THE ESSENTIALS OF LABORATORY WEATHERING

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I. Introduction

Pressure sensitive tapes are used in a variety of applications, many of which are subject to the forces of weathering and light exposure. Weathering testing is critical to any industry whose products must last outdoors. This includes building materials, automotive, solar energy, and any sub-component part made from polymeric materials. Damage caused by weathering includes gloss loss, fading, yellowing, cracking, peeling, embrittlement, loss of tensile strength, and delamination. Several of these modes of degradation can be critical for pressure sensitive tapes. As a result, it is crucial to formulate products that can withstand weathering and light exposure.

Two market realities have magnified the need for testing. First, the increasing globalization of markets intensifies the need for testing to improve product durability, meet quality standards of export markets, or decrease material costs to compete with imported products from emerging markets. Second, rising prices of chemical feedstocks and increasing supply chain uncertainty have accelerated the demand for product reformulation and consequent re-qualification.

Weathering testing is composed of two interdependent parts: natural and accelerated outdoor exposures and laboratory accelerated weathering tests. Outdoor testing is an important supplement to accelerated testing as it provides real-time results and exposes test specimens to complex weathering patterns not easily duplicated in an accelerated laboratory environment. Florida and Arizona are recognized as international benchmarks for outdoor durability testing of materials. Florida has high intensity sunlight, high annual UV, high year-round temperatures, high annual rainfall and high humidity. Arizona features a hot, dry, high UV radiation environment particularly suited for the weathering of materials under extreme conditions such as: high UV radiation, large temperature fluctuations, and low moisture.

Accelerated weathering and light stability testers are widely used for research and development, quality control, and material certification. They provide fast and reproducible results. The most frequently used accelerated weathering testers are the fluorescent UV accelerated weathering tester (ISO 4892-3, ASTM G154) and the xenon arc test chamber (ISO 4892-2, ASTM G155). In recent years, low cost and easy-to-use testers have been developed. However, the importance of outdoor testing cannot be overlooked.

This paper explores the various weathering test options available, including both outdoor and accelerated methods. Special attention is given to evaluating the emission spectra, methods of moisture simulation, specialty testing methods, uniformity, and practical considerations in tester use of the two specific types of accelerated testers. 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. In addition, this paper will briefly compare static array xenon arc testers versus rotating rack xenon arc testers.

Fluorescent UV testing is based on the precept that, for durable materials, short-wave UV causes most weathering damage. The QUV accelerated weathering tester from Q-Lab Corporation is the world's most widely used weathering tester.

Xenon test chambers reproduce the full spectrum of sunlight, including ultraviolet, visible light, and infrared. Shown here are is the Q-SUN xenon test chamber from Q-Lab Corporation

In this paper, the brand name QUV® will sometimes be used to indicate a fluorescent tester. The brand name Q-SUN® will sometimes be used to indicate a xenon tester.

II. Outdoor Weathering

Various mounting and exposure techniques are available for conducting natural outdoor exposure tests. Each has advantages and limitations, depending on the material or product’s end use application. The following are significant weathering issues affecting outdoor testing. These descriptions are meant to outline a few of the factors concerning an outdoor test program, and are not exhaustive. For a more detailed description of these factors, refer to Q-Lab Corporation Technical Bulletin LL-9025 *Outdoor Weathering: Basic Exposure Procedures*.

Exposure Methodology

To maximize sunlight dosage, test specimens are normally mounted facing toward the Equator. Any object exposed outdoors will receive more solar energy when sunlight strikes it directly than when the light strikes it at an angle. Therefore, the angle at which a test specimen is exposed affects the amount of solar radiation that it receives. As a general rule, the exposure angle should be representative of the material’s expected service environment. Exposure at the correct angle ensures that the test will be realistic, and increases confidence in the results. One way that outdoor exposure may be accelerated is by changing the exposure angle. For example a material that is typically at a 90° angle when in service may be exposed at 45° to increase the radiant dosage and time of wetness.

Common Mounting Methods

Natural weathering exposures are typically conducted in standard frames or racks designed to securely hold test specimens in place without causing damage, and without interfering with the progress of the test. Most racks used in the industry are made from aluminum, and are easily adjusted to any angle of exposure.

The basic exposure rack is typically 5 feet by 12 feet, and consists of a support framework, with the specimen mounting hardware on top. There are two basic mounting systems: one for flat, rigid, self-supporting panels and another for three-dimensional products, parts or components.

Most exposure racks are made from aluminum, and can be easily adjusted to any angle of exposure.

There are several common mounting methods used in the industry today to simulate a wide range of conditions. *Direct exposure* specimens are mounted on an exposure rack so that the front surface of the test specimen faces the sun, and has no cover. Direct exposure specimens are affected by all elements of the atmosphere. *Open backed mounting* is a method of direct exposure in which specimens rest on an open framework, usually facing south, and are open to the elements on both the top (face) and the bottom (rear). *Backed mounting* is a method of direct exposure in which specimens are backed with another material, usually plywood. This solid backing will typically result in higher temperature exposures than in an open backed mounting. *Under glass exposures* are used to test materials intended for interior use. Test specimens are exposed inside a ventilated framework, 3 inches below a glass cover. A layer of glass filters out the most damaging portion of sunlight - the short wavelength UV. This cover also protects the specimen from direct rainfall, and most condensation. Most under glass exposures are conducted with the specimens mounted on a wood backing.

Seasonal Variability in Exposure Conditions

The most important conditions affecting the seasonal variability of exposure conditions are the quantity and quality of sunlight, the amount of humidity and time of wetness, and the average maximum specimen temperature. Seasonal variability can vary greatly from year to year, and must be accounted for in your test program.

III. Accelerated Weathering: A 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, in-expensive, 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 testers 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).

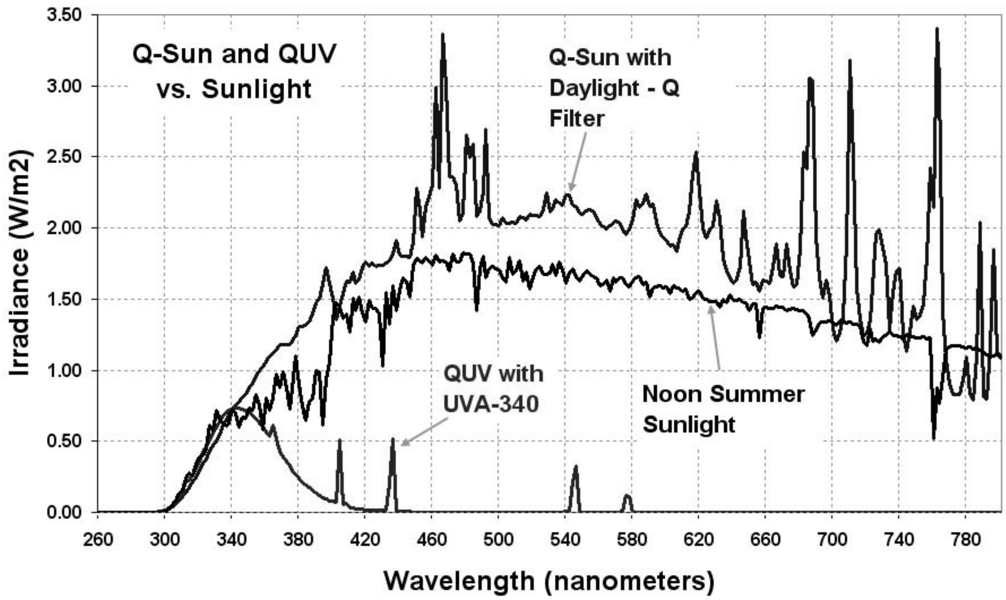


Figure 1. Sunlight compared to the Q-SUN and the QUV testers. The QUV tester provides the best available simulation of sunlight in the short-wave UV region from 365 nm down to the solar cutoff. However, it is deficient in longer wavelengths. The Q-SUN chamber reproduces sunlight's full spectrum, which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

The QUV test chamber, on the other hand, does not attempt to reproduce sunlight, just the damaging effects of sunlight that occur from wavelengths between 295 nm and 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. Fluorescent UV lamp devices are more economical, which can be important when obtaining large amounts of data is needed in quality control or research environments. On the other hand, wavelength deficiencies from fluorescent UV lamps may increase the risk of unrealistic results, necessitating the use of full spectrum xenon arc test chambers to varying degrees depending on the polymer systems in use. In most cases, use of both technologies ensures the optimum balance between economy, sufficient data throughput, and managing the risks associated with accelerated testing. As always, outdoor testing is a necessary tool to manage the risks of using either or both technologies.

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

IV. 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.

Moisture

Dew, rain, and high humidity are the main causes of moisture damage. 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.

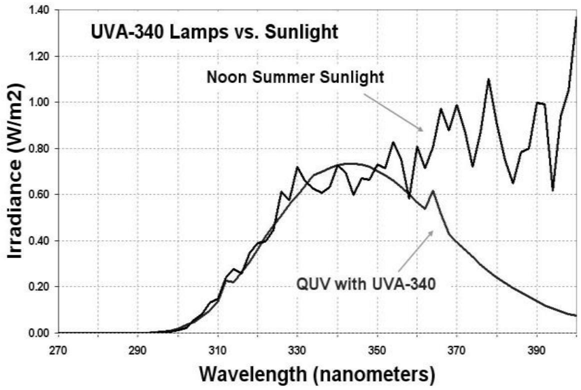
Of course, rain can also be very damaging to some materials. Rain can cause thermal shock, a phenomenon that occurs, for example, when the heat that builds up in an automobile over the course of a hot summer day is rapidly dissipated by a sudden shower. Mechanical erosion caused by the scrubbing action 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.

The QUV and xenon arc testers each reproduce light, temperature, and moisture in different ways.

V. QUV Weathering Tester

QUV Sunlight Simulation

The QUV tester 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 the spectrum they produce is quite different than common fluorescent lamps. The coatings in the glass of the tubes are carefully designed to produce mainly UV rather than visible light or infrared energy.



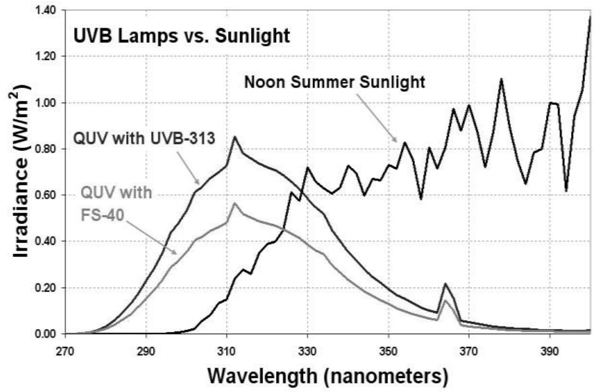


Figure 2. UVA-340 lamps provide the best available simulation of sunlight in the critical short-wave UV region.

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

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 test chamber. 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.

QUV Control of Irradiance

Control of irradiance (light intensity) is necessary to achieve accurate and reproducible test results. Q-Lab Corporation introduced the SOLAR EYE® irradiance controller in 1992. 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 monitoring sensors are individually calibrated by the operator on a regular basis. The calibration is traceable to the National Institute of Standards and Technology (NIST) for ISO 9000 compliance.

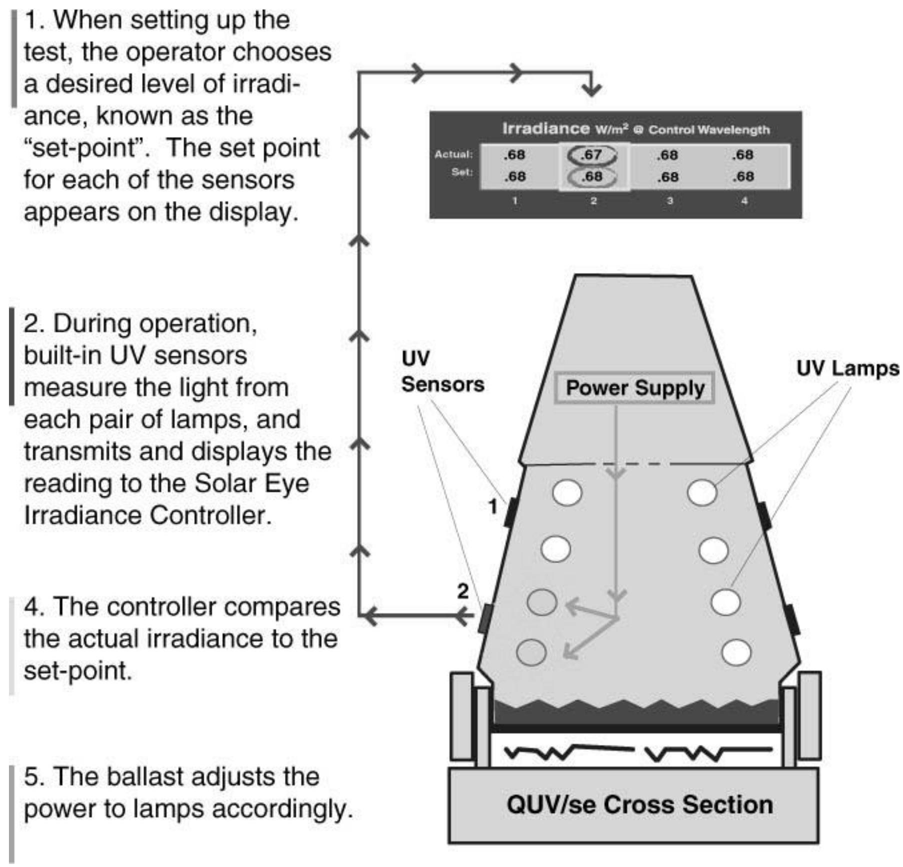


Figure 4. The QUV tester with the SOLAR EYE irradiance controller allows better reproducibility and repeatability than testers with manual irradiance control. Maintenance is simplified because lamps do not have to be rotated.

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. In the past, it was recommended that lamps in fluorescent testers be rotated every 400 hours. With irradiance control, lamps routinely last over 5000 hours. The SOLAR EYE Control system largely eliminates variations in UV intensity and therefore greatly reduces variations in test results.

In the QUV tester, 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 two 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. The SOLAR EYE system allows for easy calibration and traceability for ISO compliance.

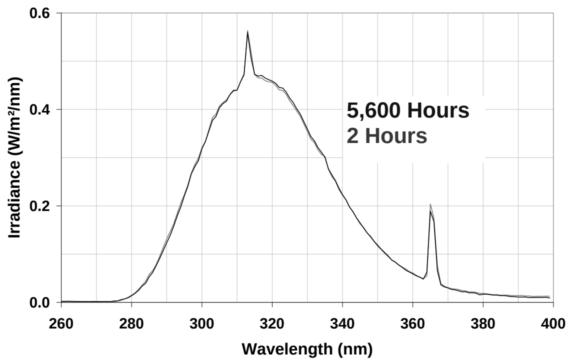


Figure 5. While all light sources decline in output as they age, the QUV tester's SOLAR EYE control system keeps the irradiance at a consistent level by varying the power to the lamps.

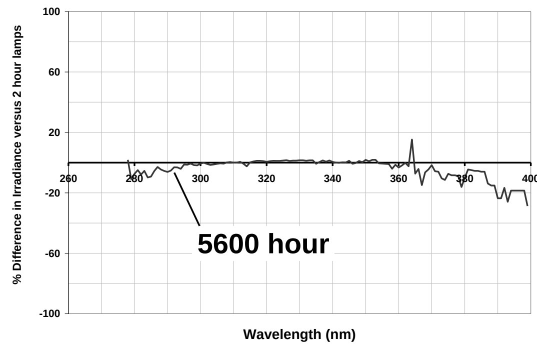


Figure 6. Because of the inherent spectral stability of fluorescent lamps, the QUV tester's spectrum changes very little. Variations in values at the edges of the spectral output where values are very low are due mainly to statistical noise.

The programmable, automatic irradiance control system allows the operator to choose a higher than standard level of irradiance for UV exposure tests. For many materials, this results in faster degradation and therefore shorter test times. [1]

QUV Tester Temperature Control

Fluorescent UV lamps produce some radiated heat energy. This is primarily because the glass tubes used in their construction are not 100% transparent. The energy they absorb is converted into heat. However, to achieve test temperature higher than approximately 45°C, convective heat is produced by an air heater and blower system, which is controlled to achieve the programmed temperature set point. The control point is a black panel thermometer, which is constructed from a piece of black coated metal with a resistance thermometer mechanically attached to it. Because of a relative lack of visible and infrared radiation created by fluorescent UV lamps, there is little color dependency on specimen temperatures inside the chamber.

QUV Tester Moisture Simulation

A major benefit of using the QUV accelerated weathering tester 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 tester uses a unique condensation mechanism to reproduce outdoor moisture.

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 tester is designed so that the test specimens actually form the side wall 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

[1] Fedor, G.R., Brennan, P.J. (1993), "Irradiance Control in Fluorescent UV Exposure Testers," *Accelerated and Outdoor Durability Testing of Organic Materials*, ASTM STP 1202, Warren D. Ketola and Douglas Grossman, ed. Philadelphia, PA, American Society for Testing and Materials.

causes liquid water to continually condense on the test surface throughout the condensation cycle (Figure 7).

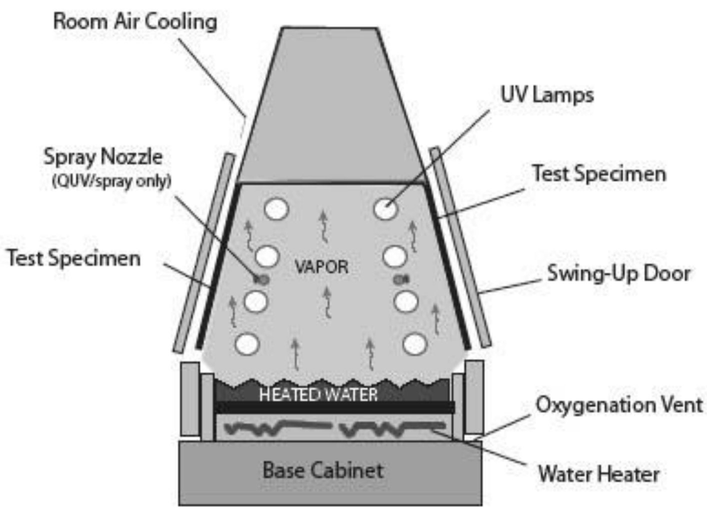


Figure 7. The QUV tester simulates outdoor moisture attack through a realistic condensation

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 tester installation and operation.

Because materials experience such long wet times outdoors, the typical QUV condensation cycle is at least four hours. Furthermore, the condensation is conducted at an elevated temperature (typically 50˚C), which greatly accelerates the moisture attack. The QUV tester'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 chamber 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 UV to produce cycles of wetness alternating with UV, a situation that is identical to natural weathering.

The QUV fluorescent weathering tester simulates the damaging effects of sunlight, dew, and rain. It is the most widely used weathering tester in the world.

VI. Xenon Test Chamber

Xenon Sunlight Simulation

Xenon arc testers are considered the best simulation of full-spectrum sunlight because they produce energy in the UV, visible, and infrared regions. To simulate natural sunlight the xenon arc spectrum must be filtered. The filters reduce unwanted radiation and/or heat. 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.

Daylight Filters and Sunlight

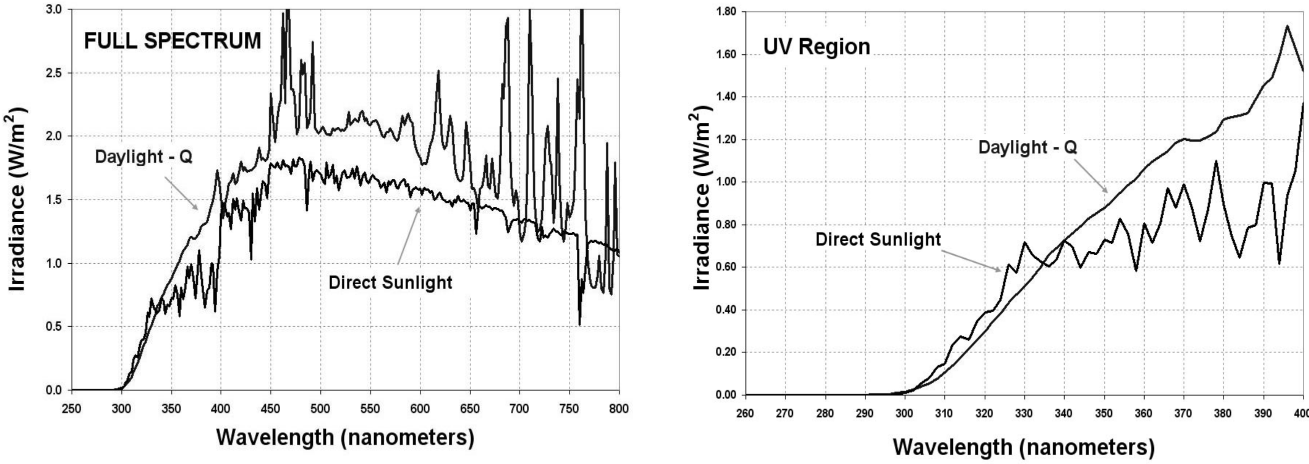


Figure 8. Sunlight compared to the Q-SUN chamber with Daylight Filters. Daylight Filters are commonly used for simulations of outdoor exposure. They are an excellent reproduction of the full spectrum of natural sunlight, and are recommended for studies that value correlation to natural weathering.

Window Glass Filters and Sunlight Through Glass

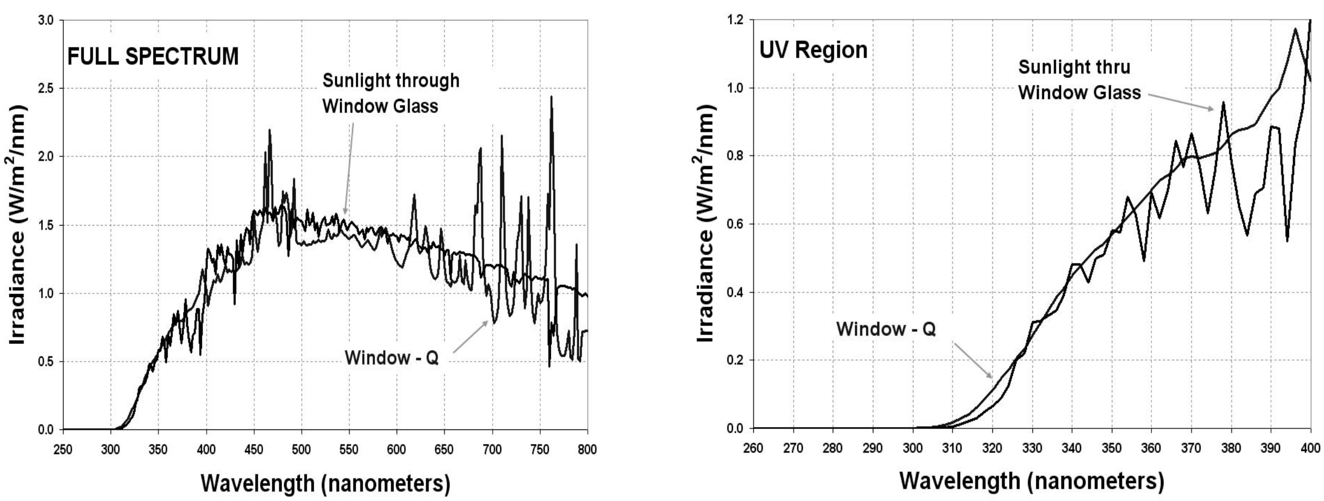


Figure 9. Sunlight through glass compared to the Q-SUN test chamber with a Window Glass Filter. Designed for indoor light stability testing, this filter provides a spectrum that is essentially identical to sunlight through window glass. The spectrum is also useful for simulating general lighting conditions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

Q/B Extended UV Filters and Sunlight

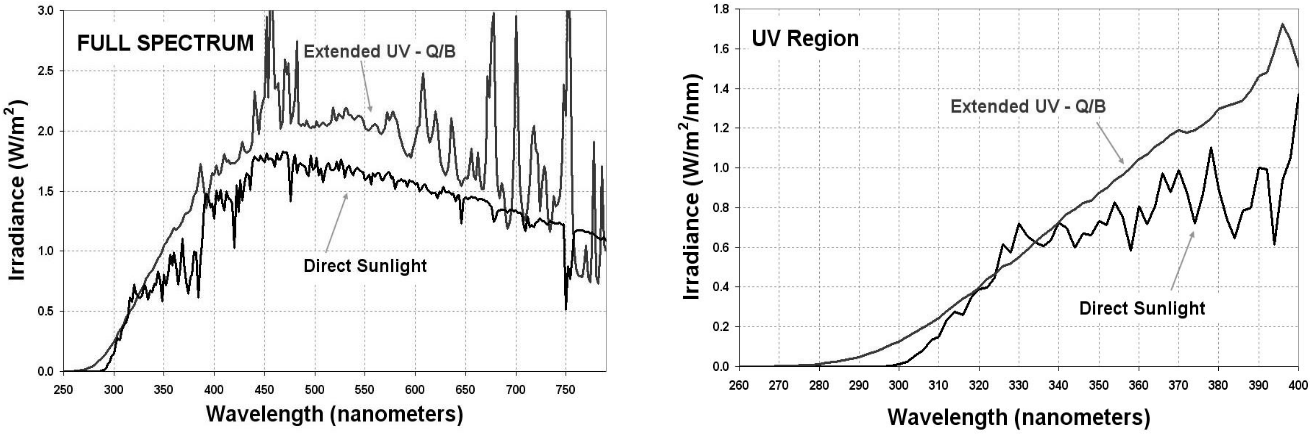


Figure 10. Sunlight compared to the Q-SUN test chamber with Extended UV Filters. Certain automotive test methods require a spectrum that includes short-wave UV below the sunlight cutoff of 295 nanometers. Q/B Filters produce that spectrum. Although they allow an unrealistic amount of short-wave UV, these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

Xenon Control of Irradiance

Control of irradiance is especially important in a xenon tester, because xenon lamps are inherently less spectrally stable than fluorescent UV lamps. Xenon arc testers are typically equipped with an irradiance control system. The Q-SUN xenon chamber's control system is illustrated in Figure 11.

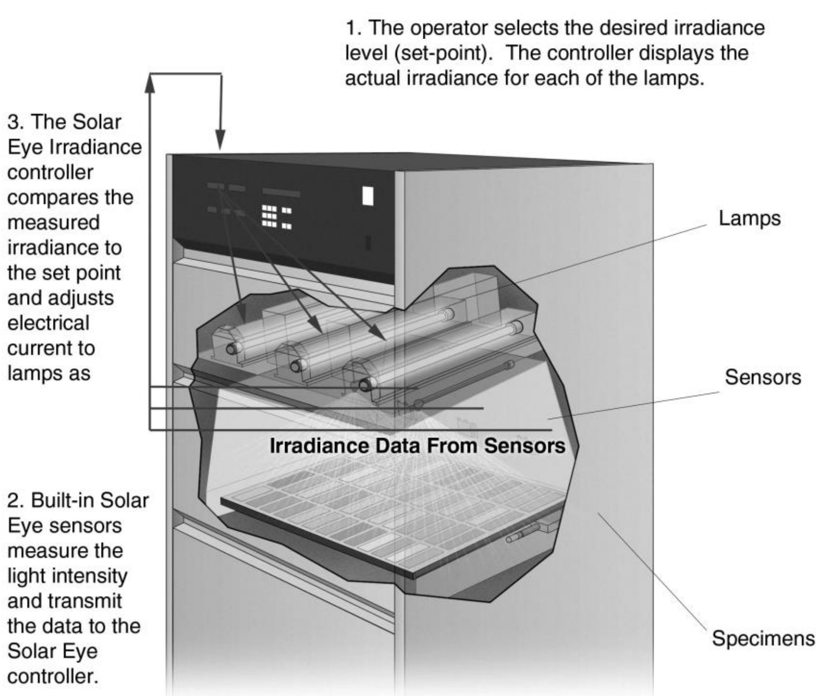


Figure 11. The Q-SUN tester's SOLAR EYE Irradiance Controller automatically monitors and maintains the chosen light intensity.

The change in spectrum is due to aging, an inherent characteristic of xenon arc 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, there are ways to compensate for spectral shift. 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.

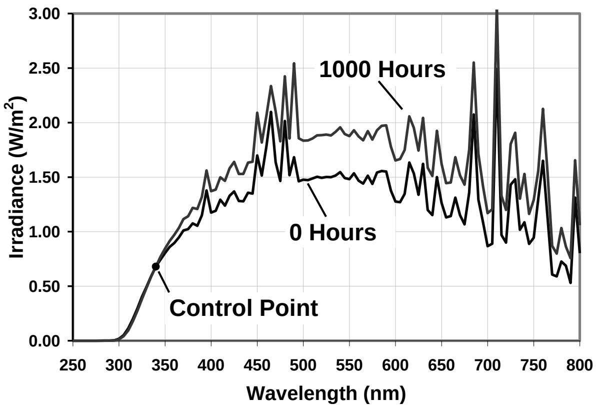


Figure 12. After 1000 hours of use, xenon lamps change in spectral output, but the controller does a good job at maintaining the spectrum at the control point.

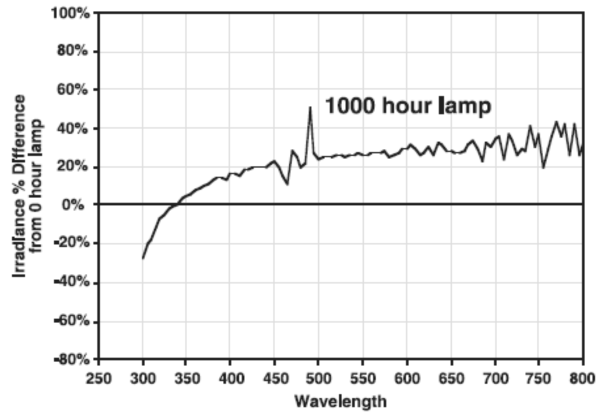


Figure 13. As xenon lamps age, the spectral output shifts in both the short and long wavelengths of light.

Xenon 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. However; water spray is very useful for simulating thermal shock and erosion. In a xenon arc tester, 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. Modern xenon test chambers are available with relative humidity control.

Static Array Xenon Arc Tester Compared to Rotating Rack Xenon Arc Tester

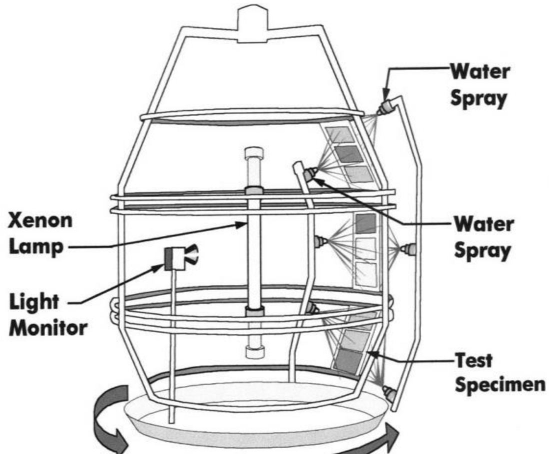


Figure 14. Specimens travel around one or multiple xenon lamps on a rotating rack carousel.

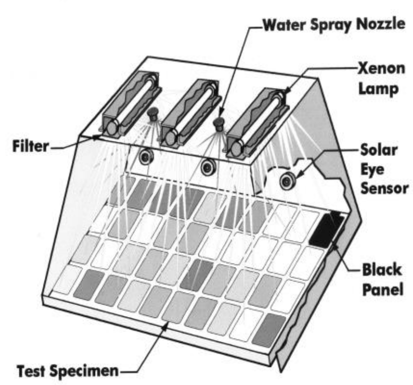


Figure 15. The static-array's three lamp irradiance control system and flat exposure area allow simplified specimen mounting.

The first rotating-rack light stability testers were developed around 1918 and used a carbon arc as the light source. This device features a central light source or lamp(s), positioned vertically, with a filter system surrounding it. The test specimens are mounted facing the light. The most popular xenon arc version of this tester uses a water cooling system for its lamp, but a growing number are air cooled. This is often called a rotating rack tester.

More recent technology features a chamber with one or more air-cooled lamps mounted in the ceiling. In this system, the filters are flat and fitted below the lamps. A reflector system built into the top and the sides of the chamber enhances irradiance uniformity. The test specimens are mounted below the lamps on a tray. Regardless of the hardware configurations used, modern xenon testers typically have systems to control light intensity (irradiance), temperature and relative humidity.

Optical Filter System

All xenon arc testers use optical filters to eliminate the unrealistic short wavelengths emitted by these lamps. Additionally, optical filters are available with a wide variety of wavelength cut-on characteristics. ASTM G155 and ISO 4892-2 categorize these as daylight filters, window glass filters, and extended UV filters. Daylight filters are intended to reproduce direct, outdoor sunlight. Window glass filters are designed to simulate sunlight through a window, such as may exist in a kitchen or automobile. The last category, extended UV filters, allow shorter wavelengths than seen in natural sunlight. This may be appropriate for some high altitude applications, but mostly these filters are used as a way to accelerated UV induced photodegradation, similar to the use of UVB-313 lamps in the QUV tester. Static-array and rotating rack testers use, out of necessity, different filter configurations, but as a general rule it is possible to achieve very similar spectra from most commercially available xenon arc test chambers on the market today.

Filter solarization is a potential weakness in some xenon arc testers, primarily those that use water cooling. As filters age due to exposure to UV, they lose their ability to transmit the shorter wavelengths of light. This phenomenon is called solarization. The resulting shift in the spectrum can affect the reproducibility of test results. Consequently, filters in many xenon arc devices must be replaced on a frequent basis. Many filters used in static-array or air cooled testers have been designed not to solarize with extended use.

Heat and Temperature

As mentioned above, the QUV tester controls the test temperature by applying convective heat. Although the fluorescent UV lamps do radiate heat, temperatures higher than approximately 45°C require additional convective heating. The result is that there is little temperature differentiation based on the color of test specimens. Xenon arc chambers, because they use a full spectrum light source, provide significant radiated heat. Darker colored specimens absorb more visible and infrared radiation and become hotter than lighter colored ones, given the same irradiance and air temperature. Like the QUV weathering chamber, xenon arc devices use a black panel thermometer for temperature control. However, the relationship between a black panel temperature and specimen temperature is very different in a xenon arc device than in a QUV weathering tester. In a xenon arc device, the black panel temperature will typically be significantly hotter during light cycles than light colored specimen temperatures, while in a QUV tester the black panel and light colored specimens will be similar. Care should be taken when attempting to compare exposures in the two technologies. Setting both with the same black panel temperature will almost always result in hotter specimens in the QUV tester.

Moisture
Both the static-array xenon test chamber and rotating-rack xenon chambers simulate the effects of outdoor moisture by spraying water onto the test specimens. This method is especially good for simulating the effects of thermal shock or mechanical erosion. In the static-array, test specimens are mounted on a flat specimen tray which is tilted at 5-10˚ from horizontal. The static-array's water spray covers the specimens uniformly and, because of the near horizontal position of the specimens, the water does not quickly run off. In the static-array, making sure specimens stay wet during the entire moisture cycle is generally not difficult.

Rotating-rack testers have a spray bar and nozzles which spray the specimens with water as they rotate past it. Specimens are wetted for approximately 5-10 seconds out of each one minute revolution. Because of the vertical position of the specimens, the water quickly runs off the surface. Historically, this has made it more difficult for rotating rack machines to achieve moisture uptake levels seen in Florida exposures. Recent work in the automotive coatings industry has largely overcome these shortcomings. The result of this work is ASTM D7869 a relatively new test standard for xenon arc exposures of automotive materials.

Specimen Mounting
A static array tray accommodates different sizes of flat panels or three dimensional specimens like parts, components, bottles, and test tubes. Rotating-rack testers are mainly used to expose flat panels in a vertical position, although with some modifications, some testing of three dimensional parts is possible in such devices.

Lamp Cooling
Xenon arc lamps produce a lot of heat that must be dissipated. The static-array removes excess heat by means of moving large volumes of air through the lamp housing. Some rotating-rack testers use air cooling, while others utilize water cooling. Since water is an excellent heat transfer agent, this is highly efficient. Consequently, testers using water cooling may have lamps can be operated at a very high wattage to produce high irradiance. Water cooling requires a somewhat complex lamp/filter apparatus with inner and outer filters. The cooling water must be very pure to mitigate any build up impurities on the lamps and filters. Lamp cooling is not an important consideration when creating a test standard, but it is mentioned here due to common misunderstandings about its importance.

Irradiance Calibration
Two systems for calibrating xenon arc testers are in use. In one type, the irradiance calibration system uses a radiometer and can be performed by the machine operator. In other testers, the irradiance is calibrated with a multi-step procedure using a special calibration lamp. The wattage of the lamp power system is adjusted so that the irradiance display on the tester matches the calibrated irradiance of the special lamp.

Uniformity
Although rotating rack testers may at times be able to achieve better irradiance uniformity than static array designs, other factors lead to non-uniform results in tests. Research was done to compare the uniformity of degradation of test specimens within both rotating rack and flat array chambers.[2] Twenty-five different

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[2] Brennan, P., Fedor, G., and Pausch, G. (2003), "Static and Rotating Xenon Arc Exposures Compared," *1st European Weathering Symposium*, Proceedings of the XXIII Colloquium of Danubian Countries on Natural and Artificial Aging of Polymers, Prague, Czech Republic.

uniformity tests were done. In both the rotating rack and in the static specimen mounting system, the uniformity of degradation with a single chamber varied between ± 3% to ± 13%, depending on the material. The uniformity in the static array tester was as good as, or better than, the rotating rack for some material/exposure conditions. Because other researchers agreed with these results, ASTM D7869 actually requires specimen repositioning, regardless of tester form factor, to compensate for chamber non-uniformity.

Technical Summary: The Right Testing Program for the Right Job

Deciding on the right weathering test program can be confusing, especially if you're new to this type of testing. What is best accelerated tester for you? Below are some general guidelines. As with any generalization, there may be exceptions to the rule.

Table 1. Fluorescent UV and Xenon Arc Testers Compared

QUV Fluorescent Tester	Xenon Arc Tester
The QUV tester is better in the short-wave UV.	A Xenon arc tester is a better match with sunlight in the long-wave UV and visible spectrum.
The QUV weathering tester 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.	Long-wave UV and even visible light can cause fade and color change in pigments and dyes. Where color change is the issue, xenon arc testers are recommended, though in many cases QUV testing also produces realistic fade and color change.
QUV fluorescent UV lamps are spectrally stable.	Xenon lamps are inherently less spectrally stable than fluorescent UV lamps.
The QUV tester is better at simulating the effects of outdoor moisture. The QUV chamber's condensation system (100% RH) is aggressive and realistic. This type of deeply penetrating moisture may cause damage such as blistering in paints.	Xenon arc testers are better for controlling humidity. This can be important feature for humidity-sensitive materials. High humidity can cause color shift and uneven dye concentrations.
The QUV tester controls temperature through convective heat, which results in specimen temperatures which are mostly independent of color.	Xenon arc testers provide significant radiant heat, which results in specimen temperatures largely dependent on color. This is more representative of the heating associated with sunlight.

Discussion

Weathering testing is a tool to mitigate risks arising from introducing new products into the market, qualifying new vendors, cost reduction or cost containment programs, and from competitors' actions. Accelerated testing is used because market forces require rapid decisions, but the use of accelerated methods presents a new set of risks. It is possible for an accelerated test to deliver inaccurate results. In fact, accelerated weathering tests never provide perfect correlation to outdoor tests. Because of this, outdoor weathering continues to serve as the fundamental science required to validate laboratory tests. Therefore, it is essential to pair your accelerated tests with a natural outdoor exposure program in Florida and/or Arizona to obtain the most complete results. Outdoor testing can account for factors, such as seasonal variations and external variables that accelerated devices simply cannot reproduce.

Putting It All Together – What Does a Complete Weathering Program Look Like?

In most weathering laboratories, the bulk of the data is generated from economical yet highly repeatable fluorescent UV lamp tests. The economy of these devices allows for sufficient quantities of data to be generated for statistically significant evaluations. Relying on statistically insignificant results creates a huge risk factor. Full spectrum xenon arc testers are necessary for those cases where longer wavelengths of UV and visible light energy are likely to cause photodegradation that may not be seen in a fluorescent UV lamp device, or not seen in a reasonable number of test hours. In addition, a full spectrum light source may better represent the effect of color on degradation because specimen temperature differences due to color are more accurately achieved in a xenon arc device. If a material's sensitivity to longer UV wavelengths and visible light is unknown, testing in both a xenon arc and fluorescent UV chamber may help determine the spectral sensitivity.

Often overlooked in weathering laboratories is the importance of experimentation. Temperature and moisture cycling and specimen design experiments may reduce risk either by creating greater test acceleration or generating results that better match outdoor weathering and real-world use. Experimentation is difficult because of budget constraints. This is why the cost of testing is a technical issue and not simply one of accounting. Fluorescent UV lamp devices are less expensive to purchase and operate, thus allowing greater experimentation in the laboratory. Xenon arc testing, however, is becoming more economical.

Outdoor weathering completes a weathering testing program because it provides the data by which laboratory test methods can be evaluated. Companies with the best weathering programs typically collect specimens for testing from various internal teams and put them on exposure on a regular schedule. From a short-term perspective, it may be difficult to see the value, but over time the data from these outdoor weathering tests becomes highly valuable. When the same materials are tested in the laboratory, relationships between outdoor and laboratory results can be made. Test method experimentation can improve the results so that decisions based on the accelerated tests come with less and less risk over time.

A test program has the best ability to predict performance of materials in a real world application by combining various outdoor and accelerated tests. The effort spent setting up a testing program is worth the savings that come from a more cost-effective formulation or fewer warranty claims.