

Essentials of Laboratory Weathering

实验室加速老化测试的本质

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What We Will Talk About

- Basics of Weathering
老化的基础知识
- Why Perform Laboratory Weathering?
为什么要做实验室老化测试？
- Laboratory Weathering Testing
实验室老化测试
 - Xenon 氙灯
 - Fluorescent UV 荧光紫外
- Elements of an Effective Testing Program
有效的测试方案

What We Will Talk About

- Basics of Weathering

老化测试的基本概念

- Why Perform Laboratory Weathering?
- Laboratory Weathering Testing
 - Xenon
 - Fluorescent UV
- Elements of an Effective Testing Program

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.

由于暴露于阳光中受到紫外辐射，以及热（包括温度循环）和水（主要是湿度、露水和雨水）而导致的材料性能的变化。

Forces of Weathering

Know Your Enemy!

- Sunlight

阳光

- Heat

热

- Water

水



**Other factors can impact weathering as well but we will not focus on those today*

Sunlight



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Sunlight

- A form of energy

能量的形式

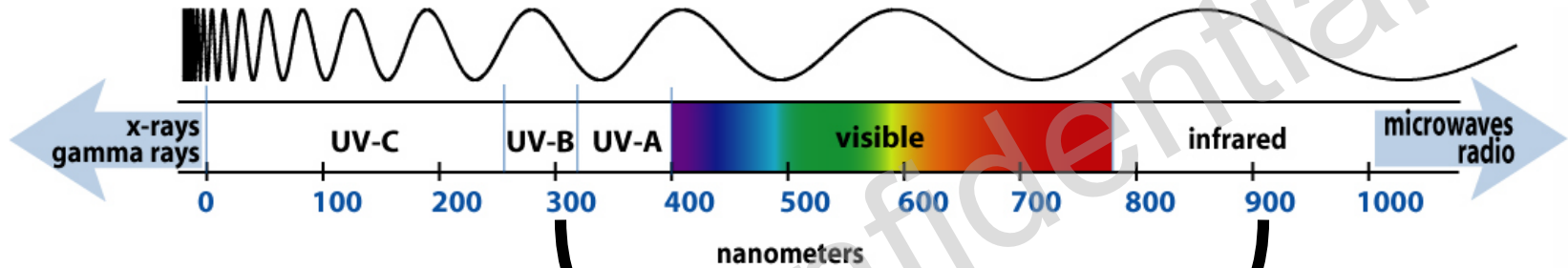
- Electromagnetic radiation

电磁辐射

- Usually described in terms of irradiance & wavelength (λ)

通常用辐照度和波长进行描述

Electromagnetic Spectrum



Sunlight

UV	295-400 nm	~7%
Visible	400-800 nm	~55%
IR	800-3000 nm	~38%

Even though it is only 7% of sunlight's total radiant energy...

即使只占太阳总辐射的7%

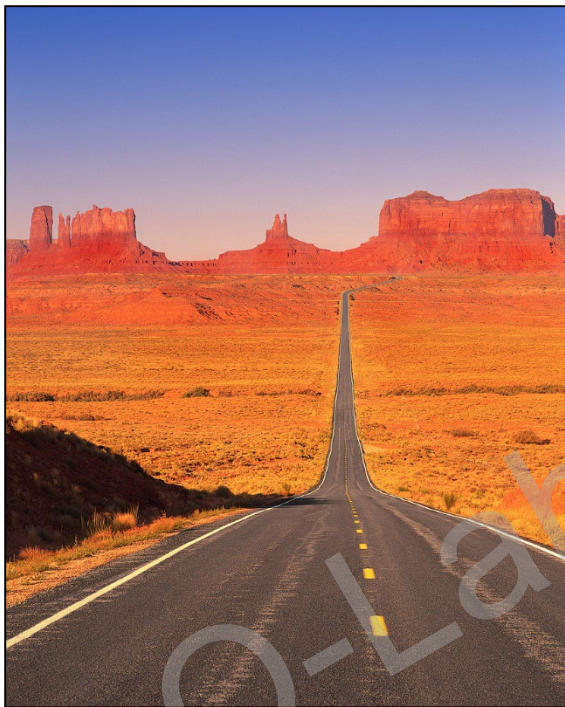


UV causes virtually all polymer degradation!

紫外线几乎导致所有聚合物降解

Irradiance

辐照度



Irradiance¹ is the rate at which light energy falls on a surface, per unit area

[W/m²] or [J/s·m²]

辐照度 – 单位面积上的功率

Spectral irradiance² is the irradiance of a surface per unit wavelength

[W/m²/nm]

光谱辐照度 – 某波长下的辐照度

Radiant exposure¹ (or radiant dosage) is irradiance over a period of time

[J/m²] or [W·s/m²]

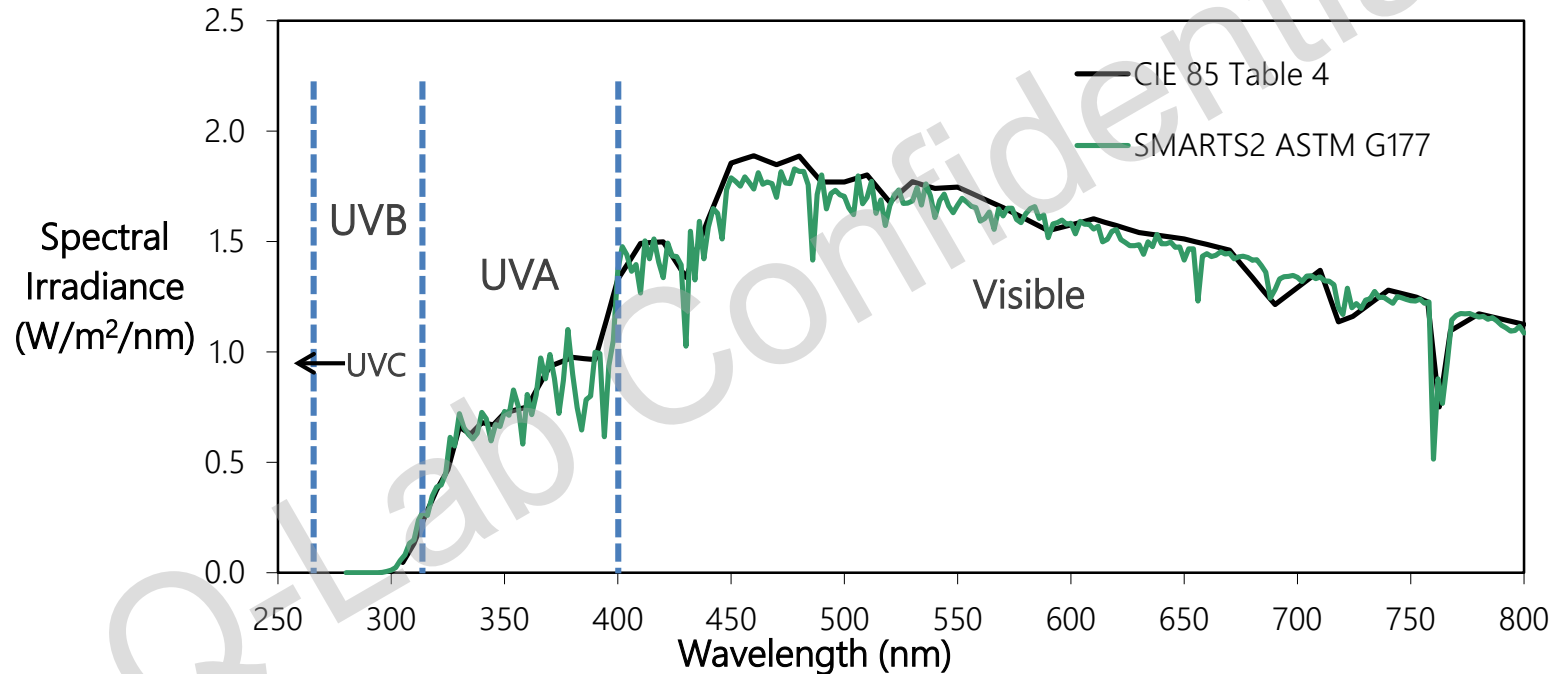
1 ASTM G113 – Terminology

2 ISO 9288 – Physical quantities and Definitions

辐射曝晒总量 – 辐照度和时间的乘积

Spectral Power Distribution (SPD)

Noon Summer Sunlight 夏季正午日光



SPD: The absolute or relative radiant power emitted by a source, or incident upon a receiver as a function of wavelength. (ASTM G113)

Spectrum Modifiers

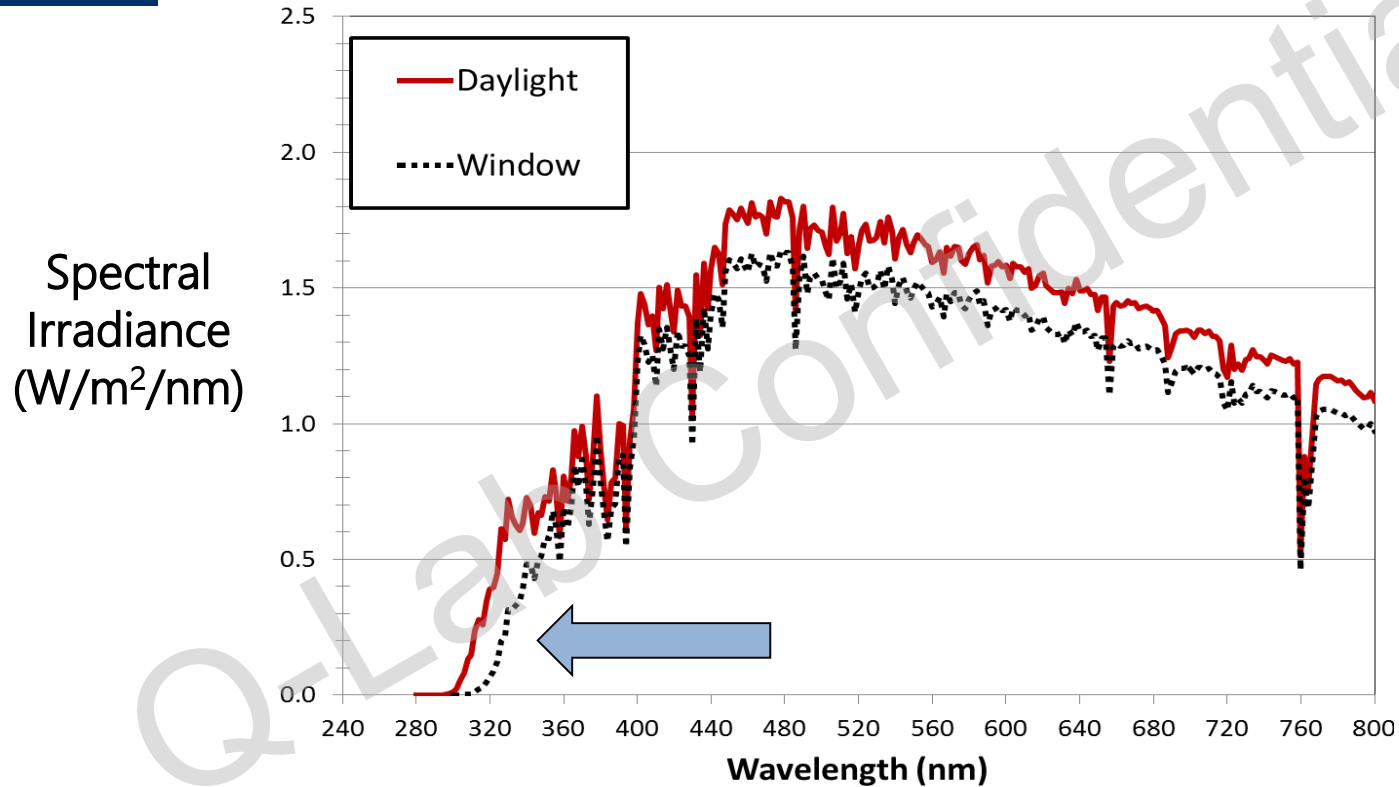
光谱变化



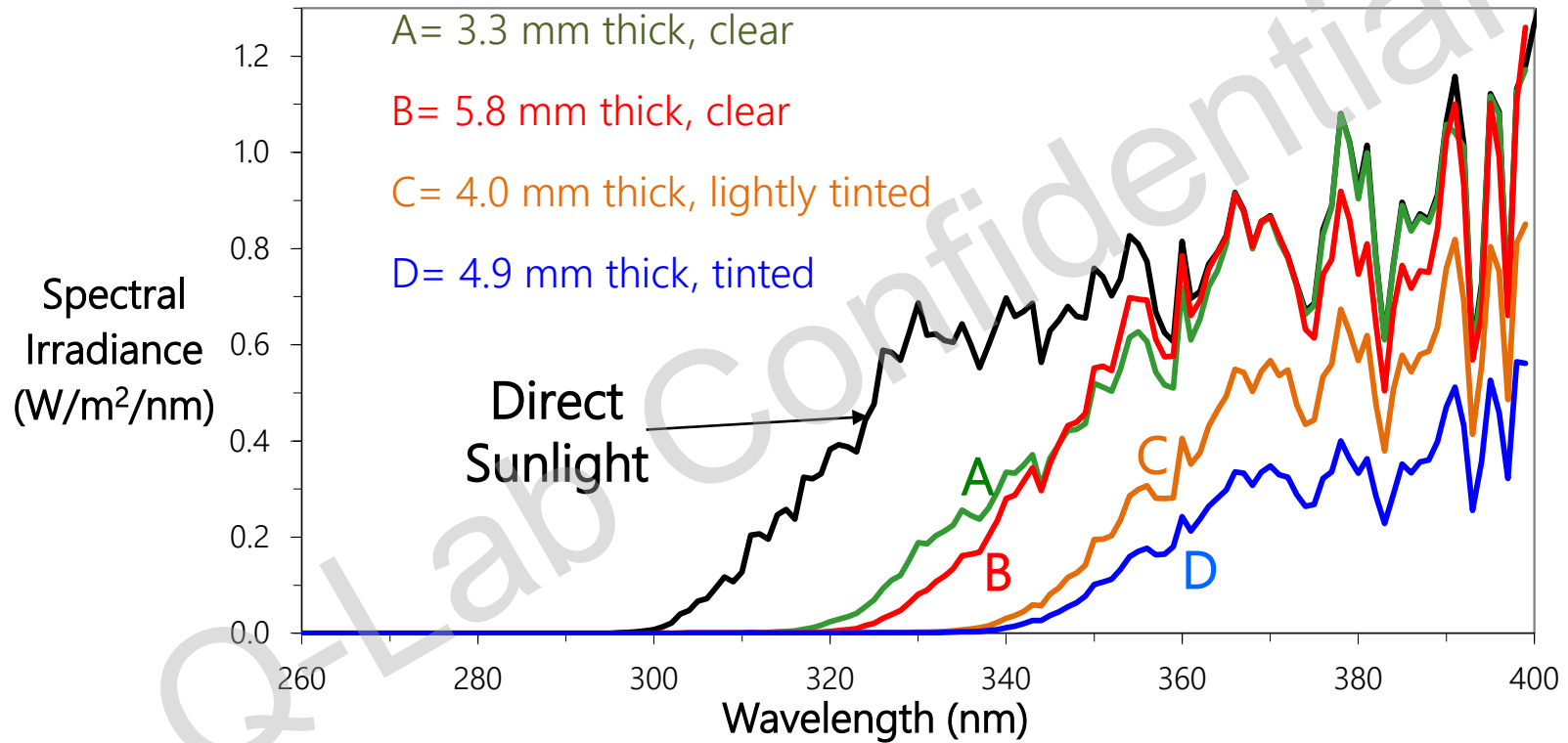
- Sun angle 太阳角度
 - Time of Year (e.g. summer)
 - Time of Day (e.g. noon)
 - Latitude
- Altitude 海拔

Sunlight Through Window Glass

透过窗玻璃的阳光



Sunlight Through Automobile Glass 阳光透过不同车玻璃



Heat



Heat Effects

热效应

- Elevated specimen temperature

样品温度升高

- Dimensional change

形变

- Evaporation

蒸发

- Thermal aging

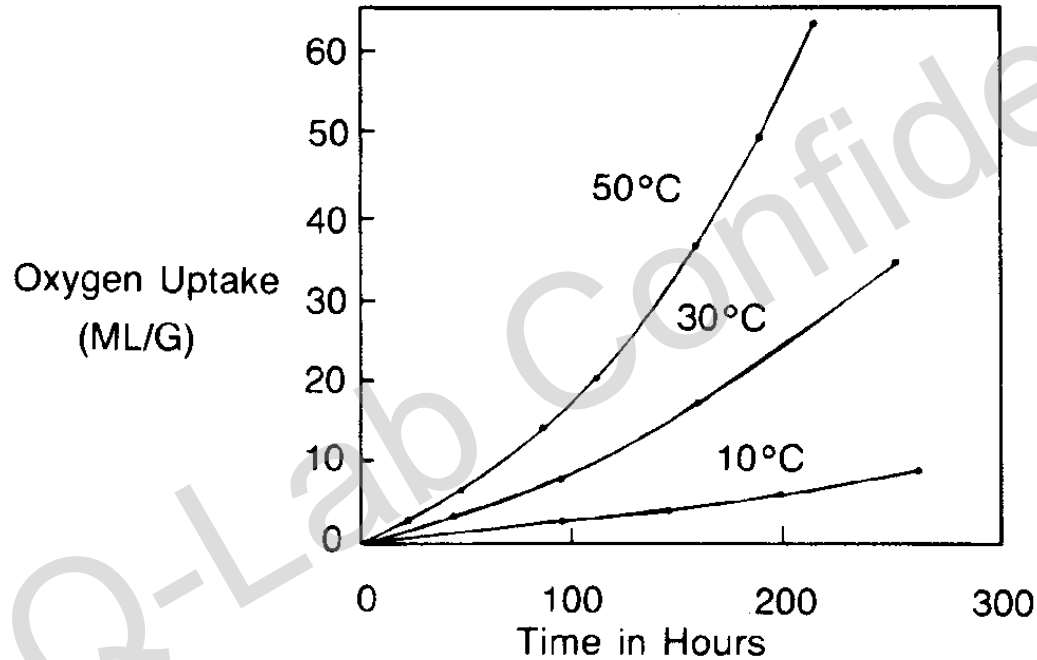
热老化

- Thermal cycling

热循环

Effect of Temperature: 温度影响

Oxidation Rate of Polyethylene 聚乙烯的氧化速率



**Time In Hours Exposed to UV lamps*

Thermal Cycling in Florida

佛罗里达热循环

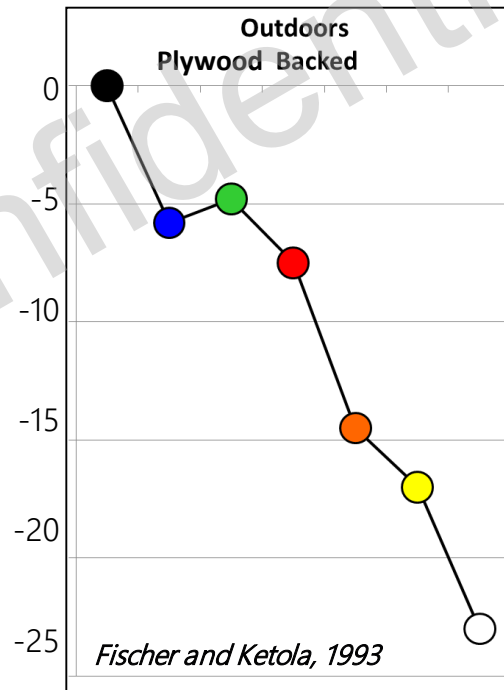
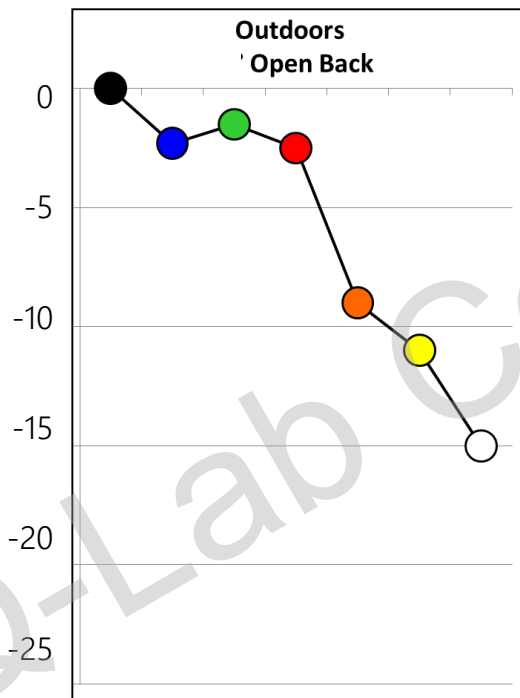
- 75°C to 25°C in 2 minutes
2分钟内75°C to 25°C
- Causes physical stress
造成物理应力
- Affects coatings on plastics and assemblies
影响塑料和组件上的涂层



Temperature and Color 温度和颜色

Darker Colors Have Higher Temperatures! 深色样品有更高的温度

Temperature Δ
($^{\circ}\text{C}$)



Heat behind Window Glass

在窗玻璃后面的热量



Temperature of automobile interior components behind window glass can exceed 100 °C

车窗玻璃后的汽车内饰部件温度可超过100°C

Water



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Major Effects of Water

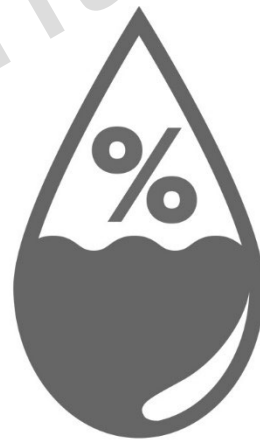
潮湿的主要影响

- Chemical Reactions 化学反应
 - Reactions in solution
溶液中的反应
 - Facilitates reaction via increase in oxygen transport
通过增加氧气输送促进反应
- Physical Effects 物理反应
 - Erosion 侵蚀 (雨水冲刷)
 - Absorption/freeze-thaw 吸收/冻融
 - Thermal shock 热冲击
 - Impact (material loss) 冲击 · 剥离脱落



Humidity 湿度

- Measure of amount of water in air
在空气中的水含量
- Can lead to physical stress
可能导致形变
- Humidity affects products both indoors and outdoors
湿度影响室内室外的产品
- Often expressed as Relative Humidity (RH), where 100% is the most water that air of a given temperature can hold
用相对湿度表示，100%RH是在特定的温度下能达到的最大水含量



Rainfall 降雨

- Surface effects 表面效应
 - Washing away surface layers
冲洗表层
 - Chalking
粉化
 - Dirt removal
清洗
- Thermal shock
热冲击



Dew 露水

- Moisture from the atmosphere that forms in the form of small drops upon any cool surface

大气中的水分，以小水滴的形式在任何凉爽的表面上形成

- High O₂ content

富含氧

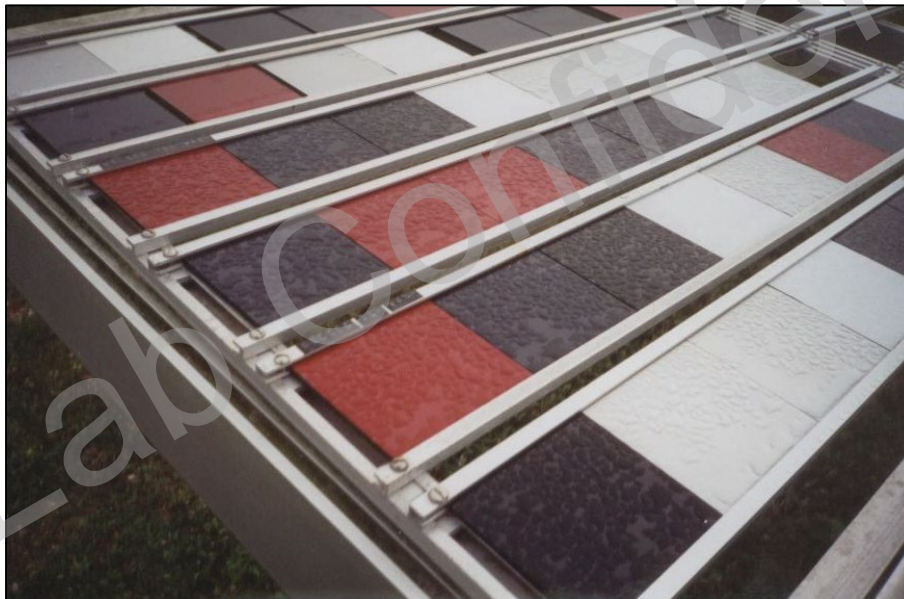
- Long dwell time

停留时间长



Dew, not Rain, Is the Source of Most Outdoor Wetness!

露水，不是雨水，是户外主要的潮湿因素



Dew Is Not Simulated in Many Accelerated Lab Weathering Tests!

露水在实验室加速老化设备中很难模拟

Don't Underestimate the Effect of Moisture!

不要低估潮湿的影响

- Changes the **rate** of degradation
改变老化的速率
- Changes **mode** of degradation
改变老化的模式
- Difficult to accelerate
很难加速

Summary: Forces of Weathering

- Sunlight 阳光
 - UV light causes virtually all polymer degradation
紫外造成聚合物老化
 - Small changes in material formulation and/or spectrum can have large effects on material degradation
很小的配方改变或者光谱变化对材料老化会有很大的影响
- Heat (Temperature) 温度
 - Sunlight + Heat = increased rate of degradation
阳光+热 = 老化速率的提高
 - A material's color strongly affects how hot it will get in sunlight
材料的颜色会影响其在阳光下的温度
- Water (Moisture) 潮湿
 - Sunlight + Heat + Water = Weathering
光+热+水 = 耐候老化
 - Dew, not Rainfall, is the source of most outdoor wetness
露水 · 不是雨水 · 是户外潮湿的主要原因
 - Products outdoors are wet much longer than you think
户外产品处于潮湿的时间远比你想象的要长

Weathering includes synergistic effects between these factors!
老化包括了以上因素的协同效应

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- Why Perform Laboratory Weathering?

为什么要做实验室加速老化测试？

- Laboratory Weathering Testing
 - Xenon
 - Fluorescent UV
- Elements of an Effective Testing Program

Why Test? 为什么要测试？

- Meet specifications

满足规范

- Avoid catastrophes

避免灾难

- Enhance your reputation

提高声誉

- Verify supplier claims

验证供应商

- Improve product durability

提高产品耐候性

- Save on material costs

材料成本下降

- Expand existing product lines

扩大现有产品线

- Enter new markets

进入新市场

- Outrun the competition

超越竞争对手

- Stay ahead of regulations

保持领先于法规

Laboratory Testing is a Tool for Directional Decision-Making

实验室测试是定向决策的工具

Laboratory Accelerated tests can help you:

实验室加速测试可以帮你：

- Make decisions better and/or faster
做更好更快的决策
- Reduce risk of making bad decisions
降低做出错误决策的风险
- Reduce risk of making decisions too slowly
降低决策速度过慢的风险

What Kind of Test Should I Run?

我应该做什么测试？

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control 质量控制	Pass / fail 通过/失效	<ul style="list-style-type: none">• Defined 确定的• Short 短时间	Material specification 材料规格

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Correlative 相关性	Rank-ordered data 排序相关	<ul style="list-style-type: none">• Open-ended 不确定• Medium 中等时间	Natural exposure (Benchmark site) 自然曝晒 (户外基准点)

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Predictive 寿命预测	Service life Acceleration factor 加速因子	<ul style="list-style-type: none">• Open-ended 不确定• Long 长时间	Natural exposure (Service environment) 自然曝晒 (实际环境)

What is Natural Weathering?

什么是自然老化

Outdoor exposure of materials to unconcentrated sunlight, the purpose of which is to assess the effects of environmental factors on various functional and decorative parameters of interest.

材料在室外暴露于真实阳光下，其目的是评估环境因素对各种功能和外观参数的影响。

Global benchmark weathering sites:

全球基准户外老化测试点：

- South Florida (Subtropical) 南佛州 (亚热带)
- Arizona (Dry Desert) 亚利桑那 (干燥沙漠)
- Midwest (Northern Industrial) 中西部 (北部工业园区)

Why Is Natural Weathering Important?

为什么自然老化如此重要？

- Natural weathering is more complex than artificial (laboratory) weathering

自然曝晒比人工加速老化更复杂

- Accelerated laboratory tests are not always realistic

加速老化测试不总是真实的

- Laboratory test accuracy should always be verified by outdoor tests

实验室测试数据总是要被户外数据验证

- Ongoing outdoor weathering tests build a library of highly valuable data, at low cost

户外数据可以建立高价值的数据库

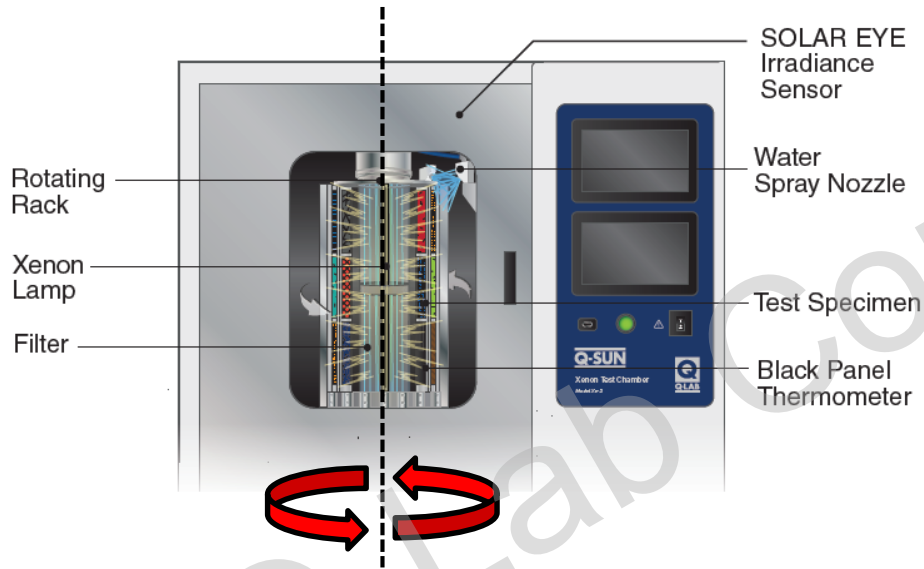
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- **Laboratory Weathering Testing 实验室加速老化测试**
 - Xenon 氙灯
 - Fluorescent UV 荧光紫外
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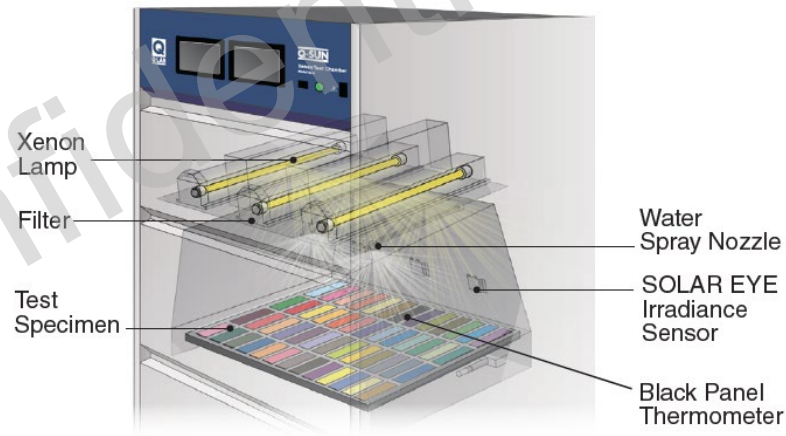
Xenon Arc Laboratory Weathering 氙灯老化

Xenon Arc Test Chamber

氙灯老化测试箱



Rotating Rack
转鼓式



Flat Array
平板式

Xenon Arc Lamps

氙弧灯管

Air-cooled



Water-cooled



Water-cooled
Assembly



Xenon Arc Spectra - Major Influencing Factors

氙灯光谱 - 主要的影响因素

- Optical filters

光过滤片

- Irradiance level (intensity)

辐照强度

- Wavelength at which irradiance is controlled (“control point”)

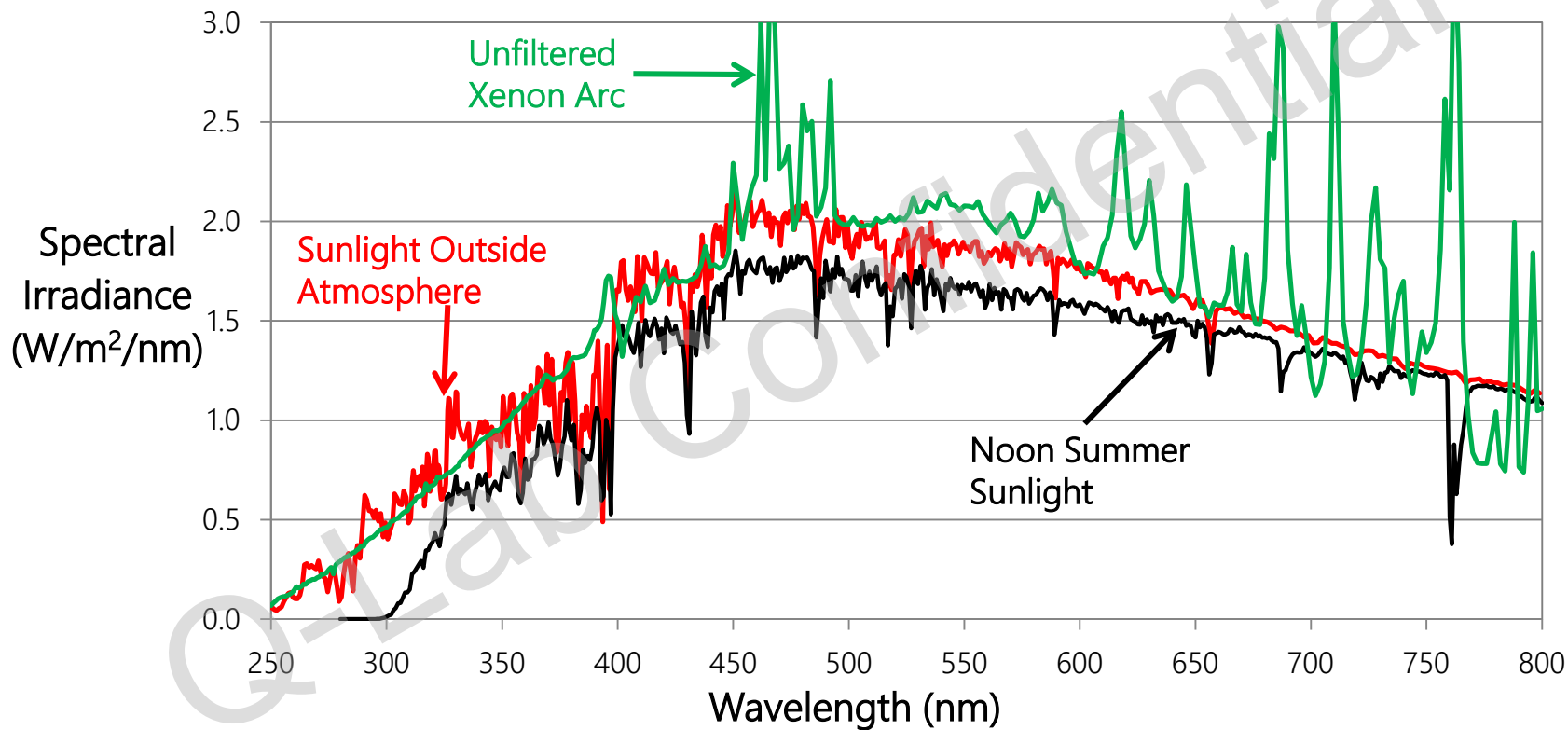
辐照度控制点

- Lamp aging

灯管老化

Unfiltered Xenon Arc vs. Sunlight

未过滤氙灯 vs. 太阳光



Overview of Filters

过滤片总结

- Daylight 日光
- Window 窗玻璃
- Extended UV 紫外延展

Rotating drum "lantern"



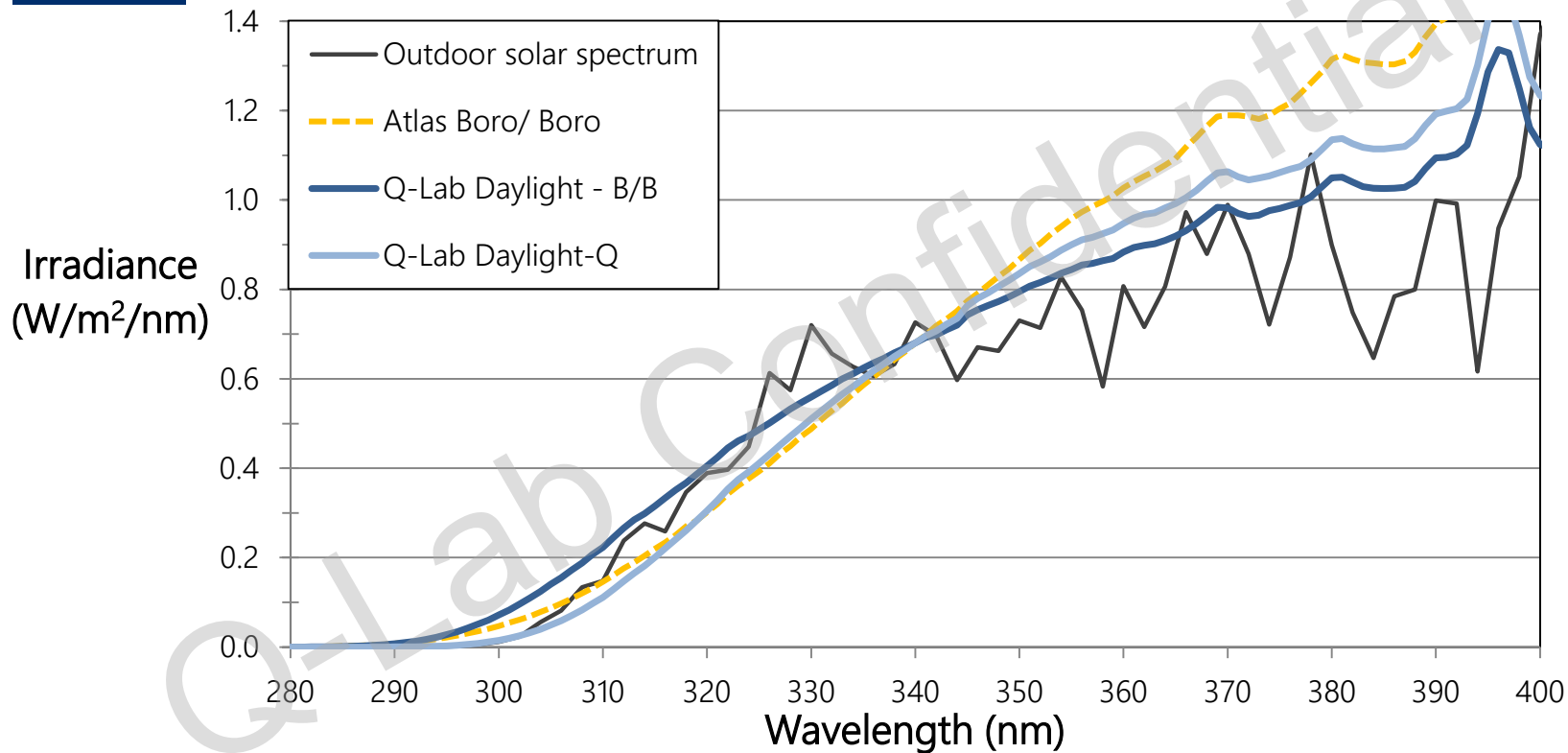
Flat array filter



**Other specialized filters used occasionally*

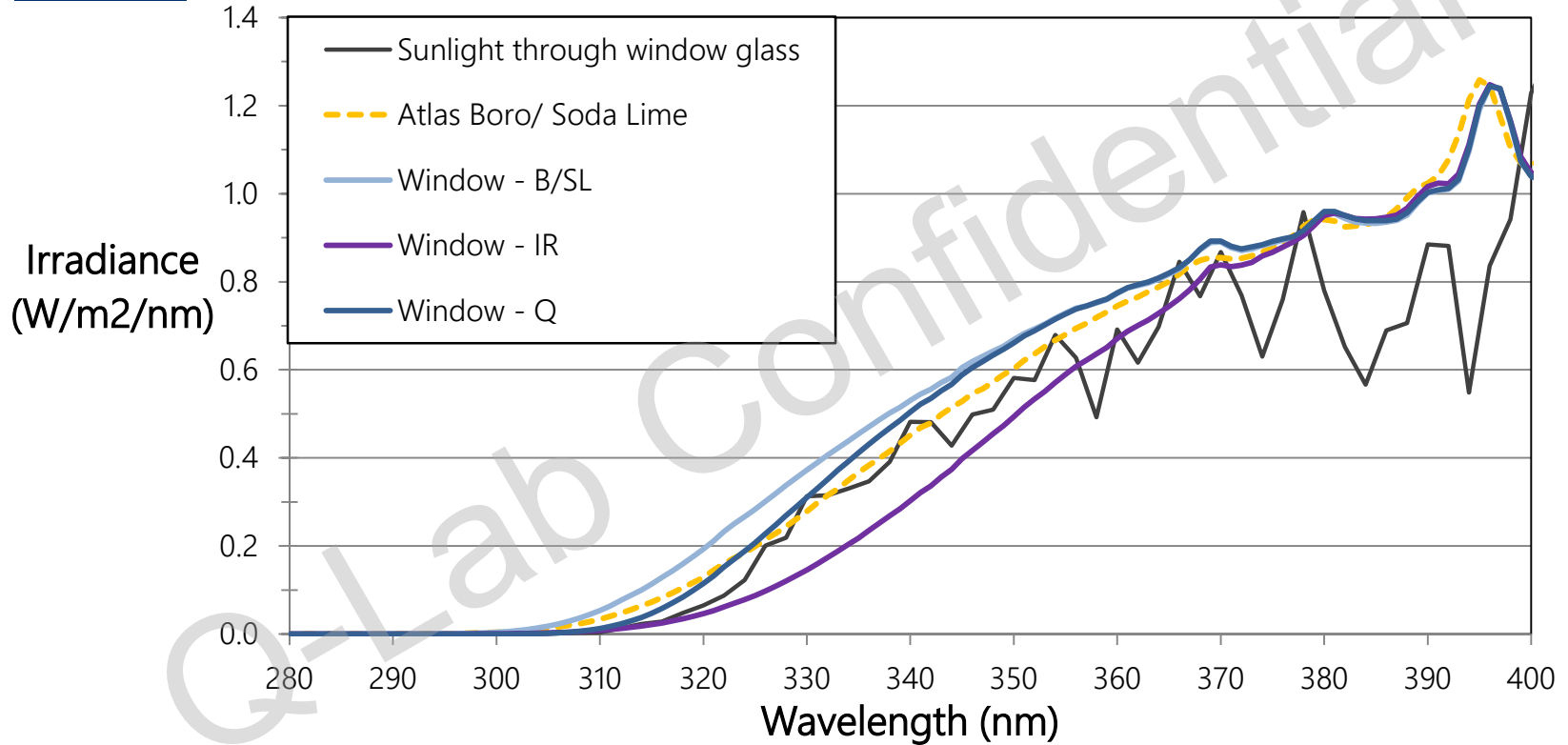
Daylight Filter Comparison

日光滤片的比较



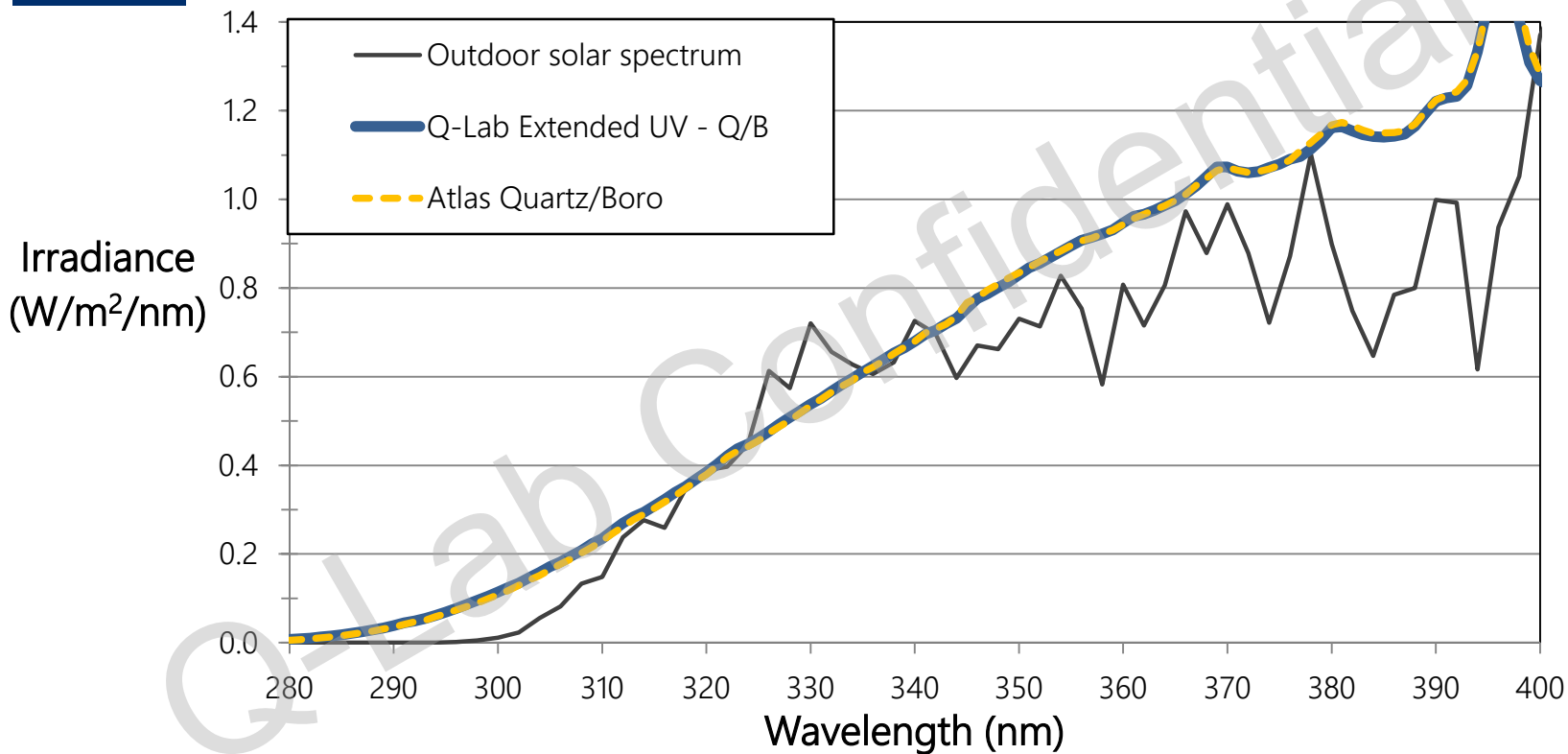
Window Filter Comparison

窗玻璃滤片的比较



Extended UV Filter Comparison

紫外延展滤片的比较



Optical Filter Aging - Water-Cooled vs Air-Cooled

滤镜老化 - 水冷 vs 风冷

- Filters for water-cooled lamp systems need to be replaced every 400-2000 hours

水冷灯管的滤镜需要每400-2000小时更换

- Contaminants, even in ultra-pure de-ionized water, reduce filter transmittance over time

污染物，即使在超纯去离子水中，也会随着时间的推移降低过滤器的透射率

- Almost all filters for air-cooled lamp systems do not age or need to be replaced

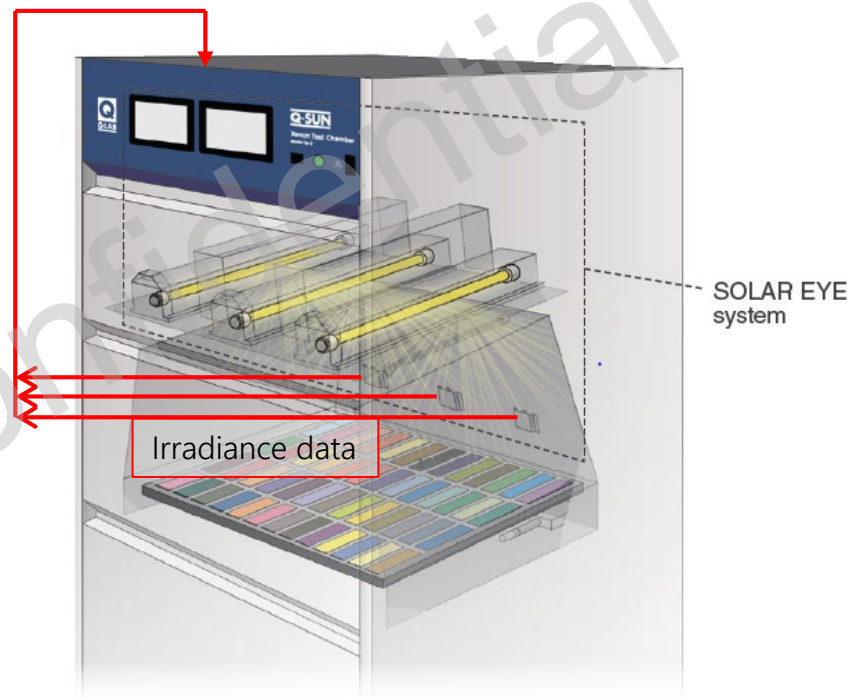
几乎所有的风冷的滤镜不老化，不需要更换

Q-SUN SOLAR EYE™

Irradiance Control

- Feedback Loop Control 闭环反馈
 - Xenon-arc lamp 氙灯
 - Light sensor 光探头
 - Control module 控制模块
- Wavelength at which irradiance is controlled is referred to as Control Point

控制辐照度的波长称为控制点



Irradiance Control Point Options

辐照度控制选项

- Narrow Band 窄带
 - 340 nm
 - 420 nm
- Wide Band 宽带
 - Total UV TUV (300-400 nm)
 - Global (300-800 nm) – not recommended 不推荐300-800nm控制
 - Shorter wavelengths cause more photodegradation
短波造成光老化
 - Fails to account for xenon lamp aging
无法弥补灯管老化产生的问题

Why Is Choice of Control Point Important?

为什么控制点如此重要？

- Xenon Arc lamps age with use
随着使用氙灯会老化
- Spectral shift limits useful lamp life
光谱漂移限制了灯管寿命
- Controlling irradiance in **wavelength region of interest** maximizes repeatability and reproducibility
控制关注波长区域的辐照度可最大化测试可重复性和可再现性

Black Panel Temperature Control

黑板温度控制

- Most common in test standards

在测试标准中很普遍

- Approximates maximum specimen surface temperature

大概室样品表面的最高温度

- Can be used in combination with chamber air temp sensor and control

和箱体空气温度探头同时控制

Black Panel Temperature Sensors

黑板温度传感器

Panel	Construction	ASTM Designation	ISO Designation
 A photograph of an uninsulated black panel temperature sensor. It consists of a small black rectangular panel with a black handle and a blue probe with a silver tip. A blue pen with the 'q-lab.com' logo is placed next to it for scale.	Black painted stainless steel	Uninsulated Black Panel 非绝缘黑板	Black Panel 黑板
 A photograph of an insulated black panel temperature sensor. It features a black panel mounted on a white base, with a black handle and a blue probe. A blue pen with the 'q-lab.com' logo is placed next to it for scale.	Black painted stainless steel mounted on 0.6 cm white PVDF	Insulated Black Panel 绝缘黑板	Black Standard 黑板

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

To maximize acceleration, use maximum service temperature

使用最大的环境温度来加速

To **minimize** error, *DO NOT* exceed maximum
service temperature

为最小化测试错误，请勿超过最高工作温度

Chamber Air Temperature Control

空气温度控制

- Required by certain test methods
有些标准要求
- Necessary for control of relative humidity (RH)
湿度控制时候是需要空气温度控制的
- Sensor must be shielded from light
探头必须避光
- BP temp always hotter than chamber air temp from absorbing radiant heat
黑板温度在光照下大于空气温度

Relative Humidity Control

相对湿度控制

- Required by many test methods

很多测试需要湿度控制

- Textiles 纺织
- Automotive 汽车

- Many xenon testers can generate and control relative humidity

很多设备可以控制相对湿度

- Boiler-type system 蒸汽
- Nebulizer system 超声波

- For many durable materials, RH makes very little difference compared to spray and condensation

对很多耐候产品，相较于水喷淋和冷凝，湿度产生的作用很小

Xenon Arc Water Spray

氙灯水喷淋

Front spray 前喷

- Primary method of water delivery
水施加的主要方法
- Calibration technique for front spray recently developed (ASTM D7869)
ASTM D7869对喷淋收集量的校准

Back spray 背喷

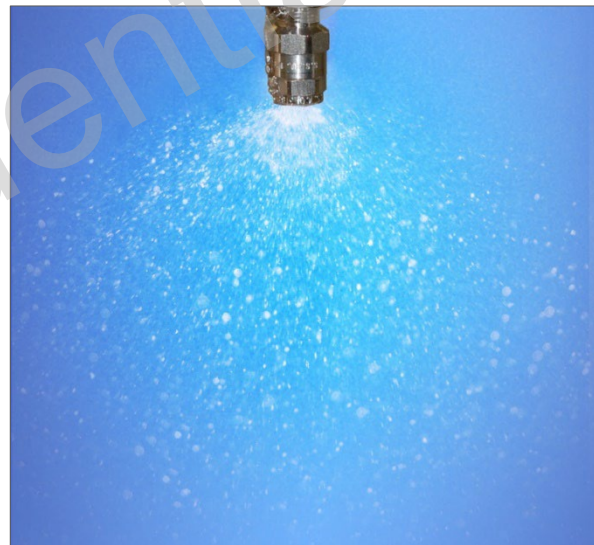
- Result of a failed experiment intended to generate condensation;
persists in some standards
为产生冷凝而开发的失败实验，一些标准中存在

Dual spray 双喷淋

- For delivering a 2nd solution, e.g. acid rain, soap
施加第二种溶液，比如酸雨

Immersion (Ponding) 水浸

- Alternative to front spray called out in some standards
替代某些标准中规定的前喷淋



Xenon Arc Summary

- Best simulation of full-spectrum sunlight
全光谱太阳光模拟
- Lamps experience aging (fulcrum effect)
灯管老化 (支点效应)
- Temperature effects
温度影响
- Water spray and RH control
水喷淋和湿度控制
- Additional cost, maintenance, and complexity compared to fluorescent UV testers
和荧光紫外相比 · 成本更高 · 维护更复杂

Q-SUN Xenon Arc Testers

Xe-1



Xe-2



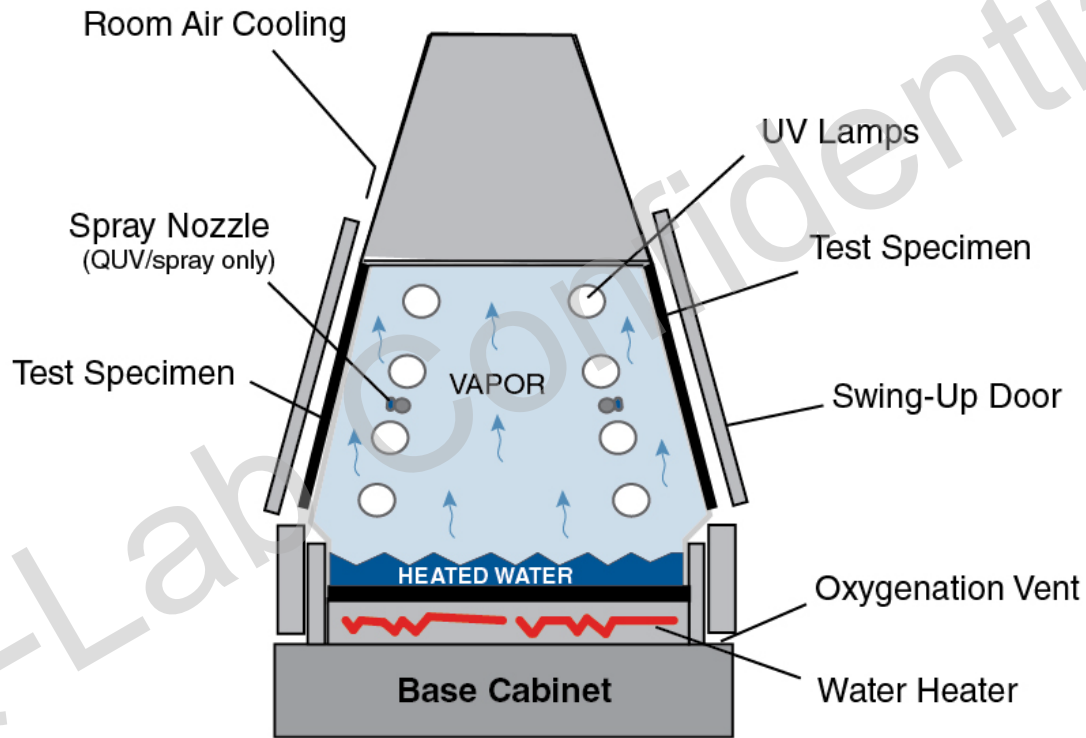
Xe-3



Fluorescent UV Laboratory Weathering 荧光紫外老化

Fluorescent UV Schematic

荧光紫外示意图



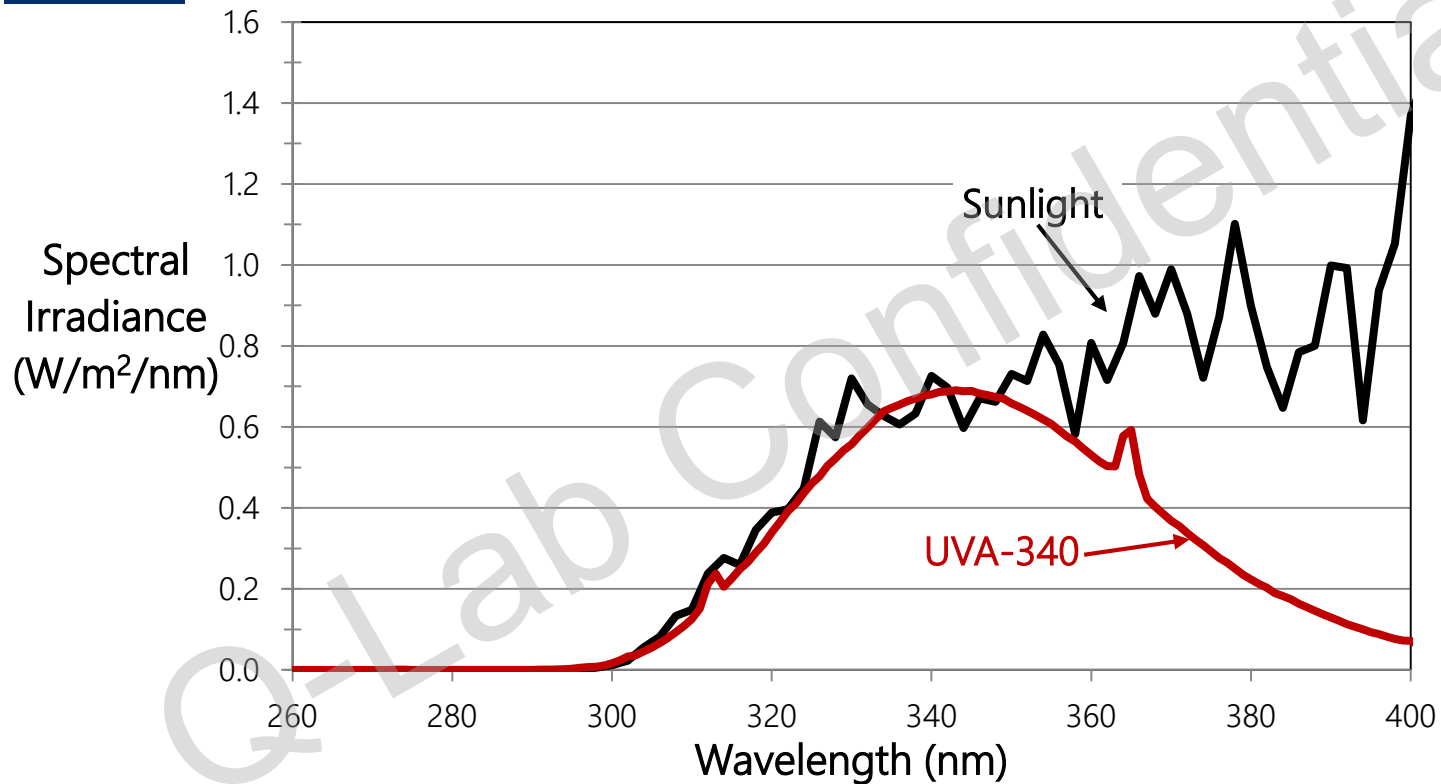
Fluorescent UV Lamps



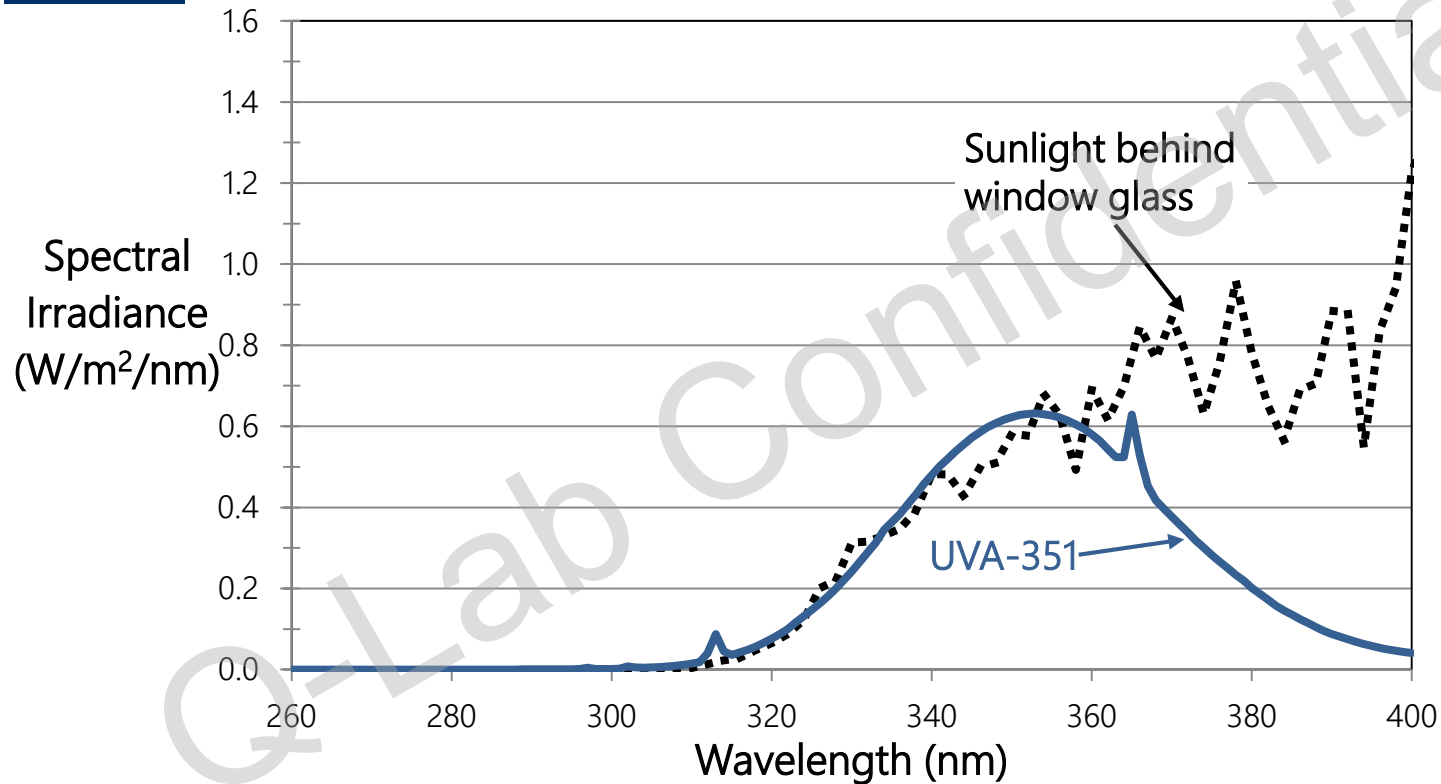
QUV Lamp Summary

- UVA-340 (Daylight UV)
- UVA-351 (Window UV)
- UVB-313EL/FS-40 (Extended UV)
- UVC-254 (UVGI)
- Cool White (Indoor, office)

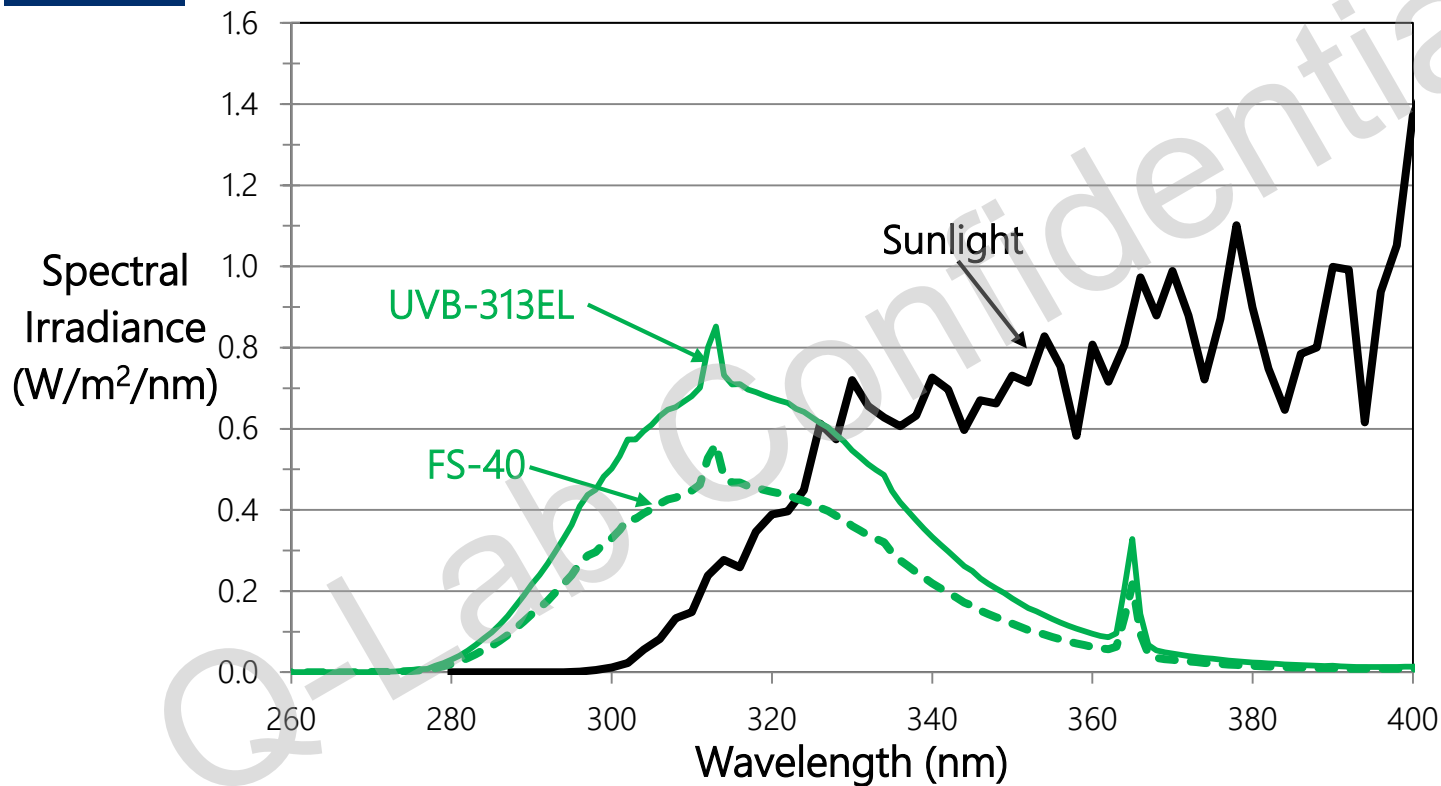
UVA-340 Lamps



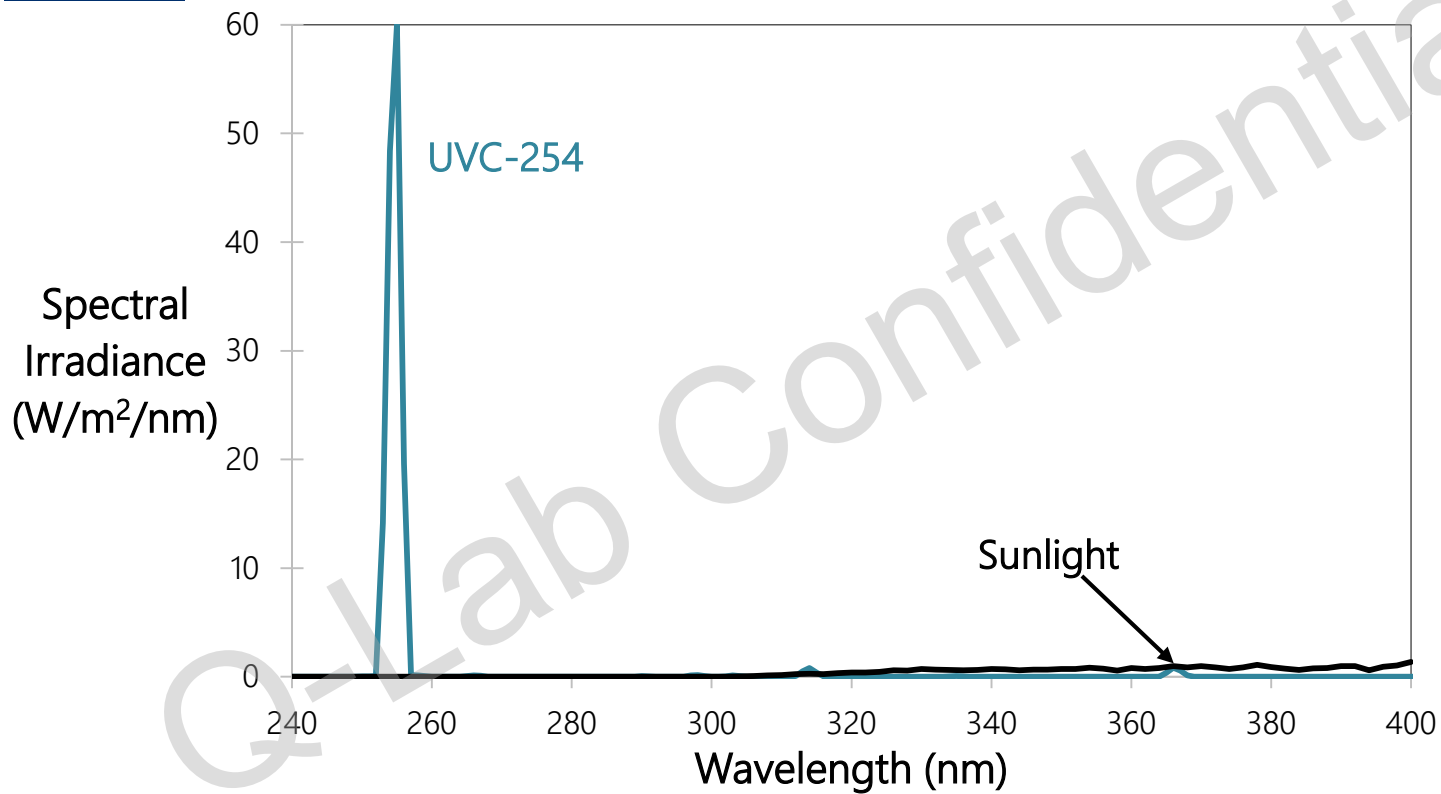
UVA-351 Lamps



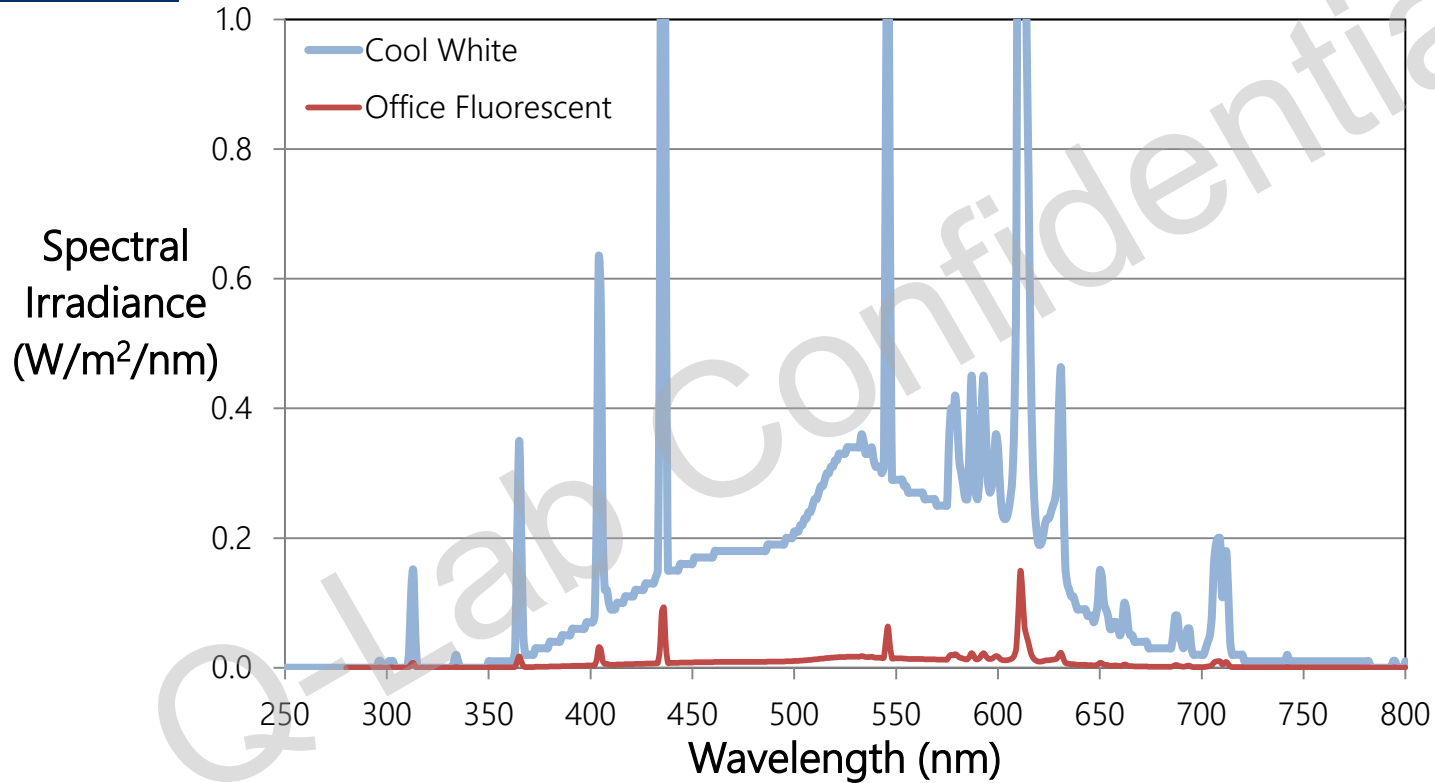
UVB Lamps



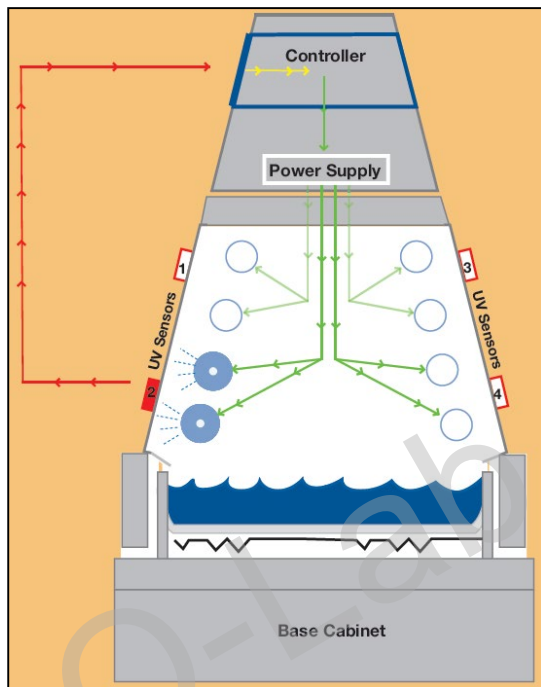
UVC Lamps



Cool White Lamps



QUV SOLAR EYE™ Irradiance Control



Feedback Loop Control 闭环反馈控制

- Fluorescent UV lamp 紫外灯
- Light sensor 光探头
- Control module 控制模块

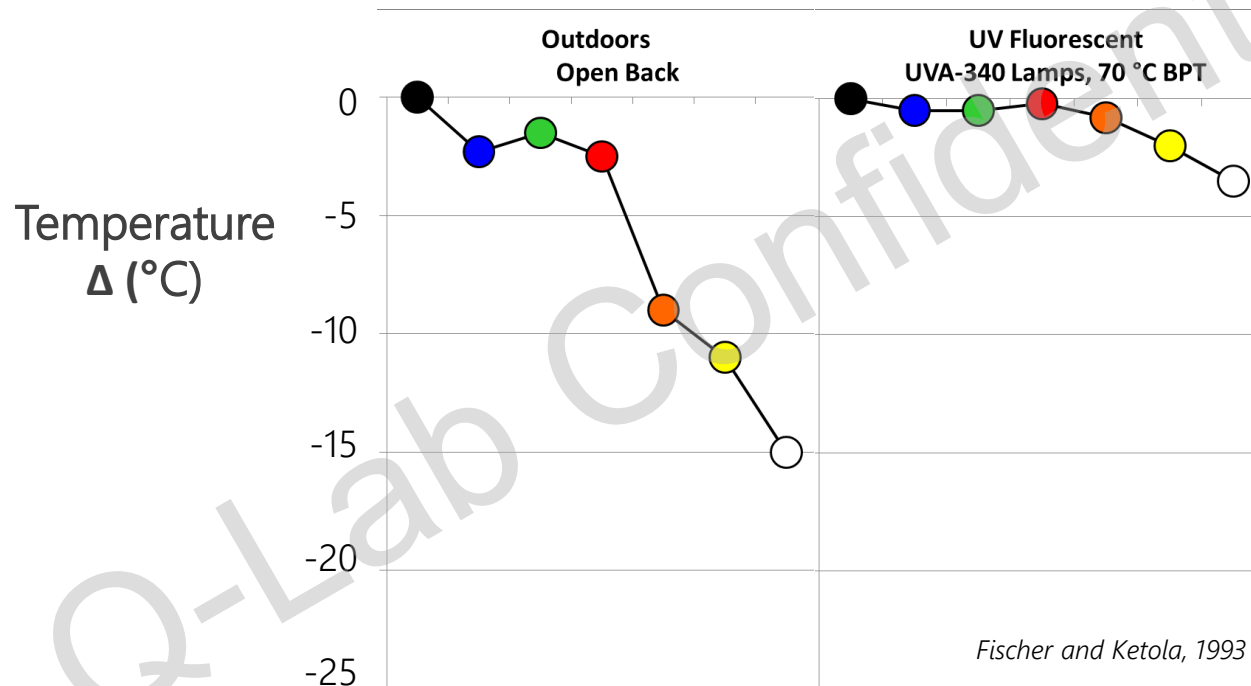
Fluorescent Lamp Advantages

荧光紫外灯优势

- Fast Results
快速结果
- Simplified irradiance control
简化辐照度控制
- Very stable spectrum – no aging
光谱稳定 – 不老化
- Low maintenance
低维护
 - Simple calibration 校准简单
- Low price and operating cost
低购机成本和运行成本
- Simple and easy to maintain
维护简单

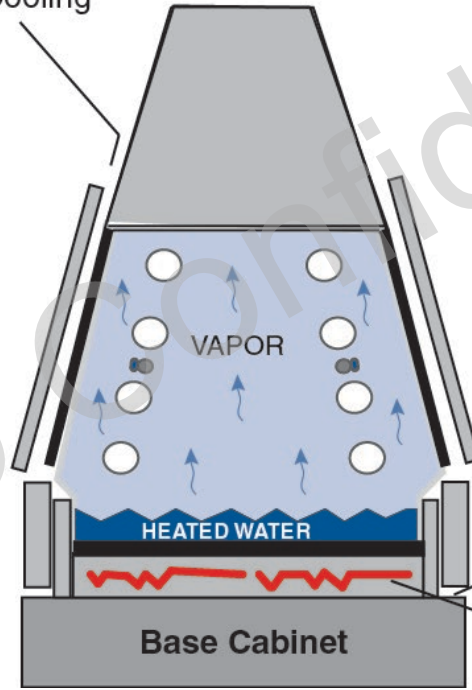
Temperature & Color 温度和颜色关系

Temperature difference between colored panels and Black Panel



Condensation 冷凝

Room Air Cooling



Oxygenation Vent

Water Heater

Condensation Advantages

冷凝优势

- Closest match to natural wetness
充分模拟户外潮湿
- Best way to accelerate water in an laboratory tester
实验室测试最好的水加速
- Elevated temperature
升温
- High O₂ content
高氧含量
- Tester performs distilling – you cannot deposit debris on specimens! Water is guaranteed to be clean.

样品表面无污染 · 冷凝产生蒸馏水



Creating condensation in the QUV is easy and does not require expensive, pure water

Water Spray 水喷淋

- Ensures that parts get fully saturated
保证样品充分水饱和
- Creates erosion & thermal shock
产生腐蚀和热冲击



Creating spray in the QUV is difficult and relatively expensive
在QUV中做水喷淋是困难和昂贵的

Fluorescent UV Summary

- UVA-340 best simulation of short-wave UV

UVA-340灯管最好地模拟短波紫外

- UVB-313 fastest & most severe

UVB-313灯管老化测试快

- Stable spectrum – no aging

稳定的光谱 – 不老化

- No visible light

没有可见光

- Condensation realistic & rigorous

冷凝真实模拟露水，充分潮湿

- Water spray available but not RH control

有水喷淋但没有湿度控制

QUV Accelerated Weathering Tester

Model QUV/se



Fluorescent UV and Xenon Arc - Complementary Technologies

荧光紫外和氙灯 - 互补技术

Fluorescent UV

- UVA-340 best simulation of shortwave UV
- UVB-313 might be too severe
- No visible light
- Stable spectrum
- No RH control
- Condensation or water spray
- Inexpensive, simple to use

Xenon Arc

- Full spectrum (UV-Vis-IR)
- Best simulation of long wave UV & visible light
- Spectrum changes
- RH control
- Water spray
- More complex system

What We Will Talk About

- Basics of Weathering
- Why Perform Laboratory Weathering?
- Laboratory Weathering Testing
 - Xenon
 - Fluorescent UV
- Elements of an Effective Testing Program

有效测试项目的要素

What Kind of Test Should I Run?

我应该使用哪个测试？

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control 质量控制	Pass / fail 通过/失效	<ul style="list-style-type: none">• Defined 确定的• Short 短时间	Material specification 材料规格
Qualification / validation 验证	Pass / fail 通过/失效	<ul style="list-style-type: none">• Defined 确定的• Short 短时间	Reference material or specification 参比材料
Correlative 相关性	Rank-ordered data 排序相关	<ul style="list-style-type: none">• Open-ended 不确定• Medium 中等时间	Natural exposure (Benchmark site) 自然曝晒 (户外基准点)
Predictive 寿命预测	Service life Acceleration factor 加速因子	<ul style="list-style-type: none">• Open-ended 不确定• Long 长时间	Natural exposure (Service environment) 自然曝晒 (实际环境)

Putting It All Together

- Identify the kind of accelerated test

辨别加速测试的目的

- Outdoor data is imperative to correlative and predictive testing
户外数据对于相关性研究和寿命预测至关重要

- Identify service environment

识别环境因素

- Indoor or Outdoor 室内还是室外
- Wet or Dry 潮湿还是干燥
- Hot or Cool 热或冷

Putting It All Together

- Use Best Practices

最佳实践

- Run until a defined failure mode

一直测试到定义的失效模式出现

- Use multiple replicates

使用重复样

- Perform evaluations and reposition frequently

定期评估和轮换样品

- Pick an appropriate Test Architecture

选择适当的测试体系结构

- What does the standard say?

标准怎么说？

- Is full spectrum important?

全光谱重要么？

- How important is water uptake?

水吸收有多重要？

Thank you for your attention!

Questions?

Send your inquiry to:
kqu@g-lab.com

Q-LAB中国微信公众号及视频号: 耐候腐蚀测试技术

- ✓ 技术研讨会、网络研讨会信息
- ✓ 老化及腐蚀技术文章、最新测试标准解读等
- ✓ 参与视频直播- 设备维保操作培训
- ✓ 相关技术问题，也可通过平台留言，我们会在24小时内和您联系



微信公众号



微信视频号