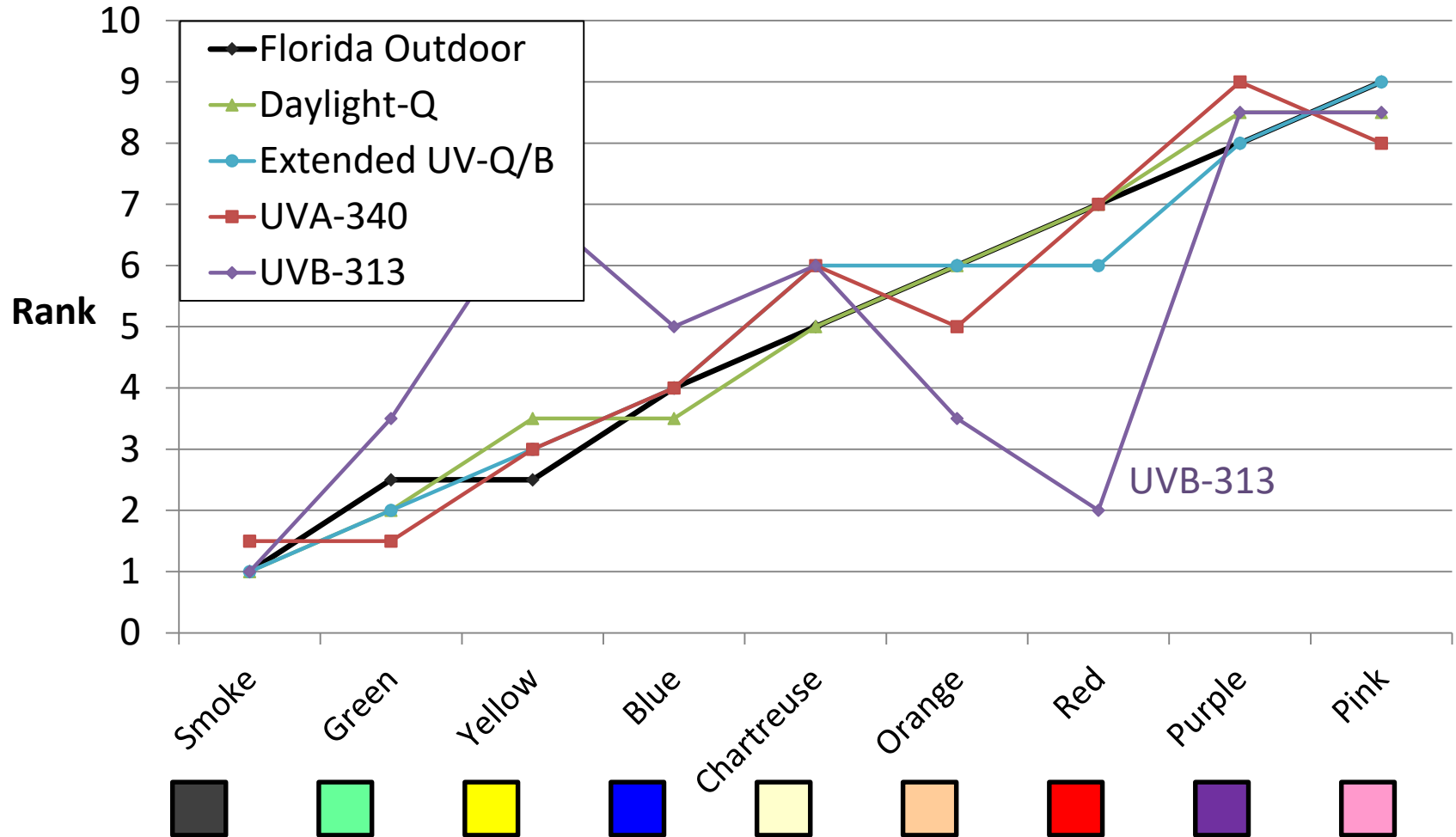
# Correlation: Accelerated vs Outdoor

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



# Correlation: Accelerated vs Outdoor

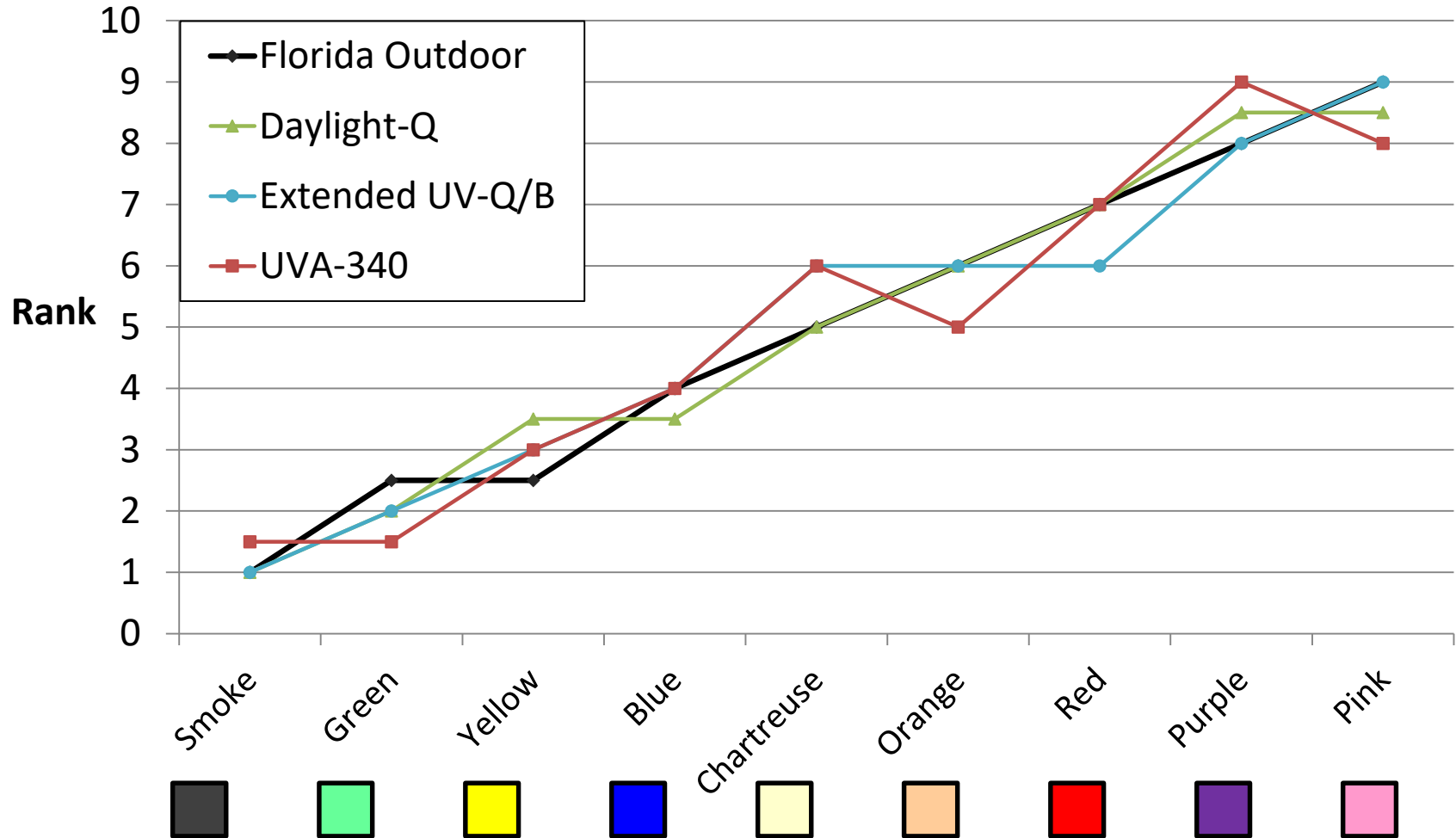
## Rank Order Correlation





# Correlation: Accelerated vs Outdoor

## Rank Order Correlation (without UVB-313)



# Summary

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

# Conclusions

- Correlation for color change can be compared for accelerated tests vs 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 is observed for pigments and base plastics
  - Darkening from plastic yellowing resulting 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, for instance, does not necessarily mean good correlation for physical properties. **Understanding your 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!



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