TECHNICAL BULLETIN LU-0822

Sunlight, UV, & Accelerated Weathering

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INTRODUCTION

Sunlight is an important cause of damage to plastics, textiles, paints, and other organic materials. Short wavelength ultraviolet light has long been recognized as being responsible for most of this damage[2]. Spectroradiometric measurements were made to quantify the wide variations in UV content of sunlight under the following conditions: direct summer sunlight, winter sunlight, sunlight filtered through ordinary window glass and sunlight filtered through automotive glass.

Accelerated weathering testers are widely used for research and development, quality control, and material certification. They employ a variety of light sources to simulate sunlight and the damage caused by sunlight. Comparative spectroradiometric measurements of various types of accelerated testers also showed a wide variety of UV spectra. These measurements help highlight the advantages and disadvantages of the various accelerated light sources: enclosed carbon arc, sunshine carbon arc, xenon arc and fluorescent UV. The measurements suggest recommendations for the use of different light sources for different applications. Two new types of fluorescent UV lamps show promise for improved correlation with natural exposures.

EXPERIMENTAL

A spectroradiometer was used to measure the spectral irradiance received by test samples exposed to sunlight or accelerated testers. "Irradiance" is the rate at which light energy falls on a unit area of surface. "Spectral irradiance" is the distribution of irradiance with respect to wavelength. In this case the irradiance was measured at each 1 nanometer (nm) wavelength band throughout the wavelength region of interest. The Resulting Spectral Power Distribution (SPD) curves were plotted as graphs of irradiance versus wavelength. Measurements of sunlight were taken at solar noon with the sensor kept at normal incidence to the sun with a solar tracking equatorial drive system. The sensor viewed the whole sky, so that complete *global* sunlight was measured. Measurements of the accelerated light sources were taken with the sensor in the same position as an ordinary test sample, so that the irradiance measured would be the same as a sample receives.

All measurements were taken with the same instrument to ensure that the various SPD curves would be strictly comparable. Attempting to compare SPD curves generated by different spectroradiometers is a frequent source of error in this field, due to different types of input optics, different wavelength bandpasses, or simply due to limitations in the state of the art in spectral irradiance calibrations of diffuse UV sources like the sky or fluorescent lights.

The instrument used was an International Light IL 700 Spectroradiometer, No. 504, consisting of the following components as shown below:

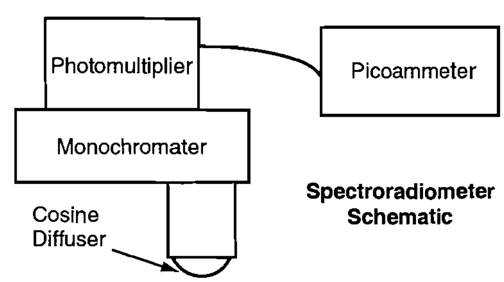
Input Optics: IL-2WE Double Wide Eye, quartz double lens cosine diffuser for wide viewing angle

Monochromater: Kratos GM-200, double grating monochromator with calibrated 1.0 nanometer band pass, stray light less than 1 part per million.

Detector: PM 270C Photo-multiplier, with an S-5 response, operated from an IL 760 power supply.

Picoammeter: IL 700A Radiometer.

Calibration: Microwatts per square centimeter per nanometer, traceable to the National Bureau of Standards. Calibration Certificate: 404045901.



Spectroradiometer Schematic

1. Presented at the Society of Plastics Engineers Automotive RETEC, Nov. 1987.
2. Searle, N. and Hirt, R. "UV SPD of Sunlight," J. Optical Soc. America, Vol. 55, No. 11, 1965.

Q-PANEL LAB PRODUCTS

SUNLIGHT

The electromagnetic energy from sunlight is normally divided into ultraviolet light, visible light, and infrared energy. Figure 2 shows the spectral power distribution (SPD) of noon midsummer sunlight, measured in Cleveland Ohio, June, 1986. Infrared energy (not shown) consists of wavelengths longer than the visible red wavelengths and starts above about 760 nanometers (nm). Visible light is defined as radiation between 400 and 760 nm. Ultraviolet light consists of radiation below 400 nm.

The International Commission on Illumination (CIE) further subdivides the UV portion of the spectrum into UV-A, UV-B and UV-C as shown below[3].

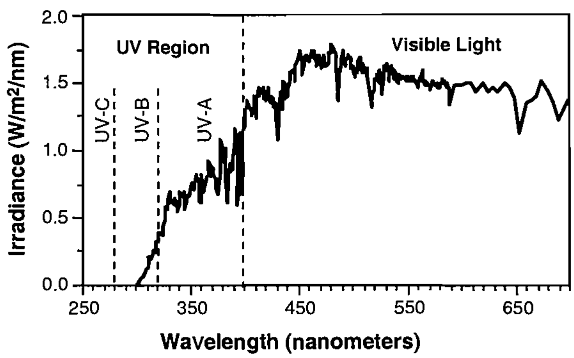


Figure 2 — The Sunlight Spectrum

The effects of the various UV wavelength regions can be summarized as shown in the following table[4].

WAVELENGTH REGIONS OF THE UV

UV-A **400 to 315 nm**	Causes polymer damage
UV-B **315 to 280 nm**	Includes the shortest wavelengths found at the earth's surface; responsible for severe polymer damage; absorbed by window glass.
UV-C **280 to 100 nm**	Found only in outer space; filtered out by earth's atmosphere; germicidal

VARIABILITY OF SUNLIGHT

Because UV is easily filtered by air mass, cloud cover, pollution, etc., the amount and spectrum of natural UV exposure is extremely variable. Figure 3 shows a comparison of the UV regions of sunlight, measured at Cleveland at noon on:

- The summer solstice (longest day of the year),
- The winter solstice (shortest day of the year),
- The spring equinox.

These measurements are in essential agreement with data reported by other investigators[5].

Because the sun is lower in the sky during the winter months, it is filtered through a greater air mass. This creates two important differences between summer and winter sunlight: changes in the intensity of the light and in the spectrum. Most important, the shorter, more damaging UV wavelengths are filtered out during winter. For example, the intensity of UV at 320 nm changes about 8 to 1 from summer to winter. This is especially significant for polymeric materials such as PVC. In addition, the short wavelength solar cut-off shifts from about 295 nm in summer to about 310 nm in winter. Consequently, materials sensitive to UV below 310 nm would degrade only slightly, if at all, during the winter months. The sunlight spectrum at the March 21 equinox falls between the June and December curves.

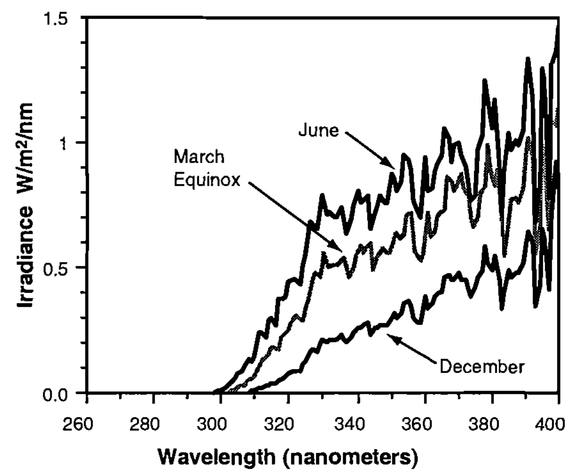


Figure 3 — Seasonal Variation of Sunlight UV

ACCELERATED LIGHT SOURCES COMPARED TO SUNLIGHT

The following discussion of light sources will confine itself to the question of UV spectrum. It will not address problems of light stability, the effects of moisture and humidity, the effects of cycles, or the reproducibility of results.

For simulations of direct sunlight, artificial light sources should always be compared to what we will call the Solar Maximum condition: global, noon sunlight, on the summer solstice, at normal incidence. The Solar Maximum is the most severe condition met in outdoor service, and as such it controls which materials will fail. It is misleading to compare light sources against so-called "average optimum sunlight", which is simply an average of the much less damaging March 21 and September 21 equinox readings. Graphs labeled "sunlight" in this paper refer to the Solar Maximum - noon, global, midsummer

3. CIE Standard No. 20.
4. Grossman, D. " Know Your Enemy: The Weather," J. Vinyl Techn., Vol. 3, No. 1, 1981.
5. Zerlaut, G. "Accelerated Weathering & UV Measurements", ASTM STP 781, pp 10-34, 1982.

sunlight. Despite the inherent variability of solar UV, our measurements show surprisingly little variation in the Solar Maximum at different locations. Figure 4 shows noon summer solstice measurements at three widely varied locations.

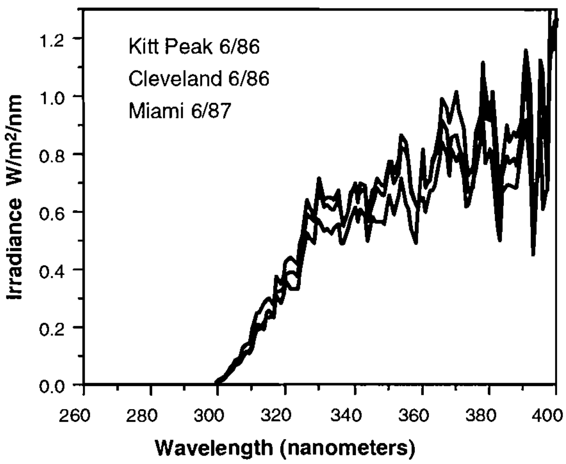


Figure 4 — Solar Maximum, 3 Locations

IMPORTANCE OF SHORT WAVELENGTH CUT-OFF

Photochemical degradation is caused by photons of light breaking chemical bonds. For each type of chemical bond there is a critical threshold wavelength of light with enough energy to cause a reaction. Light of any wavelength shorter than the threshold can break the bond, but longer wavelengths of light cannot break it—regardless of their intensity (brightness). Therefore, the short wavelength cut-off of a light source is of critical importance. For example, if a particular polymer is only sensitive to UV light below 295 nm (the solar cut-off point), it will never experience photochemical deterioration outdoors. If the same polymer is exposed to a laboratory light source that has a spectral cut-off of 280 nm, it *will* deteriorate. Although light sources that produce shorter wavelengths produce faster tests, there's a possibility of anomalous results if a tester has a wavelength cut-off too far below that of the material's end use environment.

ARC TYPE LIGHT SOURCES

Enclosed Carbon Arc (ASTM G-23). The enclosed carbon arc has been used as a solar simulator in accelerated weathering and lightfastness testers since 1918. Many ASTM and Federal Test Methods still specify its use. When the light output of this apparatus is compared to sunlight, some deficiencies become evident. Figure 5 shows the UV spectral power distribution (SPD) of summer sunlight (Solar Maximum) compared to the enclosed carbon arc. The UV output of the enclosed carbon arc primarily consists of two very large spikes of energy, with a very small amount of output below 350 nm. Figure 6 shows the same SPD comparison graphed on a different vertical scale to include all of the output from the spikes. Since the shortest UV wavelengths are the most damaging, the enclosed carbon arc gives very slow tests on most materials and poor correlation on materials sensitive to short wavelength UV.

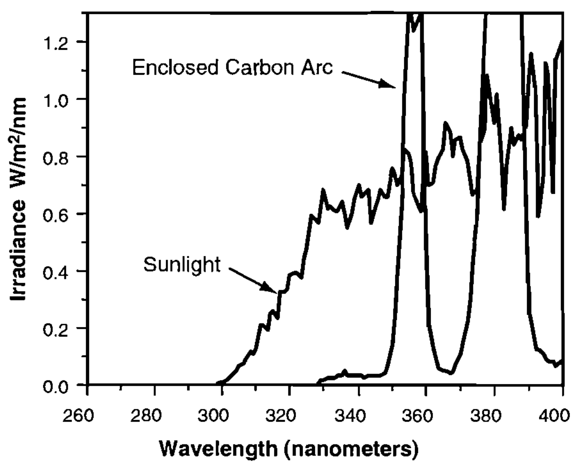


Figure 5 — Enclosed Carbon Arc and Sunlight

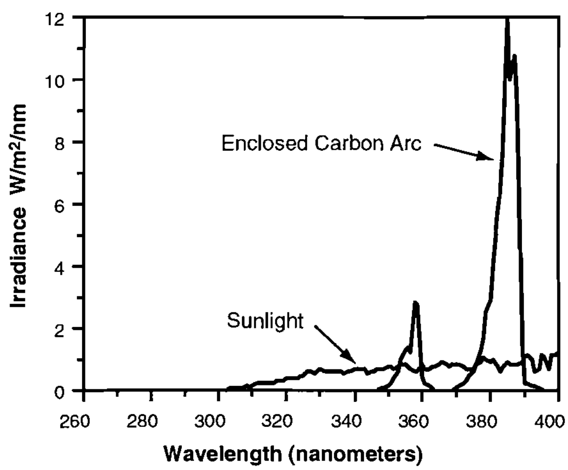


Figure 6 — Enclosed Carbon Arc and Sunlight

Sunshine Carbon Arc (ASTM G-23 Open Flame Carbon Arc). The introduction of the sunshine carbon arc in 1933 was an advance over the enclosed carbon arc. Figure 7 shows the UV SPD of summer sunlight compared to the SPD of a sunshine carbon arc (with Corex D filters). While the match with sunlight is superior to the enclosed carbon arc, there is still a very large spike of energy, much greater than sunlight, at about 390 nm.

A more serious problem with the spectrum of the sunshine carbon arc is found in the short wavelengths. To illustrate this, a change of scale is necessary to expand the low end of the graph. Figure 8 shows Solar Maximum compared to sunshine carbon arc between 260 nm and 320 nm. The carbon arc emits a great deal of energy in the UV-C portion of the spectrum, well below the normal solar cut-off point of 295 nm. Radiation of this type is realistic for outer space, but is never found at the earth's surface. These short wavelengths can cause unrealistic degradation when compared to natural exposures.

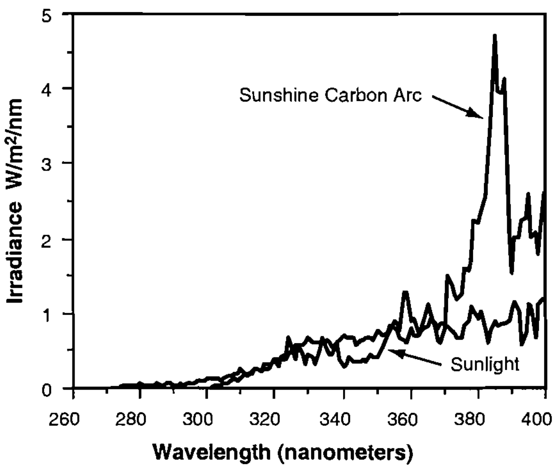


Figure 7 — Sunshine Carbon Arc and Sunlight

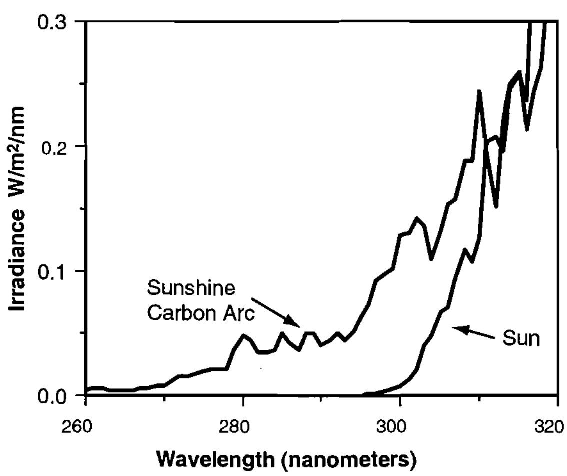


Figure 8 — Sunshine Carbon Arc and Sunlight

Xenon Arc (ASTM G-26). The xenon arc was adapted for accelerated weathering in Germany in 1954. Understanding xenon arc spectra is complicated by two variables: the effect of filters and the effect of irradiance settings.

Effect of Xenon Filters: Xenon arcs require a combination of filters to reduce unwanted radiation. Automotive test methods that call for xenon arc exposure usually specify quartz inner and borosilicate outer filters. Figure 9 shows a xenon arc with quartz/boro filters compared to Solar Maximum. This filter combination allows severe, unrealistic short wavelength UV as low as 270 nm.

The most common filter combination is borosilicate inner and outer filters (boro/boro). Figure 10 shows the SPD of summer sunlight compared to a xenon arc with boro/boro filters. This is a better simulation of sunlight UV than the quartz/boro filters, because the cutoff wavelength of the boro/boro is approximately 280 nm, somewhat closer to the sunlight cutoff of 295 nm.

Effect of Irradiance Setting: Recent xenon arc models have a light monitoring system to compensate for the inevitable light output decay due to lamp aging. The most common irradiance settings are .35 or .55 watts per meter^2 at 340 nm. Figure 11 shows how these two settings (with boro/boro) filters compare with Solar Maximum. While .55 compares better with summer sunlight, .35 is more like winter sunlight. However, for practical operational reasons, .35 is the setting most often used.

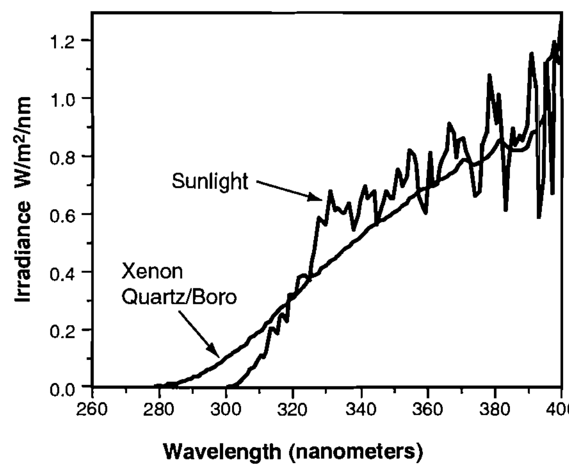


Figure 9 — Xenon with Quartz/Boro Filters

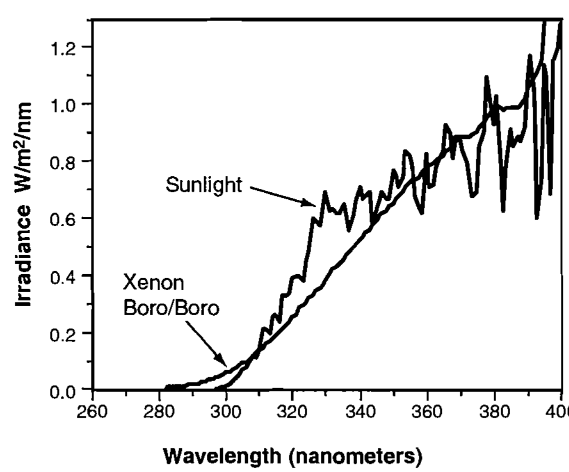


Figure 10 — Xenon with Boro/Boro Filters

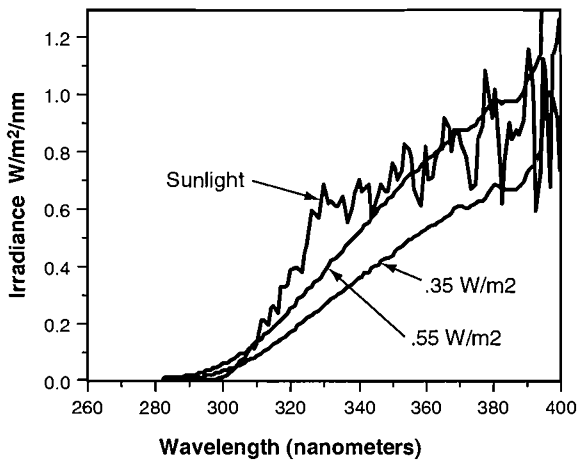


Figure 11 — Effect of Irradiance Setting

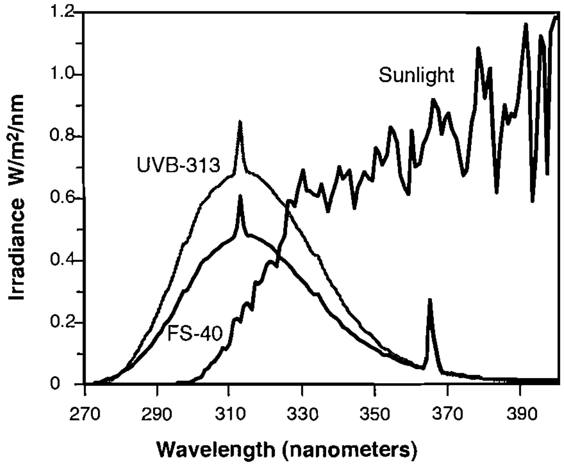


Figure 12 — UVB-313 and FS-40

FLUORESCENT UV LAMPS

Over the past 10 years, Fluorescent UV and Condensation testers have come into wide use. There are now different types of fluorescent lamps, with different spectrums, for different exposure applications. The fluorescent UV testers use a different approach than the arc testers. They do not attempt to reproduce sunlight itself, just the damaging effects of sunlight. This approach is effective because short wavelength UV causes almost all of the damage to durable materials exposed outdoors. Consequently, fluorescent UV testers confine their primary emission to the UV portion of the spectrum.

FS-40 Lamp (F40-UVB) (ASTM G-53). In the early 1970's the FS-40 became the first fluorescent UV lamp to achieve wide use. This lamp is currently specified in some automotive specifications, particularly for coatings. Most of the FS–40's output is in the UV-B portion of the UV spectrum, along with some UV-A. This lamp has demonstrated good correlation to outdoor exposures for the gloss retention on coatings[6] and for the material integrity of plastics. However the short wavelength output below the solar cut-off can occasionally cause anomalous results, especially for color retention of plastics and textile materials[7].

UVB-313 Lamp (ASTM G-53). Introduced in 1984, the UVB-313 is essentially a second generation FS-40. It has the same SPD as the FS-40, but with higher, more stable output. Figure 12 shows the SPD of sunlight compared to the UVB-313 and the FS-40. Because of its higher output the UVB-313 gives significantly greater acceleration over the FS–40 for most materials. With the exception of the automotive industry, the UVB-313 is the most widely used light source for the ASTM G-53 devices.

UVA-340 Lamp (ASTM G-53). The UVA-340 was introduced in 1987 to enhance correlation in the G–53 devices. Most of this lamp's emission is in the UV-A region, with a small amount in the UV-B. The UVA-340 has been tested on both plastics and coatings and greatly improves the correlation possible with the Fluorescent UV and Condensation devices[8]. The Society of the Plastics Industry VSI and VWDI are currently using this lamp in extended outdoor correlation studies on rigid vinyl.

Figure 13 shows the UVA-340 compared to Solar Maximum. This new lamp is an excellent simulation of sunlight from about 370 nm, down to the solar cut-off of 295 nm.

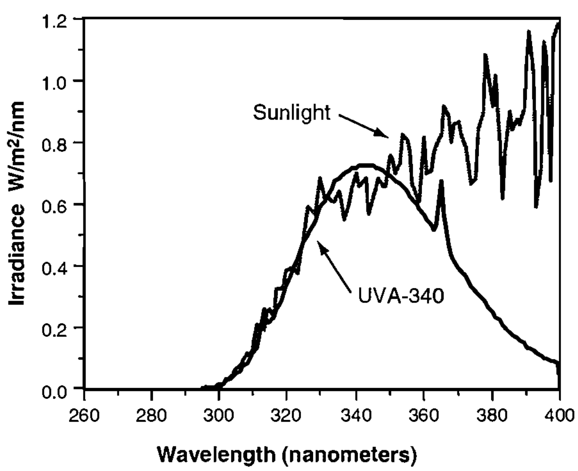


Figure 13 — UVA-340 and Sunlight

6. Grossman, G. "Correlation of Weathering," J. Coatings Technology, Vol. 49, No.633. 1977
7. Dick, J., et al, "Weatherability of Pigmented Plastics," SAE Technical Paper, No. 850350, 1985
8. Fischer, R. "Accelerated Test w. Fluorescent UV-Condensation," SAE Tech. Paper No. 841022, 1984

FILTERING EFFECT OF GLASS ON SUNLIGHT

Common Window Glass. Glass of any type acts as a filter on the sunlight spectrum. The shorter, more damaging wavelengths are the most greatly affected. Figure 14 shows direct summer sunlight compared to sunlight filtered through ordinary, single strength, untinted, 0.125 inch thick window glass. As the figure shows, ordinary glass is essentially transparent to light above about 370 nm. However, the filtering effect becomes more pronounced with decreasing wavelength. The most damaging wavelengths below about 310 nm are completely filtered out.

Automotive Glass. Automotive glass is thicker than window glass. The thicker glass acts as a more efficient filter. In addition, auto glass windshields are often tinted and usually contain a layer of plastic for safety enhancement. Each of these factors adds to the filtering efficiency. Figure 15 shows direct summer sunlight compared to sunlight filtered through tinted automotive windshield glass. Almost all of the most damaging ultraviolet light has been filtered out. Figure 16 shows that various other types of auto window glass filter sunlight less than windshield glass but more than ordinary window glass. Further data on sunlight through automotive glass compared to laboratory light sources has been reported elsewhere.[9]

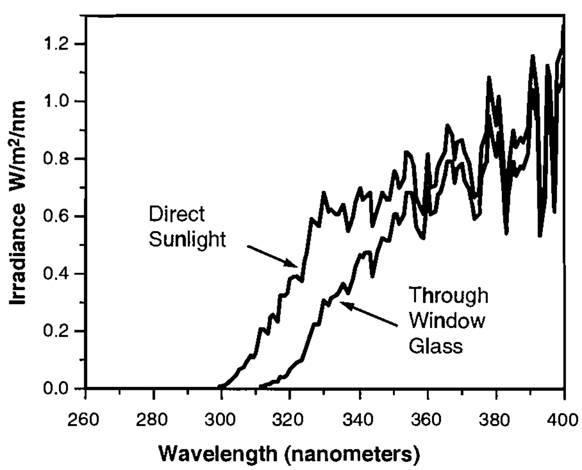


Figure 14 — Sunlight Through Window Glass

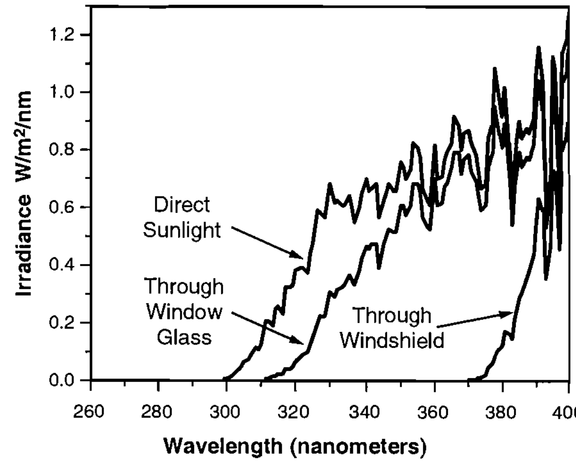


Figure 15 — Sunlight Through Windshield Glass

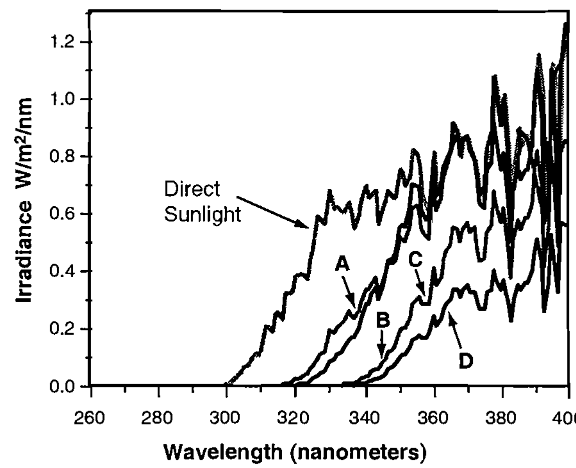


Figure 16 — Sunlight Through Auto Glasses

Figure 16, Sunlight Through Various Types of Auto Window Glass

A = 0.128 inch thick, Clear
B = 0.228 inch thick, Clear
C = 0.159 inch thick, Lightly Tinted
D = 0.194 inch thick, Tinted

9. Brennan,"Lab Spectra and Sunlight Through Auto Glass", IFAI Auto Fibers & Fabrics Seminar, 1987.

ACCELERATED LIGHT SOURCES AND SUNLIGHT THROUGH GLASS

UVA-351 Fluorescent Lamp (ASTM G-53). Figure 17 shows the UVA-351 compared to sunlight through ordinary window glass. This fluorescent lamp is an excellent simulation of sunlight for most interior applications.

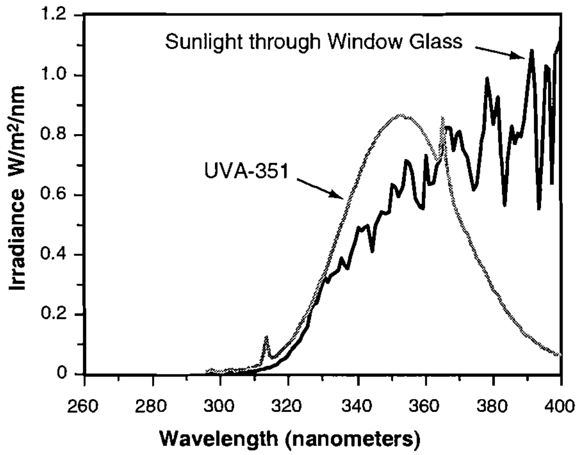


Figure 17 — UVA-351 & Sunlight Through Glass

Xenon Arc (ASTM G-26). The current xenon arc automotive test method for textiles and soft trim specifies the quartz/boro filter combination (at .55 w/m2). Figure 18 shows this xenon method compared to sunlight through ordinary glass.

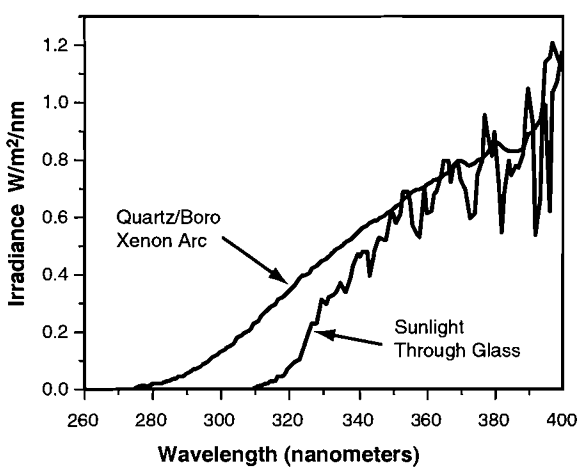


Figure 18 — Xenon & Sunlight Through Glass

CONCLUSIONS AND CAVEATS

Correlation between laboratory and natural exposure test results will probably always be controversial. As Fischer has shown[8], test speed and accuracy tend toward opposition. Accelerated light sources with short wavelength UV give fast tests, but may not always be accurate. Usually where they are wrong, they are wrong on the safe side—they are too severe. Light sources that eliminate wavelengths below the solar cut-off of 295 nm will give better, more accurate results, but the price for increased correlation is reduced acceleration. The user must educate himself to make this choice. In addition we should point out that, despite the current interest in light energy, the spectrum of a test device is only one part of the picture. With any accelerated tester, there are a number of parameters that can be programmed: UV spectrum, moisture, humidity, temperature and test cycle. Furthermore, the parameters that one chooses are, to a certain extent, arbitrary. No single test cycle or device can reproduce all the variables found outdoors in different climates, altitudes and latitudes. Consequently, even the most elaborate tester is really just a screening device. The real usefulness of accelerated testers is that they can give reliable, *relative* indications of which material performs best under a specific set of conditions.

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