Modern Automotive Weathering Testing: ASTM D7869

Standard Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings

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Q-Lab’s Technical Applications Team

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Q-Lab's Automotive Standards Webinar Series

- Today is the fourth of our four-part webinar series on automotive testing standards.
- Our upcoming and complete archive of past webinars, available on demand, are hosted at: q-lab.com/webinars

Date	Topic
23 Apr	CATCH
30 Apr	SAE J2334
21 May	SAE J2412 / J2527
28 May	ASTM D7869

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Presentation materials, Q&A

- You’ll receive a follow-up email from info@email.q-lab.com with links to a survey, registration for future webinars, and to download the slides
- Use the Q&A feature in Zoom to ask us questions today! We’ll stay on after the presentation is completed to answer all questions

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Thank you for attending our webinar!

We hope you found our webinar on **ASTM D7869, *Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings*** to be helpful and insightful. You can download today's presentation at any time - a link to the recording is included on the title slide. Subtitles can be accessed through YouTube for the video recording.

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ASTM D7869 Outline

- Xenon arc weathering testing standards and history
- Collecting outdoor weather data
- Developing the ASTM D7869 test cycle
- Performing the test
- Validating ASTM D7869 results

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Xenon arc weathering testing

Introduction to weathering
Types of laboratory tests
History of modern tests
Development of ASTM D7869

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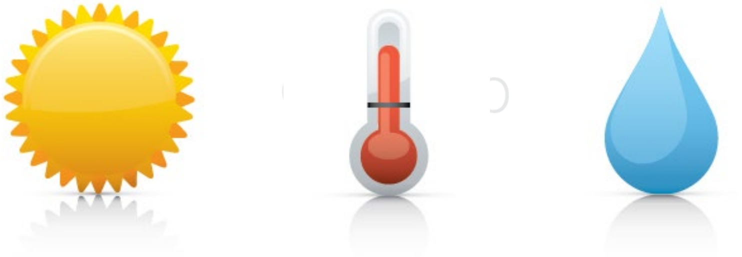
What is Weathering?



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.

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Why Do Weathering Testing?

High gloss and color integrity

OR

Fading, cracking, peeling

Weathering testing can mean the difference between happy customers and … the customer on the right

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Qualification / Correlative Testing

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification
Correlative	Rank-ordered data	• Open-ended • Medium	Natural exposure (Benchmark site)
Predictive	Service life Acceleration factor	• Open-ended • Long	Natural exposure (Service environment)

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Historical Xenon Test Standards

- Carbon Arc and Xenon arc weathering testing have been performed for over 100 years
- Xenon testers reproduce full-spectrum sunlight
- Hardware-based "102/18" light / light+spray standards were the first widely-used weathering standard tests
  - Almost 100 years old but still in use
  - Most common examples are ISO 4892-2 and ASTM G155
  - *Not realistic!*

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Accelerated Weathering Tests

Commonly Used on Automotive Parts

International standards

- ASTM G154/G155
- ISO 4892-2, -3
- SAE J2412
- SAE J2527
- ASTM D7869

Automaker standards

- Renault D27-1911
- VW PV 1303, PV 3929
- Daimler DBL 5555
- Fiat 50451
- Ford BO 116
- Toyota TSL 3600G

Most are for QC/Qualification purposes

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The Industry Standard: SAE J2527

- SAE J2527 introduced in 1980's
  - Authors researched light, water, heat
  - Test replicated gloss loss seen in Florida
- Standard was well-researched but did not match real-world weathering factors
  - Light spectrum
  - Water delivery
- As a result, test does not always predict Florida outdoor field failures
  - Chemical changes
  - Physical changes
- *Check out our webinar about this test from last week!*

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Why Develop a New Standard?

- SAE J2527 was developed to reproduce common failures of coatings in that era, primarily color fade and gloss loss.

- Over years, coatings became very resistant to color fade and gloss loss, and SAE J2527 doesn't reproduce more common failures in modern coatings, primarily cracking and delamination.

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ASTM D7869: Modern Weathering Testing

INTERNATIONAL

Designation: D7869 – 17

Standard Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings[1]

This standard is issued under the fixed designation D7869; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

- Initial release in 2013
- Minor modifications in 2017
- Reapproved in 2025; 2017 version remains current

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Development Process

- Outdoor weather data collected to understand real-world weather conditions: light, heat, and water
- Outdoor weathering test dataset collected to provide basis for correlation
- Accelerated test cycle developed to match those real-world conditions and degradation mechanisms
- Variety of materials and failure modes evaluated with accelerated testing to verify validity of test

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Test Development

- Many years of experimentation
  - 1st group: BASF, Bayer, Ford, Q-Lab
  - 2nd group: Honda, Boeing, Atlas
- Dozens of different approaches
- Multiple runs of final test to ensure repeatability & reproducibility

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Collecting outdoor weather data

Laying the groundwork for a new accelerated test

Outdoor weather data

Approach: collect outdoor weather data to better understanding the forces of natural weathering:

- Sunlight
- Heat
- Water

Goal: Obtain suitable body of field data to develop the Accelerated laboratory test

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Outdoor Weather Data Collected

- Solar Radiation (Sunlight)
- Temperature
  - Air, Black Panel, Relative Humidity and Dew Point
- Wind
  - Speed and Direction
- Rain
  - Amount, Duration, Rate Accumulation
- Panel Weight
  - Wetness, Dew Events and Rain Events

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Outdoor Weather Data Collection Sites

- Weather Station installed Jacksonville, FL (Bayer)
  - 2004 to 2007
- Moved to Homestead, FL (Q-Lab)
  - 2008 to 2014

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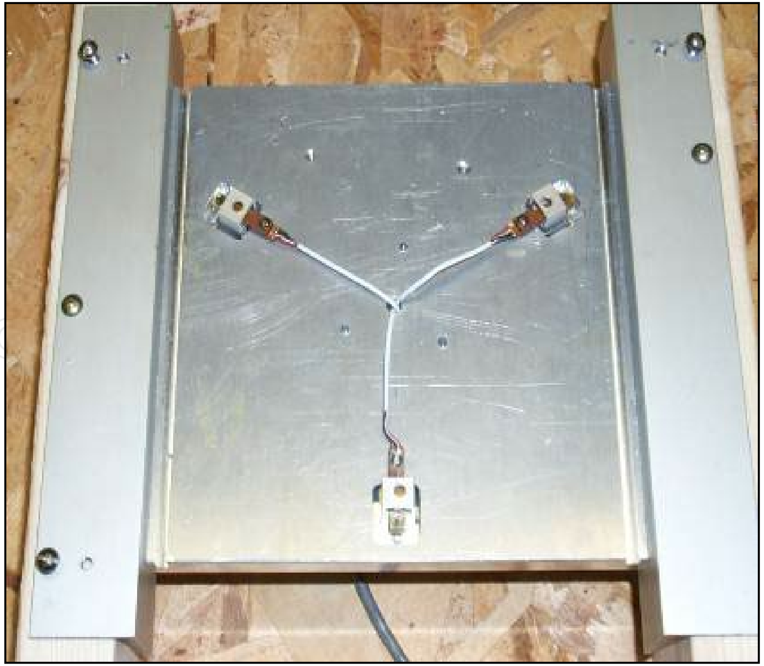
Outdoor Weather Water Data Measurements

- Mass of panel measured every 5 min
  - Panel + Water
- Calibrated regularly
- Care taken to ensure no animal or bird influence
- Able to see rain vs dew + water uptake



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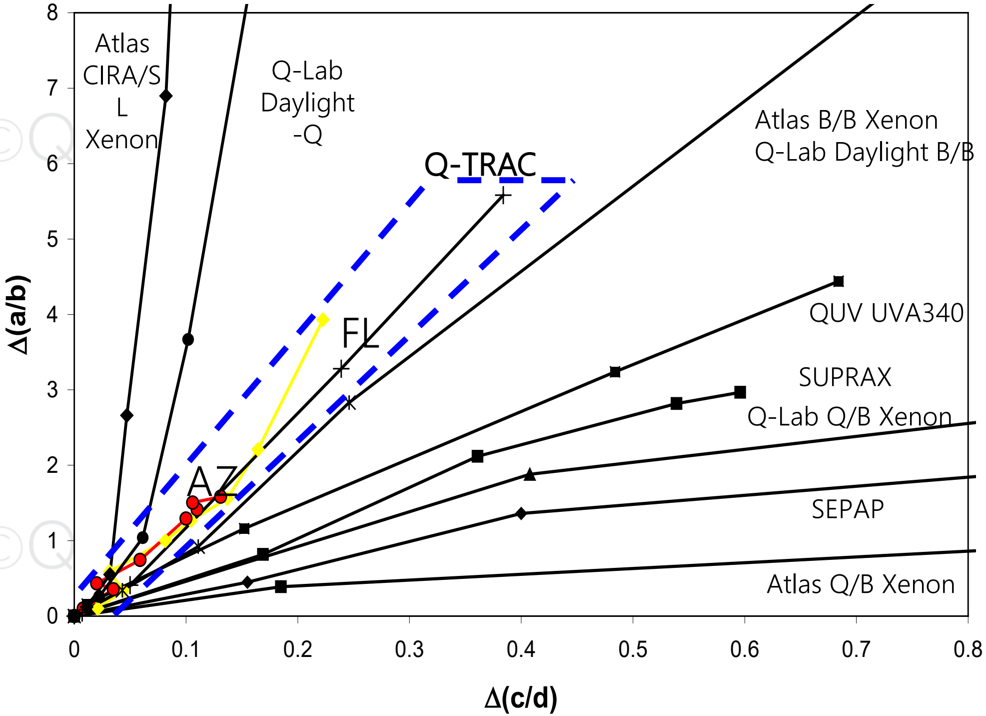
Outdoor data: Accelerating irradiance

- Two measures of photooxidation (Δa/b) and (Δc/d) evaluated with multiple light sources

- No available filters properly reproduced it

- Q-TRAC solar concentrator gave similar results to FL/AZ outdoor



Peters/Misovski/Roberts/Lemaire/Fischer

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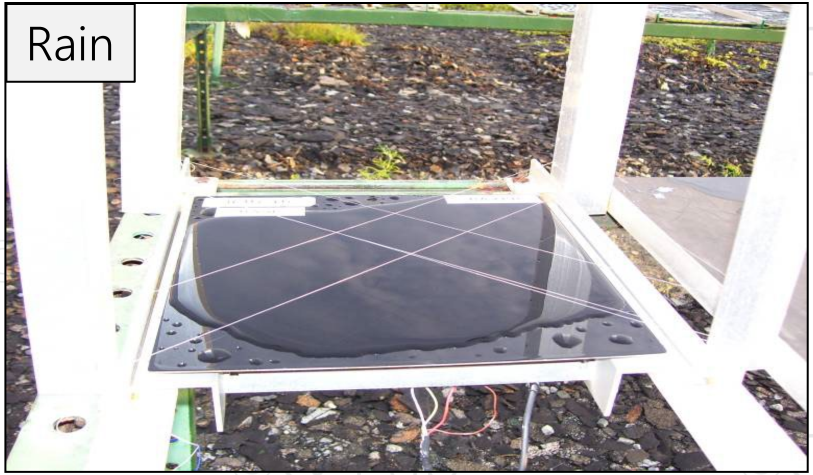
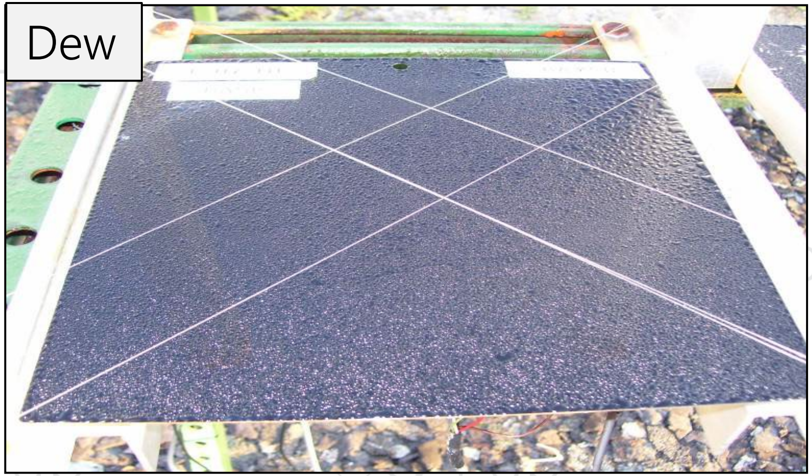
Water Information from Outdoor Data





Materials outdoors are wet for longer than you think!

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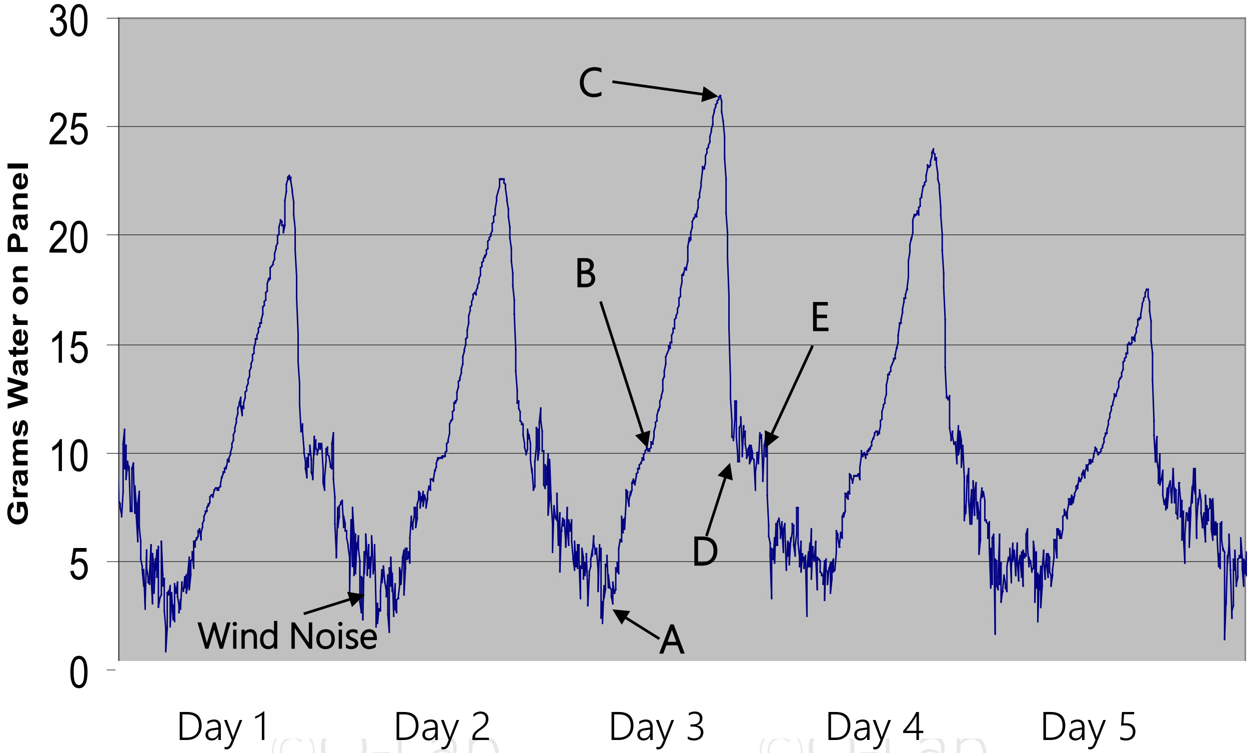
Dew on Painted Panels



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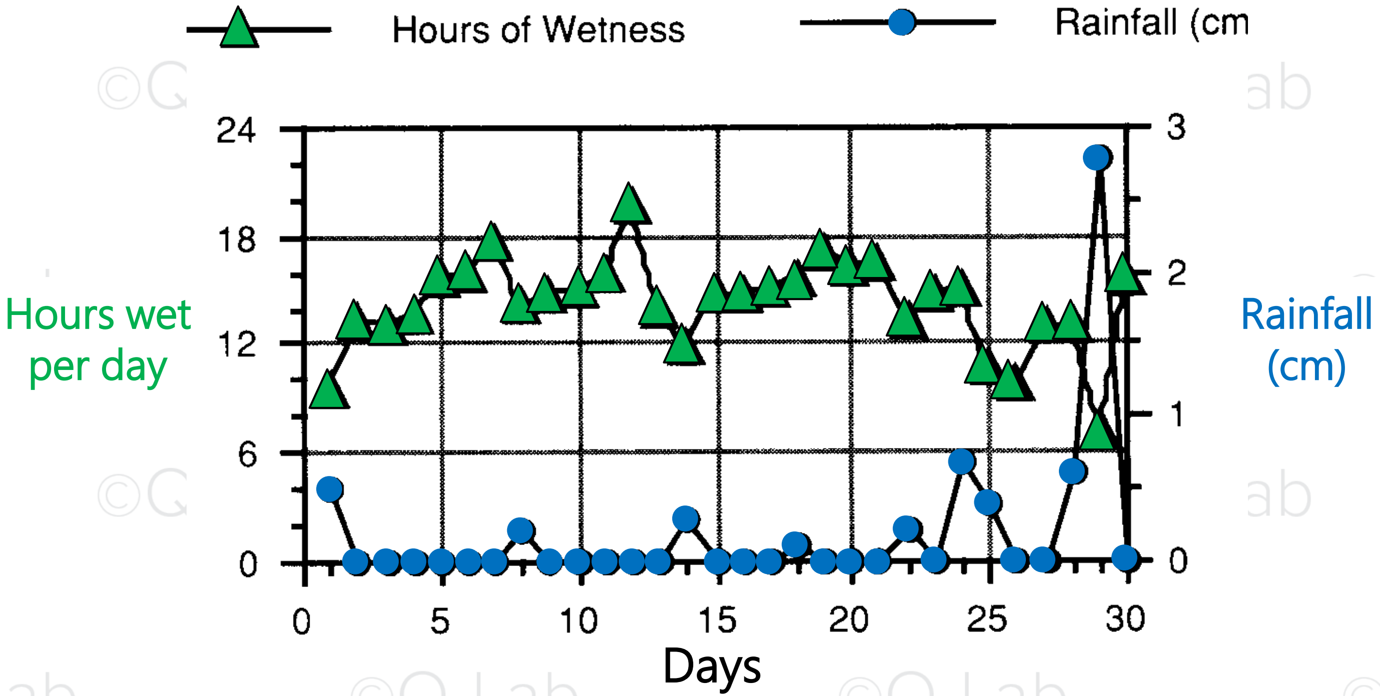
Time of Wetness vs. Rainfall



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Developing the ASTM D7869 Cycle

Applying key learnings from Outdoor benchmark testing

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Learnings Applied to ASTM D7869

- **Global benchmark location**: South Florida
- **Light intensity**: use higher-intensity light with correct spectrum to increase acceleration
- **Heat**: Keep temperatures realistic, at or below service
- **Time of wetness**: Increase! Mimic real-world behavior - panels wet 12+ hrs/day in Florida
- **Water spray**: Never spray panels during light step; it never rains when sun is shining brightly!

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Sunlight

- Explored different light sources
- Explored different optical filters
- Accelerated outdoor weathering (Q-TRAC) provided tantalizing results
- Better match to sunlight just might work, but be careful ...

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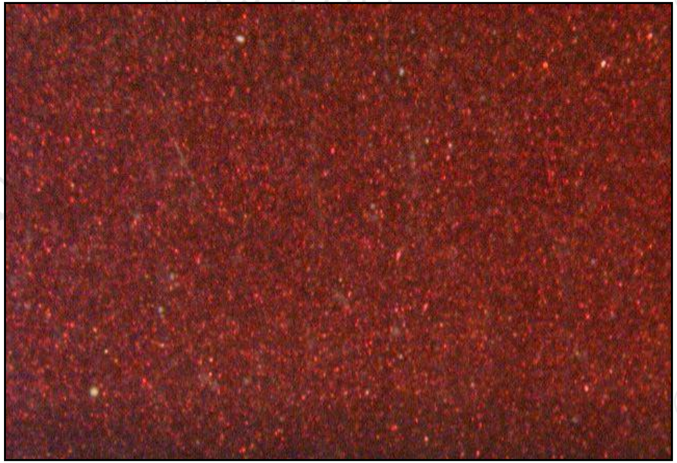
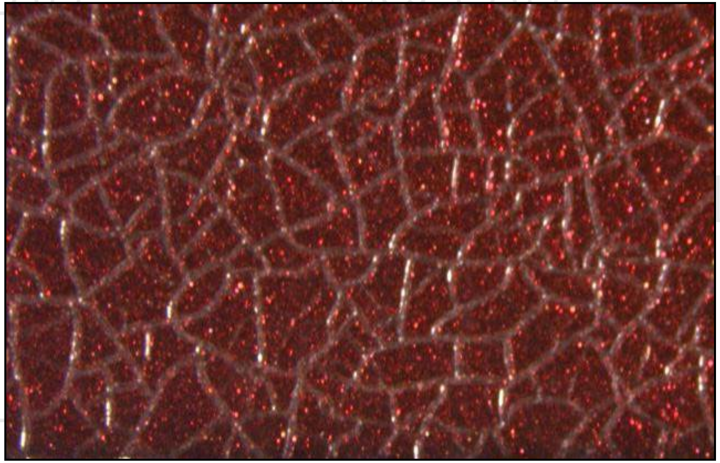
The wrong light source gives the wrong results!

Florida



Borosilicate filtered xenon arc



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Accelerated Light Source

- Light source must have very good match to the solar spectrum
- ASTM D7869 calls for a new optical filter
  - Q-Lab version is called **Daylight–F**
- Produces more realistic results
  - Higher irradiance
  - Better, more realistic acceleration

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Spectral Irradiance: Tables

Spectral irradiance is very narrowly specified in ASTM D7869

Daylight-F meets this but not all Type I Daylight Filters do

Wavelength Band (nm)	Total Irradiance Over Indicated Wavelength Band (W/m^2) Minimum	Maximum
$\lambda < 290$	0.00	0.005
$290 \leq \lambda < 295$	0.00	0.01
$295 \leq \lambda < 300$	0.01	0.04
$300 \leq \lambda < 305$	0.10	0.20
$305 \leq \lambda < 310$	0.38	0.56
$310 \leq \lambda < 320$	2.29	3.10
$320 \leq \lambda < 330$	4.76	5.82
$330 \leq \lambda < 340$	6.84	7.56
$340 \leq \lambda < 350$	7.69	9.40
$350 \leq \lambda < 360$	8.13	11.00
$360 \leq \lambda < 370$	8.32	12.47
$370 \leq \lambda < 380$	8.30	13.83
$380 \leq \lambda < 390$	8.64	14.40
$390 \leq \lambda < 400$	9.23	17.15

Note: Irradiance in W/m^2 normalized to 0.80 $W/(m^2 \cdot nm)$ at 340 nm.

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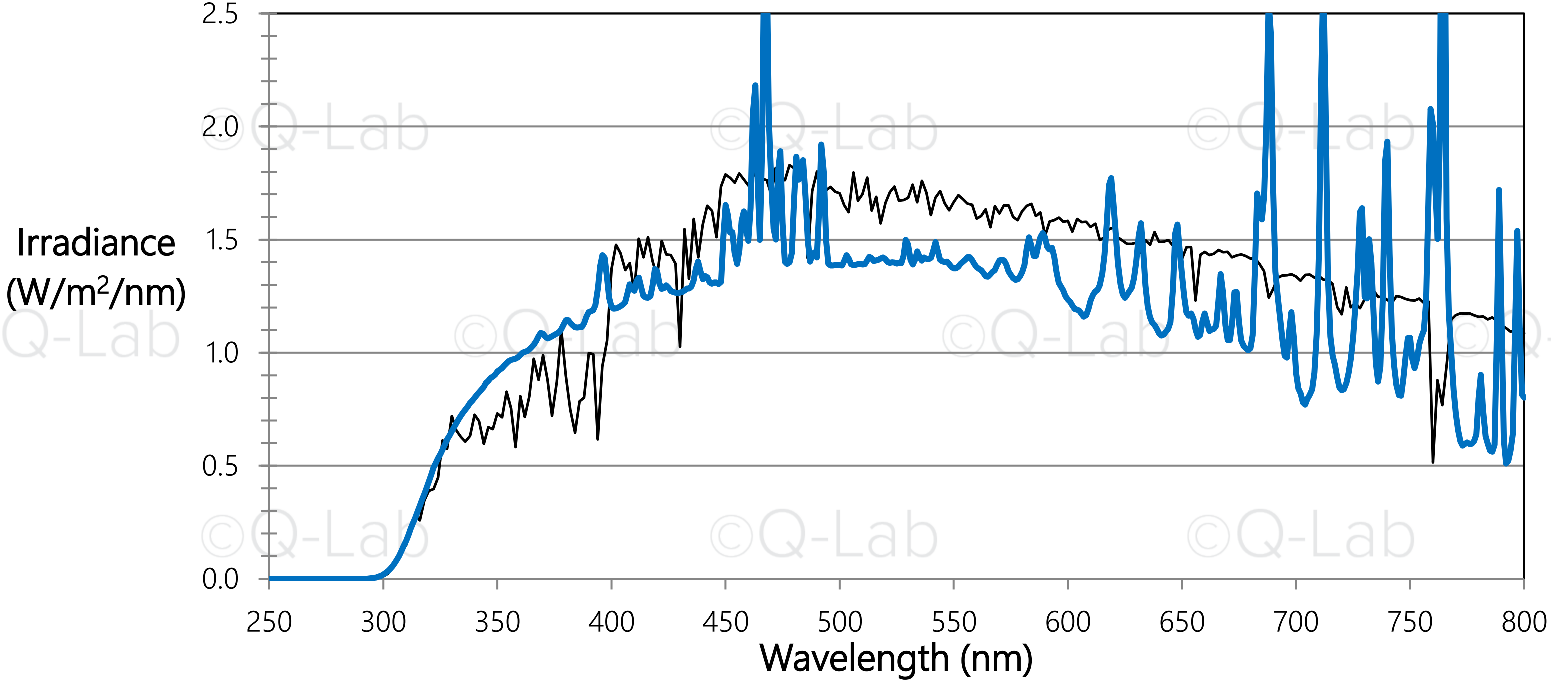
New Optical Filters (UV+VIS)



Very good match to sunlight, setpoint 0.80 W/m²/nm @340 nm

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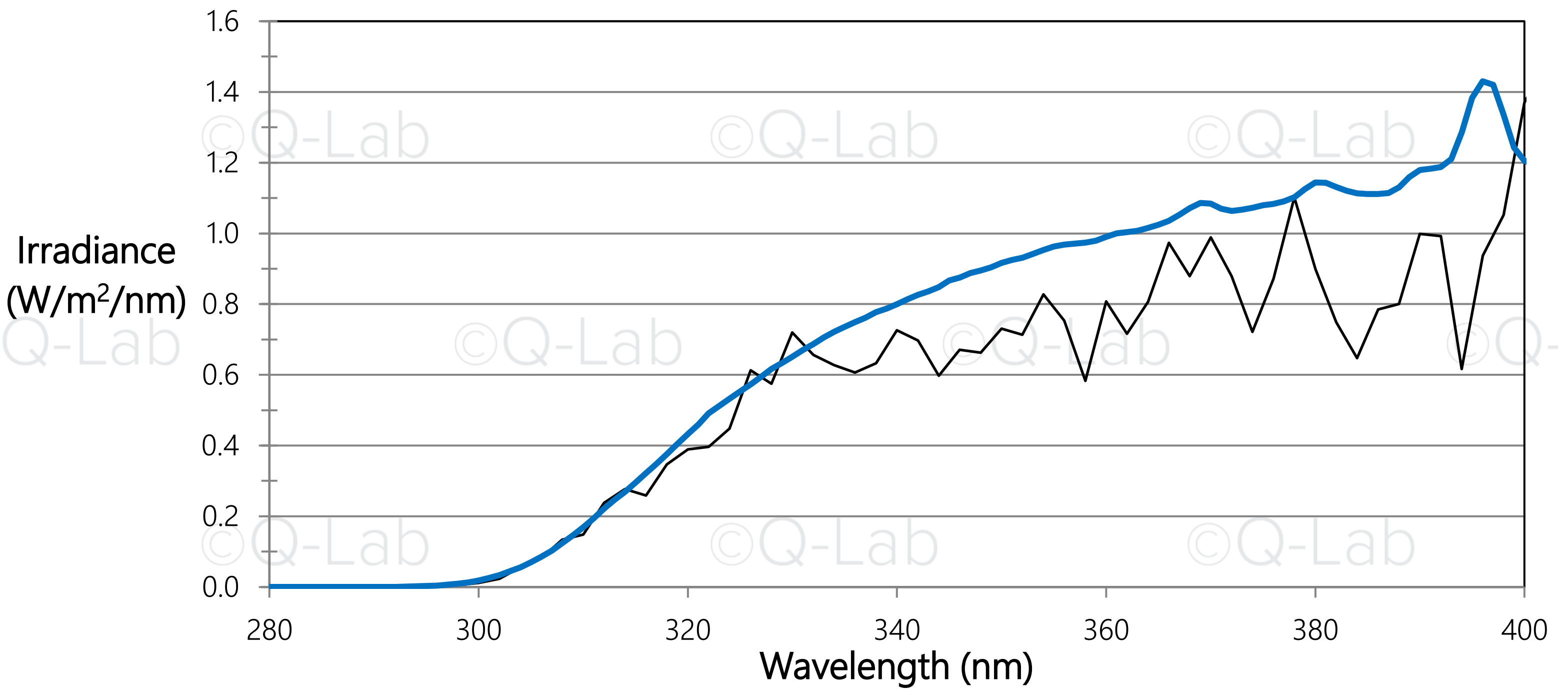
New Optical Filters (UV only)



Very good match to sunlight, setpoint 0.80 W/m²/nm @340 nm

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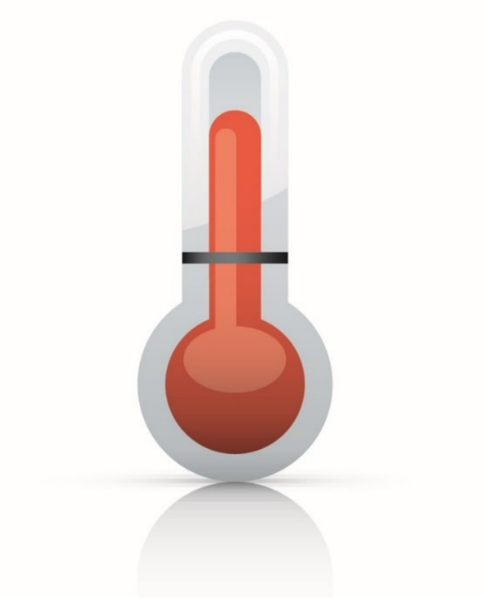
Heat

- High temperature serves primarily to accelerate water uptake.
- Two key guiding principles:
  - Do not exceed maximum service temperature
  - Use realistic temperatures to increase correlation



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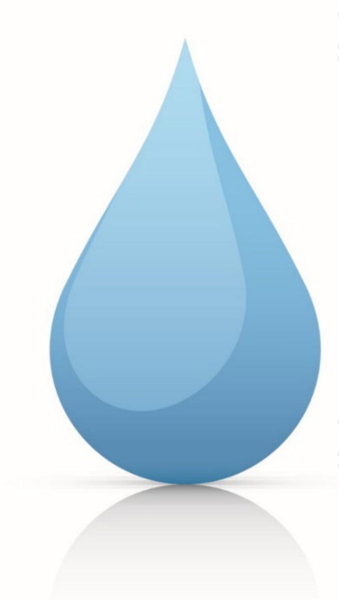
Water contributes to material degradation in many ways

- Plasticization
- Swelling
- Blistering
- Adhesion
- Mass transport
- Mass loss



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Water Delivery Calibration: Sponge Test

- Determine actual water delivery to specimens in both flat array & rotating rack testers
- Same sponge in both machines
- Results are **Repeatable** & **Reproducible**

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Sponge Water Calibration Tests

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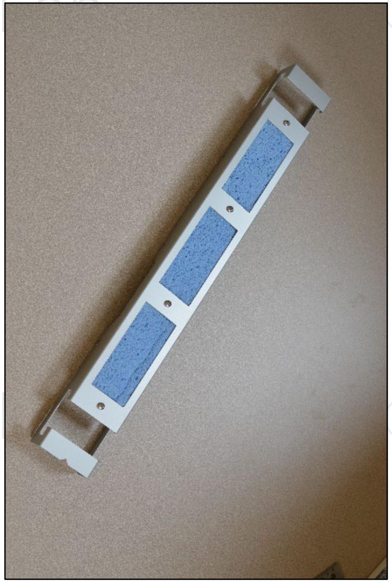
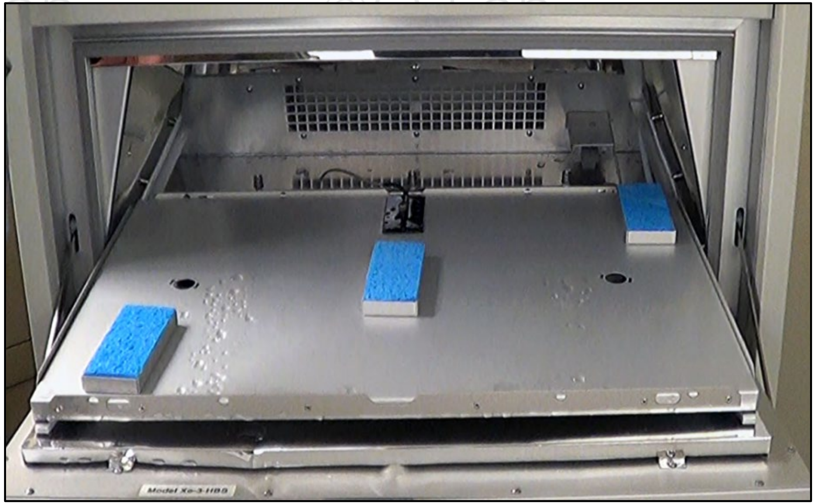
Rotating Rack



Flat Array



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ASTM D7869 Test Cycle and Guidance on Performance

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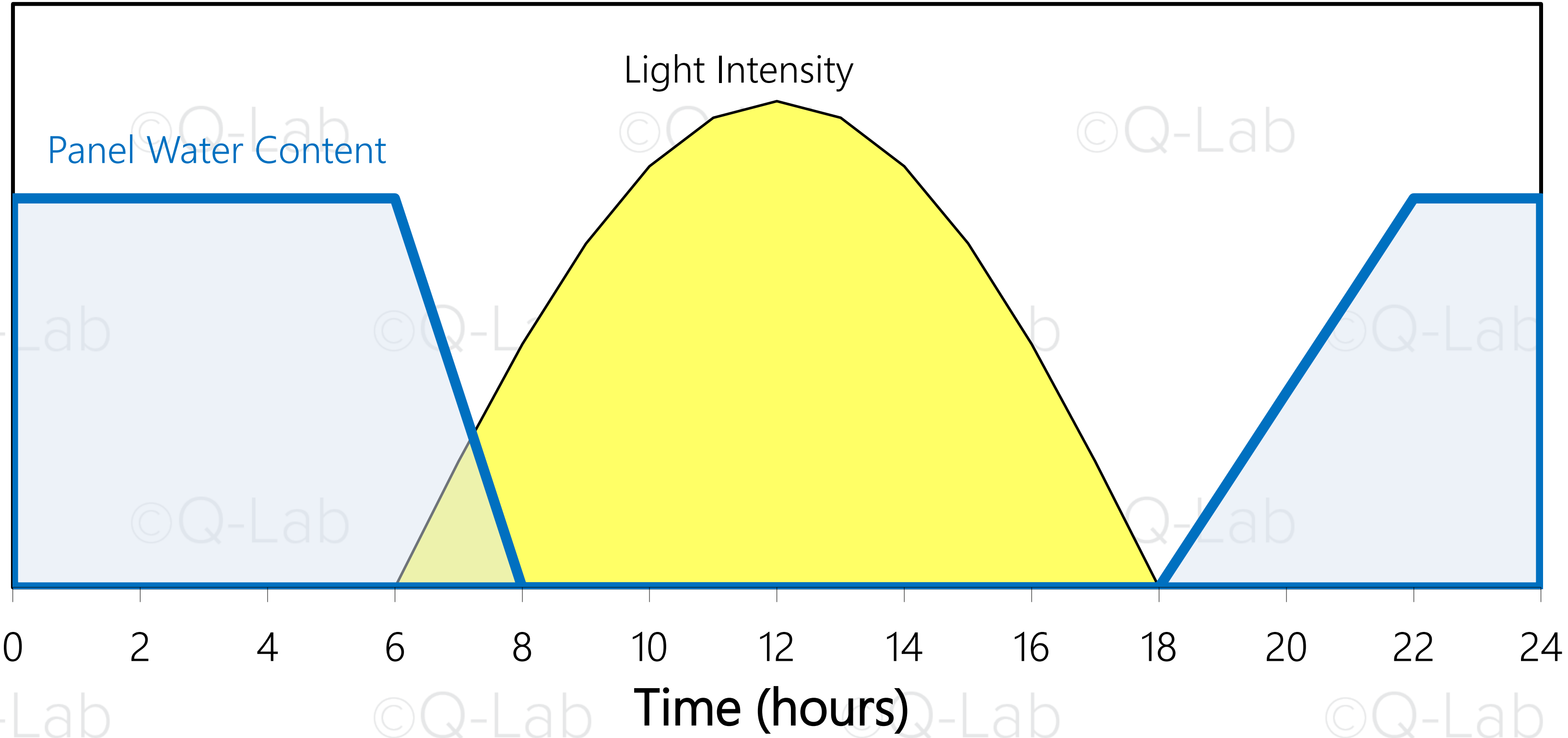
Florida outdoor daily cycle



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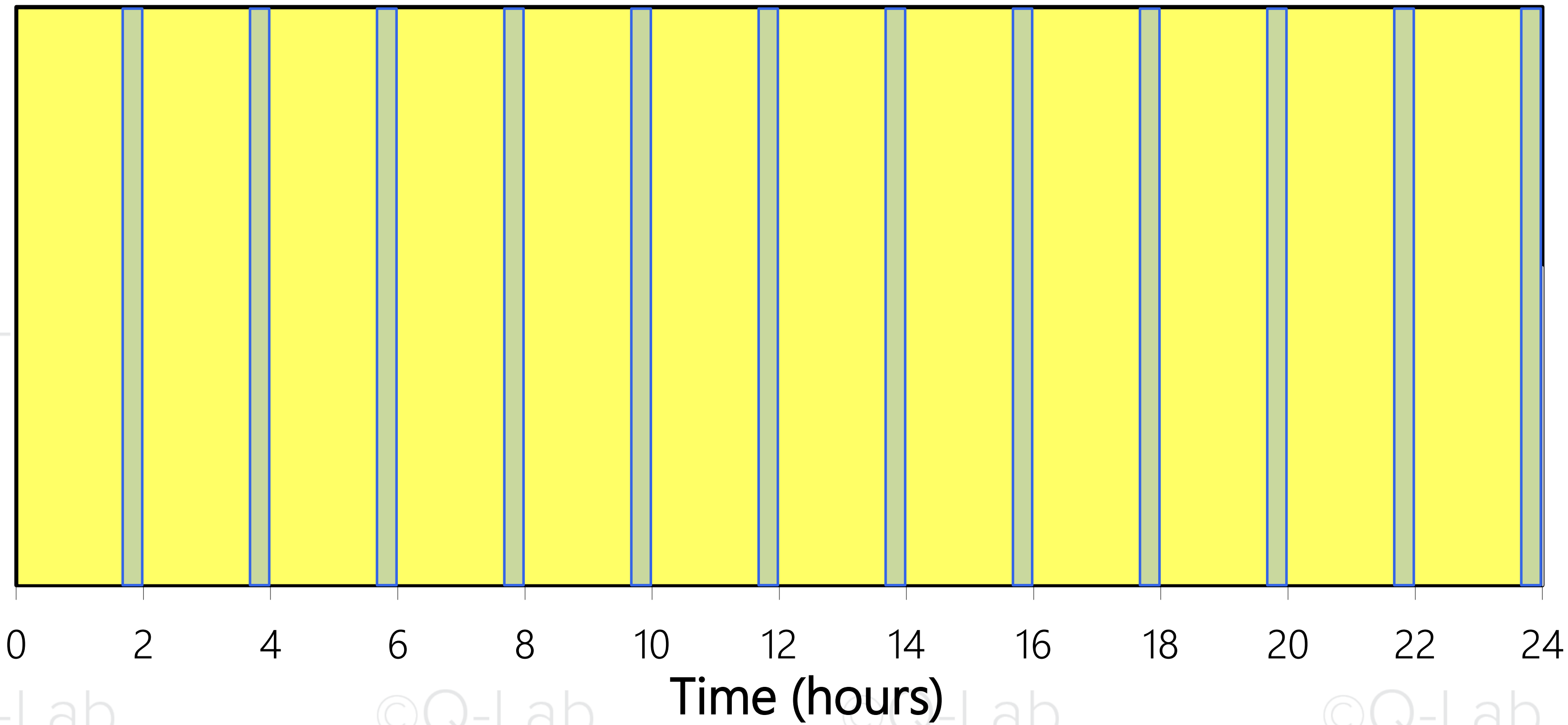
"102/18" - Not a Good Match



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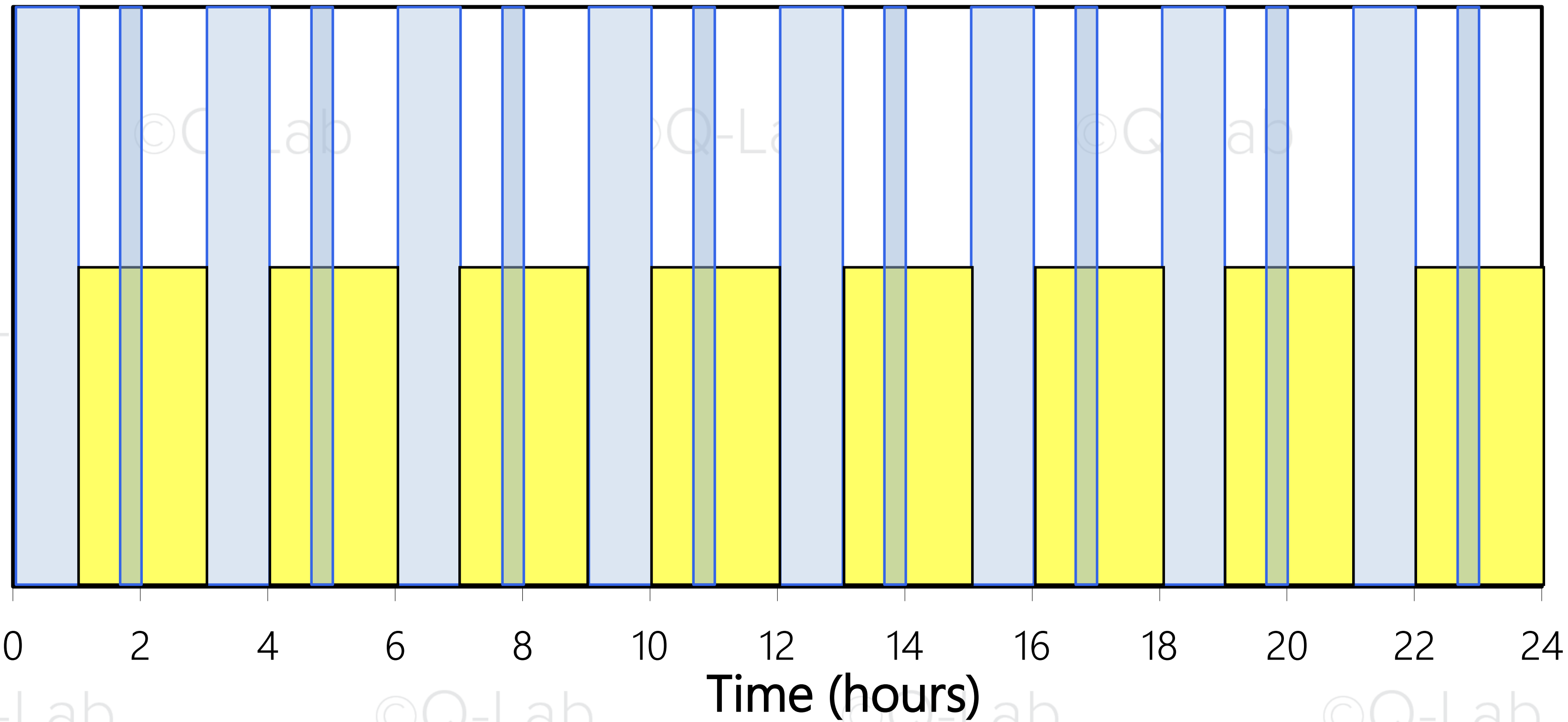
SAE J2527: Better but not great



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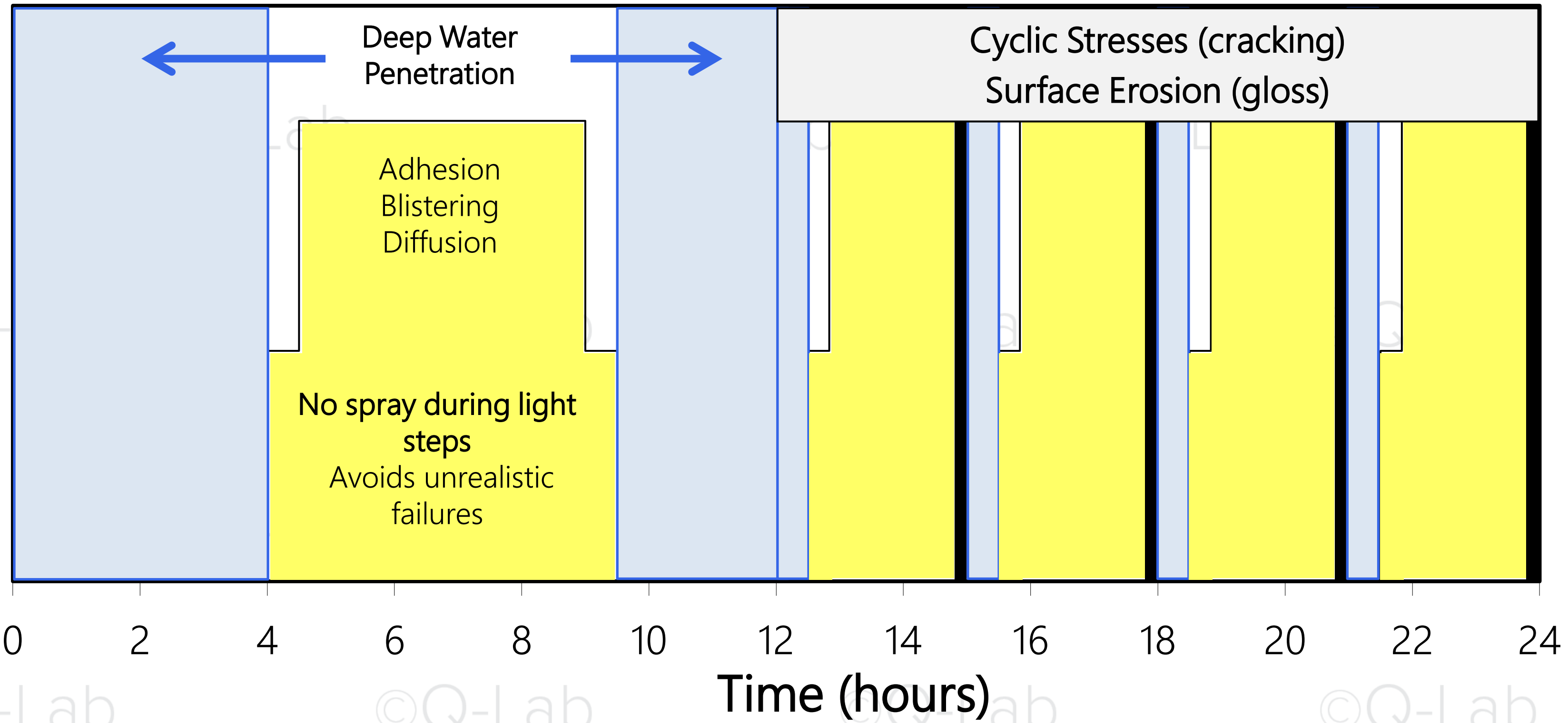
ASTM D7869: Natural Weather Cycles



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Tester Configuration for ASTM D7869

- Q-SUN Xe-2, Xe-3, or Xe-8
- Daylight-F optical filter
- Narrowband 340 nm Sensor
- Uninsulated Black Panel

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ASTM D7869 Test Cycle Summary

The test conditions consist of a primary test cycle and a sub-cycle. The primary test cycle includes two long water exposures and a single, long light exposure with precise spectral match to daylight. It is designed to reproduce water penetration failures, such as adhesion, blistering and diffusion of small molecules. The sub-cycle consisting of shorter alternating water and light exposures is designed to simulate cyclic stresses such as cracking and surface erosion. These two cycles are designed to replicate the common types of failures driven by the interaction of photo-oxidation during daylight and hydrolysis during water exposure that are seen in a subtropical climate such as gloss loss, color change, adhesion, blistering and cracking.

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ASTM D7869 Test Cycle and Conditions

TABLE 1 Exposure Cycle

Step Number	Step Minutes	Function	Irradiance Set Point[A] at 340 nm W/(m^2·nm)	Black Panel Temperature Set Point[A]	Chamber Air Temperature Set Point[A]	Relative Humidity Set Point[A]
1	240	dark + spray	—	—	40°C	95 %
2	30	light	0.40	50°C	42°C	50 %
3	270	light	0.80	70°C	50°C	50 %
4	30	light	0.40	50°C	42°C	50 %
5	150	dark + spray	—	—	40°C	95 %
6	30	dark + spray	—	—	40°C	95 %
7	20	light	0.40	50°C	42°C	50 %
8	120	light	0.80	70°C	50°C	50 %
9	10	dark	—	—	40°C	50 %
10	Repeat subcycle steps 6 to 9 (shown in bold) an additional 3 times (for a total or 24 h = 1 cycle).					

[A] The set point is the target condition for the sensor used at the operational control point and is programmed by the user. When the exposure cycle calls for a particular set point, the user programs the apparatus to use that exact number. Operational fluctuations are deviations from the indicated set point during equilibrium operation. The maximum allowable operational fluctuation during equilibrium conditions for the exposure cycle above is ±0.02 W/(m^2·nm) for irradiance, ±2.5°C for black panel temperature, ±2°C for chamber air temperature, and ±10 % for relative humidity.

Detailed information on the science behind these steps is in the Appendix

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Operational Fluctuation

- Operational fluctuation refers to the allowed variance in the **measured value** of any given parameter, **at the location where it is being measured**
  - It IS a tester performance stability requirement
  - It is NOT a uniformity requirement
  - Is does NOT allow you to choose any setpoint within the specified range
- For example, consider a requirement of **CAT = 42 ± 3 °C**
  - This doesn't mean the air has to be between 39-45 °C everywhere in the test chamber. It means the CAT sensor must always measure between 39-45 °C
  - It also doesn't mean you can program any CAT setpoint from 39-45 °C that you like. You have to program 42 °C.

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How to Program ASTM D7869

Step	Function	Relative Humidity	Irradiance	Black Panel Temp	Chamber Air Temp	Step Time (hh:mm)
1	Dark + Spray	95 %	-	-	40 °C	4:00
2	Light	50 %	0.40 $W/m^2/nm$	50 °C	42 °C	0:30
3	Light	50 %	0.80 $W/m^2/nm$	70 °C	50 °C	4:30
4	Light	50 %	0.40 $W/m^2/nm$	50 °C	42 °C	0:30
5	Dark + Spray	95 %	-	-	40 °C	2:30
6	*Subcycle (4× repeat)*					
7	Dark + Spray	95 %	-	-	40 °C	0:30
8	Light	50 %	0.40 $W/m^2/nm$	50 °C	42 °C	0:20
9	Light	50 %	0.80 $W/m^2/nm$	70 °C	50 °C	2:00
10	Dark	50 %	-	-	40 °C	0:10

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Test Requirements

- Xenon arc weathering tester (ASTM G151, G155)
- DI Water Supply: < 1 ppm solids and < 0.1 ppm silica (ASTM D4517)
- Specimen preparation (ASTM G147)
- Reporting (ASTM G151)

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Specimen Repositioning

- Specimen repositioning is **mandatory**
  - Different than most xenon standard requirements
- Ensures best repeatability and reproducibility
- Perform *at least* every two weeks
- Required for both flat array and rotating rack

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Chamber Sensor Calibration

Sensor	Device
Irradiance	UC20/340
Black Panel	UC202/BP
Chamber Air Temperature	Chamber Air Temperature / Relative Humidity Sensor
Relative Humidity	

UC20/340 Smart Sensor

UC202/BP Smart Sensor

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Validating the test method

Determining if ASTM D7869 accurately reproduces outdoor failure modes

Paint Systems Tested

- Automotive
  - ~20 systems, multiple colors
  - All systems were base coat / clear coat
  - Fortified and unfortified
  - Positive controls & known Florida exposure failure mechanisms

- Aerospace
  - Four systems, two colors (blue and white)
  - Two monocoat systems, two base coat / clear coat systems
  - Florida and in-service performance both known

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Outdoor Testing: Sample selection

- Sample set includes both common field failures & controls
- 106 Combinations Prepared
  - 4 colors: Black, White, Blue, Red
  - Waterborne & Solventborne Base
  - Solventborne Clear
  - Different layering systems
  - With and without Stabilizers
- All Samples prepared by one lab

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Outdoor Testing: Test Protocol

- Testing conducted per SAE J1976
- Evaluations every 6 months
- Exposure times
  - Full Set Summer 2006
  - Partial Set Summer 2007
  - Expose Until Failure

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Reproducing Failure Mechanisms

- Chemical changes
- Cracking
- Blistering
- Adhesion loss
- Color
- Gloss loss

Important to "test the test" and validate that the scientific approach to standard development leads to good correlation with natural exposures

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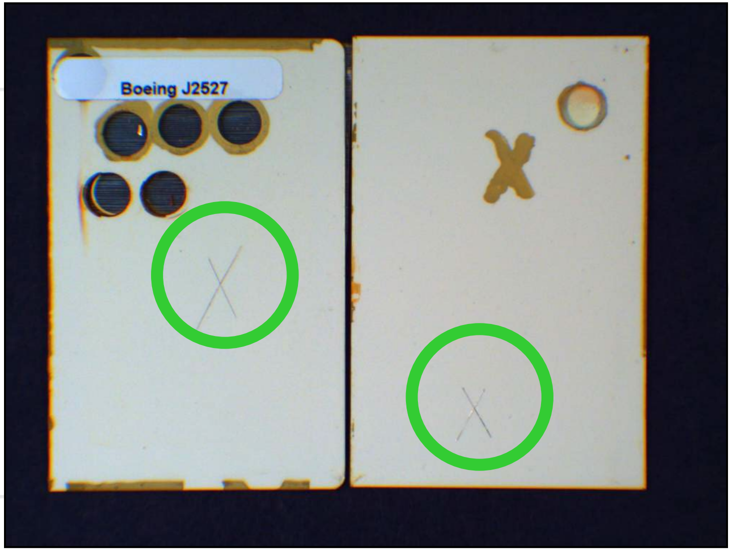
Control System

Florida Exposure

SAE J2527

ASTM D7869



Expected Failure Mode: None – positive control

Observed: Excellent performance in all tests

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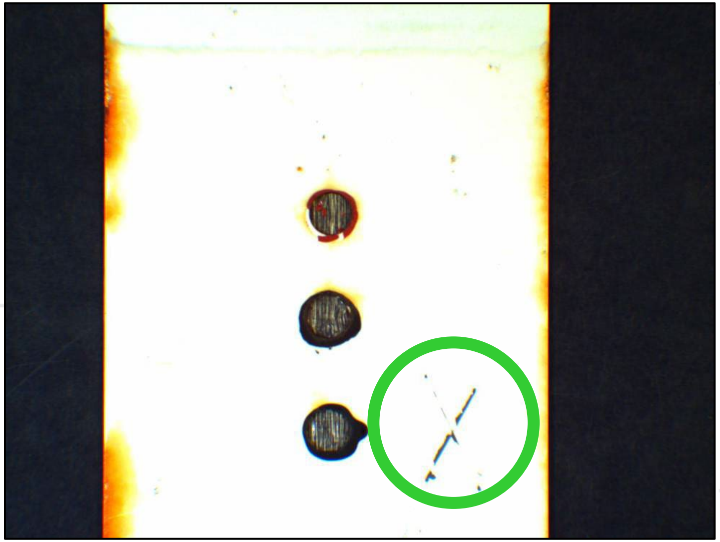
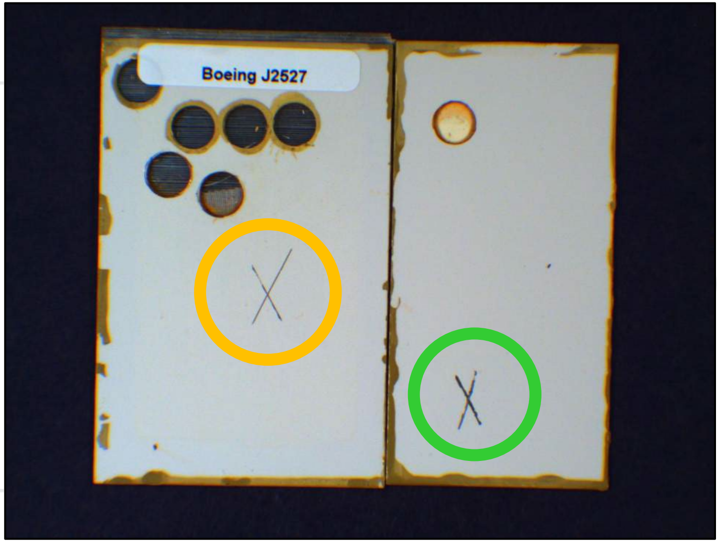
Coating Pick-Off

Florida Exposure



SAE J2527

ASTM D7869



Expected Failure Mode: Slight BC/E-coat pick off

Observed: Slight BC/E-coat pick-off ASTM D7869, maybe SAE J2527

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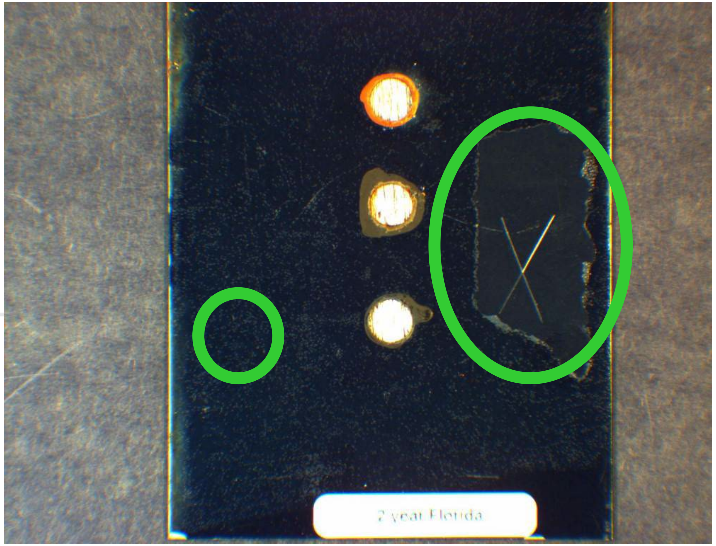
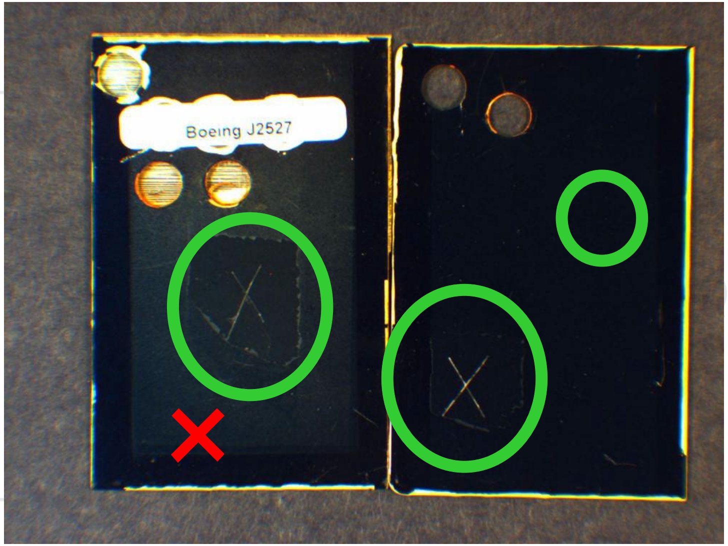
Gloss and Adhesion Loss

Florida Exposure



SAE J2527

ASTM D7869



Expected Failure Mode: Blistering, gloss loss, adhesion loss

Observed: Gloss and adhesion loss on both. Blistering ASTM D7869

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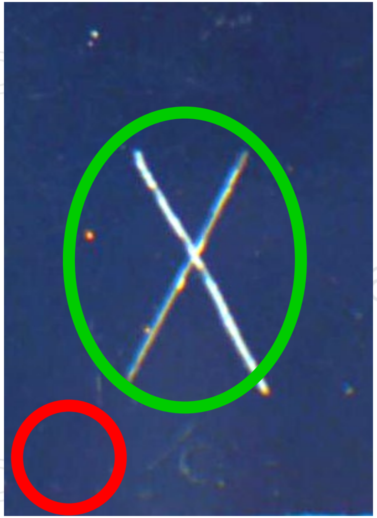
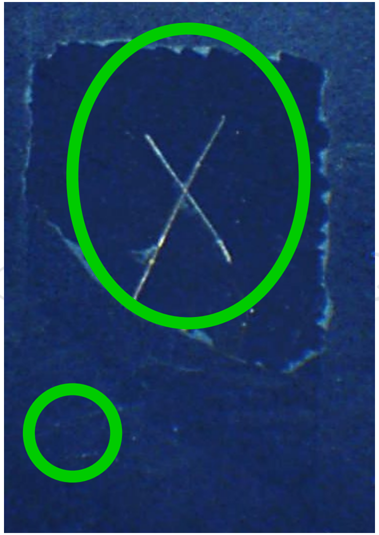
Delamination

Florida Exposure

SAE J2527



ASTM D7869



Expected Failure Mode: Blistering, gloss loss, adhesion loss

Observed: Gloss and adhesion loss on both. Blistering ASTM D7869

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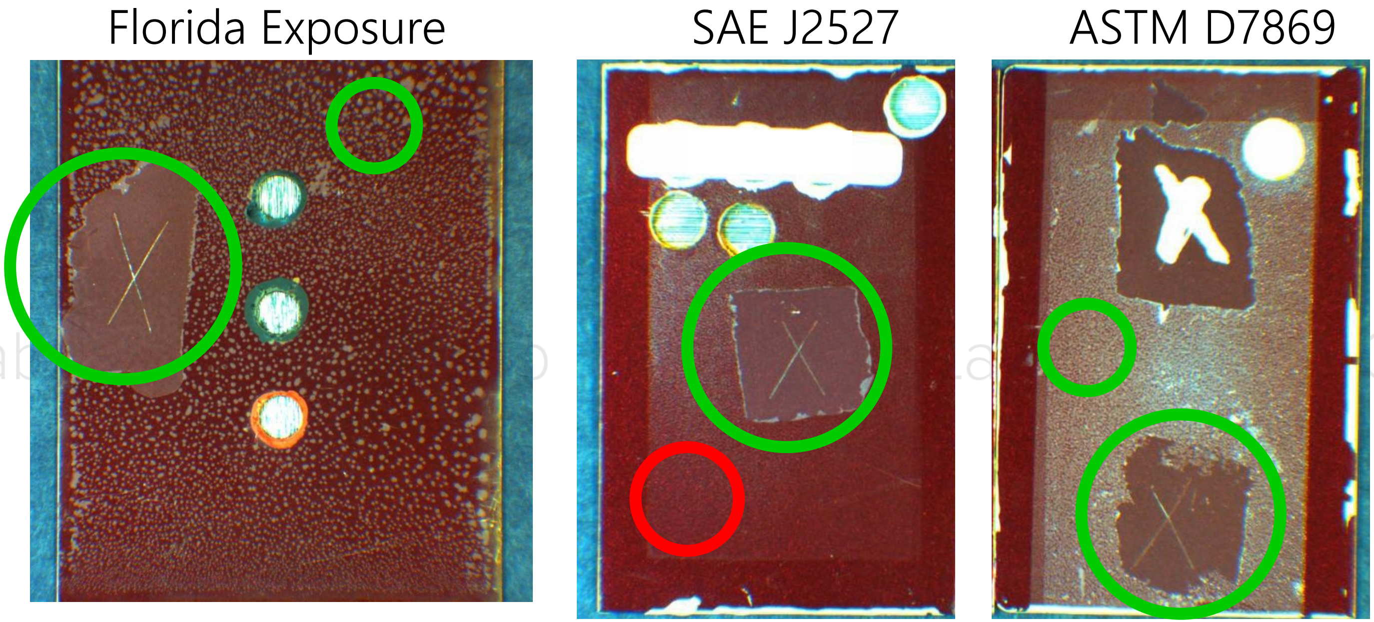
Blistering



Expected Failure Mode: Blistering, gloss loss, adhesion loss

Observed: Gloss loss and adhesion loss seen on all panels. Blistering on ASTM D7869 mimics that seen in Florida

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Evaluate Validation Testing

Example from ASTM D7869

• Chemical change	correctly reproduced
• Cracking	correctly reproduced
• Blistering	correctly reproduced
• Adhesion loss	correctly reproduced
• Color	correctly reproduced
• Gloss loss	correctly reproduced

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Conclusions: ASTM D7869

- ASTM D7869 accelerated lab weathering test cycle is **thoroughly researched** - uses scientific understanding of outdoor weather – light, heat, and water
- Test cycle **validated** by comparing to long-term outdoor weathering data of a variety of coatings systems
- ASTM D7869 is **realistic** - it reproduces faithfully almost all physical failure mechanisms and is **40% faster** than current test method.
- Introduction of this new weathering protocol allows for more rapid and accurate accelerated weathering results. These can be **correlated** with outdoor test data to give powerful information.

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Thank you for your time.

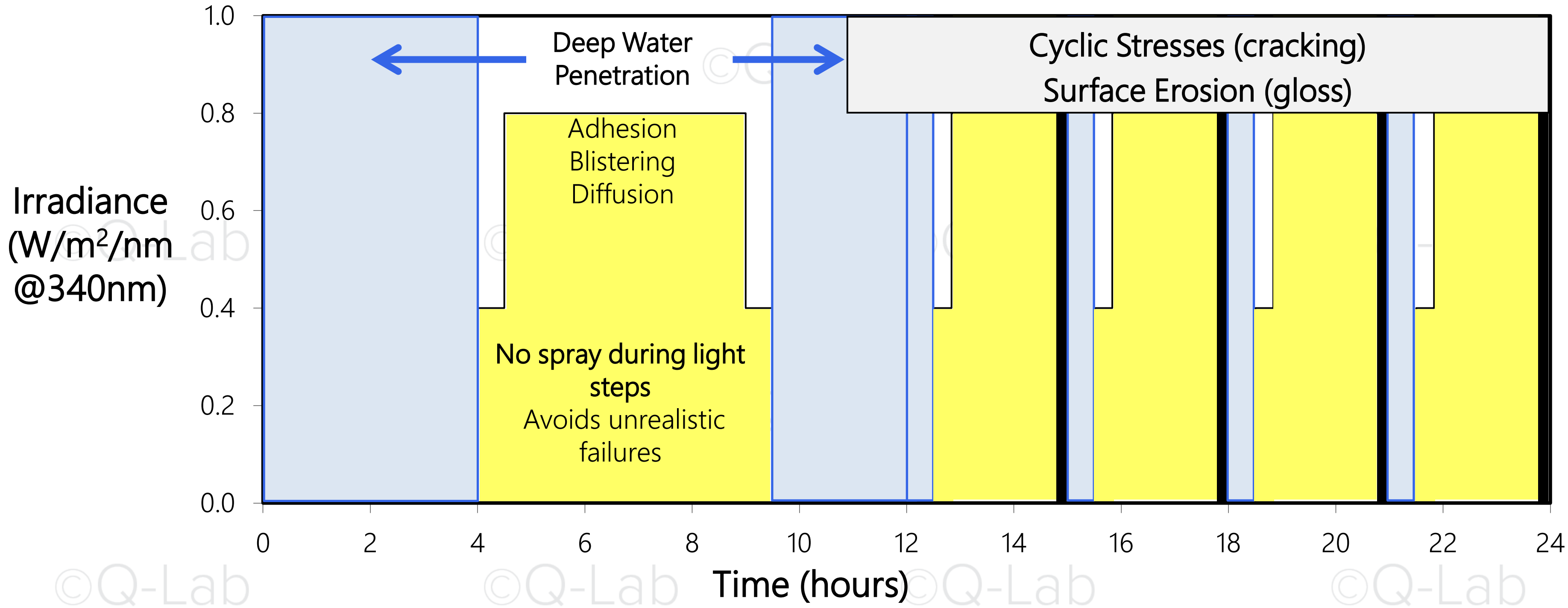
Questions?

info@q-lab.com

Appendix: The Science of ASTM D7869 Step-by-Step

ASTM D7869:

Reproduces Natural Weather Cycles



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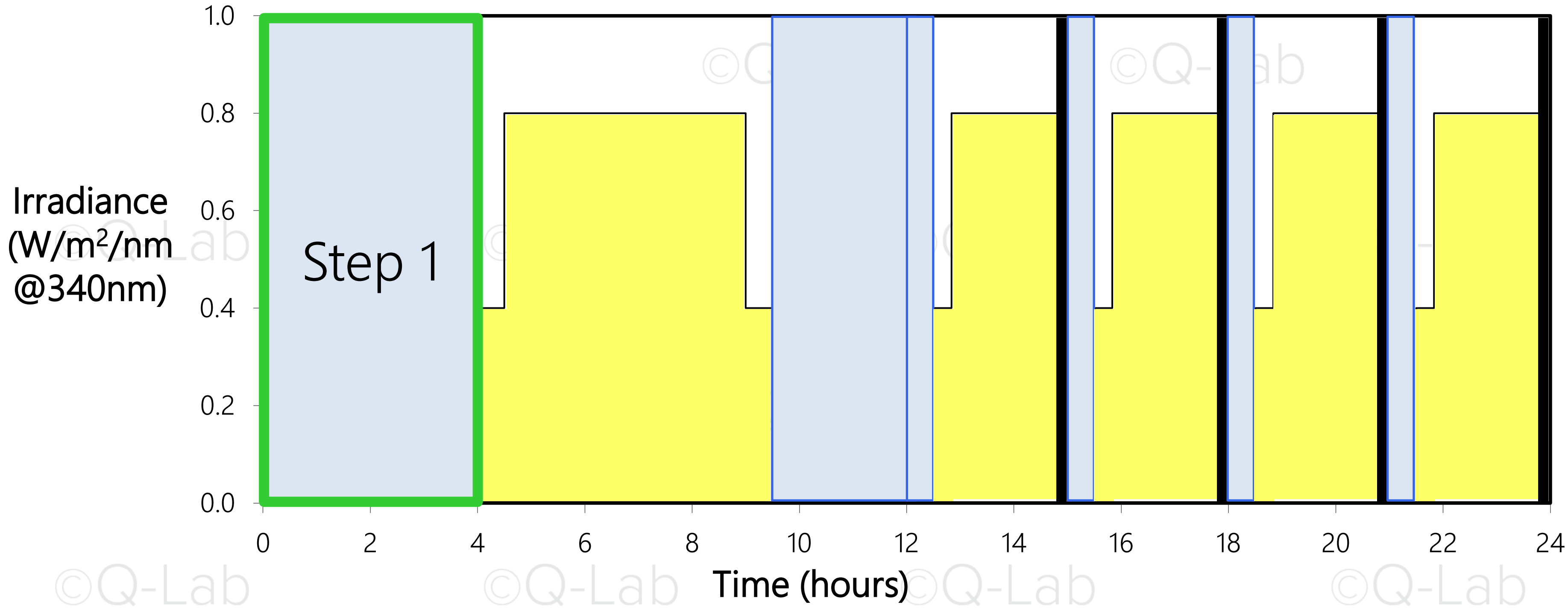
Step 1: Long Water Uptake



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Step 1 240 min Dark + Spray

Air = 40 °C RH = 95%+

Purpose: Reproduce water uptake of normal Florida night

- Multiple coating degradation modes caused by high water uptake (cracking, delamination, gloss loss)
- 40 °C doubles water uptake rate but doesn't exceed temperature prior to dry-off
- 4 hours of spray produces same water uptake as long, cool Florida wet periods (8-16 hr)

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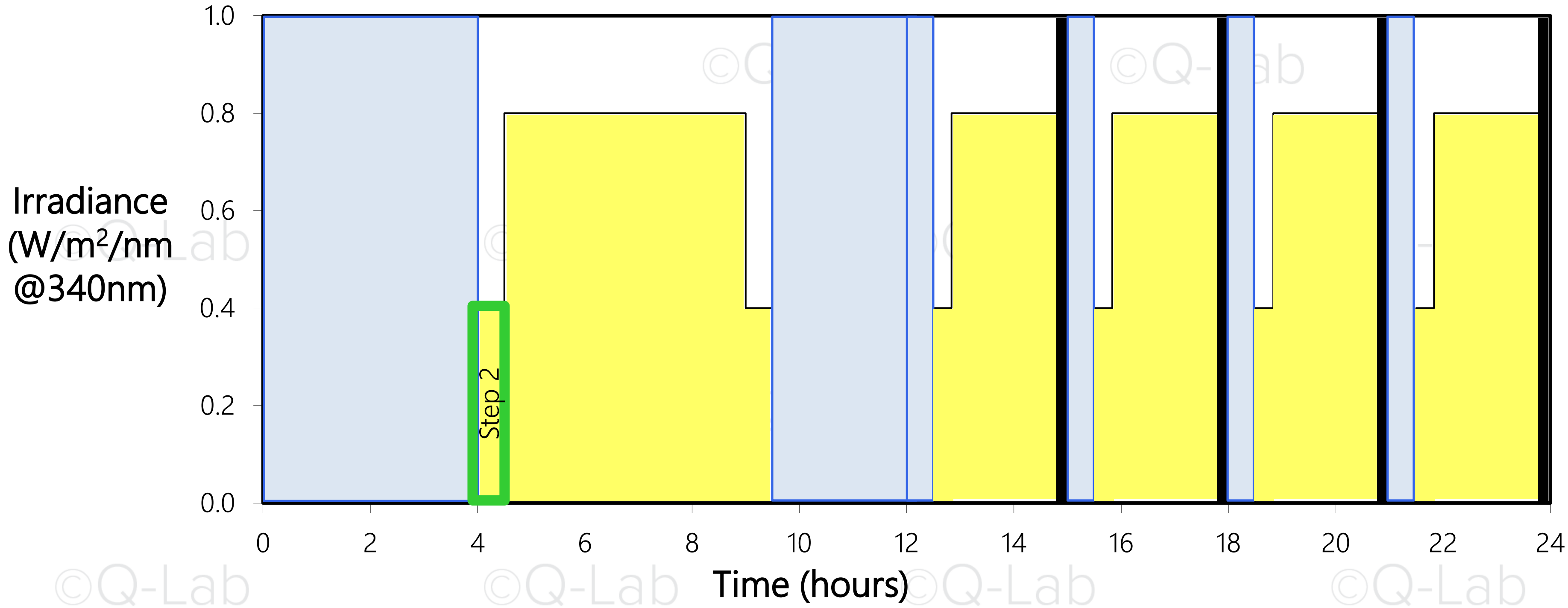
Step 2: Morning



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Step 2

30 min **Light 0.40 W/m²/nm**

BP = 50°C **Air = 42 °C** **RH = 50%**

Purpose: Totally Remove Absorbed Water

- Sun completely dries coating by mid-morning, before specimens reach 50 °C.
- Low irradiance, 0.40 W/m^2nm, because sun is not very bright by mid-morning
- 30 min is sufficient time to dry the coating
- RH affects dry-off rate; 50% RH gave most realistic results

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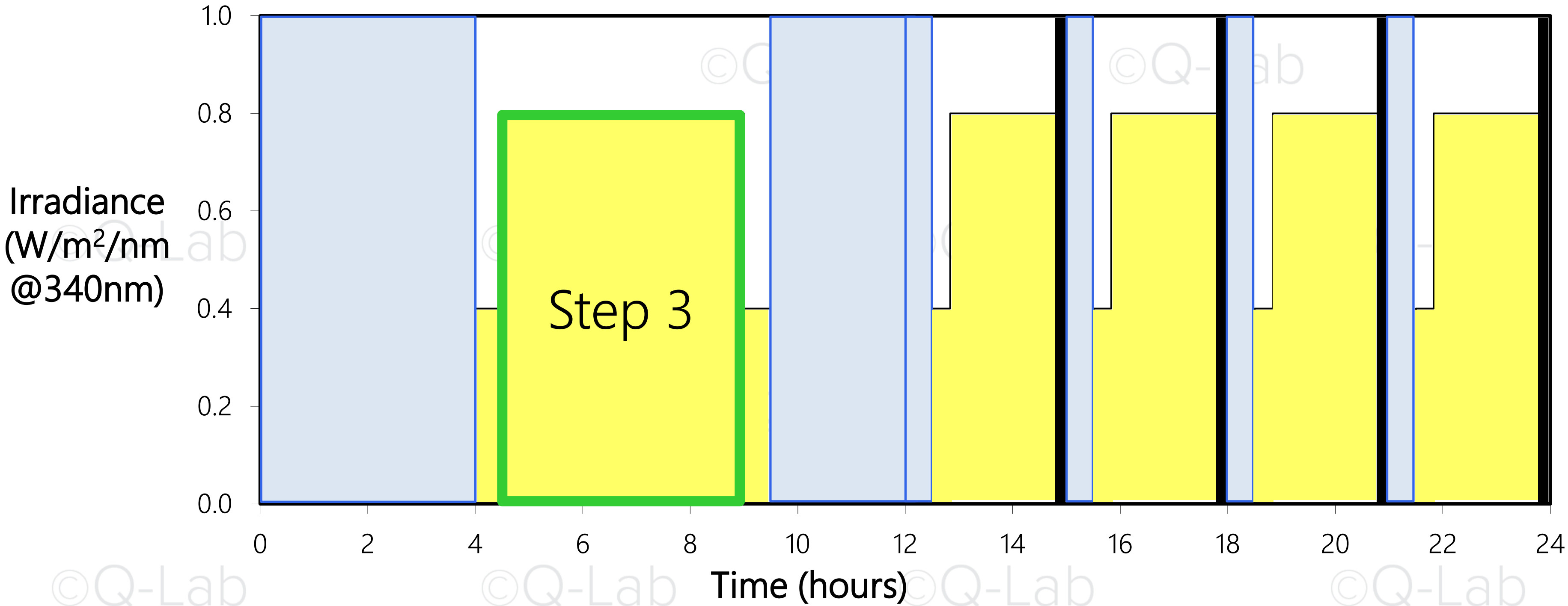
Step 3: Bright Daylight



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Step 3

270 min **Light 0.80 $W/m^2/nm$**

BP = 70°C **Air = 50°C** **RH = 50%**

Purpose: Simulate Effects of Bright Sunlight

- 0.80 $W/m^2/nm$ @340 nm is higher than maximum irradiance of noon midsummer sunlight (~0.68 $W/m^2/nm$ @340 nm)
- 70 °C is a realistic outdoor specimen temperature in hot weather like Florida
- Produces realistic accelerated aging that simulates observed surface effects. Light does not penetrate into the bulk polymer like water does

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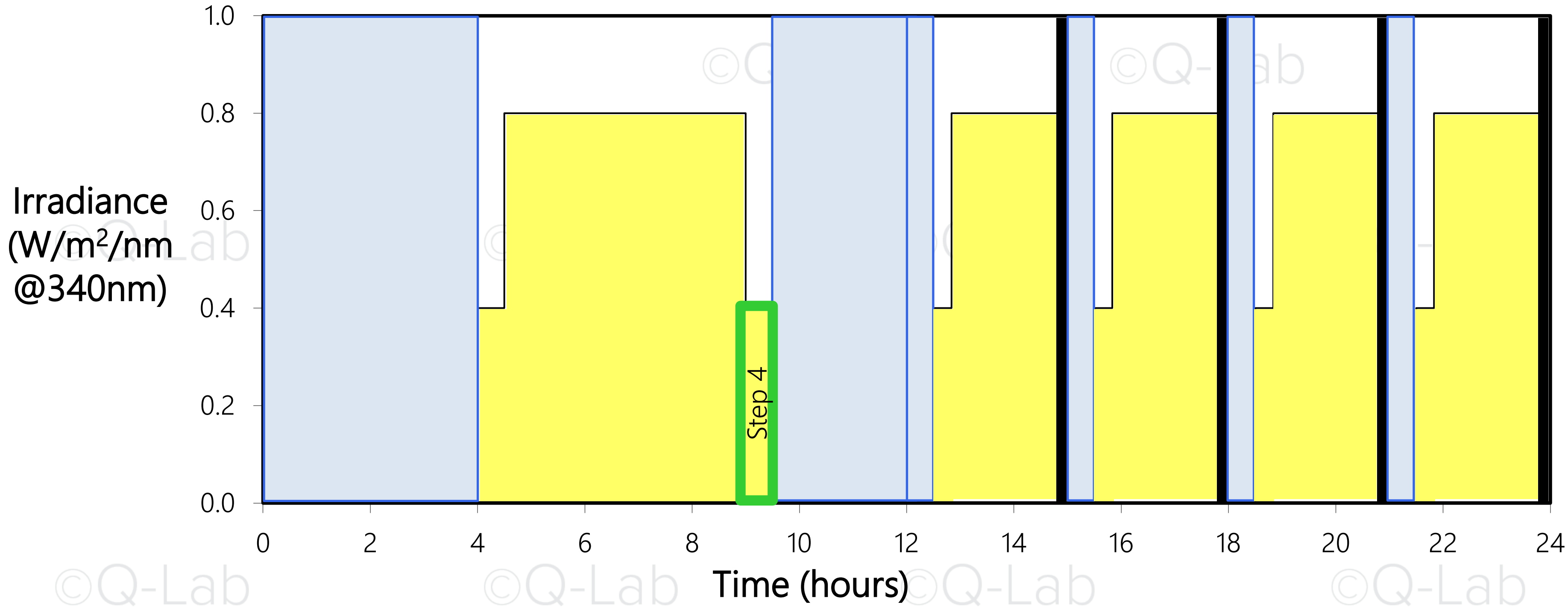
Step 4: Evening



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Step 4

30 min **Light** **0.40 W/m²/nm**

BP = 50 °C **Air = 42 °C** **RH = 50%**

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Purpose: Transitional "relaxation" from hot dry to cool wet

- Gradually reduces thermal stresses
- Similar temperature and irradiance as afternoon sun gets lower
- Unnatural cracking can occur if cold water is sprayed on a hot specimen

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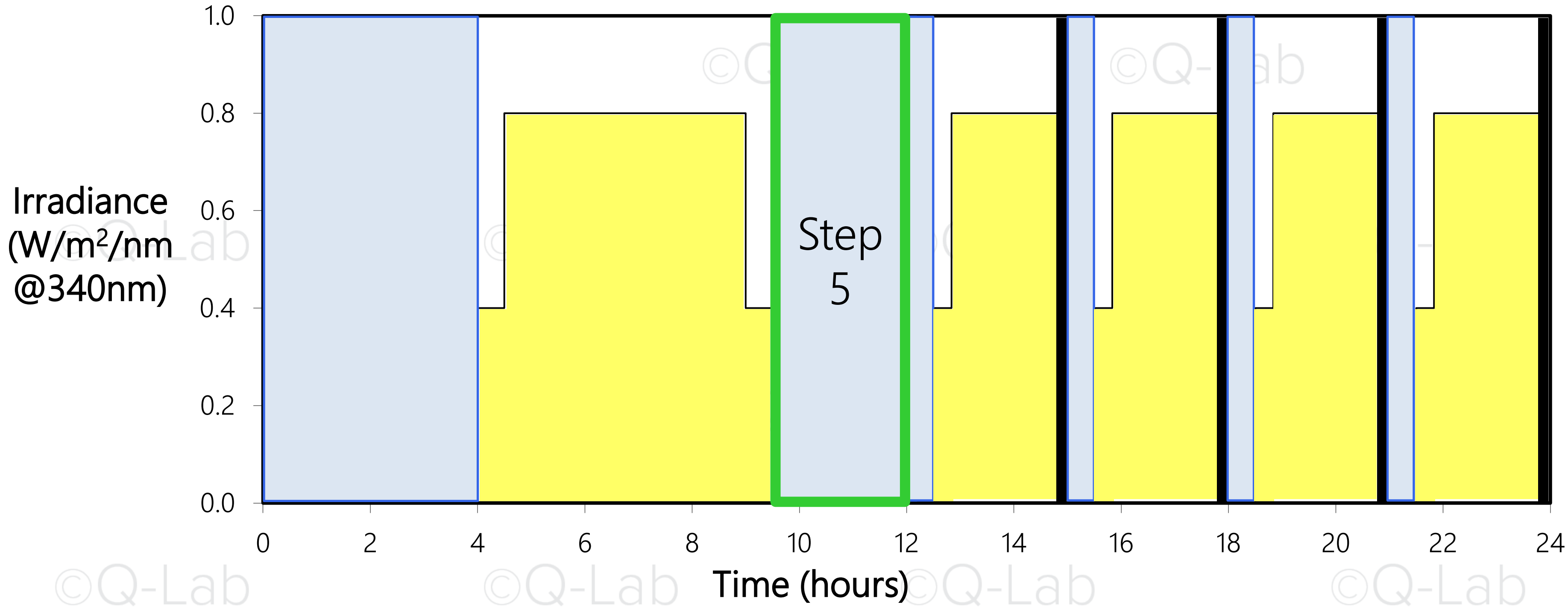
Step 5: Medium-Long Water Uptake



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Step 5 150 min Dark + Spray

Air = 40 °C RH = 95%+

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Purpose: Significant water uptake, less than maximum

- Maximum water uptake does not occur every day
- Simulates days with less than maximum water uptake

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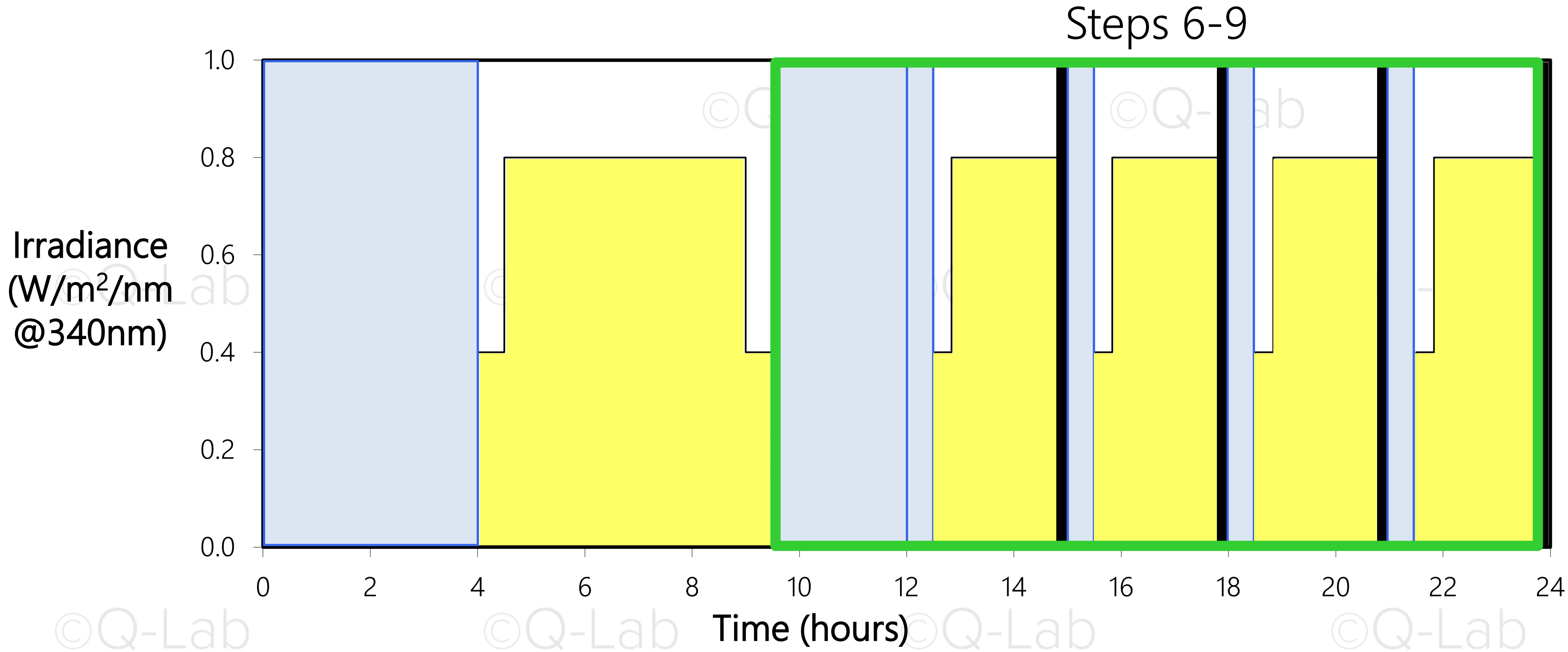
Steps 6-9: Cyclic Stress



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Steps 6 - 9 Subcycle, Repeated 4 Times

Purpose: Rapid thermal cycling and wet / dry cycling

- Tests mechanical and viscoelastic properties
- Cracking & delamination

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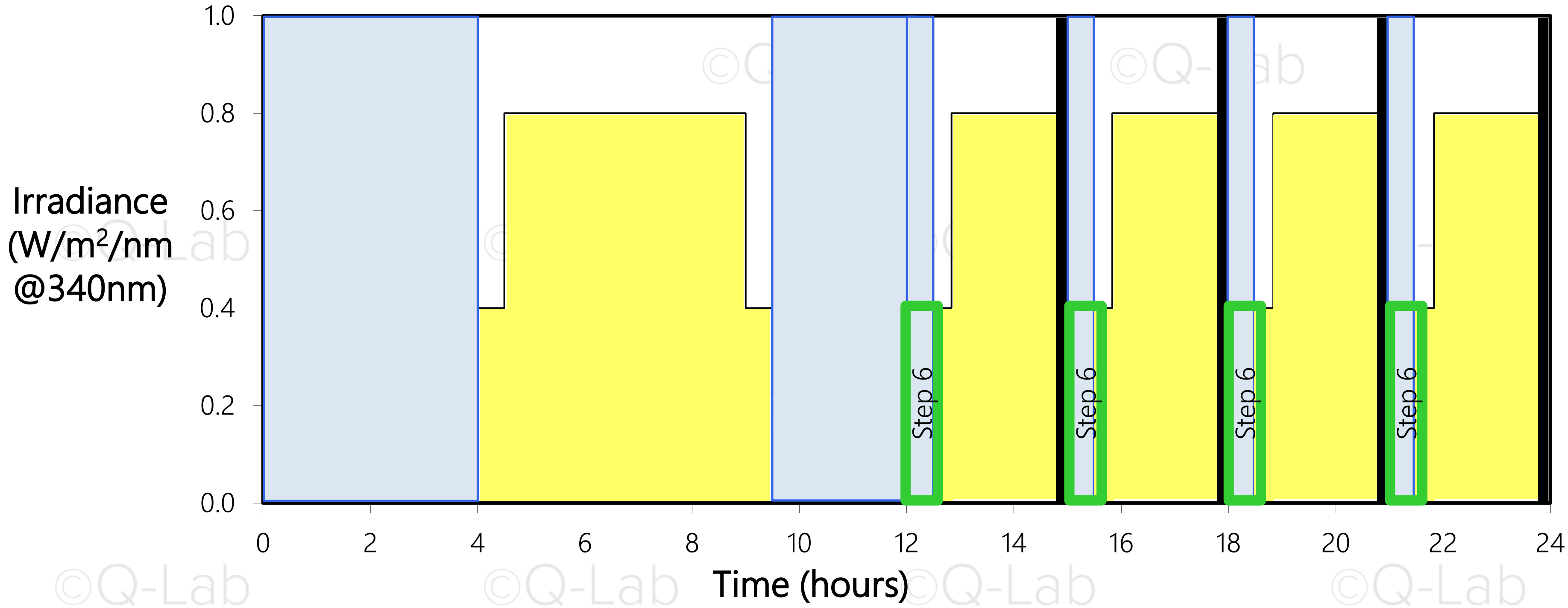
Step 6: Short Rain Event



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Step 6

30 min | **Dark + Spray**

Air = 40 °C | **RH = 95%+**

Purpose: Simulate Short Water Event

- Event such as a night with little condensation or brief rain event
- 30 minutes only creates water uptake in surface layers
- Not enough time to permeate lower layers

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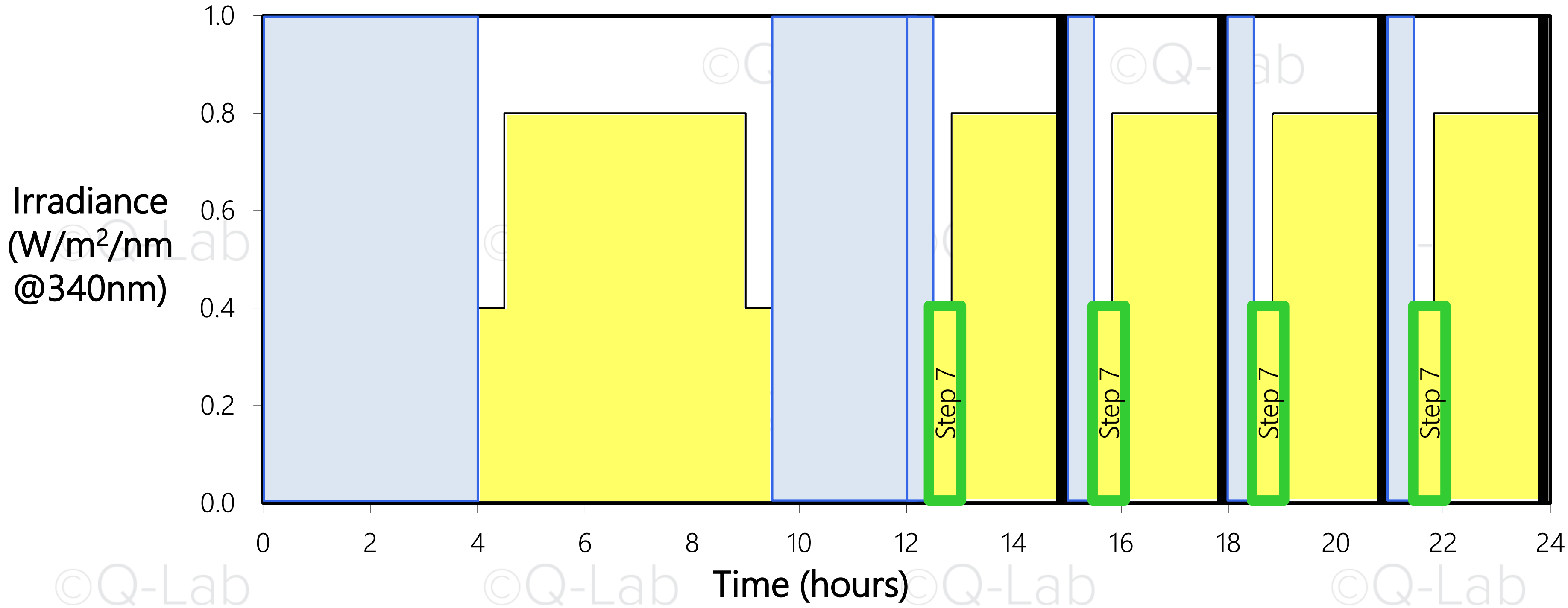
Step 7: Controlled Drying



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Step 7

20 min | **Light 0.40 W/m²/nm**

BP = 50 °C | **Air = 42 °C** | **RH = 50%**

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Purpose: Remove water from polymer at controlled rate

- Similar to Steps 2 and 4, but shorter
- Because Step 6 was short, Step 7 can also be short

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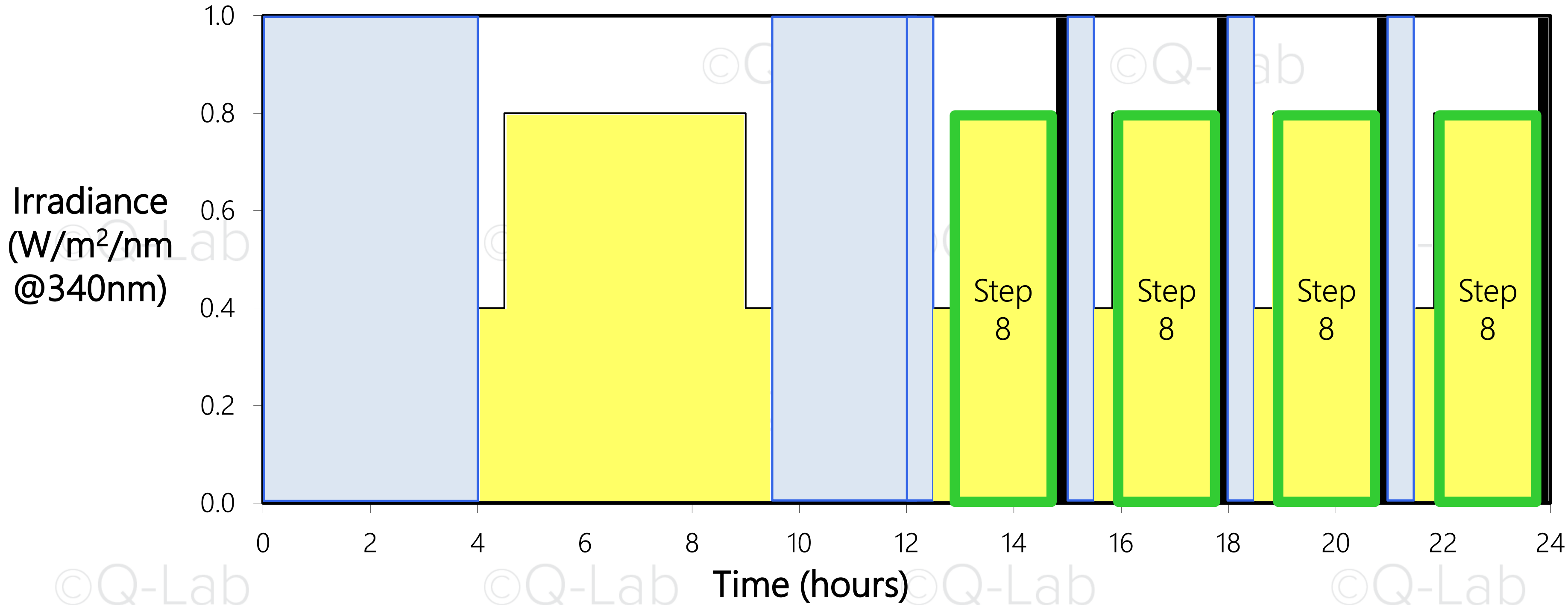
Step 8: Shorter Daylight



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Step 8

120 min **Light** **0.80 W/m²/nm**

BP = 70°C **Air = 50°C** **RH = 50%**

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Purpose: Rapid heating to create mechanical stresses

- Same conditions as Step 3, but shorter
- Time is short to promote rapid thermal cycling
  - High irradiance also contributes to photochemical damage
  - That is a secondary purpose

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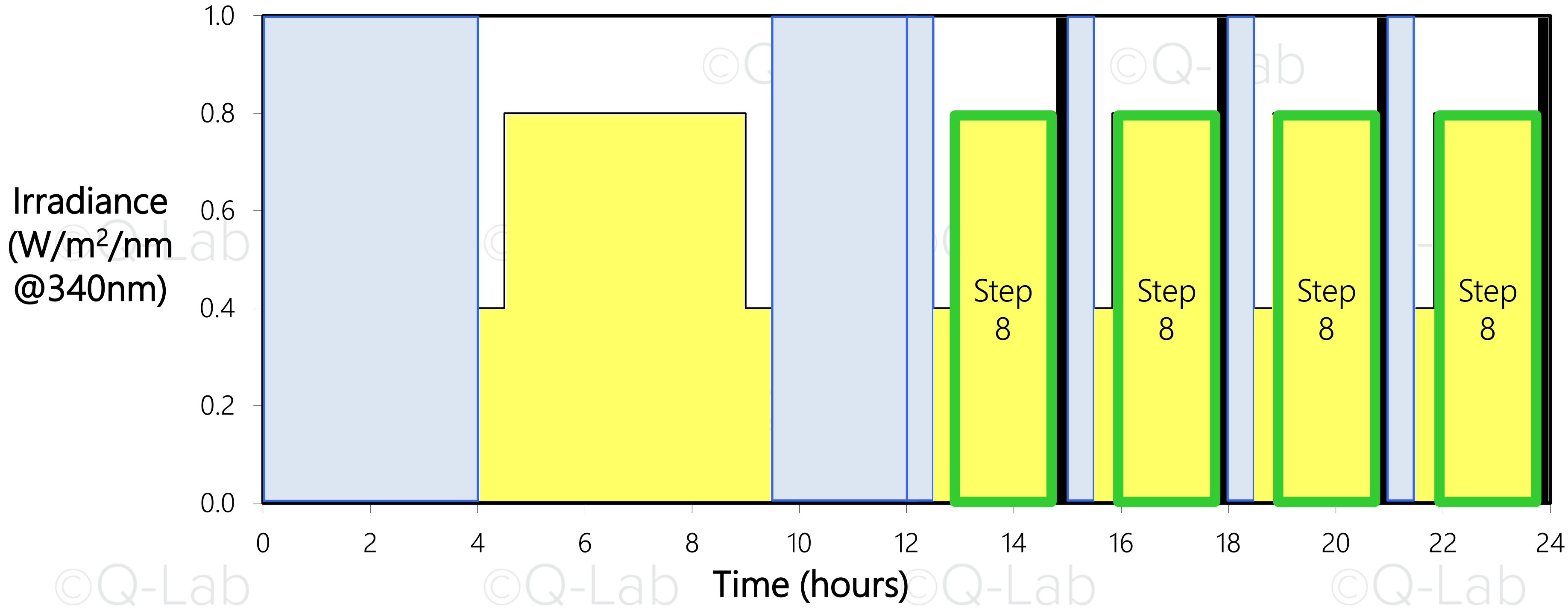
Step 9: Dark Relaxation



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Step 9

10 min **Dark**

Air = 40°C **RH = 50%**

Purpose: Total relaxation from all stress

- Natural exposure has frequent periods with no stress from sunlight, temperature or water
- A laboratory exposure with no periods of total relaxation might cause unnatural effects, like cracking

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