Accelerated Weathering Testing Using Xenon Arc Lamps

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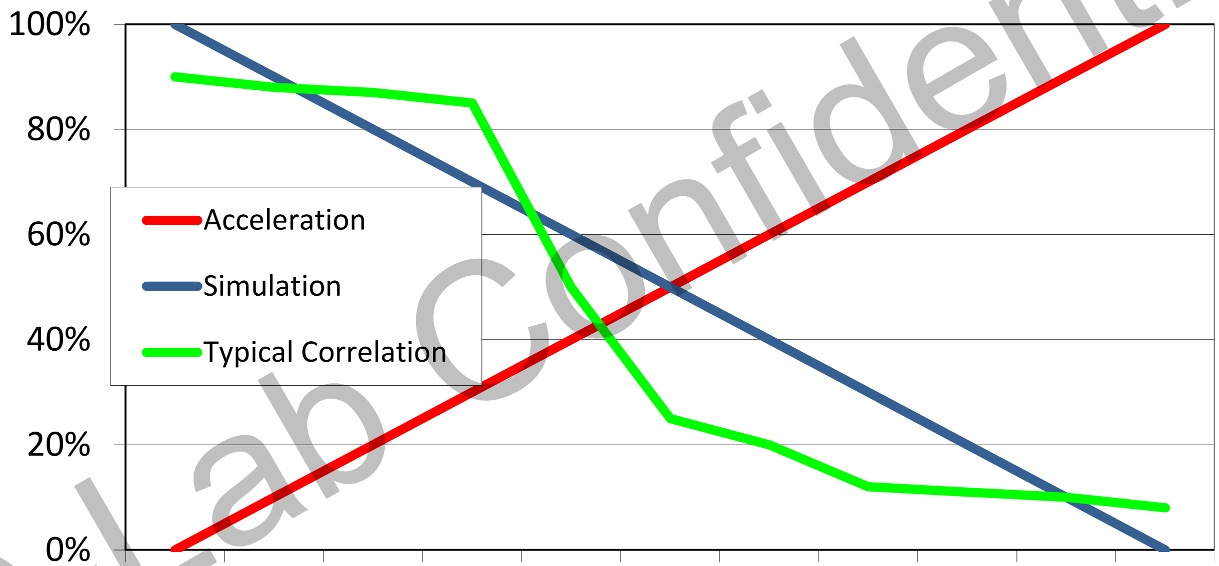
Accelerated Testing

Simulation, Acceleration, and Correlation



Forces of Weathering

Sunlight

Heat

Water

How are these accelerated in laboratory testing?

Xenon Arc
Laboratory Weathering

ASTM G155 and ISO 4892-2

Key Standards That Define Xenon Testing

- ASTM G155 and ISO 4892-2 are performance-based standards.
- ASTM G151 and ISO 4892-1 provide guidance more broadly for exposure of materials to any light source.
- Prior to the 2000's, majority of xenon arc standards were hardware-based, written for one specific instrument.
- ISO 4892-2, released in 1994, was the first performance-based xenon arc standard.
- These international standards are *practices*, and do not define a material's critical property, pass/fail criteria, or exposure duration.

ASTM G155

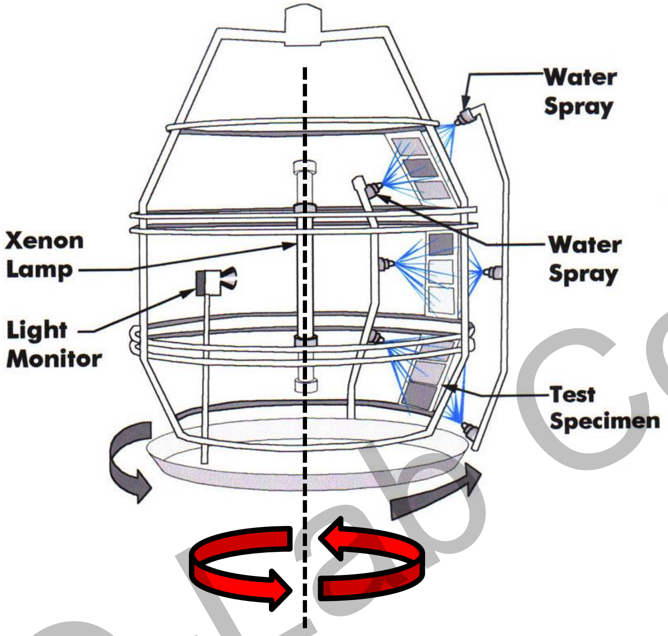
Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials

§ 6 Apparatus

The definitions and criteria for a xenon arc chamber to satisfy the standard practice is well defined in the *Apparatus* section. This section includes everything that is necessary to best simulate weathering conditions in the chamber:

- Light source
- Definition of different optical filter types
- Panel temperature sensor
- Chamber temperature sensor
- Relative humidity sensor
- Calibration of all on-board sensors
- Water spray
- Water quality
- Moisture and relative humidity
- Specimen holders

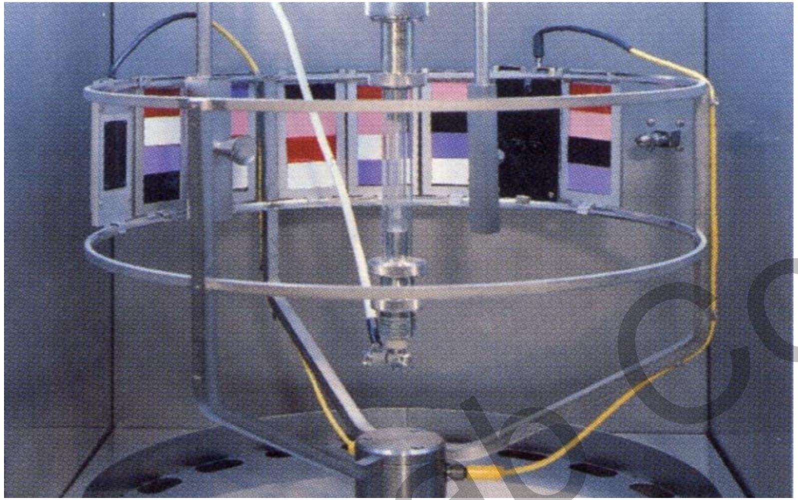
Xenon Arc Test Chamber



Rotating Rack Xenon-Arc Tester

Flat Array Xenon-Arc Tester

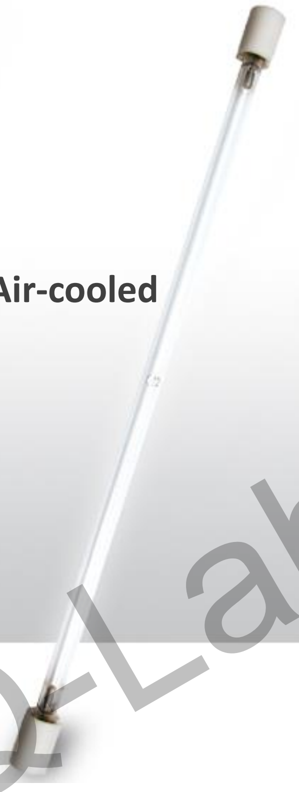
Specimen Mounting



Rotating Rack Xenon-Arc Tester

Flat Array Xenon-Arc Tester

Xenon Arc Lamps



Air-cooled

Water-cooled

Water-cooled
Assembly

Xenon Arc Lamp Cooling

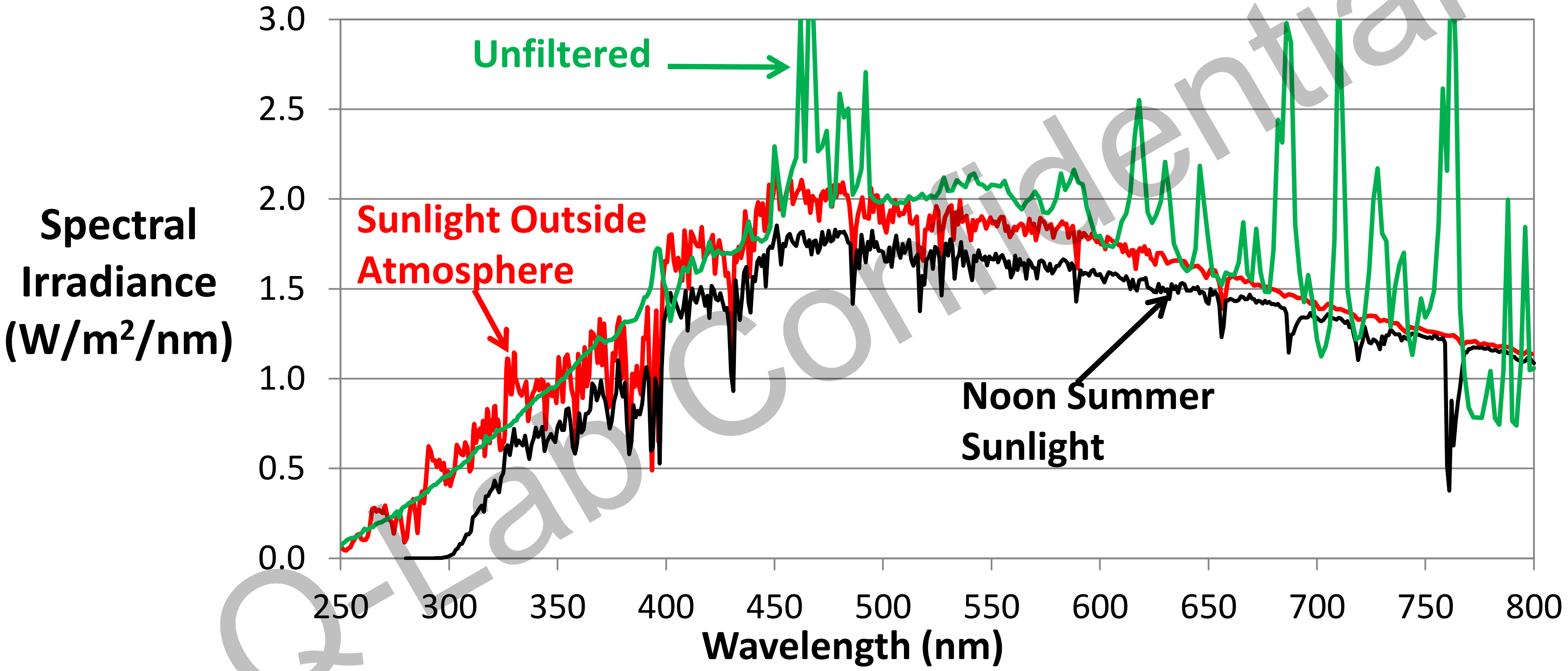
- Xenon Arc lamps operate at high power and high intensity
- Lamps generate considerable heat and must be cooled
  - Water-cooling
  - Air-cooling
  - *Lamp cooling method does not affect testing*

Xenon Arc Spectra

Major Influencing Factors

- Optical filters
- Irradiance level (intensity)
- Wavelength at which irradiance is controlled (“control point”)
- Lamp aging

Unfiltered Xenon Arc vs. Sunlight

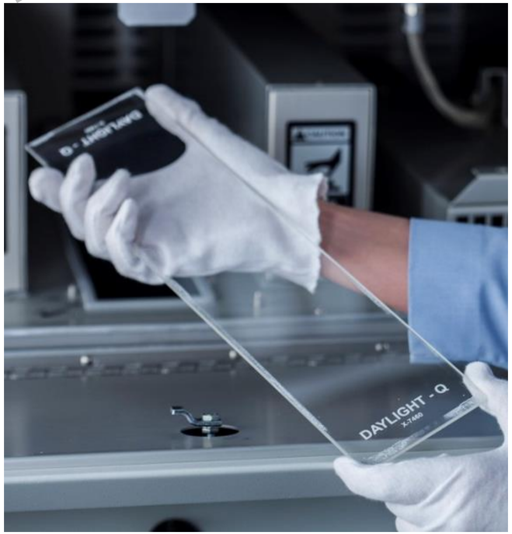


Overview of Filters

- Daylight
- Window
- Extended UV

Rotating drum "lantern"

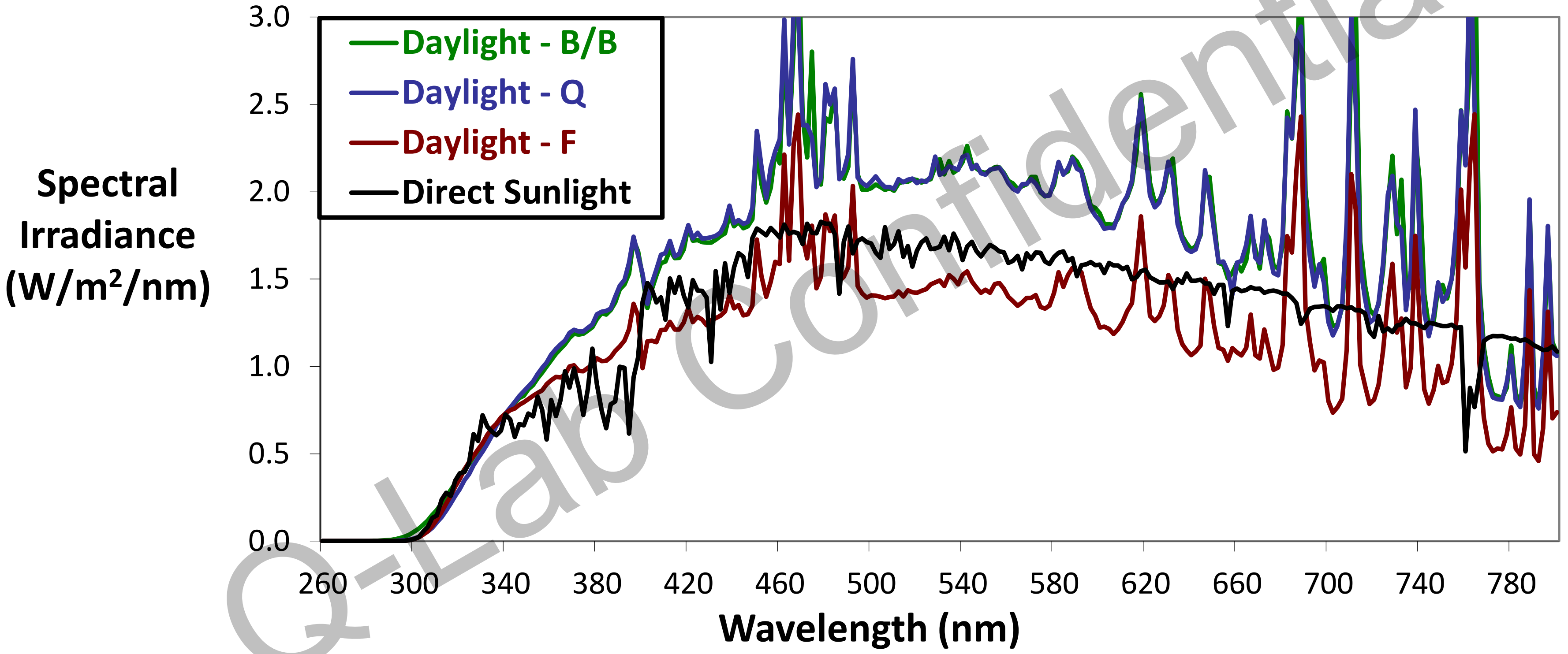
Flat array filter



**Other specialized filters used occasionally*

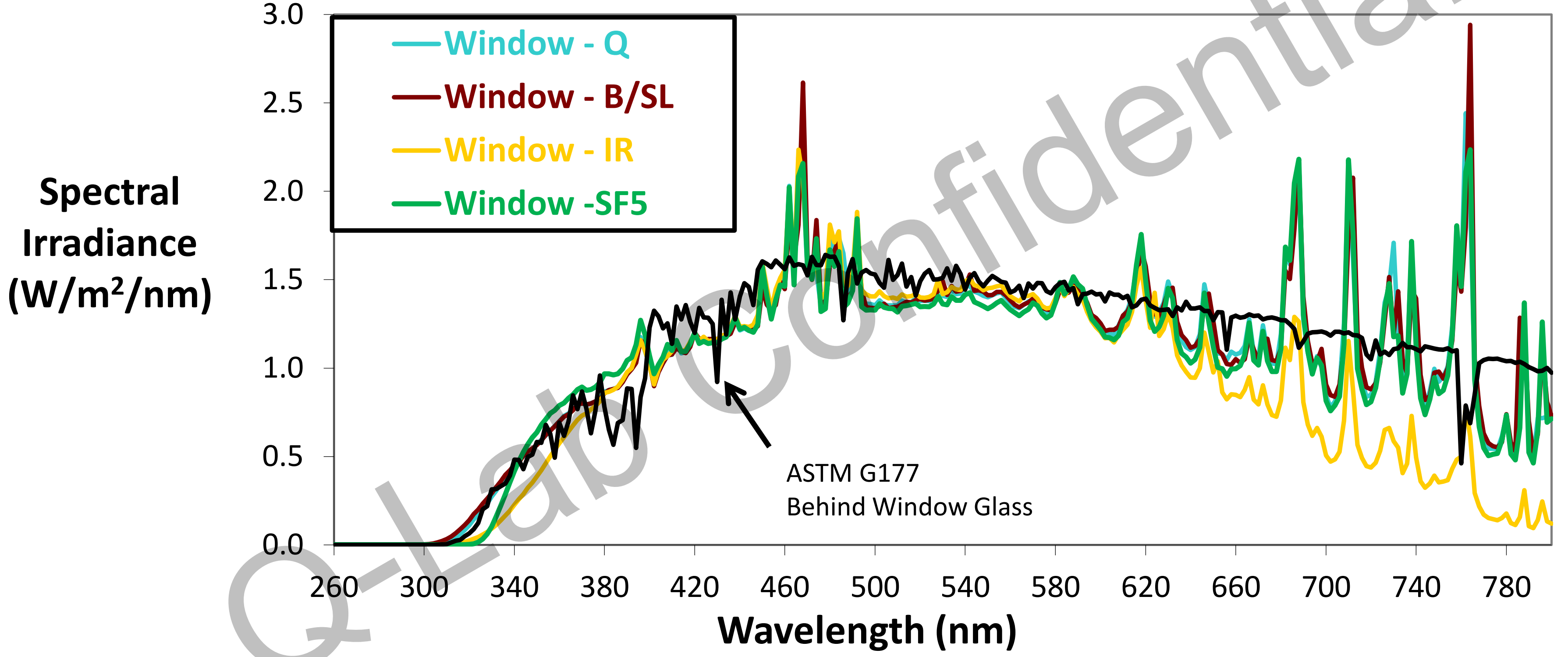
Xenon Arc with Daylight Filters

UV and Visible



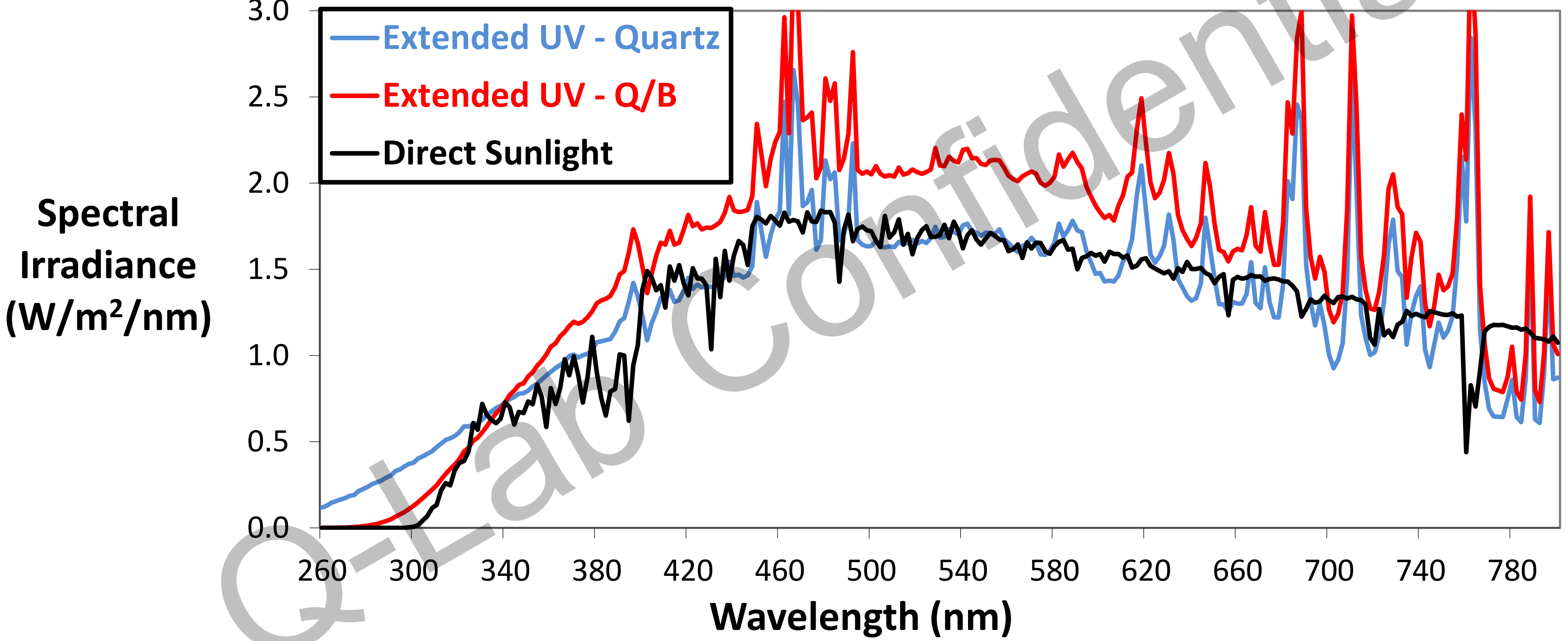
Xenon Arc with Window Filters

UV and Visible



Xenon Arc with Extended UV Filters

UV and Visible Light



Optical Filter Aging

Water-Cooled vs Air-Cooled

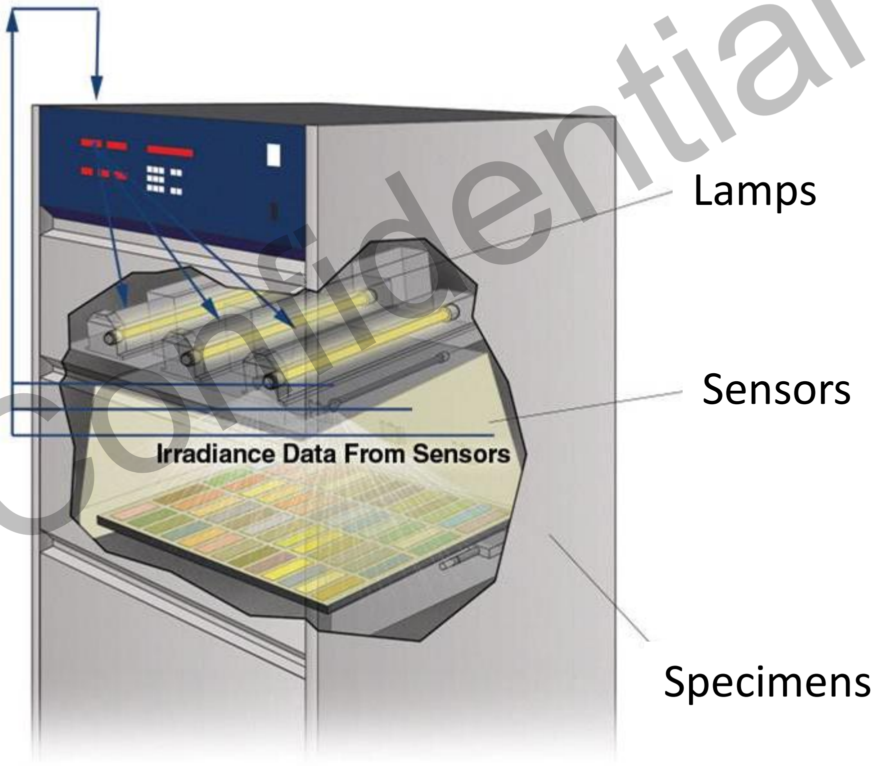
- Filters for water-cooled lamp systems need to be replaced every 400-2000 hours
  - Contaminants, even in ultra-pure de-ionized water, reduce filter transmittance over time
- Almost all filters for air-cooled lamp systems do not age or need to be replaced

Q-SUN SOLAR EYE™ Irradiance Control

Feedback Loop Control

- Xenon-arc lamp
- Light sensor
- Control module

Wavelength at which irradiance is controlled is referred to as **Control Point**



Irradiance Control Point Options

Narrow Band

- 340 nm
- 420 nm

Wide Band

- Total UV TUV (300-400 nm)
- UV+VIS (300-800 nm)
  - Shorter wavelengths cause more photodegradation
  - Fails to account for xenon lamp aging

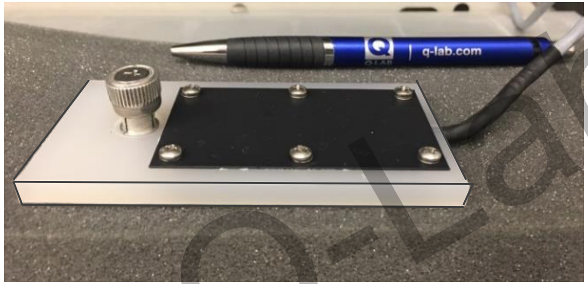
Why Is Choice of Control Point Important?

- Xenon Arc lamps age with use
- Spectral shift limits useful lamp life
- Controlling irradiance in **wavelength region of interest** maximizes repeatability and reproducibility

Black Panel Temperature Control

- Most common in test standards
- Approximates maximum specimen surface temperature
- Can be used in combination with chamber air temp sensor and control

Black Panel Temperature Sensors

Panel	Construction	ASTM Designation	ISO Designation
	Black painted stainless steel	Uninsulated Black Panel	Black Panel
	Black painted stainless steel mounted on 0.6 cm white PVDF	Insulated Black Panel	Black Standard

** White Panel versions of the above are available but far less commonly used*

Chamber Air Temperature Control

- Required by certain test methods
- Necessary for control of relative humidity (RH)
- Sensor must be shielded from light
- BP temp always hotter than chamber air temp from absorbing radiant heat
- An air conditioner or some type of cooling device can be used to reduce chamber temperatures.

Relative Humidity Control

- Required by many test methods
  - Textiles
  - Automotive (SAE)
- Many xenon testers can generate and control relative humidity
  - Boiler-type system
  - Nebulizer system
- For many durable materials, RH makes very little difference compared to spray and condensation

Water Spray

Front spray

- Primary method of water delivery
- Calibration technique for front spray recently developed (ASTM D7869)

Back spray

- Result of a failed experiment intended to generate condensation; persists in some standards

Dual spray

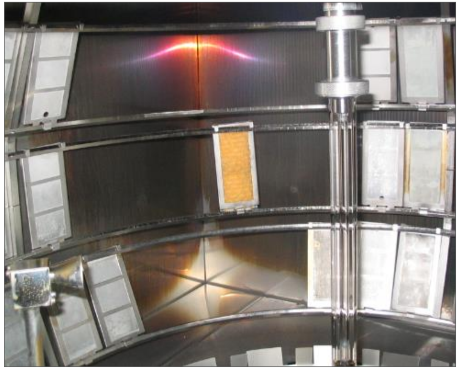
- For delivering a 2nd solution, e.g. acid rain, soap

Immersion (Ponding)

- Alternative to front spray called out in some standards

Quantifying Water Spray

- Xenon testers are, in general, water-deficient
- Each chamber model can spray vastly different amounts of water, potentially leading to poor reproducibility for identical materials.
- Most standards, including ASTM G155 and ISO 4892-2, give no guidance in the amount of water to be sprayed.
- Using calibrated sponges, ASTM D7869 water calibration designed to guarantee sufficient water delivery to specimens
- ISO 23741 uses a similar approach, but measures the volume in a collection vessel.



Xenon Arc Summary

- Best simulation of full-spectrum sunlight
- Lamps experience aging (fulcrum effect)
- Temperature effects
- Water spray and RH control
- Additional cost, maintenance, and complexity compared to fluorescent UV testers

How do the exposure of materials relate across different testers?

To show that performance-based standards are warranted, and different types of xenon-arc devices can produce comparable results, we will review three different cases which are summarized below:

- What do international standards say on repeatability and reproducibility?
- How do standard reference materials perform in different xenon arc devices?
- How do products perform in different xenon arc devices?

What do international standards say on repeatability and reproducibility?

ASTM G151

ASTM G151: Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources

§ 4.2 Use of Accelerated Tests with Laboratory Light Sources

§ 4.2.1 Results from accelerated exposure tests conducted according to this standard are best used to compare the relative performance of materials……… Comparison between materials are best made when they are tested at the same time in the same exposure device.

§ 4.2.2 Reproducibility of test results between laboratories have been shown to be good when the stability of materials is evaluated in terms of performance ranking compared to other materials or to a control.

How was this established?

ASTM G03.03 Round Robin

Weathering Variability Study

- ASTM G03.03 is ASTM's subcommittee on *Simulated and Controlled Exposure Tests*
- A task group was formed (1994) to determine the variability in accelerated weathering testing.
- From historical testing:
  - **Repeatability** of test results within one laboratory on the same device was **very good**.
  - **Reproducibility** across different labs, with identical models, was **very poor**.
- A round-robin test was conducted, exposing PVC specimens to three common accelerated weathering devices - carbon arc, xenon arc, and fluorescent UV.

R. Fischer and W. Ketola, "The Impact of Recent Research on the Development and Modification of ASTM Weathering Standards." Ed. R. Herling STP1294-EB Durability Testing of Nonmetallic Materials. West Conshohocken, PA: ASTM International, 1996. 7-23

ASTM G03.03 Round Robin

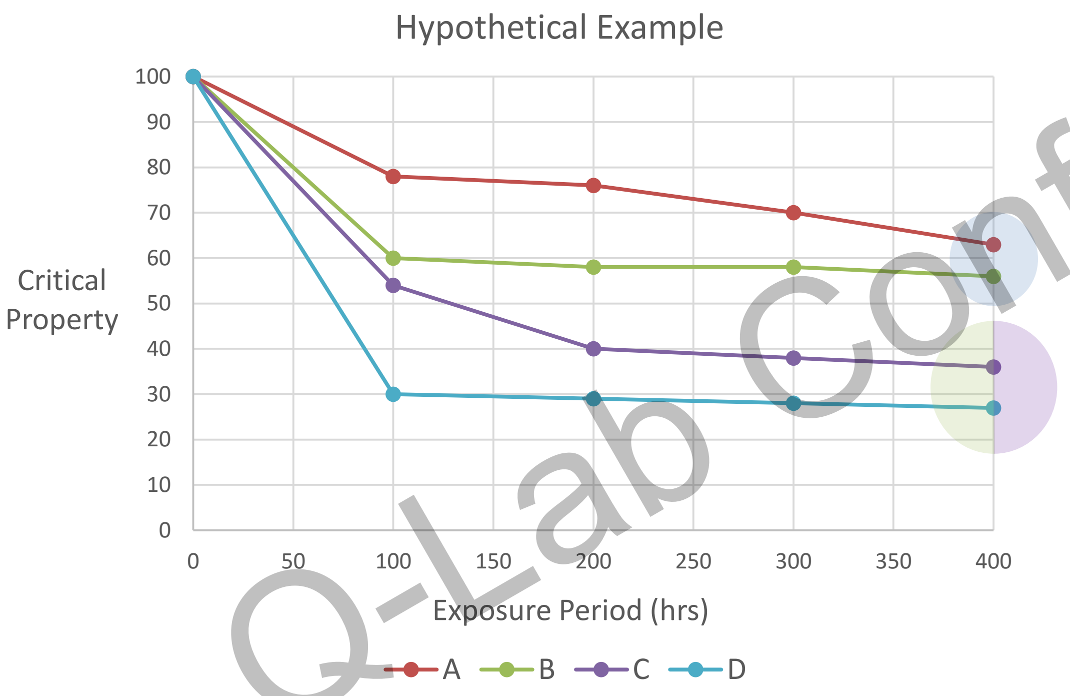
Results

- To be considered a different level of performance, the difference in gloss units needs to exceed a certain threshold value.
- Put more simply – when comparing two specimens, as long as the difference in gloss units is less than what is shown in the table, the specimens could still be considered similar performers.

	Average Repeatability	Average Reproducibility
Carbon arc	11.1	21.6
Xenon arc	7.0	44.0
Fluorescent UV	11.3	29.3

ASTM G03.03 Round Robin

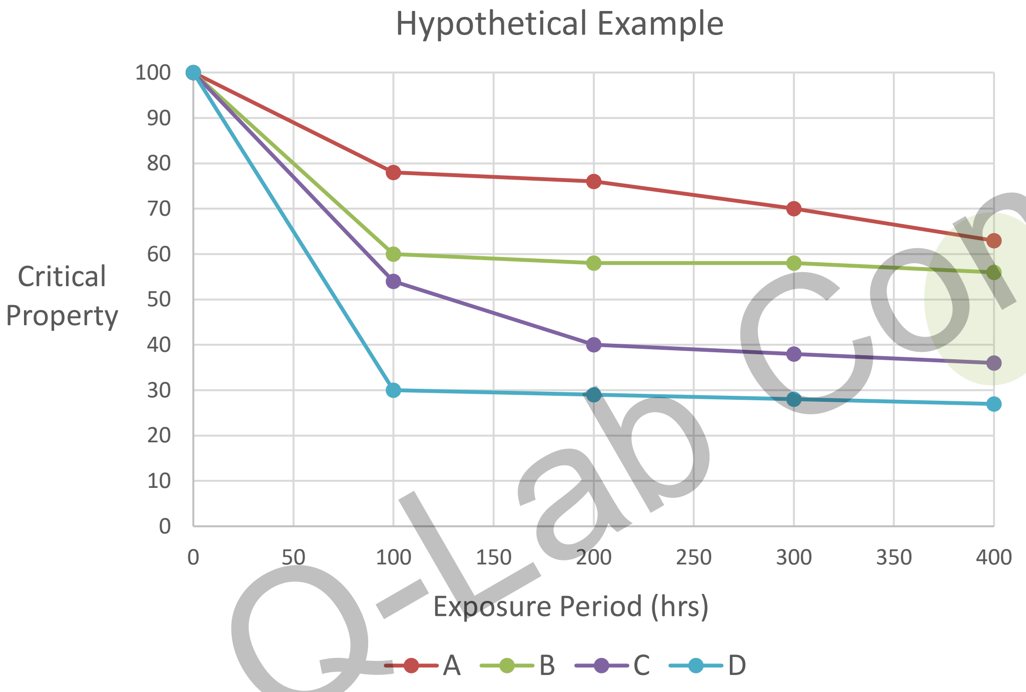
Explaining Results



	Average Repeatability	Similar Performance
Carbon arc	11.1	C & D can be grouped as similar performers
Xenon arc	7.0	A & B can be grouped as similar performers
Fluorescent UV	11.3	C & D can be grouped as similar performers

ASTM G03.03 Round Robin

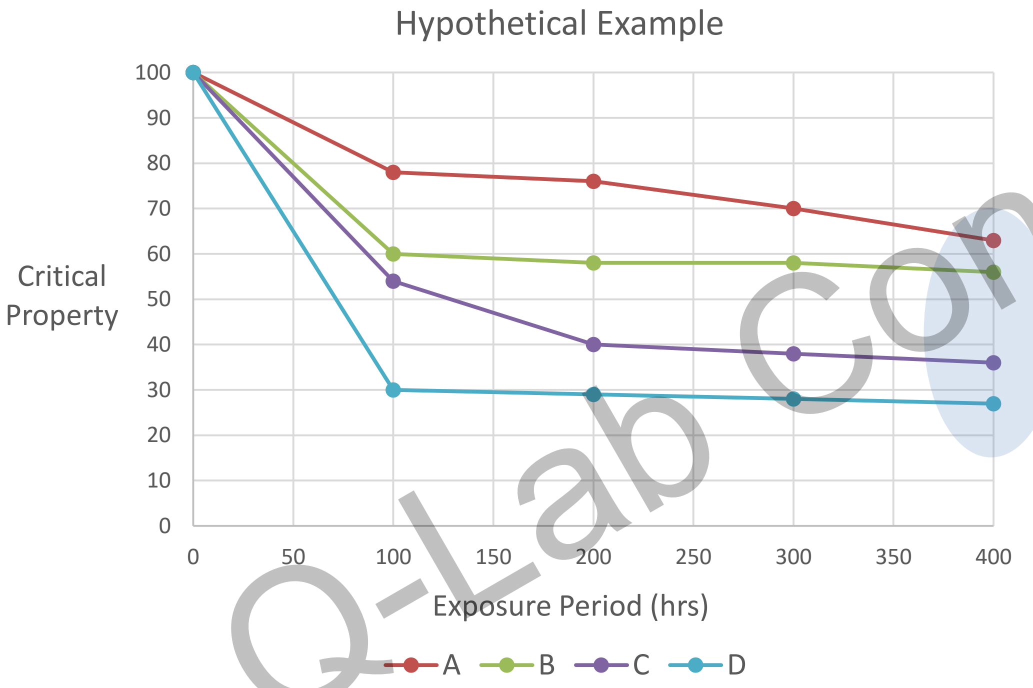
Explaining Results



	Average Reproducibility	Similar Performance
Carbon arc	21.6	A, B, C can be grouped as similar performers
Xenon arc	44.0	A, B, C, & D can be grouped as similar performers
Fluorescent UV	29.3	B, C, & D can be grouped as similar performers

ASTM G03.03 Round Robin

Explaining Results



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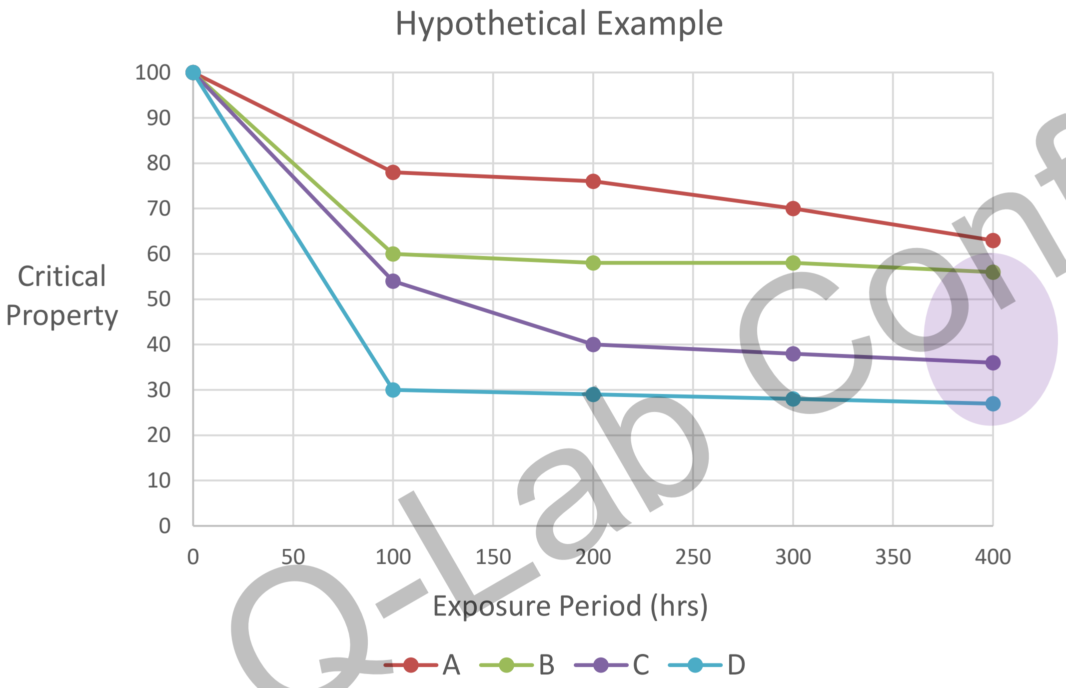
ASTM G03.03 Round Robin

Explaining Results



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ASTM G03.03 Round Robin

Conclusions

- The case is an example of the numerous variables to consider in testing:
  - Internal lab procedures
  - Lab operator
  - Device maintenance and up-keep
  - Optical filter aging
  - Lamp aging
  - Differences in optical filters SPD’s
  - Irradiance calibration
  - Temperature calibration
  - Material variability
  - Material properly being evaluated
- The issues with poor repeatability is resolved through performance ranking analysis.
- Using materials of varying degrees of performance, coupled with standard materials (or known performers), improves the laboratory to laboratory correlation greatly.
- Additionally, using performance-based standards, rather than hardware-specific, and including requirements for optical filter types, irradiance control, accredited calibrations, etc.; improves the reproducibility as well.

How do standard reference materials perform in different xenon arc devices?

ISO 105-B02 Ring Trial

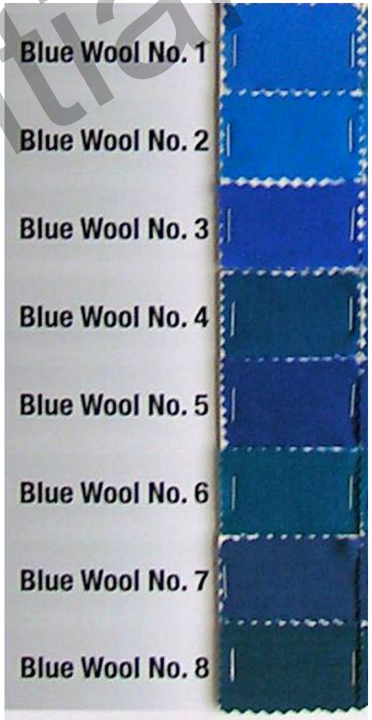
Chamber Performance Study

- ISO 105-B02 Ring trial (2004); Organized by Society of Dyers and Colorists (SDC)
- The three main purposes of the ring trial
  - Whether flat bed testing machines gave comparable results to carousel type machines
  - Irradiance control machines gave different results to non-irradiance controlled machines
  - Specimen positioning gave rise to any variation in results
- The samples were common standard reference materials, that have a known behavior when exposed to xenon arc light
- 19 different samples, 8 laboratories, 11 machines – over 2500 samples
- Results were analyzed by independent team of textile technologists who were experts in colorfastness assessment.

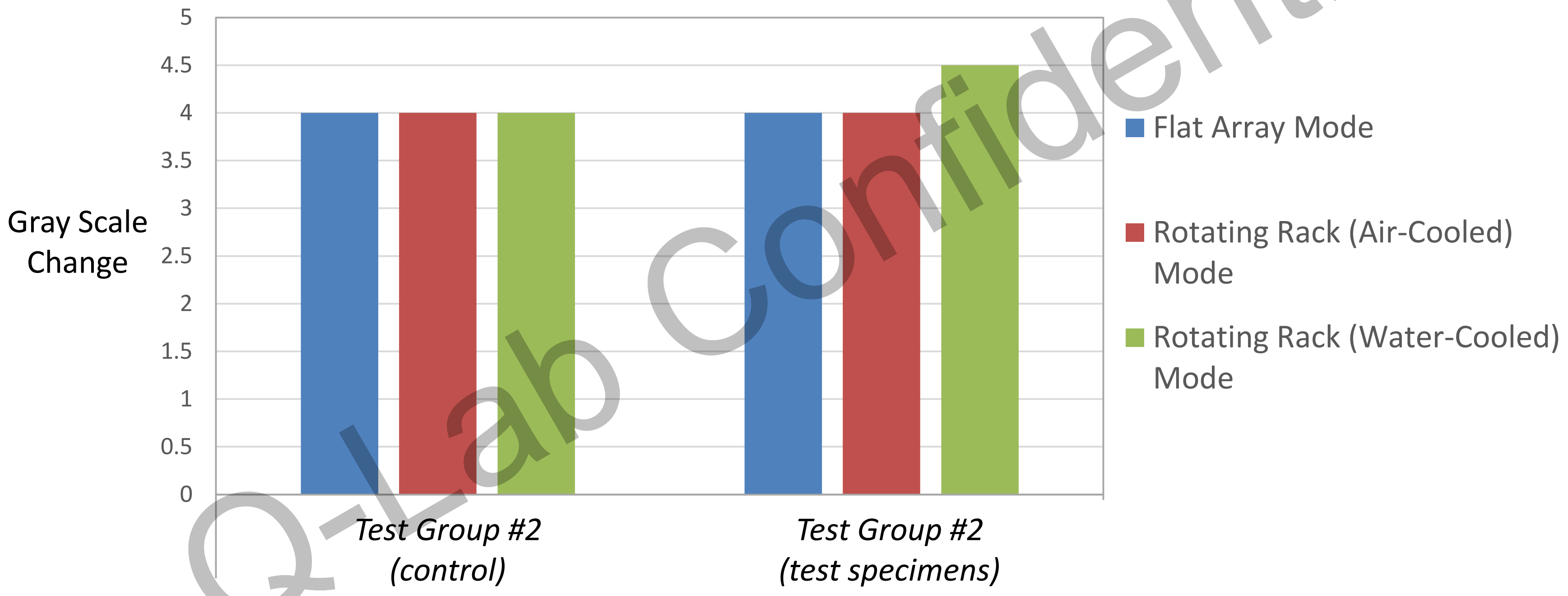
Report on Inter-laboratory Ring Trial ISO 105:B02:1994 Colour Fastness to Artificial Light:Xenon Arc (presented at ISO TC38 SC1 21 June 2007)

Gray Scale Evaluation

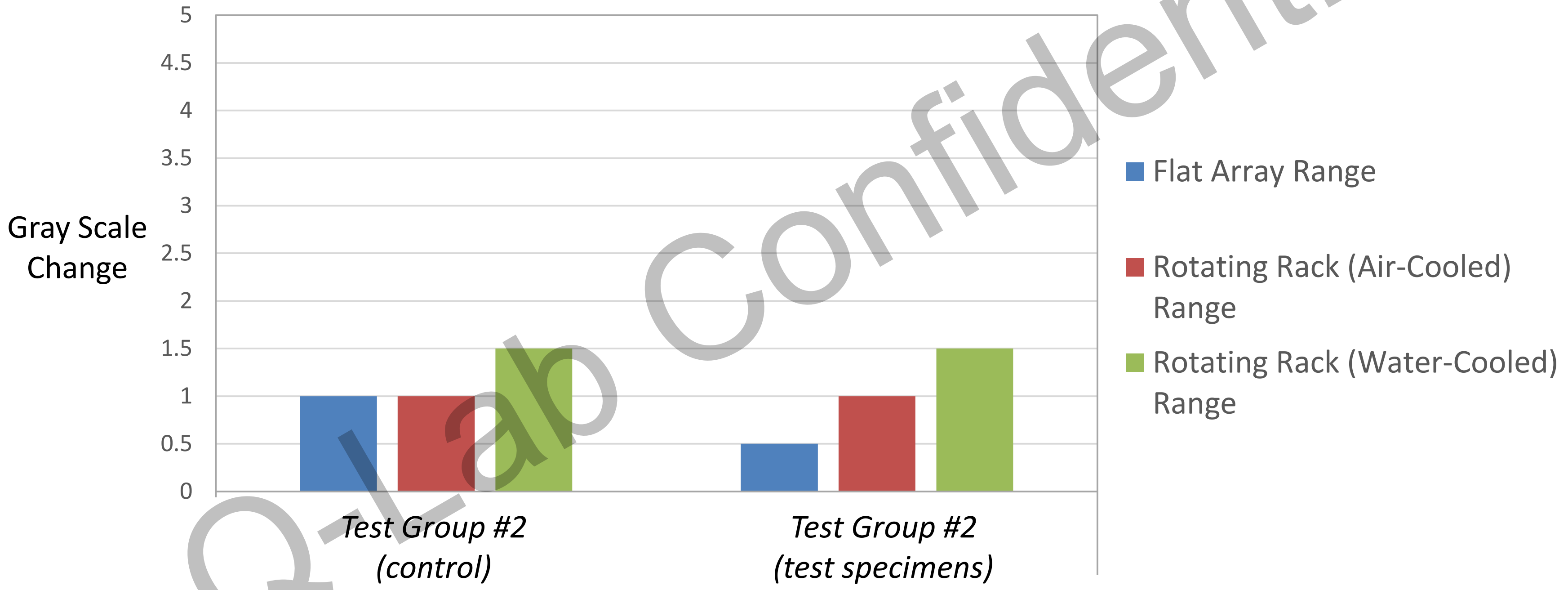
- 3x groups of specimens with various levels of durability –
  - Poor Lightfastness
  - Medium Lightfastness
  - High Lightfastness
- Each group was to age a control to grayscale 3 and 4. Visual assessment of controls and exposure period were nearly identical.
- Intra-laboratory uncertainty for color change is generally accepted as ± 0.5.
- The ring trial carried showed that the uncertainty is much closer to ± 1.0.



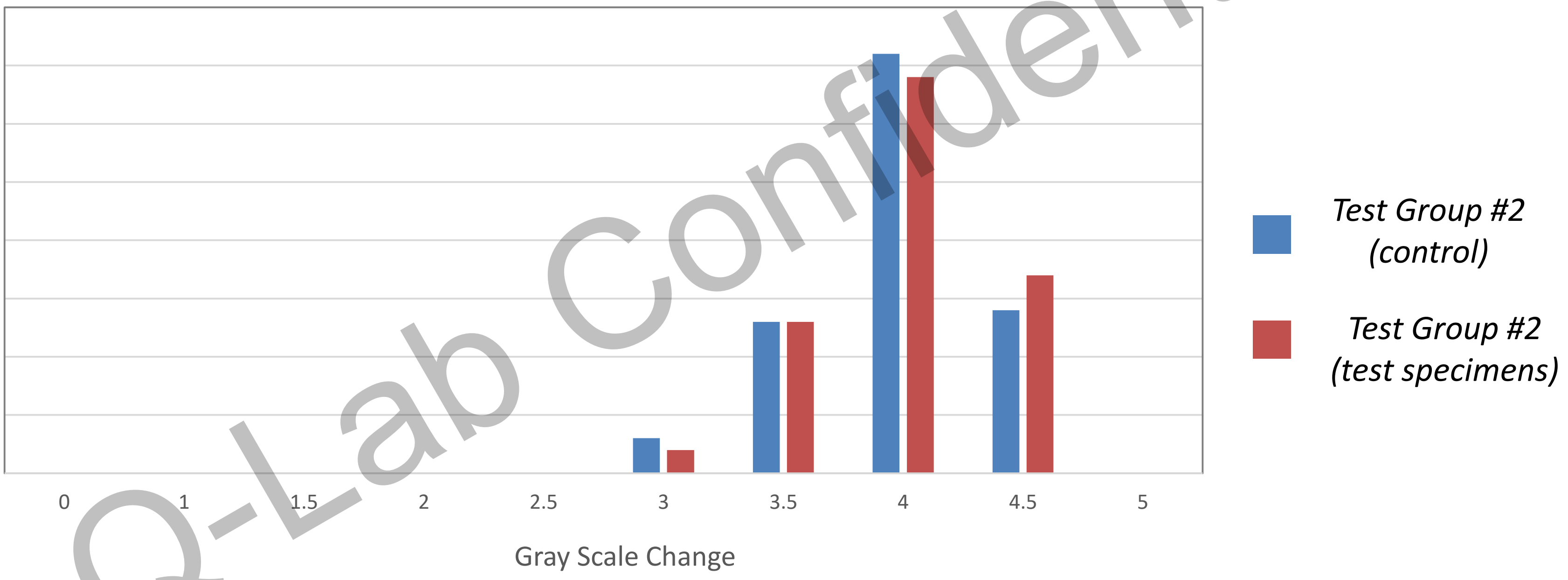
Gray Scale Change Average Mode for Blue Wool No. 4



Gray Scale Change Range for Blue Wool No. 4



Gray Scale Change Blue Wool No. 4 Distribution



ISO 105 B02 Ring Trial

Conclusions

- Flat Array testers produce comparable results to rotating rack
- Results for the same sample show the conventionally-accepted uncertainty of measurement, +/- 0.5 grades, is accurate.
- More outliers were seen in water cooled xenon arc devices, though this could potentially be explained with the fact that a handful of the apparatus did not include relative humidity control.
- A new work item was introduced to revise ISO 105 B02 to a performance-based standard, recognizing different design architectures of xenon arc devices can produce similar results.

How do products perform in different xenon arc devices?

Lightfastness of Colored Pencils

- ASTM D01.57, a subcommittee on ***Artist Paints and Related Materials***, formed a task group to develop an accelerated test standard that could distinguish the lightfastness of colored pencils.
- The goal was to determine correlation between outdoor and accelerated testing, but also investigate the correlation between different xenon arc models and devices.
- The sample set ranged in performance from very durable to poor.
- Blue pigmented paper supplied by Society of Dyers and Colorists, was also exposed, which intended to serve as a reference material, similar to blue wool.

P. Brennan and E. Everett, "Lightfastness of Artists' Pencils: Natural & Accelerated Exposure Results." eds. W. Ketola and J. Evans STP1385-EB Durability 2000: Accelerated and Outdoor Weathering Testing. West Conshohocken, PA: ASTM International, 2000. 133-147

3x Different Xenon Arc Devices

- 3x different xenon-arc devices were used, all conforming with ASTM G151 and ASTM 155.
- Each tester varied slightly in optical filter spectral power distribution, irradiance control points, and relative humidity control.

Tester Model	Design	Irradiance Control Point	Relative Humidity Control
Atlas Suntest CPS+	Air cooled, flat array, table top	490 W/m2 at 300 – 800 nm	No
Q-Lab Q-SUN Xe-1	Air cooled, flat array, table top	0.35 W/m2 at 340 nm	No
Atlas Ci35	Water cooled, rotating drum, large scale	0.35 W/m2 at 340 nm	Yes

Lightfastness of Colored Pencils

- Correlation between testers showed better for some colors than others.
- There seemed to be no reason why any one tester might create a larger ΔE than another tester.
- Outliers were identified as replicates where the ΔE was greater than 4 in the apparatus.

ΔE Color Change

Specimens	Q-Lab Q-SUN Xe-1	Atlas Suntest CPS+	Atlas Ci35
Y Red-1	5.7	1.4	1.2
Y Red-2	5.7	3.8	2.3
Z Red-1	26.7	36.5	24.4
Z Red-2	28.5	35.4	24.2
X Y Green-1	6.1	7.2	9.2
X Y Green-2	7.0	11.5	13.7
X Blue-1	10.9	9.2	11.5
X Blue-2	11.2	9.1	11.1
X Black-1	2.7	2.0	3.2
X Black-2	2.1	2.2	3.2

Lightfastness of Blue Pigment Paper

- The Blue Pigment Paper showed slightly better agreement across each tester.
- The reference material did not produce any outliers.
- For SDC 4-8, material that can be defined as ‘high lightfastness’, the Ci35 appears to produce greater color change than the tabletop devices. This is likely because of the Ci35’s relative humidity control, not available in the other devices.

ΔE Color Change

Specimens	Q-Lab Q-SUN Xe-1	Atlas Suntest CPS+	Atlas Ci35
SDC-4	9.6	7.8	11.0
SDC-4	9.3	7.7	9.9
SDC-5	10.4	8.5	12.4
SDC-5	9.5	8.8	12.8
SDC-6	7.2	5.5	10.3
SDC-6	7.2	4.6	10.2
SDC-7	6.1	4.9	9.4
SDC-7	5.9	4.8	9.1
SDC-8	3.6	2.2	5.9
SDC-8	3.3	2.2	6.3

Rank Order Correlation

Using Rank Order correlation, we see excellent agreement between each accelerated device.

Colored Pencil Accelerated Test Rank Order Correlation

Exposure	Atlas Suntest CPS+	Q-Lab Q-SUN Xe-1	Atlas Ci35
Atlas Suntest CPS+	1.00		
Q-SUN Xe-1	0.95	1.00	
Atlas Ci35	0.94	0.92	1.00

Blue Paper Accelerated Test Rank Order Correlation

Exposure	Atlas Suntest CPS+	Q-Lab Q-SUN Xe-1	Atlas Ci35
Atlas Suntest CPS+	1.00		
Q-SUN Xe-1	0.99	1.00	
Atlas Ci35	0.97	0.96	1.00

Colored Pencils Lightfastness

Conclusions

- In analyzing the actual ΔE value for the colored pencils, there appears to be no pattern in which tester might create greater degradation.
- The Ci35's relative humidity control likely led to greater color change for the blue pigmented paper reference material.
- Overall, the differences in ΔE from each tester was in good agreement, though small differences, with seemingly no pattern, do exist.
- Using rank order, as suggested by G151, we see excellent agreement between different testers.

Conclusion

- Performance-based standards and practices help reduce variability in testers by defining spectral power distributions, irradiance uniformity, temperature requirements, etc.
- All types of xenon arc devices are used in the qualification and determining of standard reference materials – polystyrene and blue wool.
- Use rank order correlation when comparing two sets of data.
- The use of standard reference materials, control materials, replicates, and exposing materials with various levels of durability, are useful in determining relation of tests and in establishing the repeatability and reproducibility.

Questions?

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