TECHNICAL BULLETIN LU-8009

QUV & Q-Sun

A Comparison of Two Effective Approaches to Accelerated Weathering & Light Stability Testing

The Need For Testing

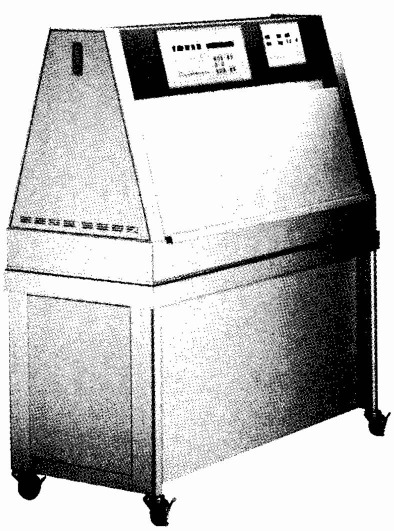
Weathering and light exposure are important causes of damage to coatings, plastics, inks, and other organic materials. This damage includes gloss loss, fading, yellowing, cracking, peeling, embrittlement, loss of tensile strength, and delamination. Even indoor lighting and sunlight through window glass can degrade some materials like pigments and dyes, causing fade and color change.

For many manufacturers, it is crucial to formulate products that can withstand weathering and light exposure. Accelerated weathering and light stability testers are widely used for research and development, quality control and material certification. These testers provide fast and reproducible results.

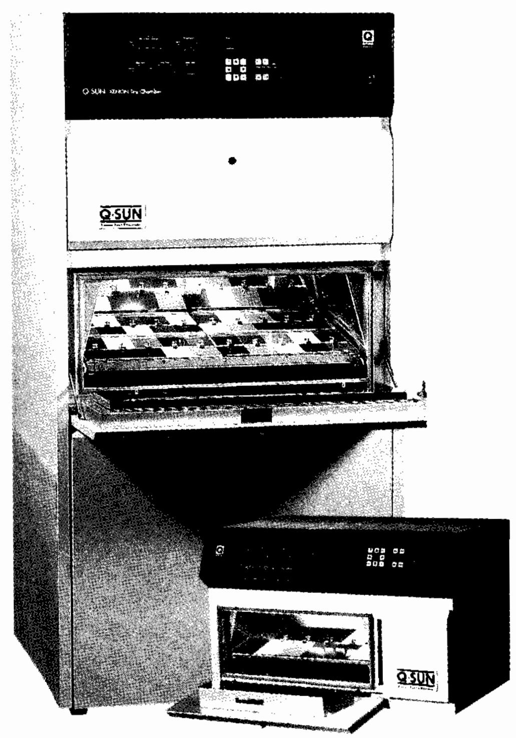
Two Different Approaches

In recent years, low-cost and easy to use laboratory testers have been developed, including the QUV Accelerated Weathering Tester (ASTM G154) and the Q-Sun Xenon Test Chamber (ASTM G155).

This paper will explore the ways in which these two testers differ, including emission spectra and method of moisture simulation. The inherent strengths and weaknesses of each tester will be discussed, including purchase price and operating costs. Guidelines will be given for which tester is generally recommended for a particular material or application.



The QUV is the world's most widely used weathering tester. It is based on the precept that, for durable materials, short-wave UV causes most weathering damage.



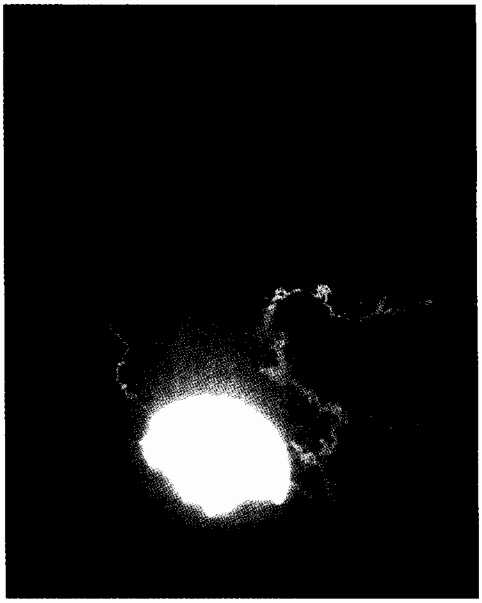
Q-Sun Xenon Test Chambers reproduce the full spectrum of sunlight, including ultraviolet, visible light, and infrared.

Q-PANEL
LAB PRODUCTS

Historical Perspective

While it is clear that weatherability and light stability are important for many products, the best way to test is sometimes controversial. Various methods have been used over the years. Most researchers now use natural exposure testing, the xenon arc, or the QUV Weathering Tester. Natural exposure testing has many advantages: it is realistic, inexpensive, and easy to perform. However, many manufacturers do not have several years to wait and see if a "new and improved" product formulation is really an improvement.

The xenon arc and QUV are the most commonly used accelerated testers. The two testers are based on completely different approaches. The xenon test chamber reproduces the entire spectrum of sunlight, including ultraviolet (UV), visible light, and infrared (IR). The xenon arc is essentially an attempt to reproduce sunlight itself, from 295 nm - 800 nm (see Figure 1 below).



The sunlight spectrum is comprised of different wavelengths that can affect materials differently.

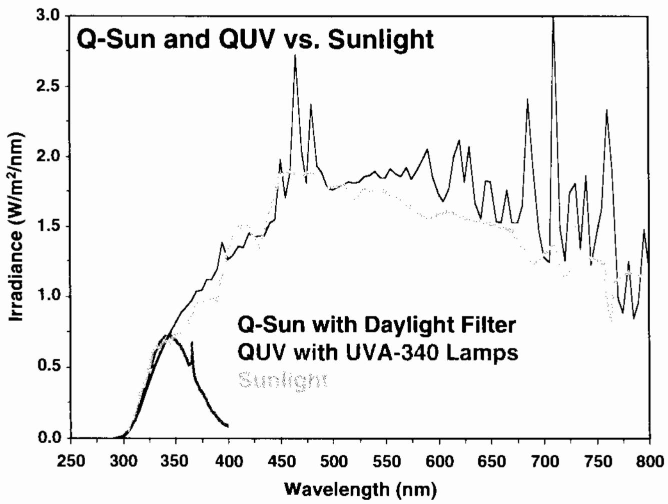


Figure 1. Sunlight compared to the QUV and the Q-Sun. The QUV provides the best available simulation of sunlight in the short-wave UV region from 365 nm down to the solar cutoff. However, it is deficient in longer wavelengths. The Q-Sun reproduces sunlight's full spectrum, which is critical for testing many products that are sensitive to long-wave UV, visible light, and infrared.

The QUV, on the other hand, does not attempt to reproduce sunlight, just the damaging effects of sunlight that occur from 300 nm - 400 nm. It is based on the concept that, for durable materials exposed outdoors, short-wave UV causes the most weathering damage (Figure 1).

Which is the better way to test? There is no simple answer to this question. Depending on your application, either approach can be quite effective. Your choice of tester should depend on the product or material you are testing, the end-use application, the degradation mode with which you are concerned, and your budgetary restrictions.

To understand the differences between the Q-Sun and the QUV, it is necessary to first look more closely at why materials degrade.

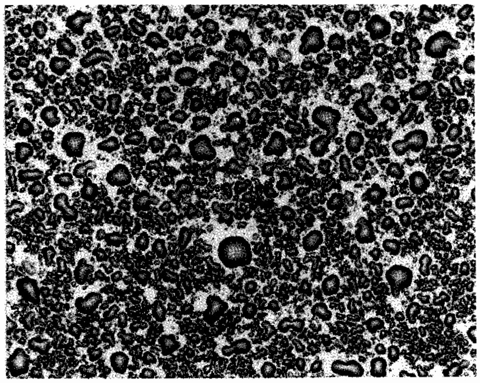
Triple Threat: Light, Temperature, and Moisture

Most weathering damage is caused by three factors: light, high temperature, and moisture. Any one of these factors may cause deterioration. Together, they often work synergistically to cause more damage than any one factor alone.

Light.
Spectral sensitivity varies from material to material. For durable materials, like most coatings and plastics, short-wave UV is the cause of most polymer degradation. However, for less durable materials, such as some pigments and dyes, longer wave UV and even visible light can cause significant damage.

High temperature.
The destructive effects of light exposure are typically accelerated when temperature is increased. Although temperature does not affect the primary photochemical reaction, it does affect secondary reactions involving the by-products of the primary photon/electron collision. A laboratory weathering test must provide accurate control of temperature, and it usually should provide a means to elevate the temperature to produce acceleration.

Products exposed outdoors often stay wet for 8-12 hours each day.



Dew, not rain, is responsible for most of the damage caused by wetness outdoors.

Indoors, both sunlight through window glass and bright indoor lighting can degrade some materials.

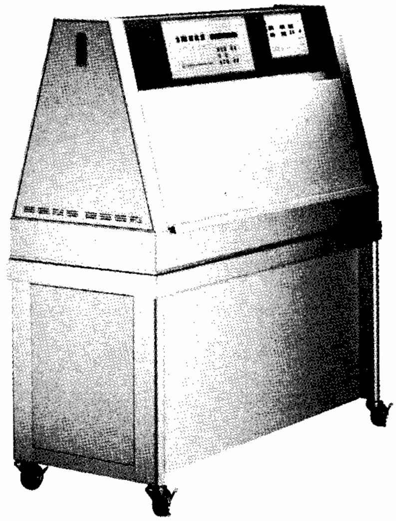
Moisture.
Dew, rain, and high humidity are the main causes of moisture damage. Our research shows that objects stay wet outdoors for a surprisingly long amount of time each day (8-12 hours daily, on average). Studies have shown that condensation in the form of dew is responsible for most outdoor wetness. Dew is more damaging than rain because it remains on the material for a long time, allowing significant moisture absorption.

Of course, rain can also be very damaging to some materials. Rain can cause thermal shock, a phenomenon that occurs, for example, when the heat that builds up in an automobile over the course of a hot summer day is rapidly dissipated by a sudden shower. Mechanical erosion caused by the scrubbing action of rain can also degrade materials such as wood coatings because it wears away the surface, continually exposing fresh material to the damaging effects of sunlight.

For indoor materials, the major effect of humidity is often the physical stress caused by the material trying to maintain moisture equilibrium with its surroundings. The greater the range of humidity the material is exposed to, the greater the overall stress. Although indoor products, such as textiles and inks, may only be exposed to moisture in the form of humidity, it can also be an important factor in the degradation of outdoor materials. Outdoors, the ambient relative humidity (RH) will affect the speed at which a wet material dries.

The QUV and the Q-Sun each reproduce light, temperature, and moisture in different ways.

QUV Weathering Tester



Sunlight Simulation.

The QUV is designed to reproduce the damaging effects of sunlight on durable materials by utilizing fluorescent UV lamps. These lamps are electrically similar to the common cool white lamps used in general lighting, but produce mainly UV rather than visible light or infrared.

There are different types of lamps with different spectra for various exposure applications. UVA-340 lamps provide the best available simulation of sunlight in the critical short-wave UV region. The spectral power distribution (SPD) of the UVA-340 matches sunlight very closely from the solar cutoff to about 360 nm (Figure 2). UV-B lamps (Figure 3) are also commonly used in the QUV. They typically cause faster degradation than UV-A lamps, but their short-wavelength output below the solar cutoff can cause unrealistic results for many materials.

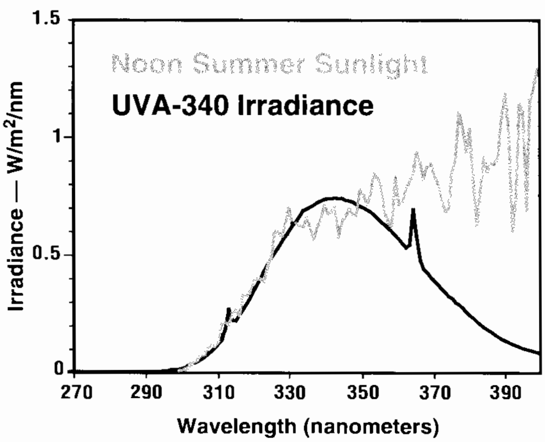


Figure 2. UVA-340 lamps provide the best available simulation of sunlight in the critical short-wave UV region.

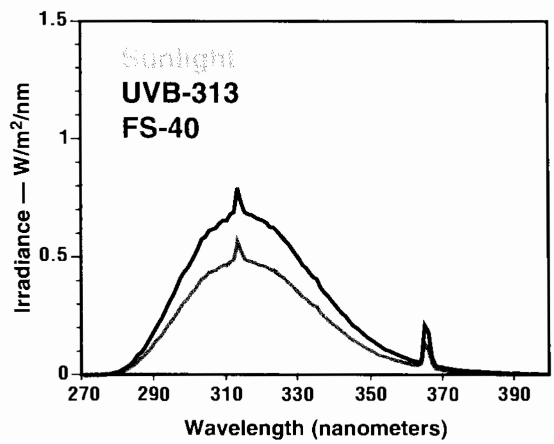
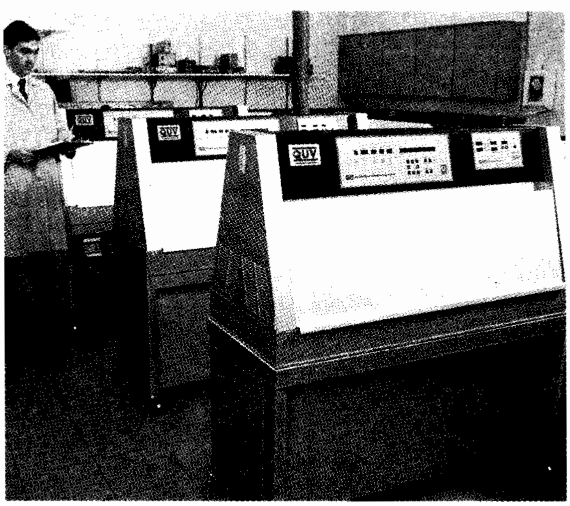


Figure 3. UV-B lamps utilize short-wave UV for maximum acceleration and are most useful for testing very durable materials, or for quality control.



In just a few days or weeks, the QUV can reproduce the damage that occurs over months or years outdoors.

Control of Irradiance.

Control of irradiance (light intensity) is necessary to achieve accurate and reproducible test results. Most QUV models are equipped with the Solar Eye Irradiance Controller.[1] This precision light control system allows the user to choose the level of irradiance. With the Solar Eye feedback-loop system, the irradiance is continuously and automatically monitored and precisely maintained. The Solar Eye automatically compensates for lamp aging or any other variability by adjusting power to the lamps. Figure 4 shows how the irradiance control system works.

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1 The Solar Eye Irradiance Control System is used in models QUV/se and QUV/spray. The Solar Eye allows better reproducibility and repeatability than the manual irradiance control system used for the model QUV/basic. The Solar Eye also reduces maintenance because the lamps do not have to be rotated and replacement of lamps is less frequent.

QUV Irradiance Control

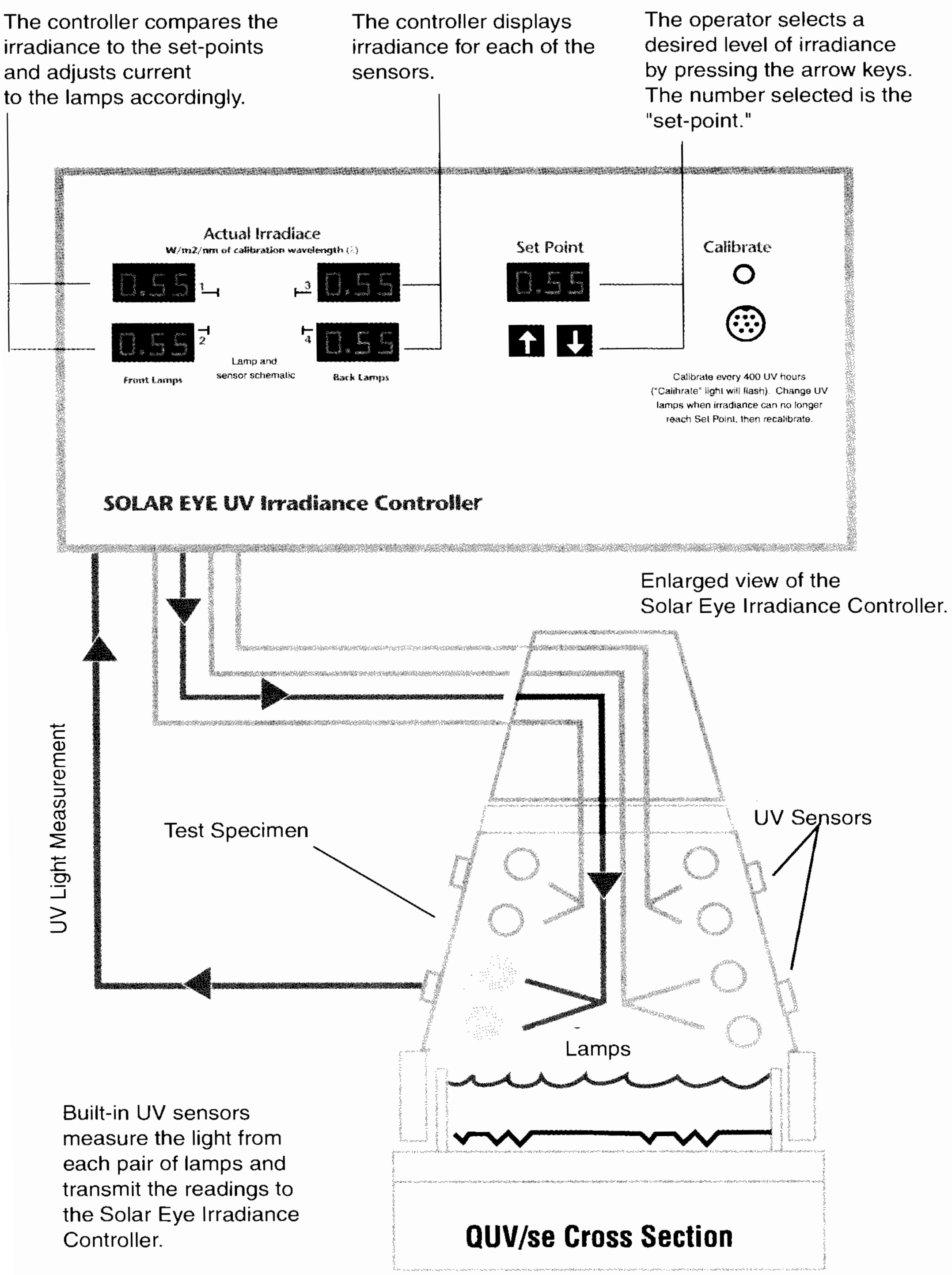


Figure 4. The QUV with the Solar Eye™ Irradiance Controller allows better reproducibility and repeatability than testers with manual irradiance control. Maintenance is simplified because lamps do not have to be rotated.

QUV *cont.*

In the QUV, control of irradiance is simplified by the inherent spectral stability of its fluorescent UV Lamps. All light sources decline in output as they age. However, unlike most other lamp types, fluorescent lamps experience no shift in spectral power distribution over time. This enhances the reproducibility of test results and is a major advantage of testing with QUV.

Figure 5 shows a comparison between a lamp aged for 2 hours and a lamp aged for 5600 hours in a QUV with irradiance control. The difference in output between the new and aged lamps is nearly indistinguishable. The Solar Eye Irradiance Controller has maintained the light intensity. In addition, due to the inherent spectral stability of fluorescent lamps, the spectral power distribution remains virtually unchanged. The same data is graphed as a Percentage Difference in Figure 6.

In addition to its other advantages, the patented Solar Eye system allows for easy calibration and traceability for ISO compliance.

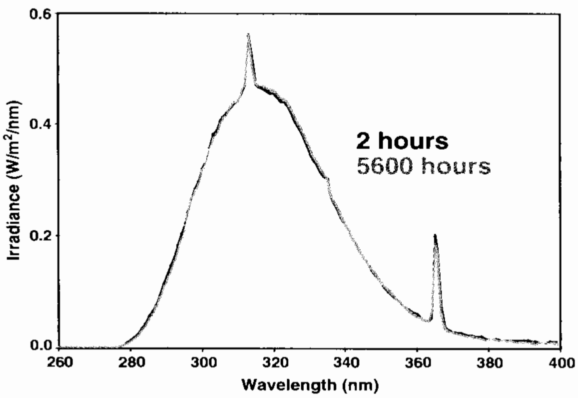


Figure 5. While all light sources decline in output as they age, the QUV's Solar Eye™ control system keeps the irradiance at a consistent level by varying the power to the lamps.

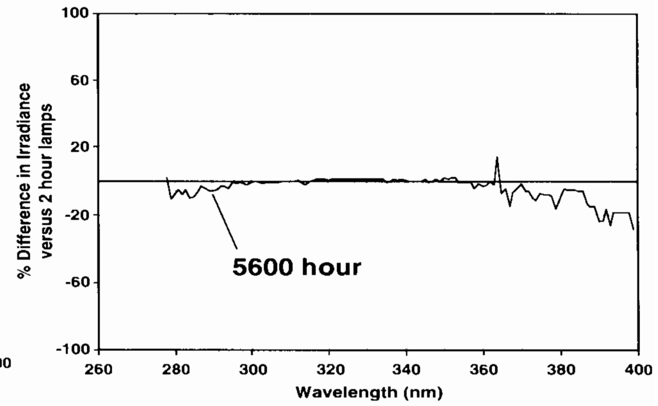
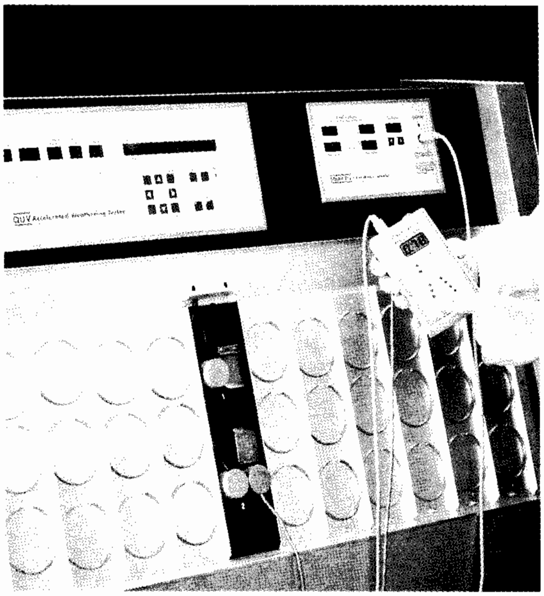
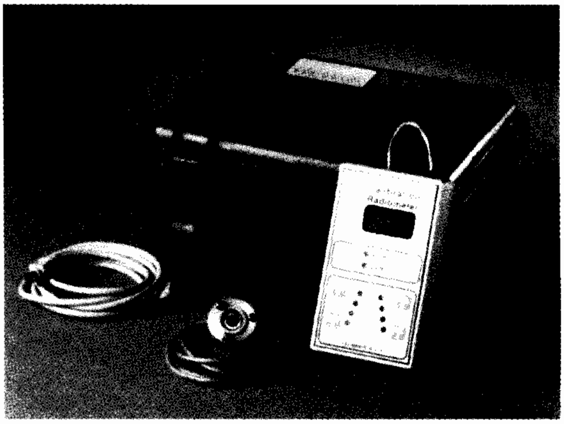


Figure 6. Because of the inherent spectral stability of fluorescent lamps, the QUV's spectrum change very little.

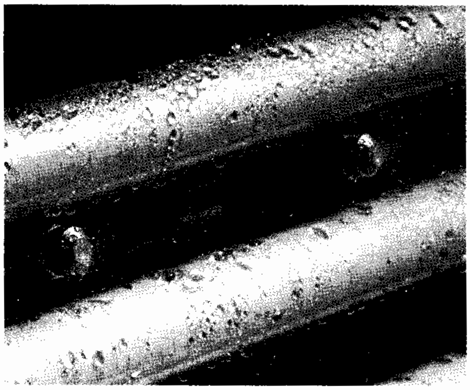


With the patented Auto Cal system and the CR10, calibration takes only minutes and complies with ISO 9000 requirements.



Calibrations with the CR10 Radiometer are traceable to the U.S. National Institute of Standards and Technology.

QUV Moisture Simulation.
A major benefit of using the QUV is that it allows the most realistic simulation of outdoor moisture attack. Outdoors, materials are frequently wet up to 12 hours a day. Because most of this moisture is the result of dew, the QUV uses a unique condensation mechanism to reproduce outdoor moisture.



Optional water spray is particularly useful for roofing materials and coatings used on wood.

During the QUV condensation cycle, a water reservoir in the bottom of the test chamber is heated to produce vapor. The hot vapor maintains the chamber environment at 100% relative humidity, at an elevated temperature. The QUV is designed so that the test specimens actually form the sidewall of the chamber. Thus, the reverse side of the specimens is exposed to ambient room air. Room air-cooling causes the test surface to drop a few degrees below the vapor temperature. This temperature difference causes liquid water to continually condense on the test surface throughout the condensation cycle. (Figure 7).

The resulting condensate is very stable, pure distilled water. This pure water increases the reproducibility of test results, precludes water-spotting problems and simplifies QUV installation and operation.

Because materials experience such long wet times outdoors, the typical QUV condensation cycle is at least 4 hours. Furthermore, the condensation is conducted at an elevated temperature (typically 50°C), which greatly accelerates the moisture attack. The QUV's long, hot condensation cycle reproduces the outdoor moisture phenomenon far better than other methods such as water spray, immersion, or high humidity.

In addition to the standard condensation mechanism, the QUV can also be fitted with a water spray system to simulate other damaging end-use conditions, such as thermal shock or mechanical erosion. The user can program the QUV to produce cycles of wetness alternating with UV, a situation that is identical to natural weathering.

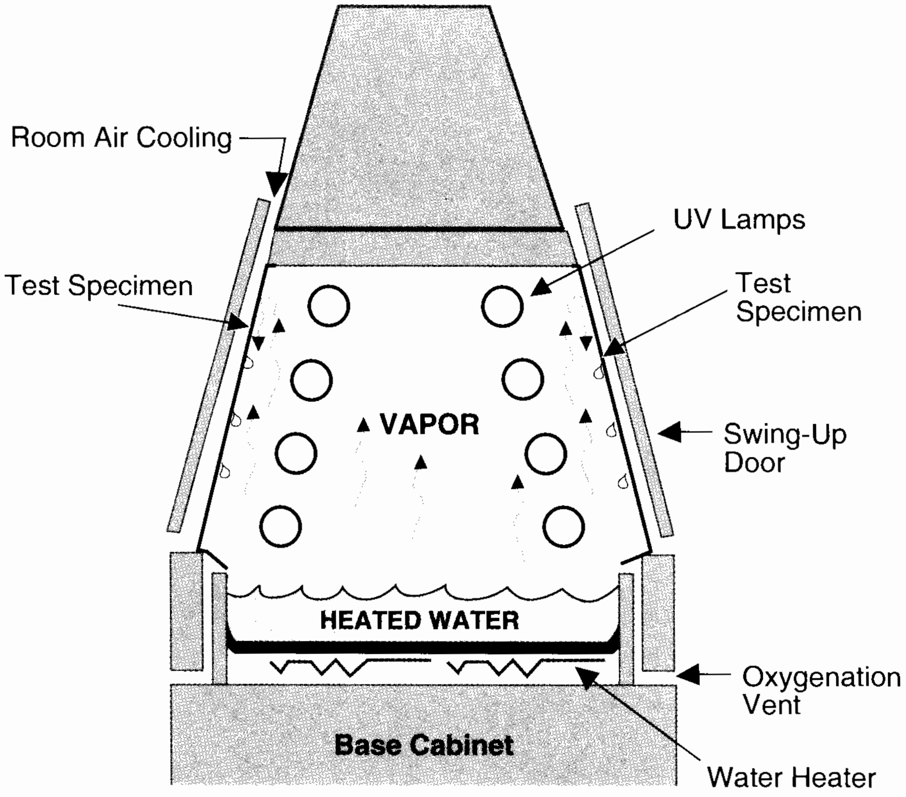
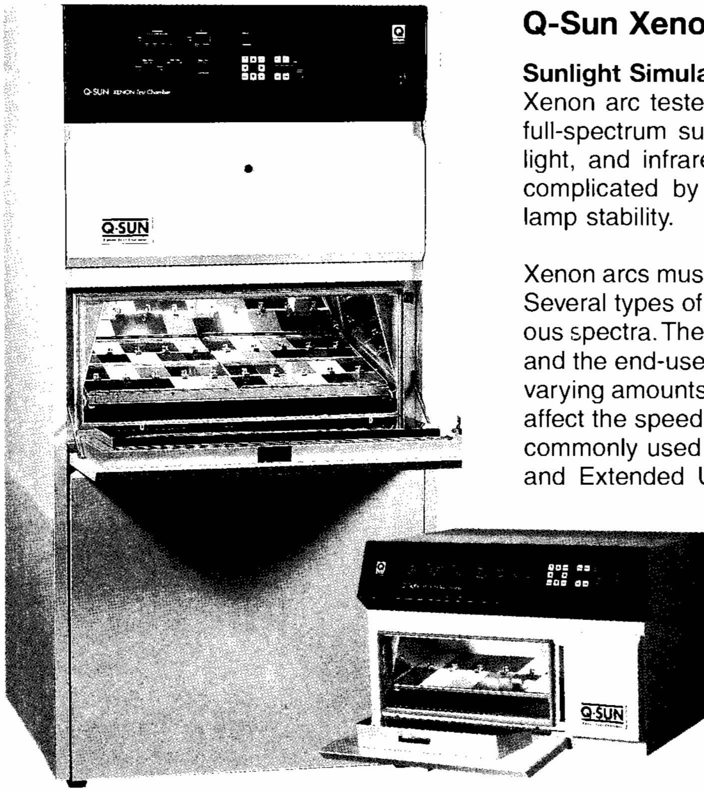


Figure 7. The QUV simulates outdoor moisture attack through a realistic condensation system.

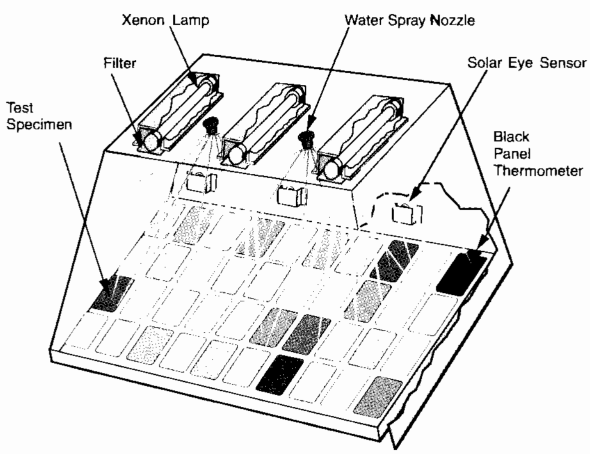
Q-Sun Xenon Test Chamber



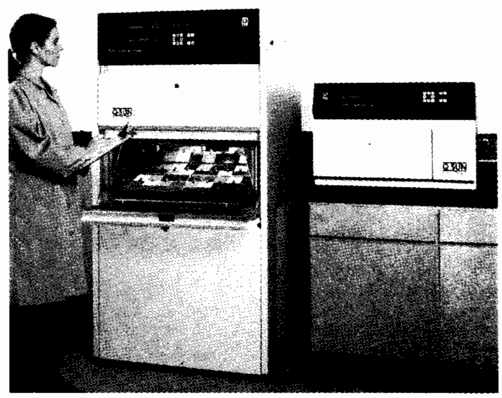
Sunlight Simulation.
Xenon arc testers are considered the best simulation of full-spectrum sunlight because they produce UV, visible light, and infrared. Understanding xenon arc spectra is complicated by two factors: optical filter systems and lamp stability.

Xenon arcs must be filtered to reduce unwanted radiation. Several types of glass filters are available to achieve various spectra. The filters used depend on the material tested and the end-use application. Different filter types allow for varying amounts of short-wave UV, which can significantly affect the speed and type of degradation. There are three commonly used types of filters: Daylight, Window Glass, and Extended UV. Figures 8-10 show the spectra that these filters produce. Also included is a close-up look at these spectra in the critical short-wave UV region from about 295 to 400 nm.

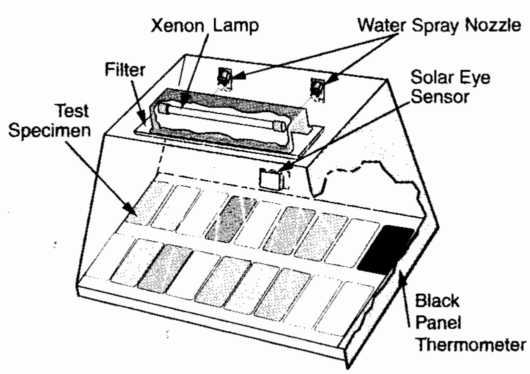
Static Specimen Mounting Cross Section



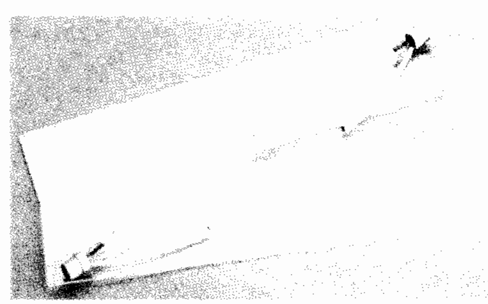
The Q-Sun Xe-3 is a full size test chamber that has three xenon arc lamps.



The Q-Sun Xenon Test Chambers reproduce full-spectrum sunlight, which is filtered to eliminate unwanted wavelengths.



The Q-Sun Xe-1 table top model uses one xenon arc lamp.



The Q-Sun's low-cost air-cooled lamp and filters are easy to install and replace.

Daylight Filters and Sunlight

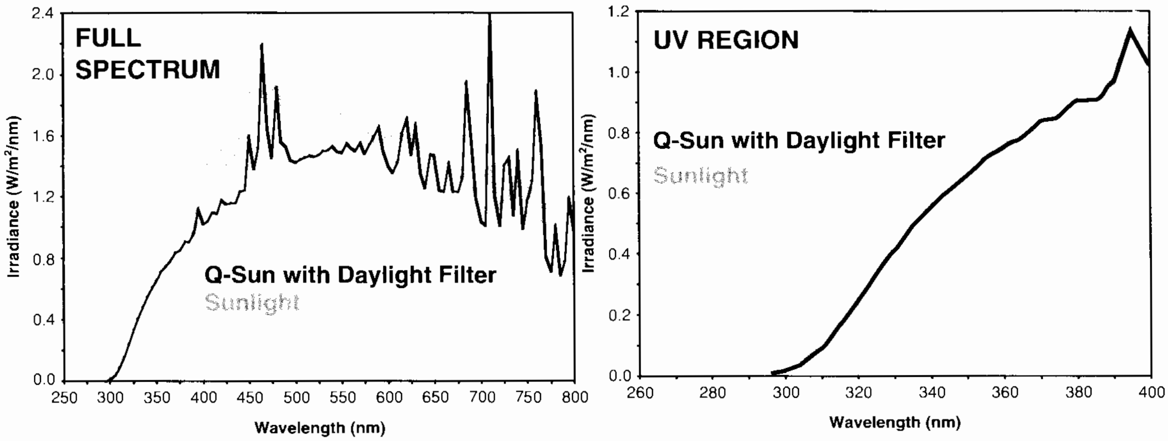


Figure 8. Sunlight compared to the Q-Sun with Daylight Filters. Daylight Filters are commonly used for simulations of outdoor exposure. They are an excellent reproduction of the full spectrum of natural sunlight, and are recommended for studies that value correlation to natural weathering.

Window Glass Filters and Sunlight Through Glass

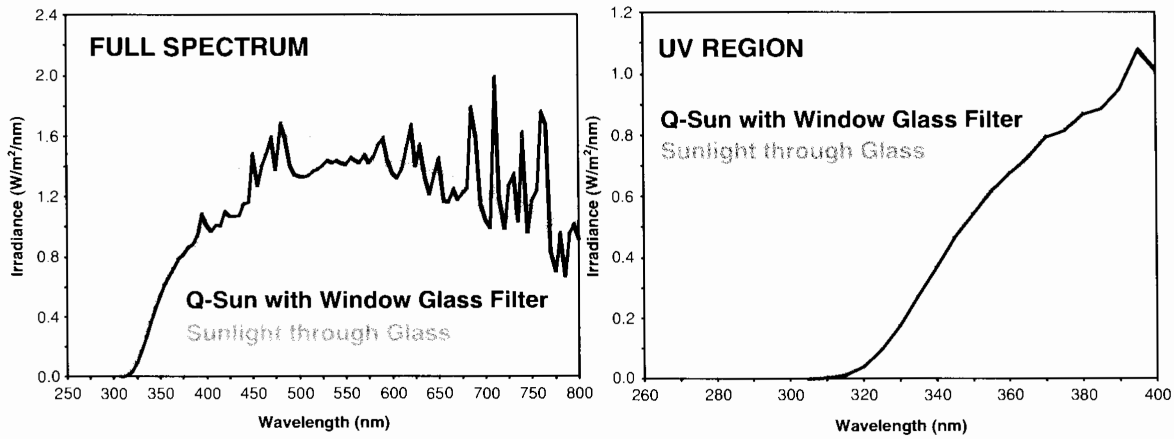


Figure 9. Sunlight through glass compared to the Q-Sun with a Window Glass Filter. Designed for indoor light stability testing, this filter provides a spectrum that is essentially identical to sunlight through window glass. The spectrum is also useful for simulating general lighting conditions because it encompasses the same damaging wavelengths.

Q/B Extended UV Filters and Sunlight

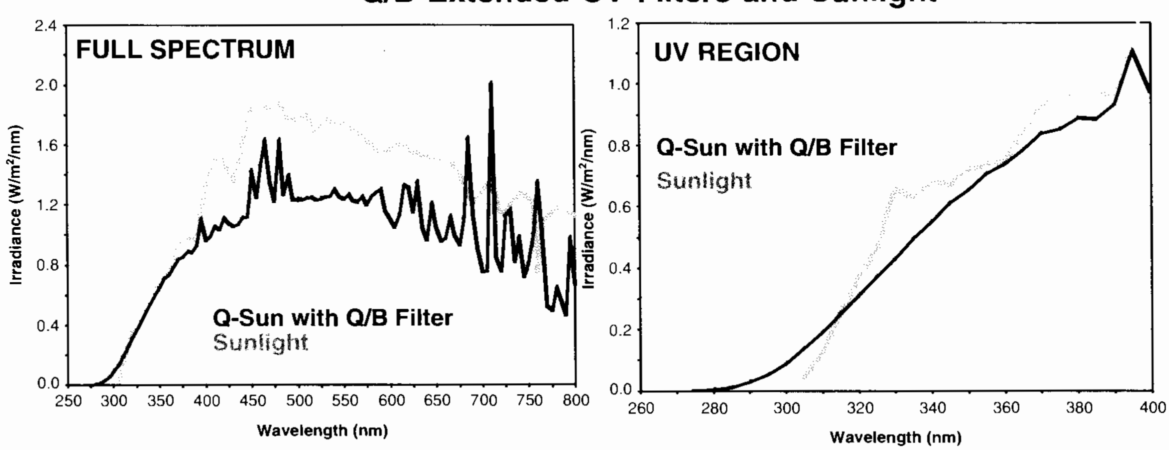
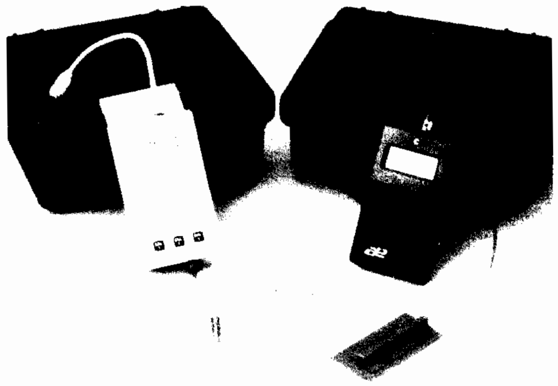


Figure 10. Sunlight compared to the Q-Sun with Extended UV Filters. Certain automotive test methods require a spectrum that includes short-wave UV below the sunlight cutoff of 295. Q/B Filters produce that spectrum. Although they allow an unrealistic amount of short-wave UV, these filters often provide faster results.

Control of Irradiance.
Xenon arc testers are typically equipped with an irradiance control system. The Q-Sun Xenon's Solar Eye system is illustrated on page 11 (Figure 11).

Control of irradiance is especially important in a xenon tester, because xenon lamps are inherently less spectrally stable than fluorescent UV lamps. Figure 12 illustrates the difference in spectrum between a new lamp and a lamp that has been operated for 1000 hours. It's clear that, over time, the spectrum changes significantly in the longer wavelengths. However, when this same data is graphed as a percentage of change over time (Figure 13), it also becomes apparent that there is a similar shift in the short-wave UV portion of the spectrum. However, the controller does an excellent job at maintaining the spectrum at the 340 nm control point.



You can easily perform necessary calibrations with the CR20 Calibration Radiometer and CT201 Calibration Thermometer.

This change in spectrum due to aging is an inherent characteristic of xenon arc lamps. However, there are ways to compensate for this. For instance, lamps can be replaced on a more frequent basis to minimize the effects of lamp aging. Also, by using sensors that control irradiance at either 340 or 420 nm, the amount of spectral change in a particular area is minimized.

Despite the spectral shift from lamp aging, the xenon arc has proven to be a reliable and realistic light source for weatherability and light stability testing.

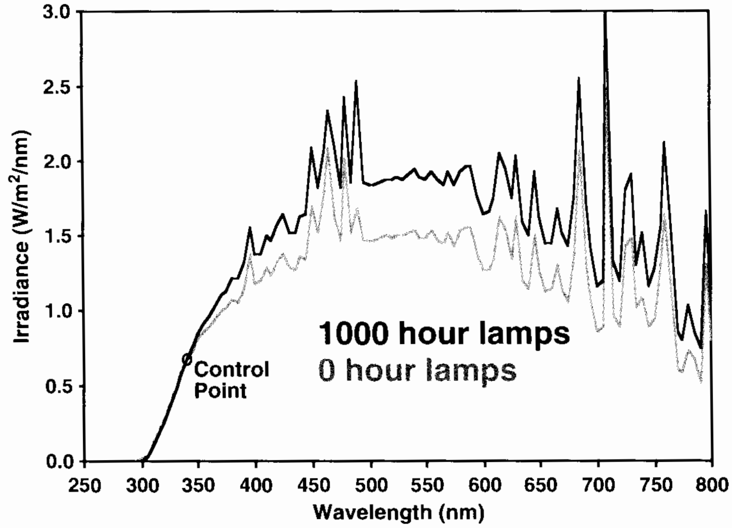


Figure 12. After 1000 hours of use, xenon lamps change in spectral output, but the controller does a good job at maintaining the spectrum at the control point.

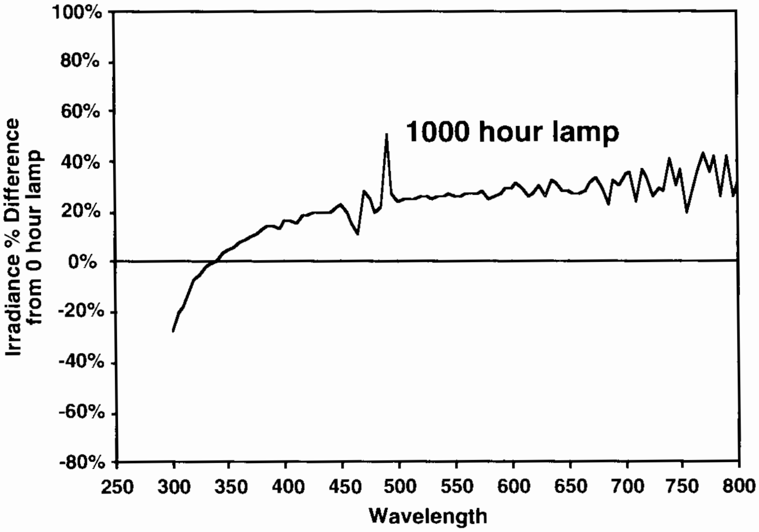


Figure 13. As xenon lamps age, the spectral output shifts in both the short and long wavelengths of light.

Q-Sun Solar Eye Irradiance Control

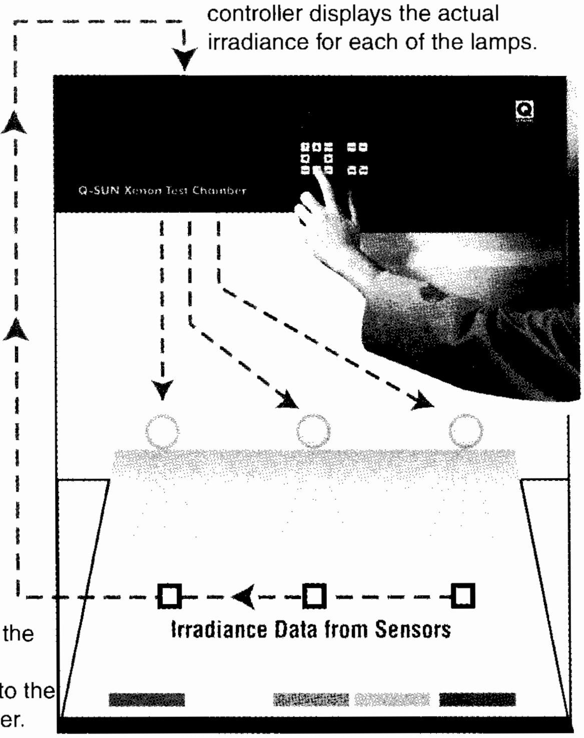
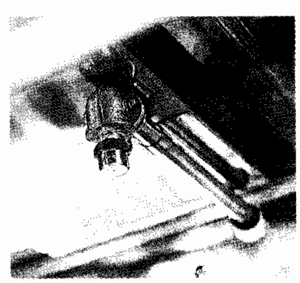


Figure 11. The Q-Sun's Solar Eye Irradiance Controller automatically monitors and maintains the chosen light intensity.

Moisture Simulation.
Most xenon arc testers simulate the effects of moisture through water spray and/or humidity control systems. The limitation of water spray is that when relatively cold water is sprayed onto a relatively hot test specimen, the specimen cools down. This may slow down the degradation.[2] However, water spray is very useful for simulating thermal shock and erosion. In a xenon arc, highly purified water is necessary to prevent water spotting.

Because humidity can affect the degradation type and rate of certain indoor products, such as many textiles and inks, control of relative humidity is recommended in many test specifications. The Q-Sun Xenon Test Chamber is available with optional relative humidity control.



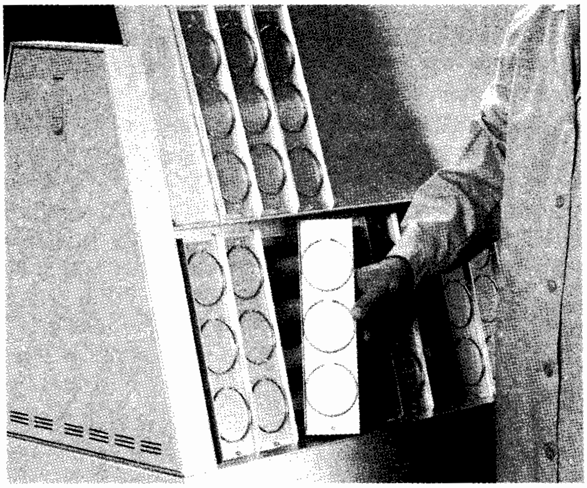
Programmable water spray periods can operate during either the light or dark periods.

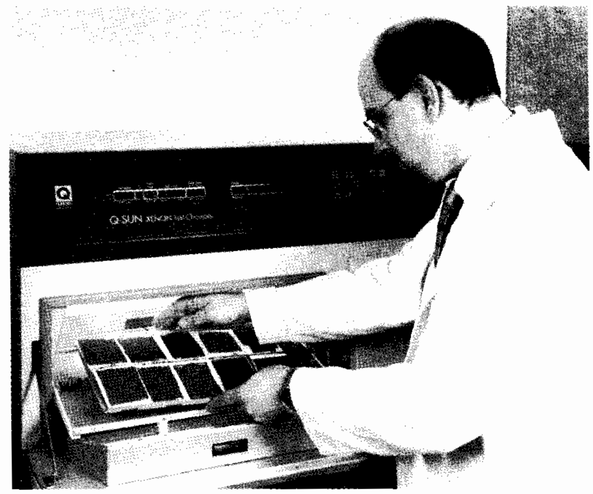
2 In competitive rotating drum type testers, relatively little water is used (about 3 seconds per 1 minute revolution). Because of the vertical specimen orientation, most of the water runs right off the surface.

Practical Considerations

Of course, no matter how informative and realistic a piece of testing equipment is, it will not be practical if it is too expensive to purchase or operate. That is why purchase price, operating costs, and maintenance are critical issues, and must be weighed against the benefits of owning a tester.

Purchase Price.
In general, the QUV is more economical than the xenon arc chamber. The Q-Sun may cost three times as much as the QUV, depending on the size of the unit and the features.[3]



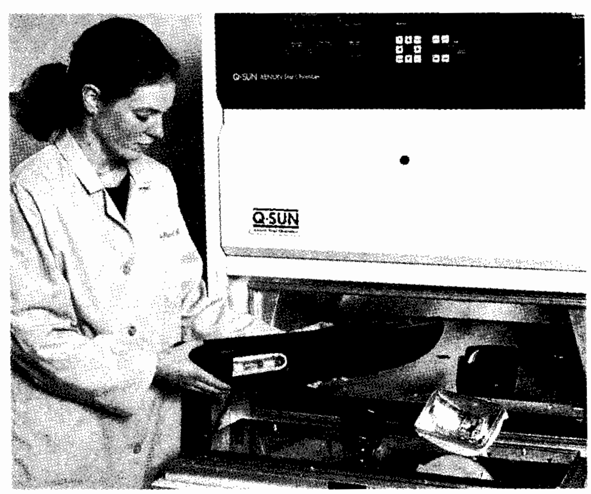


QUV has 5 times the capacity of an Xe-1 and 1.5 times the capacity of the Xe-3.

Specimen Capacity.
When evaluating the purchase price of a unit, specimen capacity should be taken into consideration.

A QUV/se and a Q-Sun Xe-1 have similar purchase prices, but they are very different in terms of specimen capacity. The QUV has almost 5 times the specimen capacity of the Q-Sun Xe-1. The QUV also has larger capacity than the Q-Sun Xe-3, which can accommodate only 72% of the specimens that the QUV can.

3D Test Specimens.
The Q-Sun allows more flexibility in terms of the types of specimens that can be mounted. It accommodates flat panels as well as 3D parts, test tubes, and petri dishes. The QUV's standard test sample holders were designed for flat, relatively thin panels or specimens.



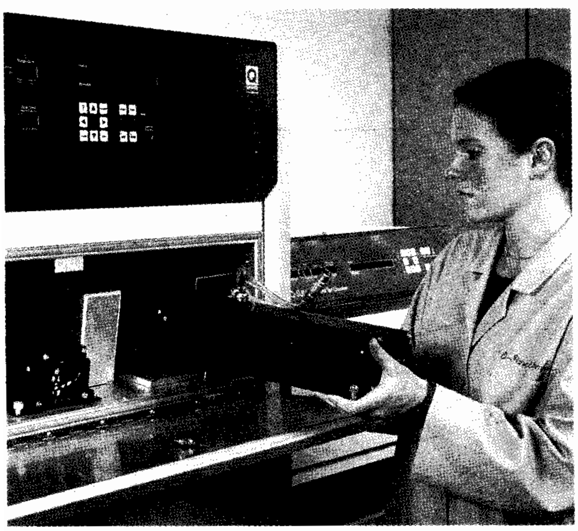
The Q-Sun Xe-3 accommodates 3D parts, test tubes and petri dishes in addition to flat panels.

3 Competitive rotating drum style xenon testers usually cost much more than the Q-Sun Xenon Test Chamber.

Ease of Use and Maintenance.
Both the QUV and the Q-Sun are easy to use and easy to maintain. Both testers are completely automated and can operate continuously, 24 hours per day, seven days per week. Automatic shutdown timers allow tests to finish at any time that is specified. Calibration is also simple with the patented Auto Cal system and calibration radiometers. Calibration is accomplished with a keystroke as the instrument automatically measures the lamp output and automatically adjusts the on-board control system accordingly. Test specimens and lamps all stay in place during the procedure.

The Q-Sun Xenon Test Chamber[4] and the QUV Accelerated Weathering Tester are both designed to be user-friendly. The Q-Sun's front access, and the QUV's double sided access, make lamp loading simple, and specimens easy to mount.

Maintenance Costs.
Both the QUV and Q-Sun offer relatively low maintenance costs. Q-Sun annual lamp costs are significantly higher than the QUV/se or QUV/spray. Q-Sun electrical costs are also higher. Additionally, ordinary tap water can be used in the QUV/se and QUV/basic, whereas the Q-Sun requires pure, de-ionized water. In summary, the QUV annual operating costs are considerably less than those of Q-Sun.[5]



Q-Sun lamp replacement is almost effortless - just open the hinged door, disconnect and slide out the lamp.

QUV/se does not require lamp rotation. However, when the time comes to change a lamp, double sided access makes the job easy to perform.

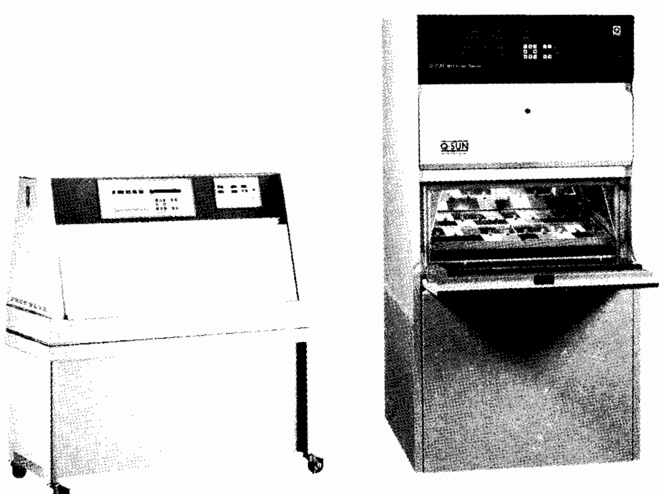
4 Competitive xenon arc models that feature a water-cooled lamp and a rotating drum generally require significantly more maintenance than the Q-Sun. Calibration is more time consuming and cumbersome. Specimens are more difficult to mount, and the lamp/filter housing is much more complicated.

5 The Q-Sun's maintenance costs, while higher than those of the QUV, are far less than those of competitive xenon arc testers. Q-Sun lamps are considerably more economical than most xenon arc lamps, and Q-Sun filters never need replacement. Electrical usage in a xenon arc can also be significant.

Technical Summary: The Right Tester for the Right Job

Deciding on the right weathering or light stability device can be confusing, especially if you're new to this type of testing. Which is the better for you? Below are some general guidelines. As with any generalization, there may be exceptions to the rule.

QUV	Q-SUN
The QUV is better in the short-wave UV. The QUV with UVA-340 lamps provides the best available simulation of sunlight in the critical short-wave UV region. Short-wave UV typically causes polymer degradation such as gloss loss, strength loss, yellowing, cracking, crazing, embrittlement, etc. In addition, the QUV's fluorescent UV lamps are spectrally stable, with very little change in the SPD over time. This enhances reproducibility and repeatability.	**The Q-Sun is a better match with sunlight in the long-wave UV and visible spectrum.** Long-wave UV and even visible light can cause fade and color change in pigments and dyes. Where color change is the issue, the Q-Sun is usually recommended. The Q-Sun, using Window Glass filters, is also generally better than the QUV for testing indoor products.
The QUV is better at simulating the effects of outdoor moisture. The QUV's condensation system (100% RH) is more aggressive and realistic than the Q-Sun's water spray and humidity control systems. Deeply penetrating moisture may cause damage such as blistering in paints.	**The Q-Sun is better for controlling humidity.** The Q-Sun can control relative humidity. This can be an important feature for humidity-sensitive materials like many textiles and inks. High humidity can cause color shift and uneven dye concentrations.



A Two Tier Approach.
Because many researchers are concerned with polymer degradation, moisture degradation and color change, a two-tier testing program is often the best approach. Many manufacturers get cost-effective results by using the QUV Accelerated Weathering Tester for polymer degradation and a Q-Sun Xenon Test Chamber for color change.

Standards (partial list)

QUV Accelerated Weathering Tester

General
- ASTM G151
- ASTM G154
- JIS D 0205
- SAE J2020

Coatings
- ASTM D3794
- ASTM D4587
- Israeli Standard No. 330,385,935,1086
- Korean Standards M598-1990
- NACE Standard TM-01-84
- NISSAN M0007
- US Government, FED-STD-141B

Adhesives
- ASTM C24.35.31
- ASTM C1442
- ASTM D904
- ASTM D5215
- Spanish Standard UNE 104-281-88

Plastics
- ANSI C57.12.28
- ANSI, A14.5
- ASTM D4329
- ASTM D4674
- ASTM D5208
- DIN 53 384
- ISO 4892
- Spanish Standard, UNE 53.104

Roofing
- ANSI/RMA IPR-1-1990
- ASTM D4799
- ASTM D4811
- ASTM D3105
- ASTM D4434
- ASTM D5019
- BS 903: Part A54
- CGSB-37.54-M
- DIN EN 534

Printing Inks/Artists' Materials
- ASTM D3424

Textiles
- AATCC Test Method 186
- ACFFA

Q-Sun Xenon Test Chamber

General
- ASTM G151
- ASTM G155

Coatings
- ASTM D3451
- ASTM D3794
- ASTM D6695
- ISO 11341

Adhesives
- ASTM C1442

Plastics
- ASTM D2565
- ASTM D4459
- ASTM D4101
- ASTM D5071
- ASTM D1248
- ISO 4892-2

Roofing
- ASTM D4798

Printing Inks/Artists' Materials
- ASTM D3424
- ASTM D5010
- ASTM D4303
- ISO 12040