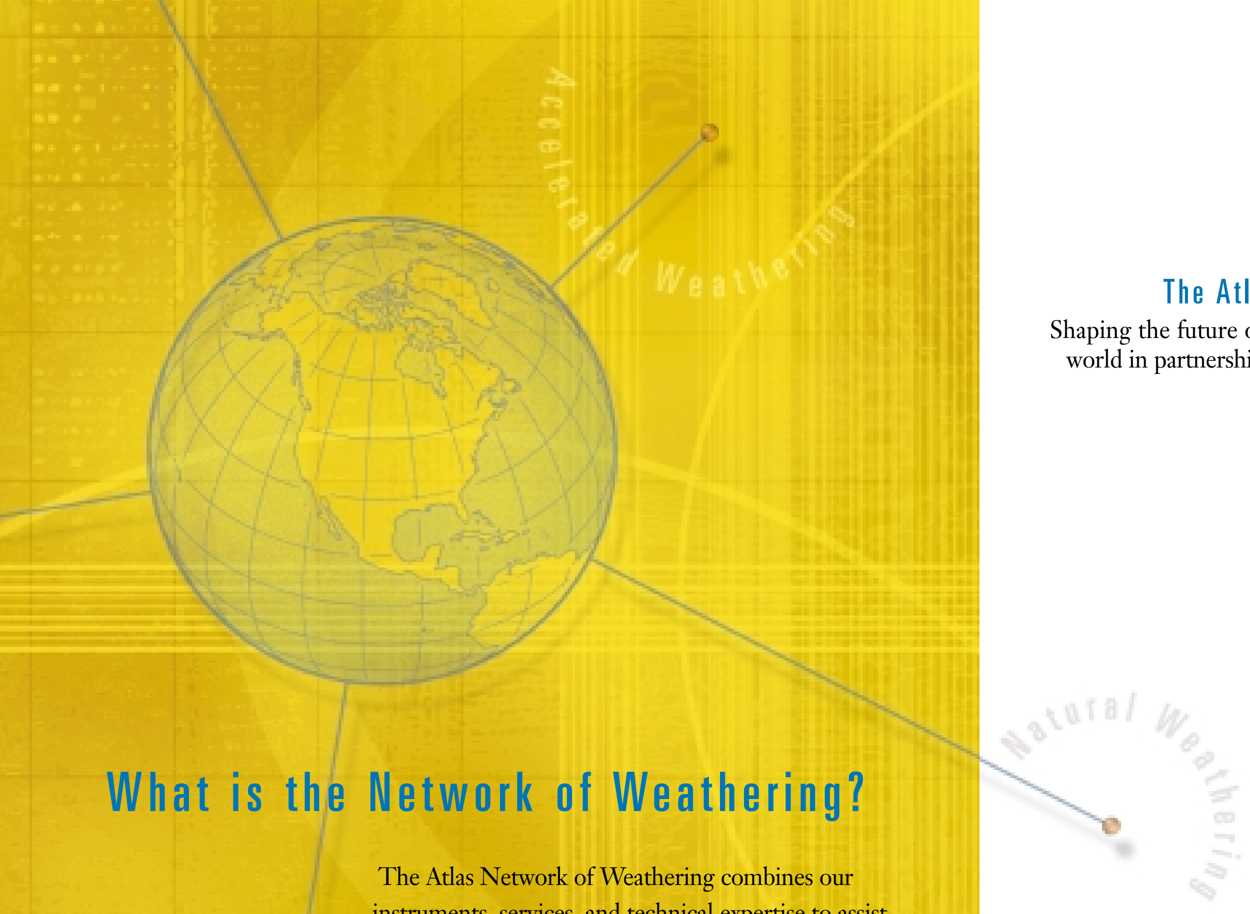
ATLAS
MATERIAL TESTING SOLUTIONS

Weathering Testing Guidebook



What is the Network of Weathering?

The Atlas Network of Weathering combines our instruments, services, and technical expertise to assist our clients as they develop their own weathering test programs. For years, Atlas has been recognized as the world leader in materials durability testing, from our weathering instruments to our outdoor weathering laboratories. With the combined resources of Atlas Electric Devices, the Atlas Weathering Services Group, and K.H. Steuernagel, our clients can have expert assistance in all areas related to natural and laboratory weathering and material testing solutions. As the Network of Weathering, we work together to provide our clients with a test program that will supply the data needed to make informed material performance decisions.

This manual is one of many steps Atlas Material Testing Solutions has taken to support the Network of Weathering philosophy. We have done our best to explain the factors of weathering, natural testing applications, and laboratory testing applications as directly as possible. We hope that this manual will be a resource to help answer the most often asked questions about weathering testing and will be a guide to the solutions Atlas has available to help you develop accurate, meaningful weathering test programs.

The Atlas Network of Weathering is a concept that supports the strategic goals of Atlas Material Testing Solutions, as well as our Mission and Vision statements.

The Atlas Vision

Shaping the future of the materials testing world in partnership with our customers

The Atlas Mission

is to advance the technology of material testing through:

Our industry expertise

Involvement in international standards development

Partnership with our customers

Provision of world-class products and services

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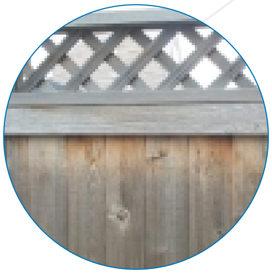
Factors of Weathering and Climate

Factors of Weathering and Climate

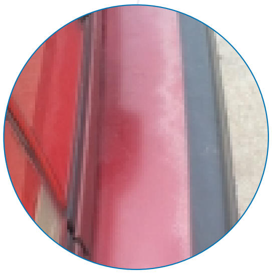
Factors of Weathering

What Is Weathering?

Weathering is the adverse response of a material or product to climate, often causing unwanted and premature product failures. Consumers spend billions of dollars per year to maintain products that inevitably degrade and to replace products that fail. Materials that fail as a result of exposure to outdoor environments account for a significant portion of this total cost.



Discoloration



Cracking and Crazing

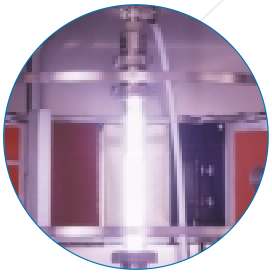
Rust

Peeling Paint

Failed materials in their end-use environment.

We attempt to prevent deterioration and premature product failure through chemical or mechanical stabilization and through weathering tests to assess a material's durability. For product development, it is vital to understand how to properly design and conduct these tests. Recognizing the key factors that cause degradation is a good start.

Static Weathering



Laboratory Accelerated Weathering

Natural Accelerated Weathering

Many different testing options are available. The best option depends on the applications and objectives.

Factors of Weathering

The three main factors of weathering are **solar radiation (light energy), temperature, and water (moisture).** But it is not just "how much" of each of these factors ultimately causes degradation to materials, because different types of solar radiation, different phases of moisture, and temperature cycling have a significant effect on materials on exposure. These factors, in conjunction with secondary effects such as airborne pollutants, biological phenomena, and acid rain, act together to cause "weathering."

Solar Radiation

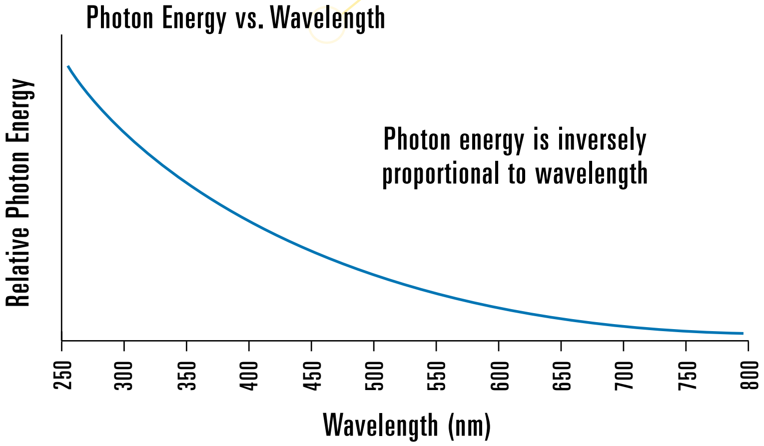
Radiant **energy** that comes from the sun is made up of **photons** that travel through space as **waves.** Their **energy** (**E**) is proportional to their **frequency** (ν) according to the following equation, where (**h**) is **Planck's constant,** (**c**) is the **velocity of light in a vacuum,** and (λ) is **wavelength.**

The relationship in this equation shows that shorter wavelengths are associated with higher photon energy (see Figure 1.1). This is an important concept when we later discuss how materials degrade as a result of solar radiation (see pg. 13).

$$\underbrace{E}_{\text{energy}} = \underbrace{h}_{\text{Planck's constant}}\overbrace{\nu}^{\text{frequency}} = \underbrace{h}_{\text{Planck's constant}}\overbrace{c}^{\text{velocity}}/\underbrace{\lambda}_{\text{wavelength}}$$

Full Component Testing

Fig 1.1



The solar radiation that reaches the earth's surface consists of wavelengths between 295 and 3000 **nanometers.** A nanometer is one billionth (1 x 10^{-9}) of a meter. This **terrestrial sunlight** is commonly separated into three main wavelength ranges: **ultraviolet** (UV), **visible** (VIS), and **infrared** (IR). Wavelengths between 295 and 400 nm are considered the ultraviolet (UV) portion of the **solar spectrum,** making up between 4–7% of the total radiation. **Ozone** in the **stratosphere absorbs** and essentially eliminates all radiant energy below 295 nm. Extremely sensitive instruments may detect radiation below 295 nm, but this amount is considered negligible by most experts.

Range Name	Wavelength Range	% of Total Solar
Ultraviolet (UV)	295 – 400 nm	6.8
Visible (VIS)	400 – 800 nm	55.4
Infrared (IR)	800 – 2450 nm	37.8

Reference Table in Accordance to CIE Pub. 85, Tab.4

Ultraviolet (UV), according to **ASTM G 113–94,** *Terminology Relating to Natural and Artificial Weathering Tests of Non-metallic Materials*, is radiation for which the wavelengths of the components are shorter than those for visible radiation.

The spectral range for the UV and its sub-components are not well defined. However, the **CIE (Commission Internationale de l'Eclairage)** E-2.1.2 committee makes the following distinction:

UV–A	315 to 400 nm
UV–B	280 to 315 nm
UV–C	< 280 nm

Visible light (the radiation the human eye can detect) is between 400 and 800 nm, making up just over half of the solar spectrum. About 40% of the radiation from the sun is contained in the infrared portion of the solar spectrum beyond 800 nm.

Where Does the UV Stop and the Visible Range Start?

The defined break between the UV and visible portion of the spectrum may be different depending on the source of information. Some consider the break to be at 400 nm, some at 385 nm and others at 380 nm. While this might be considered a trivial point, it must be understood when calculating radiant dosages for exposure, whether in outdoor or artificial conditions. The variance between a break at 385 nm and a break at 400 nm could be more than 25%, which could be extremely important when attempting to estimate the service life of a material.

Table of wavelength ranges defined by various sources. These ranges may be defined by radiometer sensitivities, or controlling parameters of laboratory accelerated instruments.

Spectral Range	nm	Irradiance
UV-B	280 – 315	2.19 W/m^2
	280 – 320	4.06 W/m^2
UV-A	315 – 380	49.43 W/m^2
	315 – 385	54.25 W/m^2
	315 – 400	72.37 W/m^2
	320 – 400	70.50 W/m^2
Total UV	≤ 380	51.62 W/m^2
	≤ 385	56.44 W/m^2
	≤ 400	74.56 W/m^2
Total UV+VIS	≤ 780	658.53 W/m^2
	≤ 800	678.78 W/m^2
IR	780 - 2450*	431.87 W/m^2
	800 - 2450*	411.62 W/m^2
Total	≤ 2450*	1090.40 W/m^2

* limit of CIE Pub. 85, Tab.4

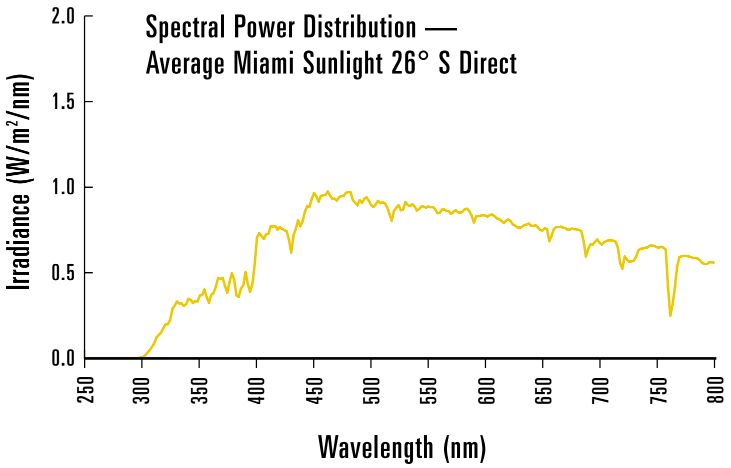
Global Solar Spectral Irradiance at Sea Level.
In accordance to CIE Pub. 85, Tab. 4

There are several terms that must be defined as we continue our discussion of solar radiation. **Irradiance** can be defined as the radiant flux incident on a surface per unit area, commonly expressed in W/m^2. For this parameter, it is necessary to indicate the spectral range in which the measurements were taken or for which the values were calculated, such as 295-3000 nm (total solar) or 295-400 nm (total UV). If we turn our attention to narrow wavelength intervals, we obtain the **spectral irradiance,** measured in $W/m^2/nm$. For weathering tests, the concept of **radiant exposure,** which is the time integral of (spectral) irradiance, may be more important, stated in J/m^2. Most radiant exposures are measured in either kJ/m^2 or MJ/m^2 to convert this energy into numbers to which we can more easily relate. Again, we would want to define the spectral range for any specified radiant dosage.

Term	Definition	Units
Irradiance	The radiant flux incident on a surface per unit area	W/m^2
Spectral Irradiance	Irradiance measured as a function of wavelength	$W/m^2/nm$
Radiant Exposure	Time integral of irradiance	J/m^2
Spectral Radiant Exposure	Radiant exposure measured as a function of wavelength	$J/m^2/nm$

Fig 1.2

Using the definitions in the table above, we can now introduce the concept of **spectral power distribution,** *and the* **spectral power distribution (SPD) graph.**



On the Spectral Power Distribution (SPD) graph, the X-axis represents wavelengths of radiation found in the solar spectrum *(see Figure 1.2)*. On the Y-axis of the graph, irradiance at each wavelength is indicated. The curve on the graph identifies the wavelength range of natural sunlight and the irradiance associated with each wavelength of radiation. In looking at the curve for natural sunlight on the graph, we see that there is essentially no irradiance below 295 nm. Understanding SPD graphs such as this is critical when we begin to compare various artificial light sources for weathering with natural sunlight.

DETOUR

Langleys

Another unit of measurement, the **langley**, is sometimes used to determine radiant exposure. A langley is a unit of total solar radiation equal to one gram-calorie per square centimeter of irradiated surface. One langley is equal to 0.04184 MJ/m^2 of total solar radiation. Since the term implies ***all*** wavelengths of the solar spectrum, a "langley of UV" does not exist. Also, it can be applied only to natural sunlight and not artificial light sources.

and Climate

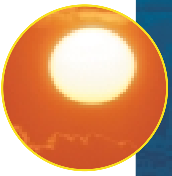
Taking a "Bath" in Sunlight

The terms used for measuring solar radiation can be thought of as similar to a bathtub being filled with water. Irradiance would be the rate the water is coming out of the faucet, and radiant exposure would be how much water is in the tub at any specific time. Spectral irradiance, which defines the wavelength range, would be the quality of the water used to fill up the tub.

DETOUR

Variations in Solar Radiation

In order to simulate solar radiation in weathering instruments, a well-defined "reference sun" is required. Although the sun does not follow man-made standards, it has existed for billions of years and is emitting its radiation – at least in UV, VIS, and IR – very constantly in time. The first "reference sun" which was agreed on at an international level is defined in CIE Publication No. 20 (1972). This is still a valid document for solar simulation testing. With the advancement of measurement techniques, CIE Publication No. 85 defines the "reference sun" in smaller wavelength steps and provides more accurate data than CIE Pub. 20. The values given for UV, visible, and infrared radiation in this section are derived from this newer publication.



Climatic Effects on Solar Radiation

Direct radiation is radiant energy that reaches the earth's surface directly from the sun, excluding the scattered radiation of the atmosphere. For **radiometry** measurements, this is defined as radiant energy within a 6° field of view of the solar disk. **Diffuse radiation** is a component of radiant energy that has been scattered by the atmosphere, and therefore, reaches exposed surfaces at all angles (that are not defined as direct) in a 180° field of view. Hence, for an exposed horizontal surface, both direct and diffuse solar radiation are received. This is referred to as **global solar radiation** *(see Figure 1.3)*.

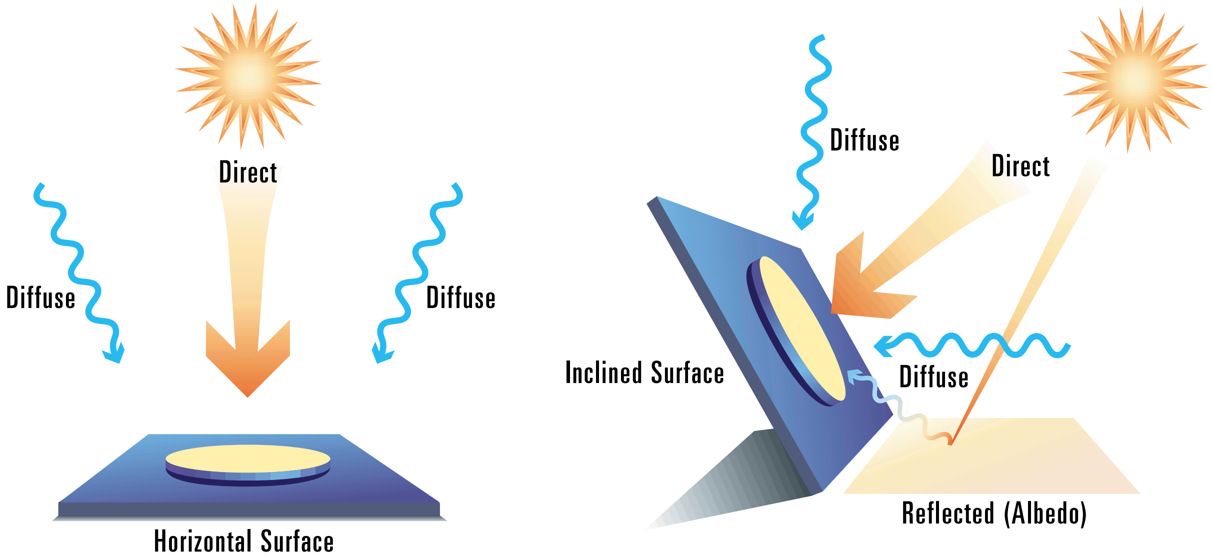
One easy way to understand direct and diffuse radiation is if we imagine a tall building. The direct light causes the sharp shadow of the building. Diffuse radiation creates general ambient light, allowing us to see if we are standing in the shadow of that building.

As we will discuss later, it is common to expose specimens in natural conditions with some kind of tilt that will increase solar radiation received or better simulate end-use conditions. Under these conditions, the surface of a specimen still receives the direct and diffuse radiation as discussed previously. In addition, there is radiation that reflects off the earth's surface (sometimes referred to as **albedo** radiation) that also reaches the surface of a specimen. The amount of radiation reflected off the earth's surface is dependent on the ground covering. Bare rocks, sand, or gravel will reflect much more radiant energy than a grass-covered surface. Water or snow will reflect an even greater amount of radiant energy.

The ratio between direct and diffuse radiation reaching the earth's surface is strongly influenced by atmospheric conditions. Water vapor (humidity) and pollution will increase the amount of radiant energy found in the diffuse component. A desert climate has a much higher percentage of radiant energy in the direct component than a subtropical climate. This occurs because there

Fig 1.3

The percentage of direct, diffuse, and reflected radiation striking a material is determined by the angle of exposure, as well as the atmospheric conditions.



is much less water vapor in the desert than in a subtropical climate. By contrast, a location with higher levels of pollution dramatically reduces the amount of direct radiant energy.

Based on **Rayleigh's Law**, shorter wavelengths of radiation are more likely to be scattered than long wavelengths. Therefore, the percentage of UV in the direct component will always be less than that of total solar radiation. This difference can be seen in graphs comparing the percentage of direct irradiance between total solar radiation (including all regions of the solar spectrum) and the UV only (*see Figure 1.4*).

The discussion of direct and diffuse radiation is important when considering radiant energy received at different orientations to the sun. Because of the high water vapor in a subtropical climate such as south Florida, about 50% of the UV radiation is diffused on clear days. Many days in Florida are not clear, which results in an even greater percentage of radiation in the diffuse component. To maximize solar radiation, specimens in a subtropical climate like south Florida should be exposed at a **tilt angle** close to horizontal, such as 5.° Conversely, a desert climate such as central Arizona would have a greater percentage of UV radiation in the direct component (as much as 75%). This means that the most radiant exposure over the course of one calendar year would be on specimens that were near the **latitude angle** of the exposure site. The selection of exposure angles for materials will be discussed later in this book.

Seasonal variability exists in both subtropical and desert environments. The amount of variation depends on the exposure angle and climate, especially the atmospheric conditions that cause different ratios of direct and diffuse radiation. Because of the high percentage of direct radiant energy in a desert environment such as central Arizona, there is a high seasonal variation for 5° exposures at that location. Exposures conducted at 5° in south Florida are relatively constant in UV because of the scattering by water vapor. Exposures conducted at the latitude angles (which are 26° in south Florida and 34° in central Arizona) result in minimized seasonal variations, because the sun is closer to the perpendicular of these surfaces over the entire year. A 34° exposure is optimal for central Arizona because of the high amount of direct radiation. Overall, south Florida has less UV at 45° due to the diffusing of radiant energy.

DETOUR

Why is the Sky Blue?

This question is asked every day by children around the world. The answer relates to our discussion of direct and diffuse radiation. According to the Rayleigh Law of scattering, shorter wavelengths of light are more easily scattered than longer wavelengths. In the visible portion of the spectrum, the shortest wavelengths are blue. The atmosphere acts like a prism, scattering all wavelengths of visible light. Rayleigh scattering is responsible for the blue sky, because the shorter wavelength blue light is scattered more than any other color. Scattered light beams are not necessarily lost but rather diverted from their normal course, which also means that they have a higher chance of being absorbed.

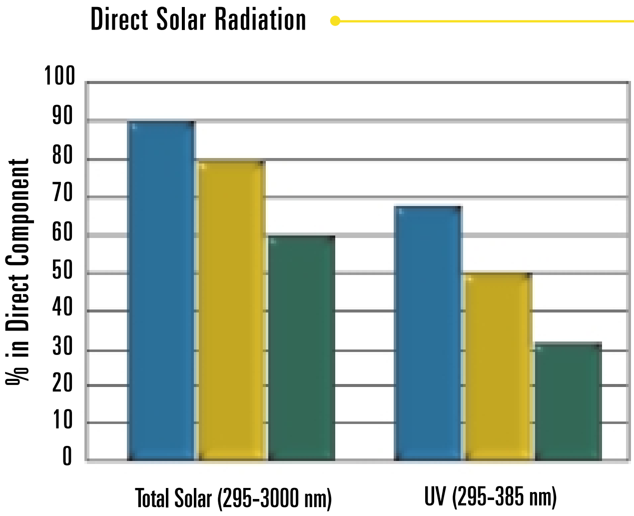


Fig 1.4

Water vapor, pollutants, and blowing dust in the atmosphere greatly affect the percentage of direct radiation reaching the earth's surface. Shorter wavelengths of radiation are more easily scattered, so the direct component in the UV range is even further diminished.

The Effect of Radiant Energy on Materials

While radiant exposure is an important factor in understanding the degradation of materials or determining the length of a weathering test, it really tells us only half the story. Radiant exposure tells only how much radiation has been deposited onto the surface of a material. It says nothing about how much of that radiation has been **absorbed** by the material.

According to the **Grotthus-Draper principle,**

> ***Absorption of radiation by any component of the system is the first necessary event for photochemical reaction occurrence.***

To put this in layman's terms, "If radiation can get into a material, it potentially can cause it to change." But does this mean that a black paint will degrade in the sun because it is absorbing nearly all wavelengths of visible light? The answer to that question lies in understanding the chemical nature of the paint and which wavelengths of radiation will cause this paint to degrade.

The molecular structures that constitute different **polymers** are susceptible to radiation they might absorb. Following another basic principle of degradation,

> ***The amount of energy absorbed by a molecule must exceed the bond energy to cause degradation.***

Simply put, if the absorbed radiation has more energy than the energy holding the molecular structure together, polymeric bonds will be altered and degradation will begin. As previously discussed, we know that shorter wavelengths contain higher amounts of energy. Therefore, it is now easy to understand, when we are discussing the durability of a material, why UV, as the shortest wavelength region of radiation to reach the earth's surface, is the most important part of sunlight.

For example, consider Figure 1.5 at left. It has been found through experimentation that a certain plastic absorbs radiant energy and degrades when irradiated below 310 nm. From our spectral power distribution graph, we know that natural sunlight contains wavelengths of radiation as low as 295 nm. The area under the two curves represents the effective irradiance concerning that material. The curve itself is known as the **activation spectrum** for that material. Do those wavelengths of radiation

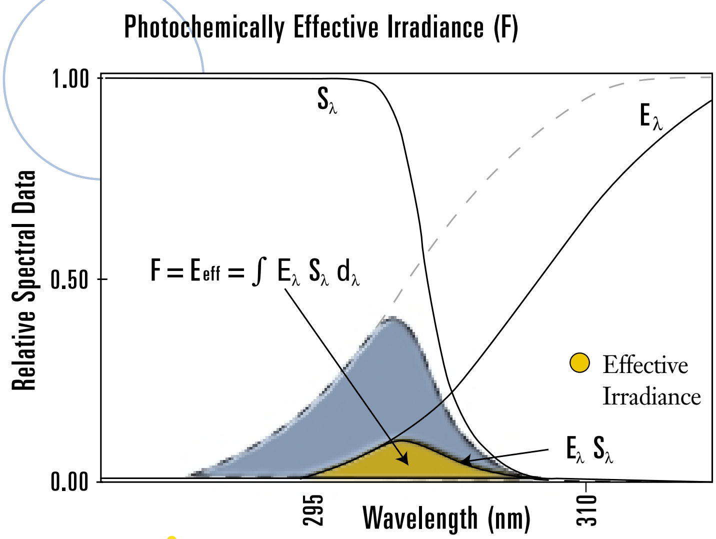


Fig 1.5

Relationship between spectral irradiance and spectral sensitivity. The area under both curves is the "effective" irradiance (E eff). El is the spectral irradiance. Sl is the spectral sensitivity of the material.

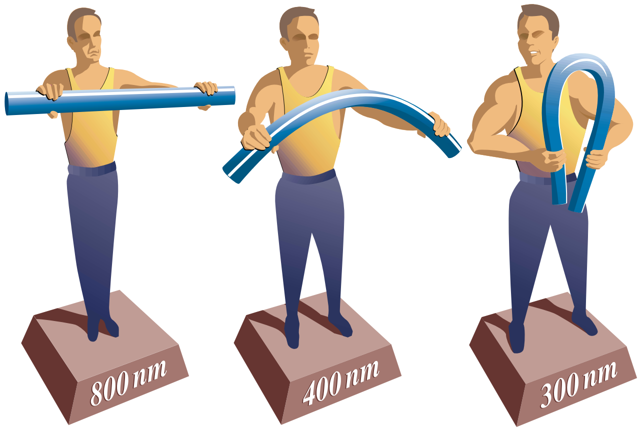
contain enough energy to alter chemical bonds? Will the material degrade? What type of degradation will we see? How will we know for sure? By conducting a weathering test, of course.

To summarize, the result of the degradation characteristics of a material as a result of radiation is dependent on:

- the quality and quantity of radiant energy deposited onto the material
- the wavelengths of radiation absorbed by the material
- whether or not that absorbed radiation has enough energy to cause a chemical change, which could lead to material degradation.

We have spent time discussing the changes that occur to a polymer as a result of short wavelength radiation. Color changes, however, are only partly related to changes of the polymer matrix. Often, they are caused by changes in the pigment or dyestuff used. Both pigments and dyestuffs absorb wavelengths in the visible range (otherwise, they wouldn't be colored) and are also damaged by UV-A radiation and visible light. From a customer's perspective, color change is undoubtedly one of the most important parameters when evaluating a material's performance. For most applications, it is necessary to simulate the full spectrum of the solar radiation.

Energy Levels at Different Wavelengths



Shorter wavelengths of radiation contain more energy to affect the chemistry of a material than longer wavelengths.

The energy of the defined wavelengths in each row is greater than the bond energies noted, which may cause a chemical change to that bond. However, we must not forget the concept of spectral sensitivity described in this section.

Bond	Bond Energy (Kcal/mol)	Wavelength (nm)
C=O	174	164
C-C (Aromatic)	124	231
C-H (Acetylene)	121	236
C-H (Ethylene)	106	270
C-H (Aromatic)	103	278
C-H (Methane)	102	280
O-H (Methanol)	100	286
O-H (Ethanol)	100	286
C-H (Ethane)	99	289
C-O (Ethanol)	92	311
C-O (Methanol)	89	321
C-C (Ethane)	84	340
C-Cl (Methyl Chloride)	84	340
C-C (Propane)	83	345
C-Cl (Ethyl Chloride)	81	353
C-O (Methyl Ether)	76	376
RO-OR (Peroxide)	64	447
RO-OR (Hydroperoxide)	36	794

Temperature

The **temperature** of materials exposed to solar radiation has an influence on the effect of the radiation. **Photochemical** reactions are usually accelerated at elevated temperatures. In addition, temperature determines the rate of subsequent reaction steps. These secondary reactions can be qualified using the **Arrhenius equation**. A general rule of thumb assumes that reaction rates double with each 10°C rise in material temperature. However, this may not be seen when measuring physical or appearance changes. Also, **thermochemical** reactions that may be initiated at higher temperatures may not occur at all or at a very low rate at lower temperatures.

The temperature of a material exposed to natural sunlight is determined by a number of factors. Specimen surface temperature is a function of ambient temperature, specimen solar absorptivity, solar irradiance, and surface conductance. Therefore, in the presence of sunlight, the surface temperature of an object is usually considerably higher than the temperature of the air. **Solar absorptivity** in both the visible and infrared regions is closely related to color, varying from about 20% for white surfaces to over 90% for black surfaces; thus, materials of different colors will reach different temperatures on exposure *(see Figure 1.6)*. This surface temperature dependency on color can have secondary (non-thermochemical) effects on materials as well. For example, as a result of different surface temperatures, mildew and other biological growth will form and accumulate at different rates on materials of different colors. White, or lighter colored materials, tend to "grow" more mildew than darker colored materials.

Much higher temperatures are obtained on painted or coated metal surfaces than in the bulk of a plastic material because the **thermal conductivity** and **heat capacity** of metals are generally higher than plastic substrates. **Ambient air temperature, evaporation** rates, and the **convective cooling** from the surrounding air during exposure all play a role in the temperature of a material, and therefore, influence degradation rates.

Temperature Dependency on Color

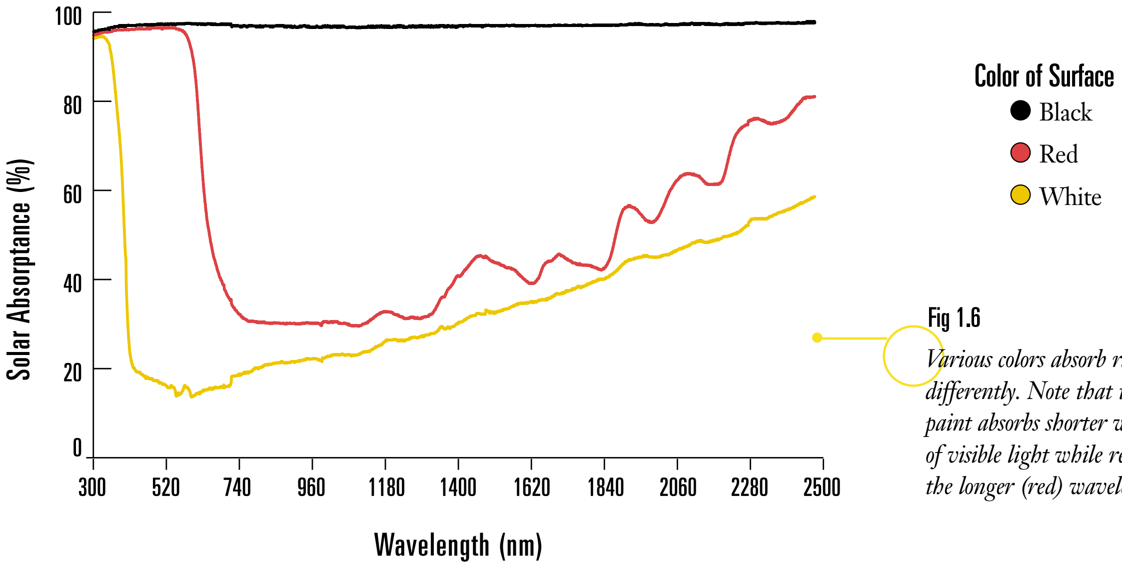


Fig 1.6

Various colors absorb radiation differently. Note that the red paint absorbs shorter wavelengths of visible light while reflecting the longer (red) wavelengths.

Water (Moisture)

Water is one of the substances in our environment that is everywhere, whether in the form of humidity, rain, dew, snow, or hail. All materials used outdoors are exposed to these influences.

There are two ways in which water affects materials. Water **absorption** by synthetic materials and coatings from humidity and direct wetness are examples of physical effects. As the surface layers absorb moisture, a volume expansion is produced that places stress on the dry subsurface layers. Following a drying out period, or **desorption** of water, the surface layers will lead to a volume contraction. The hydrated inner layers resist this contraction, leading to surface stress cracking. This fluctuation between hydrated and dehydrated states may result in stress fractures *(see Figure 1.7)*.

The **freeze-thaw cycle** is another physical effect. Because water expands when it freezes, absorbed moisture in a material causes expansion and stresses that cause peeling, cracking, and flaking in coatings. Rain, which periodically washes dirt and pollutants from the surface, has an effect on the long-term rate of deterioration that is determined more by its frequency than its amount. When rain strikes an exposed surface, evaporation processes cool the surface rapidly, which may cause physical degradation to a material. Frozen rain, or hail, may also cause physical degradation to materials because of the strong **kinetic energy** associated with its impact.

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The aging of polymeric materials is more dependent on the duration than the amount of water (either rain or dew) on the surface. The total duration that a surface is wet is called the **time-of-wetness.** For example, it makes a great difference if a certain amount of rain falls in a matter of a few minutes in a sudden shower or in the form of drizzle lasting several hours. The depth of penetration into the material, and thus the influence on the weathering behavior, is much greater in the second case than in the first.

Absorption/Desorption Cycle

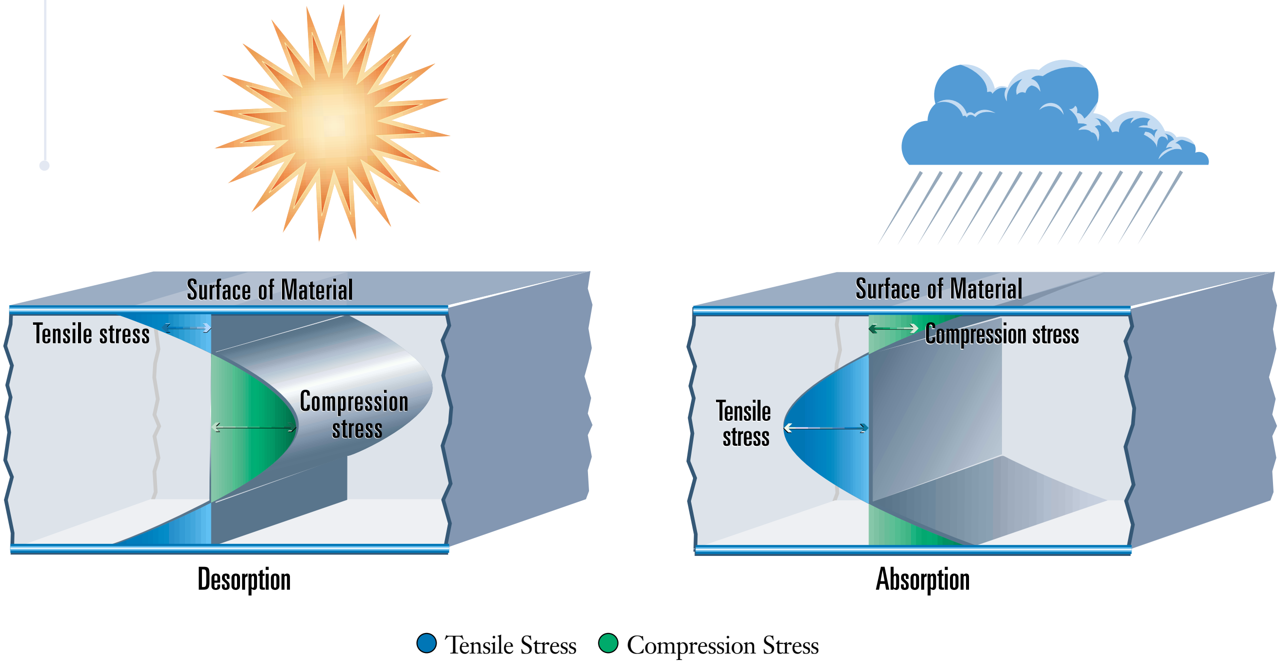


Fig 1.7

Different stresses exist through the profile of a material as it absorbs or desorbs moisture.

Water also can be directly involved in the degradation reaction in a chemical sense. The **chalking** of titanium dioxide (TiO_2) in pigmented coatings and polymers is one good example. While the structure of a polymer is changed by radiant energy, the actual release of material on the surface is enhanced, if not caused, by the cyclic action of chemically absorbed moisture. Contact with water in any phase can accelerate the rate of oxidation. Moisture also may act as a pH adjuster, especially when considering the effects of **acid rain**, which may cause an **etching** of many paints and coatings.

Secondary Effects

The secondary effects of weather or the atmosphere that may cause degradation cannot be underestimated. **Gases** and **pollutants** in the atmosphere, especially in the form of **acid rain**, may cause entirely new reactions. In highly industrialized areas, acid rain is the primary element driving the weathering process that affects a wide range of materials.

Blowing dirt and dust may have effects on the weathering process without reacting with the actual molecular structure of the material. These effects include the screening of ultraviolet radiation from the materials by dirt, which absorbs the ultraviolet portion of the spectrum. Semi-permanent “varnishes” can form on the surface of exposed materials in certain climates. **Mold**, **mildew**, and other microbiological agents may play a significant role in material degradation, particularly in tropical and subtropical climates, although they may not be generally thought of as weathering factors. Acts of Nature may not directly cause typical weathering processes to occur, but events such as **El Niño**, **La Niña**, and **volcanism** may affect climatic conditions which, in turn, result in different degradation rates.

Synergy

When considering the roles that solar radiation, temperature, moisture, and secondary effects play on products, we must realize that these factors work together to degrade materials. For example, if a material is exposed to only one of these factors, it is very unlikely that the degradation incurred will look anything like that of a material exposed to outdoor conditions, where all factors play a role in the degradation processes.

The synergistic effects of the main factors of weathering vary, depending on materials being exposed. Even small changes to a product’s formulation, such as the addition of stabilizers, flame retardants, fillers, etc., will change the degradation characteristics of that material. The use of recycled material, impurities in the polymer matrix, and the characteristics of product processing are additional variables in weathering performance. While there are literally thousands of publications that examine the durability characteristics of pure polymers, stabilizers, and specific aftermarket products, the study of a material’s durability to weathering is not an exact science. It is safe to say that a complete understanding of the effect of weathering factors on every material will never be achieved.

DETOUR

Blowing Dust from the Sahara

It is not uncommon to find dust on specimens that are exposed outdoors. Dirt and dust accumulation is an important evaluation criteria for many types of materials, including automotive paints, window moldings, and sealants. Interestingly, the dust that settles on specimens in Florida is not necessarily from the local area. Studies have shown that much of the dust accumulation has origins in the Sahara desert of Africa, blown across the Atlantic Ocean by the same prevailing trade winds that give hurricanes their predominant westerly movement. According to ***National Geographic*** magazine, over a billion tons of dust are deposited in the Caribbean each year.

and Climate

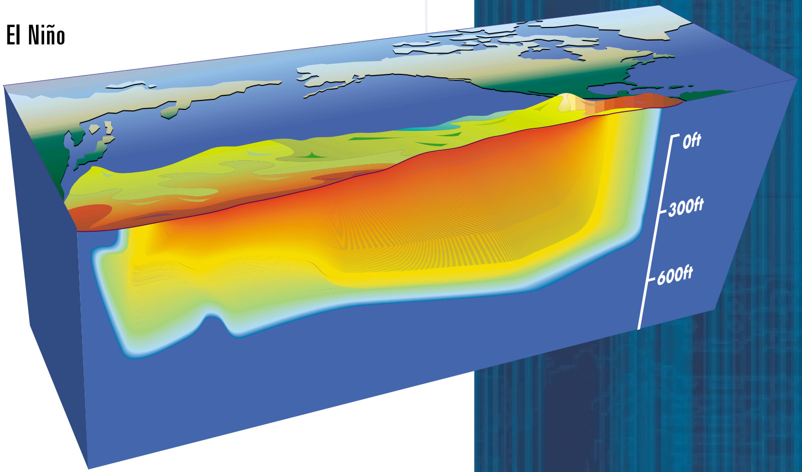
Secondary Effects

Testing in environments that emphasize these secondary effects may be crucial for some weathering applications.

El Niño's Effect on Weathering Testing

During an El Niño event, the typical trade winds in lower latitudes over the Pacific Ocean diminish, leading to changes in normal temperature distributions in the waters of the eastern and western Pacific. Without these winds, the atmospheric heat source overlaying the warmer water of the western Pacific moves east, causing changes in the normal atmospheric circulation of the earth. This changes climatic conditions worldwide, and ultimately may lead to variations in natural weathering exposures.

El Niño



Mildew

Blowing Dust

Pollution

Ozone

Climate

In viewing a climatological map of the world, it is obvious that a wide range of climates exists. These different climates are a result of latitude, weather patterns, topographical and geographical features *(see Figure 1.8)*.

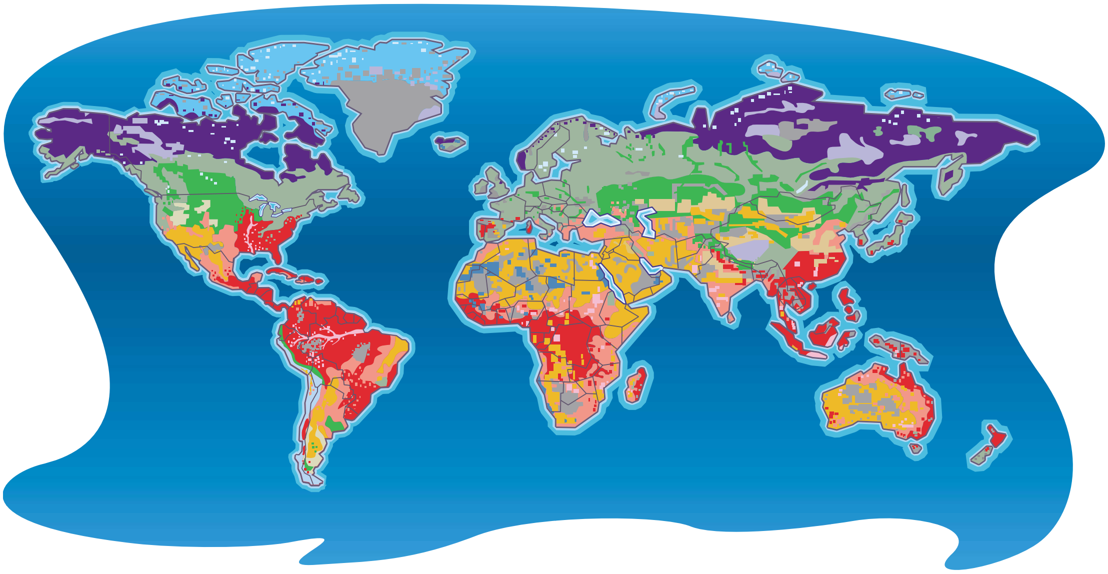


Fig 1.8

Variations in Climate

It is not practical to determine the weathering characteristics of materials in all the world's climates. Therefore, those climates selected for exposure testing are based on their known severity for the weathering of materials and the anticipated market of the product. The major marketing area of the material should be taken into consideration when selecting suitable climates and sites for weathering tests. If the material were sailcloth, a coastal marine location would be a primary climate to test. However, this location would not be suitable for materials used globally because the effect of the salt air dissipates within 12 kilometers (8 miles) of the ocean.

Each class of materials is sensitive to a specific group of environmental parameters. Humidity, rain, and salt spray can cause corrosion of metals. For plastics and coatings, ultraviolet radiation, temperature, and moisture can initiate material degradation.

Benchmark Climates for Weathering

The two most important (or benchmark) climates for weathering tests are the subtropical environment, such as south Florida, and a desert environment, such as central Arizona. While other climates are sometimes used as weathering test sites for specific applications, the subtropical and desert environments are recognized around the world as the most severe climates for materials exposed outdoors in their expected end-use application.

DETOUR

Seven Major Climates

The **World Meteorological Organization (WMO)** has identified seven major climates around the world. They are:

- Dry (desert)
- Subtropical
- Humid Micro-thermal
- Humid Meso-thermal
- Polar
- Tropical
- Undifferentiated

and Climate

Exposures in the subtropical climate of south Florida were first conducted in the 1920s and 1930s as the paint industry became increasingly concerned about the weathering resistance of its products. The largest independent test sites, such as the Atlas Weathering Services Group (AWSG) site in south Florida, are located in areas that are considered inland locations, and therefore do not receive any adverse corrosive coastal effects. Desert environment outdoor weathering sites, such as the Atlas Weathering Services Group site in central Arizona, experience higher average and annual extreme temperatures, which cause higher stresses to automotive interior materials than any other climate of the world. Independent test sites at these benchmark climates are located in areas outside of metropolitan areas to minimize industrial or urban pollution.

AWSG — South Florida

Located approximately 33 km (20 miles) northwest of downtown Miami in an unpolluted, subtropical environment, south Florida has long been the benchmark for outdoor weathering tests because of the high temperature, moisture, and total UV content.

Climatological Data — South Florida

Latitude	25° 52′ N	
Longitude	80° 27′ W	
Elevation	3 m (10 ft) above MSL*	
Temperature	Summer	Winter
Average High	34°C/93°F	26°C/79°F
Average Low	23°C/73°F	13°C/55°F
Relative Humidity		
Annual Mean	78%	
Annual Precipitation		
Rain	1685 mm/66 in	
Annual Solar Radiant Exposure:		
Total (295–3000 nm)	6500 MJ/m²	
UV (295 – 385 nm)	280 MJ/m²	
Distance From Ocean	27 km (17 mi)	

* Mean Sea Level

AWSG — Central Arizona

Located approximately 50 km (30 miles) north of metropolitan Phoenix in an unpolluted desert environment, this climate is well suited for many material weathering tests because of the wide daily temperature fluctuations, low moisture, and high solar radiation.

Climatological Data — Central Arizona

Latitude	33° 54′ N	
Longitude	112° 8′ W	
Elevation	610 m (2000 ft) above MSL*	
Temperature	Summer	Winter
Average High	39°C/102°F	20°C/68°F
Average Low	24°C/75°F	8°C/46°F
Relative Humidity		
Annual Mean	37%	
Annual Precipitation		
Rain	255 mm/10 in	
Annual Solar Radiant Exposure:		
Total (295–3000 nm)	8004 MJ/m²	
UV (295 – 385 nm)	333 MJ/m²	

* Mean Sea Level

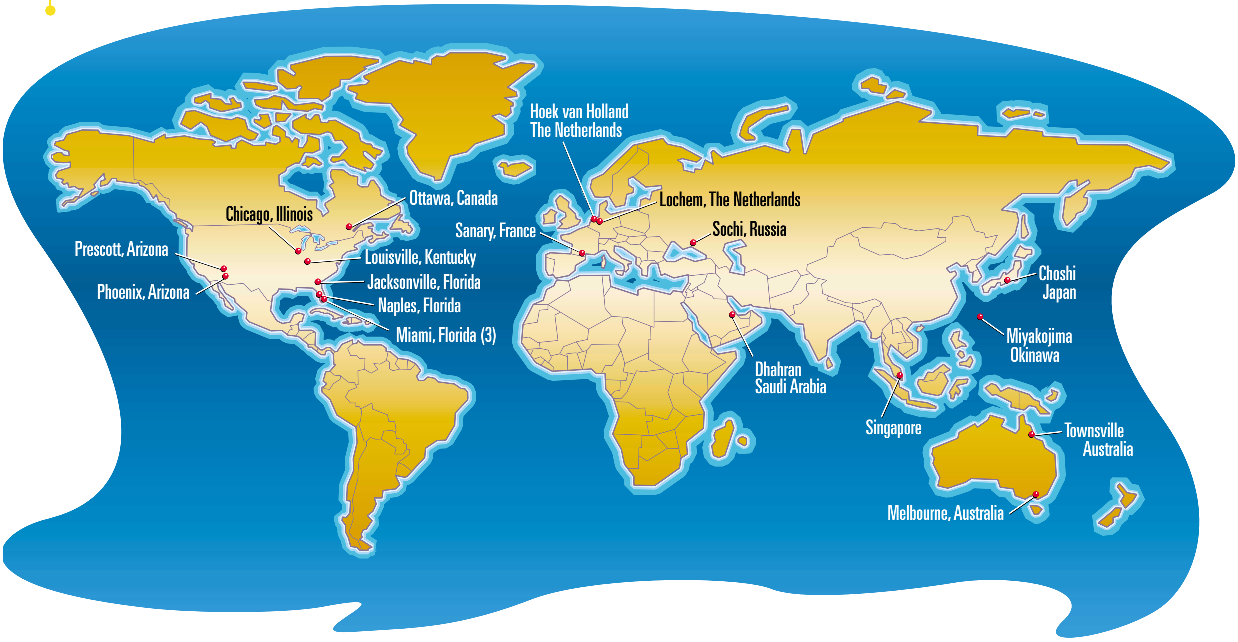
Other Climates

Testing is performed within other climates that may be important to specific markets or regions around the world. For example, many marine weathering sites around the world specifically test the corrosive effects of salt air.

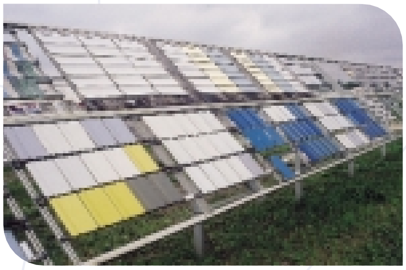
The AWSG site in **Lochem,** The Netherlands, was established to provide outdoor exposure testing for European companies and institutes performing independent weathering testing for products specifically used in that region. Located in the Ohio River Valley near several coal-fired power plants, AWSG's site near **Louisville,** Kentucky, is exposed to a constant supply of industrial pollutants. These pollutants mix with moisture in the atmosphere to form acid rain compounds. Exposure to acid rain, combined with a temperate northern climate characterized by hot, humid summers and winters with multiple freeze-thaw cycles, produces an environment that is specified for testing materials such as polyvinyl chloride (**PVC**) siding for houses.

Sanary in France, Hoek van Holland, sites in Japan, and the Kalahari and locations in Australia (representing benchmark climates in the Southern Hemisphere) also have been recognized as outdoor exposure locations for specific applications.

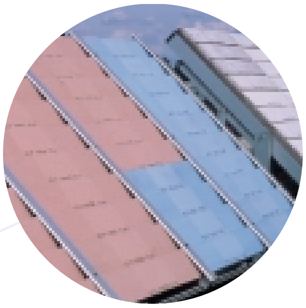
Atlas Worldwide Exposure Network



Lochem, The Netherlands



Sanary, France



Hoek van Holland,
The Netherlands

Specialized Testing for Automotive Coatings

Jacksonville, Florida is one of the largest import and export centers for automobiles in the United States. The location has relatively high annual radiant energy and humidity, but because of several industrial plants that contribute to the pollution, the area has a rather unique environment. With the development of base coat/clear coat paint systems, cars awaiting distribution to US auto dealers were found with an acid etch phenomena on the exterior paint, caused by this special combination of atmospheric conditions. This obviously created a concern for these auto manufacturers, because the cars were unacceptable to the public before they were even available for sale. Many auto manufacturers now require automotive paint systems to be exposed to this environment for acid etch resistance before they are approved for use.

Location	Latitude	Longitude	Elevation (m)	Average Ambient Temp (°C)	Average Ambient RH (%)	Annual Mean Rainfall (mm)	Annual Mean Total Radiant Exposure (MJ/m^2)
Lochem, The Netherlands	52° 30′ N	6° 30′ E	35	9	83	715	3700
Hoek van Holland, The Netherlands	51° 57′ N	4° 10′ E	6	10	87	800	3800
Sanary, France	43° 08′ N	5° 49′ E	110	13	64	1200	5500
Singapore (Changi Airport)	1° 22′ N	103° 59′ E	15	27	84	2300	6030
Melbourne, Australia	37° 49′ S	144° 58′ E	35	16	62	650	5385
Townsville, Australia	19° 15′ S	146° 46′ E	15	25	70	937	7236
Ottawa, Canada	45° 20′ N	75° 41′ W	103	6	73	1910	4050
Sochi, Russia	43° 27′ N	39° 57′ E	30	14	77	1390	4980
Dhahran, Saudi Arabia	26° 32′ N	50° 13′ E	92	26	60	80	6946

Measuring The Factors of Weathering

Radiation

Radiometers are a general class of instruments designed to detect and measure radiant energy. There are two types of radiometers commonly used to measure solar radiation. Those that measure total solar radiation (UV, VIS, and IR) are called **pyranometers.** They measure radiation in a 180º field of view. The other type of radiometer is a **TUVR,** which stands for Total UltraViolet Radiometer. These instruments measure the irradiance, which is then integrated over time to determine the radiant exposure. Since different exposure angles will receive varying amounts of radiant energy, it is common to measure radiation at angles that correspond to these angles of exposure.

Another type of radiometer that has specific applications is a **pyrheliometer,** which uses a **collimating tube** to measure only the direct radiation from the sun at normal incidence.

Spectroradiometer

Measurement With a UV Spectroradiometer

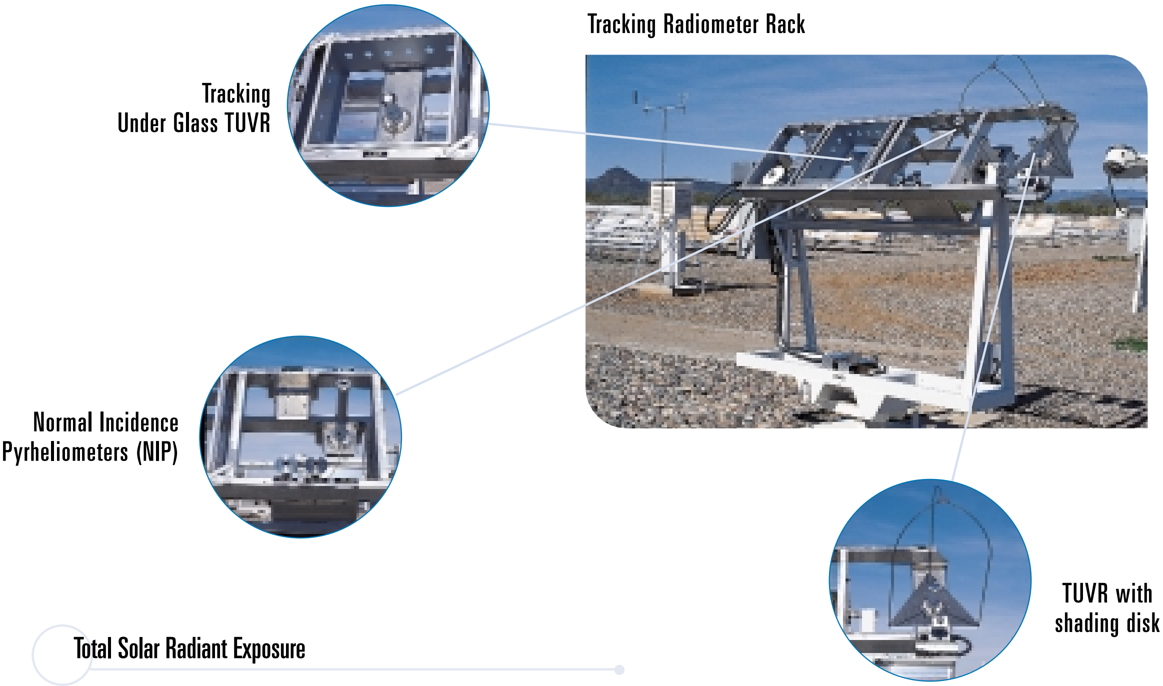
The evaluation and comparison of test results achieved under different test conditions with respect to radiant exposure can be achieved by the use of calibrated spectroradiometers. Measured with a resolution of 1-2 nm steps, the spectral power distribution is recorded, then totalled for the prescribed wavelength ranges and precisely displayed. Apart from the advantage offered by an exact control of the "UV radiation" exposure conditions, such a measurement also can be an important tool to analyze tests and test results.

As previously mentioned, each of the materials exposed to natural or artificial weathering has its own characteristic spectral sensitivity. This sensitivity is always in relation to a certain physical or appearance property change. If a material degrades rapidly in the field, it may not change when tested under laboratory conditions, even if the test was performed in accordance with the specification. The cause could be a low spectral irradiance within the particular range that has the highest effect on the degradation of this material. If the relative spectral sensitivity of the material and the detailed spectral power distribution of the light source are known, the test results can be analyzed with greater understanding and precision. A UV spectroradiometer provides this detailed information about the spectral distribution of the light source, which leads to greater confidence in accelerated test methods.

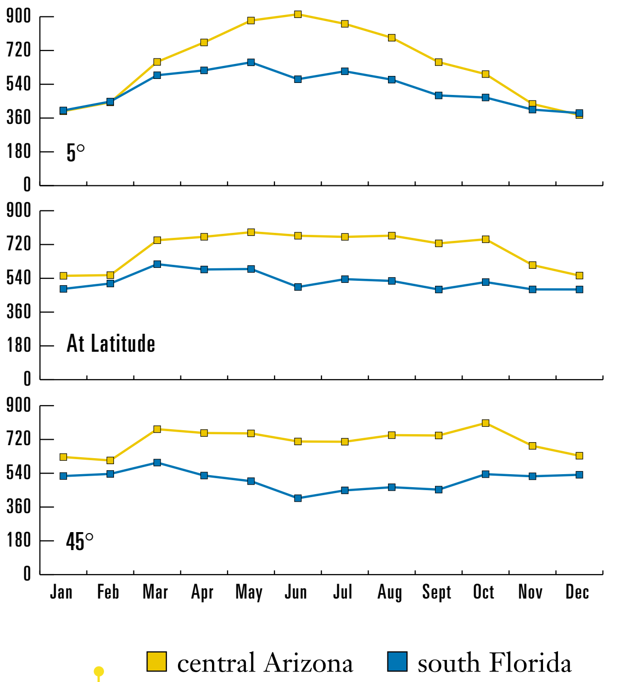
Static Radiometer Rack

45° Pyranometer

Various instruments are used to monitor solar radiation, depending on angles of exposure and wavelength range measured.



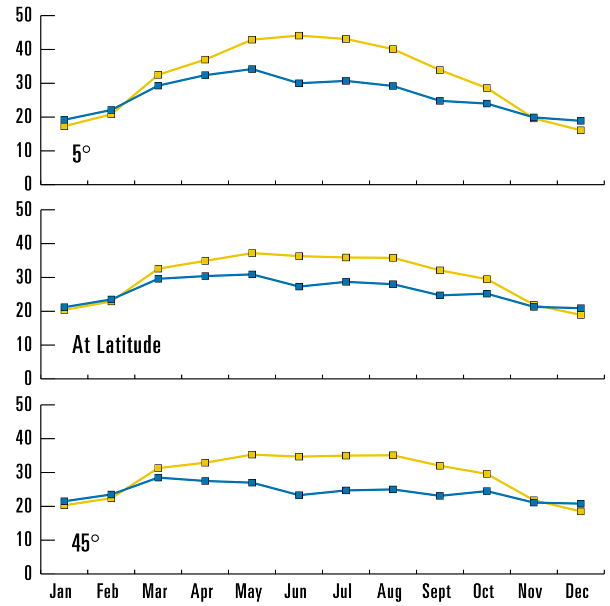
Total Solar Radiant Exposure



Monthly total solar radiant exposure (295-3000 nm in MJ/m^2) for different angles of exposure at the two benchmark climates, south Florida and central Arizona.

Monthly total UV radiant exposure (295-385 nm in MJ/m^2) for different angles of exposure at the two benchmark climates, south Florida and central Arizona.

Total UV Radiant Exposure



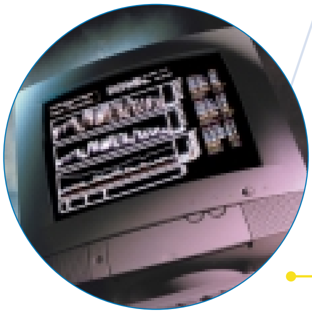
Measuring Other Factors of Weathering

Accurate and consistent monitoring of weathering factors such as ambient temperature, humidity, rain, etc., is also important. The enclosure used to house the ambient temperature and relative humidity devices is specified by the World Meteorological Organization (WMO). The WMO enclosure must have a double roof; in other words, there are essentially two pieces of wood over the top of the enclosure with a small air space between. This is to limit any radiant energy from directly striking the roof of the enclosure. The enclosure also must have louvers to allow wind to flow through the housing. In addition, the enclosure must be mounted a specific height above the ground so the reflected solar radiation does not affect either the ambient temperature or relative humidity.

Data Acquisition Systems are used to monitor solar radiation, temperature, and many other parameters of weathering. This is vital information for development of service life prediction models.

Temperature and Relative Humidity Sensors

WMO Enclosure, Data Acquisition System, and other Climatological Sensors.



All data collected with field sensors is relayed to a computer in the lab.

Wind speed and wind direction sensors, rain gauges, time-of-wetness sensors, and special radiometers are all connected to a data acquisition system for continuous monitoring of the major weather parameters.

It is not practical to measure the temperature of every specimen during an outdoor weathering test. Therefore, black panel (and white panel) temperatures are also commonly measured. Because of the high solar absorption of the black paint, black panels are used as a reference temperature that may be considered as the highest temperature that specimens on exposure may reach. Panels are usually thin metal substrates (stainless steel or anodized aluminum) coated with a primer and a quality black paint. Black panels are also used in laboratory weathering instruments, primarily as controlling devices. Standards organizations are writing specifications to define the properties of the paint, as well as developing methods to monitor and attach temperature measurement devices to the panel.

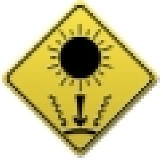
Now that we have discussed all the main factors of weathering, how they affect materials, and how they are measured, it is time to turn our attention to common exposure methods and applications.

Black & White Panels are used as a reference for specimen temperatures on exposure. 45° panels are shown.

Static Radiometer Rack

Tracking Radiometer Rack

Natural Weathering



Natural Weathering

Direct Weathering

Direct weathering, also known as outdoor or natural weathering, is defined as an exposure to direct sunlight and other elements of weather. This is typically accomplished by mounting the material on some type of **exposure rack.** The standard racks shown in Figure 2.1 are made from anodized aluminum and face directly south (in the Northern Hemisphere) at a fixed angle. The typical sample size is 150 x 305 mm (6" x 12"). Common angles of exposure are near horizontal (usually 5º), 45º, vertical (90º) and equal to the **site latitude** (26º and 34º in south Florida and central Arizona, respectively). Exposures conducted at 90º do not provide the most severe conditions, but often match the end-use of the material tested closer than any other angle. Direct weathering tests follow **ISO 877 Plastics,** *Methods of Exposure to Direct Weathering, to Weathering Using Glass-filtered Daylight, and to Intensified Weathering by Daylight Using Fresnel Mirrors*; **ISO 2810 Paints and Varnishes,** *Natural Weathering of Coatings –Exposure and Assessment*; **ISO 105-B03 Textiles,** *Tests for Colourfastness –Colourfastness to Weathering: Outdoor Exposure*; and **ASTM G7,** *Recommended Practice for Environmental Exposure Testing on Nonmetallic Materials.*

Fig 2.1

Racks in the direct weathering test field — south Florida

Open-Backed Exposures

Open-backed exposures are natural weathering tests conducted by either fastening or clamping the specimens at their extremities so that the majority of the material will be exposed to the circulation of ambient air on all sides of the sample. Typical materials for exposure on an open-backed rack are glass, **free-films,** plastic and metal sign material, **coil coatings,** and plastic lenses such as taillight assemblies. It is common to expose not just a small plaque but also components such as window assemblies, automotive components or complete vehicles, and full test "houses." Materials used against a substrate should never be exposed in this manner because the backside cooling of the material, as a result of wind or natural convection, will not allow the specimen to realize the same thermal environment it will experience in its end use. The early failures of many vinyl and paint coatings in real service life were due to the continued use of the open-backed method.

Window assemblies mounted on a 90° open-backed rack— south Florida

45° open-backed rack— central Arizona

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What's in a Name?

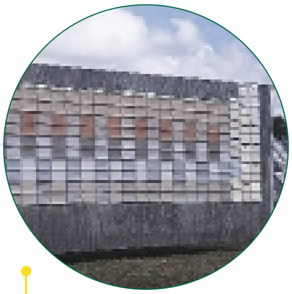
A survey of standards and commercial literature gives us a plethora of terms all referring to tests conducted outdoors. Here's a partial listing:

- Natural Exposure Testing
- Outdoor Exposure
- Exterior Exposure
- Atmospheric Exposure
- Atmospheric Environmental Exposure
- Weathering Exposure
- Florida Exposure
- Solar Radiation Weathering
- Direct Weathering
- Conventional Weathering
- Static Weathering

A rose is a rose, in any case, and we have chosen "Natural Weathering" to describe tests conducted under Mother Nature's influence.

Backed Exposures

Backed exposures are outdoor weathering tests conducted by mounting the specimens to a substrate (usually 12 mm [½"] paper-faced plywood) to simulate the end-use thermal environment of the material. Polyvinyl chloride (PVC) siding, **roofing membranes,** and automotive molding would be typically exposed on a backed exposure rack. Since weathering processes are a synergistic reaction to all factors of weathering (solar radiation, temperature, moisture, etc.), the ability to maintain the proper thermal environment of a material in a simulation of end-use conditions is fundamental to good exposure practices.



90° backed rack—
south Florida

45° backed rack—
south Florida

45° backed rack—
central Arizona

Backed vs. Open-backed

What will happen if a material is mounted in a backed exposure when the end-use of the product will be in an open-backed configuration? Since the thermal environment of a backed exposure is potentially 15°C higher than open-backed, the material may degrade in an unrealistic fashion. Unnecessary time and money may be spent to try to fix this problem, either with additional expensive additives or stabilizers or simply failing a material from further production, even though it may be acceptable in its end-use service environment. The "backed vs. open-backed" question is too often overlooked by weathering experimenters.

Specimens show thermal degradation as
a result of an incorrectly backed exposure.

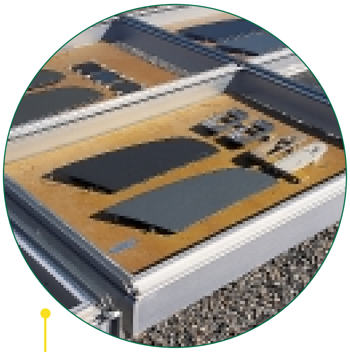
Black Box Exposures

Black Box exposure—
south Florida

Black Box exposures simulate the air heat-sink characteristics of an automobile body. They consist of a black-painted, open metal box about 150 x 200 cm (60" x 80") in length and width and 25 cm (10") deep. The panels on exposure cover the open top of the box. For many coatings and automotive paints, Black Box exposures provide greater rates of degradation than those provided by standard 5° open-backed exposures because the Black Box produces higher panel temperatures during the daytime and achieve longer time-of-wetness. Black Box panel temperatures are comparable to those encountered on the hoods, roofs, and deck lids of automobiles parked in direct sunlight. **ASTM Standard D4141 Method A,** *Standard Practice for Conducting Accelerated Outdoor Exposure Tests of Coatings* specifies the use of this Black Box exposure method.

Indirect Exposures

Indirect, or under-glass **weathering,** is the exposure of materials that are typically not exposed to all outdoor conditions. This method of testing materials is used to determine the **colorfastness**/durability characteristics of household materials such as drapes, carpeting, upholstery, etc., as well as materials used in automotive interiors. The methodology was developed initially by the **American Association of Textile Chemists and Colorists (AATCC)** for testing textiles and subsequently was adopted by the automotive industry for testing interior materials. Primary test methods for indirect weathering are **ISO 877 Plastics,** *Methods of Exposure to Direct Weathering, to Weathering Using Glass-filtered Daylight, and to Intensified Weathering by Daylight Using Fresnel Mirrors*; **ISO 2810-Paints and Varnishes,** *Natural Weathering of Coatings: Exposure and Assessment*; **ISO 105-B01 Textiles,** *Tests for Colourfastness —Colourfastness to Light: Daylight*; **AATCC 111,** *Weather Resistance: Exposure to Natural Light and Weather Through Glass*; and **ASTM G24,** *Standard Practice for Conducting Exposures to Daylight Filtered Through Glass*. Test specimens are typically placed approximately 75 mm (3") behind 3 mm (⅛")–thick, **single-strength window glass**, which absorbs radiation below 310 nm and transmits 77% of UV radiation and 85% of visible light. Specimen temperatures are generally increased over direct exposures because less moving air passes over or behind the specimens, which better simulates the end-use environment. **Tempered, tinted, or laminated glass** may be used, based on the end-use application of the material.



Under-glass exposure—
central Arizona

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How Long Do I Need to Test My Material?

Of course, the answer to this question depends on the material being tested and how long the material is expected to last in its typical service life. This may be as short as a few days or hours for items such as golf balls, printing inks, or photodegradable plastics. By comparison, items such as house paint, highway signs, sealants, electrical insulators, and roofing membranes may need to be tested for 10, 15, or even 30 years or longer to achieve 100% confidence in the material's durability. However, customers cannot afford to wait for materials to sit in these natural conditions without making some assumptions. The only other option is to accelerate the test in some manner.

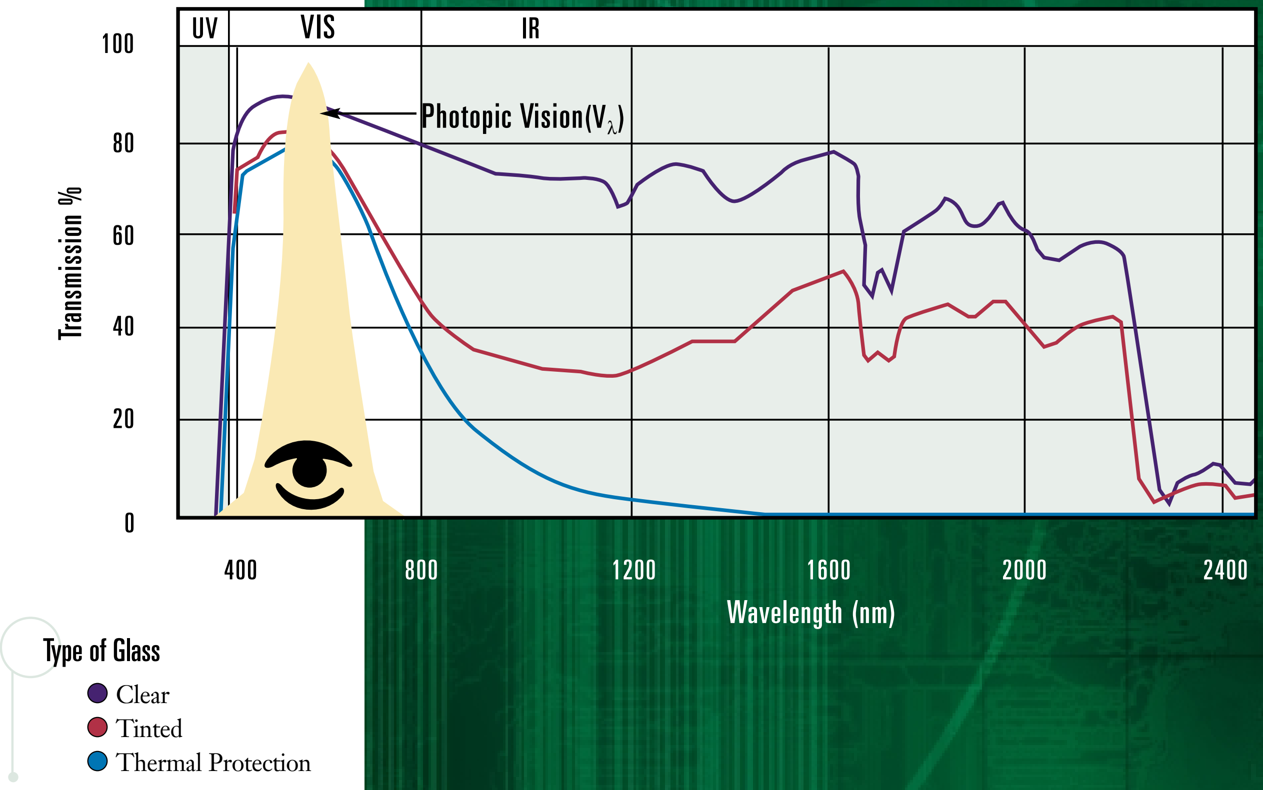
e a t h e r i n g

Types of Glass Used for Indirect Exposures

Automotive interior materials are tested in an indirect weathering cabinet. For most generic test standards, single-strength window glass is often referenced as the specified cover glass. However, most new automotive glazing systems include tinted glass in the rear passenger windows and back window, which often reflect much of the infrared radiation. Laminated windshields will have a UV transmittance that may cut on as high as 385 nm. If the normal service environment of the material will be behind laminated or tinted windows of an automobile, exposures using common single-strength cover glass could cause unrealistic failures. Because unnecessary time and money would be spent to combat these failures, it is extremely important to expose these types of materials behind glass that has the correct spectral properties.

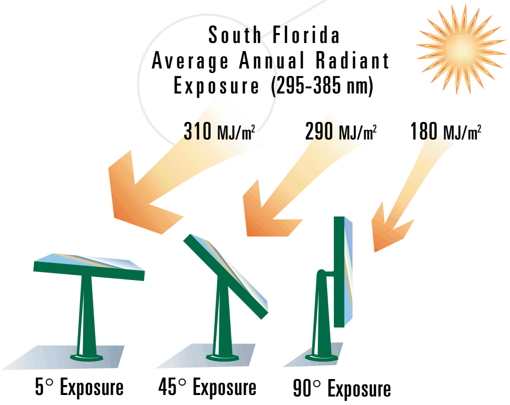
Today's Automotive Glazing

Better simulation to end-use conditions can be achieved by understanding automotive glazing properties—transmission, reflectance, and absorptance. The transmission curves of three types of laminated glass are shown in this diagram.



Natural Accelerated Weathering

Ironically, as product life is expected to increase, new materials are being processed to decrease cycle times. Therefore, **accelerated testing** is driven by economic, as well as, competitive concerns.



For all practical purposes, conducting tests in the benchmark locations of south Florida and central Arizona could be considered "accelerated" tests, because materials degrade faster in these climates than most others around the world. If we consider the fact that most materials are not always facing the sun, we can consider these tests to be accelerated even more. If the end use of a material is a vertical exposure (such as the side of a house), conducting the test at 45° could be considered an accelerated test because specimens at 45° receive at least 30% more irradiance. Studies have shown that the actual rate of degradation may be as much as 2.5 times greater. Finally, if the specimen is then tested on a "follow-the-sun" rack, keeping specimens perpendicular to the sun throughout the day, the total radiant exposure received may be as much as 1.7 times, with rates of degradation again being much higher.

EMMAQUA® Test Method

Fresnel solar concentrators, such as the **EMMA®** and **EMMAQUA** devices are among the most widely recognized and used outdoor accelerated weathering test devices. Their names are acronyms:

EMMA – **E**quatorial **M**ount with **M**irrors for **A**cceleration

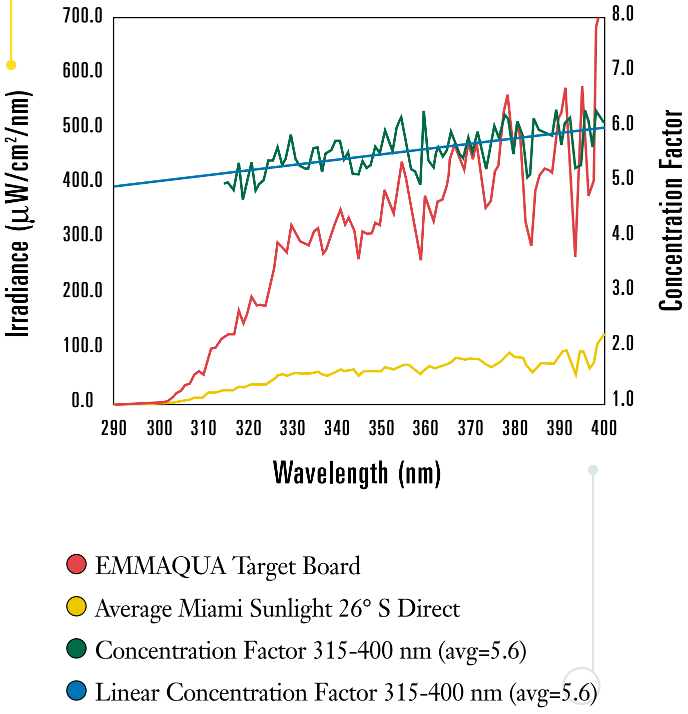
EMMAQUA - **E**quatorial **M**ount with **M**irrors for **A**cceleration, with Water (**Aqua**)

Samples on an EMMAQUA

These devices were originally developed at DSET Laboratories (part of the Atlas Weathering Services Group) during the 1960s. They employ a fresnel-reflecting system that uses 10 flat mirrors to concentrate natural sunlight onto specimens mounted on the target board of the device *(see Figure 2.2)*. The high-quality, first-surface mirrors uniformly focus sunlight onto the samples at an intensity of approximately eight times that of global daylight and approximately five times the global radiation in the UV portion of the spectrum. Because the test method exposes samples to the full spectrum of natural concentrated sunlight, it is one of the most realistic accelerated weathering tests available. The parameters of the test device, spray cycles, etc., are governed by **ISO 877,** *Plastics—Methods of Exposure to Direct Weathering, to Weathering Using Glass-filtered Daylight, and to Intensified Weathering by Daylight Using Fresnel Mirrors*; and **ASTM G90,** *Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight.* Exposures on EMMAQUA are usually timed by an equivalent "year" of average desert (central Arizona) or subtropical (south Florida) total ultraviolet exposure.

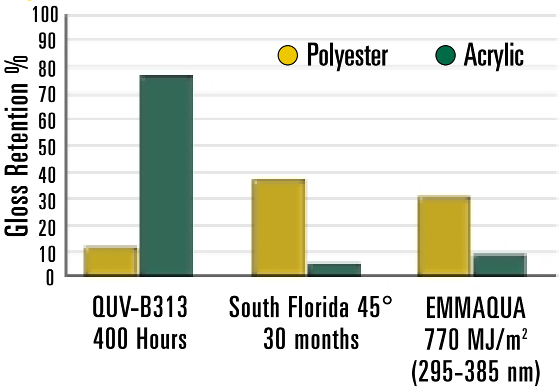
EMMAQUA field

Spectral Comparison of Natural UV Sunlight vs. EMMAQUA®



Correlation Assessment of Powder Coatings

Note the correlation in ranking between EMMAQUA and south Florida Exposures.



Metal Architecture, Sept. 1991; "Powder Coatings, Focus on Usage Trends," Dr. Richard J. Higgins, Courtaulds Coatings Ltd.

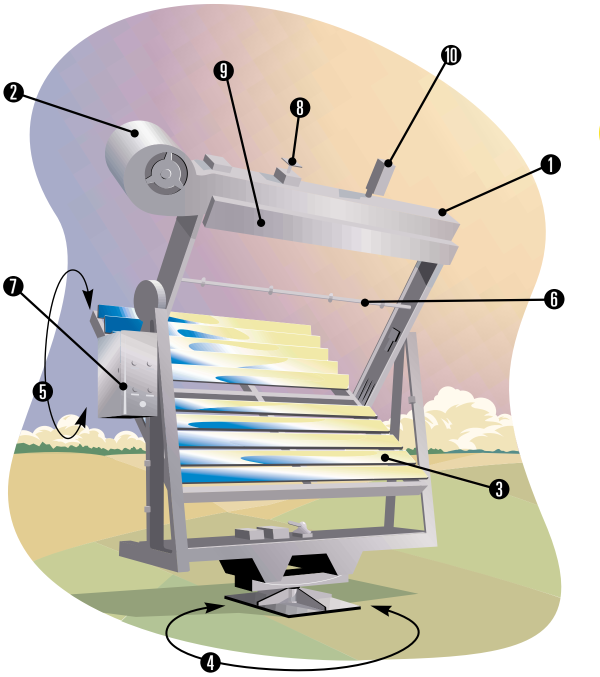


Fig 2.2

Schematic of EMMAQUA.

Only the direct radiant energy is deposited on the exposed samples. The device is a follow-the-sun rack with its axis oriented in a north-south direction. The north elevation possesses altitude adjustment capabilities to account for seasonal variation in the sun's altitude at zenith. Newer designs account for this seasonal variation automatically. The mirrors are positioned as tangents to an imaginary parabolic trough. Samples are placed in frames and mounted to a target board. Oscillating or pulsing nozzles are used to spray specimens with deionized water in accordance with established schedules.

1. *Air Tunnel*
2. *Air Blower*
3. *Mirror*
4. *Rotation, Azimuth Direction*
5. *Rotation, Elevation Direction*
6. *Water Spray Nozzles*
7. *Microprocessor Control Box*
8. *Solar Cells/Shadow Hat*
9. *Specimen Protection Door*
10. *Door Release Mechanism*

Paint and plastic test specimens on exposure are maintained within 5-10ºC of the temperatures of identical samples on real-time, static exposures. This is true especially for thin, flat specimens. Specimens are cooled by ambient air. The target board lies under an air tunnel along which an air deflector directs laminar air flowing at approximately 35 km/h (or 10 m/s). The thermal environment of the specimen is dependent on the surrounding ambient air temperature, specimen thickness, and the thermal conductivity. Thick specimens (greater than one cm) are generally not suitable for this type of test because the air blowing over the specimens is not enough to compensate for the focused radiant energy.

As mentioned previously, oscillating **spray nozzles** direct **deionized water** onto the specimens. Three common cycles are defined by the ASTM G90 specification. **Cycle One,** commonly used for plastic specimens, uses a daytime spray that provides a thermal shock effect several times during a typical exposure. **Cycle Two** does not include a spray cycle, simulating the dry climate of a desert exposure. **Cycle Three,**

Correlation of Coil Coatings

5° South Direct, South Florida vs. EMMAQUA®

	Spearmans Rank (R_{sr})		Regression Coefficient (r_{xy})	
Property	Unwashed	Washed	Unwashed	Washed
60° Gloss	0.85	0.96	0.89	0.92
Color Difference	0.92	0.86	0.94	0.89

Statistically derived values show excellent correlation between EMMAQUA® and south Florida exposures.

Advanced Coatings Technology Seminar, Detroit, MI. 1991 "Accelerated Outdoor Exposure Testing of Coil Coatings by the EMMAQUA® Test Method," G.A. Zerlaut and J.S. Robbins.

Standards Specifying the EMMAQUA® Method

Standard	Title	Test Methods
ASTM D3841	Specification for Glass-fiber-reinforced Polyester Plastic Panels	🟡 🟣
ASTM D4141	Standard Practice for Conducting Accelerated Outdoor Exposure Tests of Coatings	🟣
ASTM D4364	Standard Practice for Conducting Accelerated Outdoor Weathering of Plastic Materials Using Concentrated Natural Sunlight	🔵 🟤 🟡 🟣
ASTM E1596	Standard Test Method for Solar Radiation Weathering of Photovoltaic Modules	🟣
ASTM G90	Standard Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight	🔵 🟤 🟡 🟣
SAE J576	Plastic Materials for Use in Optical Parts Such as Lenses and Reflex Reflectors of Motor Vehicle Lighting Devices	🟣
SAE J1961	Accelerated Exposure of Automotive Exterior Materials Using a Solar Fresnel-reflective Apparatus	🔵 🟣
Ford ESB-M16J14-A	Enamel, Thermoset 2-Component Color Coat, Exterior, High-gloss	🟣
ISO 877	Plastics—Methods of Exposure to Direct Weathering, to Weathering Using Glass-filtered Daylight, and to Intensified Weathering by Daylight Using Fresnel Mirrors	🔵 🟤 🟡 🟣
ANSI/NSF 54	Flexible Membrane Liners	🟡
JIS Z 2381	Recommended Practice for Weathering Test	🔵 🟡 🟣
MIL-T-22085D	Tapes, Pressure-sensitive Adhesive Preservation and Sealing	🔵 🟡

🔵 EMMA®
🟤 EMMA – UG (Under Glass)
🟡 EMMAQUA / EMMAQUA+ (Cycle 1 of ASTM G90)
🟣 EMMAQUA – NTW (Night Time Wetting, i.e., Cycle 3)

commonly used for automotive coatings, sprays the specimens during the evening to simulate the typical dew formation one might expect for subtropical exposures. Other spray cycles, such as a soak-freeze-thaw, nighttime soak, and day-night sprays can be programmed for special test applications.

Weathering laboratories that employ these solar concentrators must have strict quality control measures in place to ensure that exposures are performed to the specifications. For example, the water quality for the sprays must be less than 200 parts per billion (total dissolved solids). The mirror reflectance must be measured at least semi-annually for accurate exposures. The mirrors must be rinsed and/or washed on a prescribed schedule. Finally, the measurement of UV irradiance must be performed according to the ASTM G90 specification.

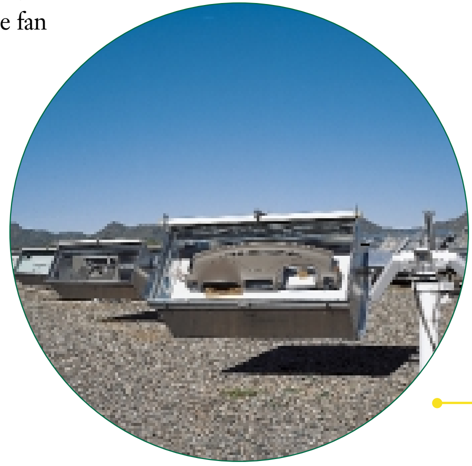
Specialized Natural Weathering Applications

The weathering test methods mentioned so far are the most common applications. They can be used for many different types of materials, and they may be applied to nearly every industry that is concerned with outdoor weathering. Over time, however, there have been test apparatus developed for very specialized applications that provide excellent correlation to the end-use environments they were designed to simulate.

IP/DP Box®

The IP/DP (Instrument Panel/Door Panel) Box offers an under-glass weathering method to determine the durability and/or colorfastness of any material used for automotive interiors. This exposure cabinet was first developed by General Motors and was primarily designed to accommodate nonstandard specimen sizes such as complete automotive assemblies. These devices meet the performance and approval requirements of **GM 9538P, Ford DMV 2000** and various associated material specifications.

Controlled azimuth tracking (for maximum solar irradiance), and fixed angle south-facing methods are available. The interior temperature of the box is limited to specific levels by activating a **linear axial fan**, which directs uniform airflow over the test specimens. The fan is automatically turned off when the temperature drops 3°C below the set point. Laminated windshield or side window glass can be installed for evaluating the effects of different types of glass on automotive interior components.



IP/DP Box

Another Type of Automotive Interior Box

Another type of test box for automotive interior material is still frequently used within the German automotive industry. Known by the name "Snow White" cabinets, or Schneewittchensarg, these boxes are of similar size and construction as the IP/DP Box®. Specimens, such as instrument panels, are most often mounted in an orientation similar to a real automobile and are commonly exposed with full instrumentation and/or temperature sensors located in various positions. The boxes are used for natural weathering tests but also have been used with artificial light sources for solar simulation testing.

CTH Glas-Trac™

The **CTH Glas-Trac** (Controlled Temperature and Humidity, Under Glass, Sun Tracking) was designed primarily to determine the durability of automotive interior materials. The test method incorporates temperature and humidity control in an outdoor weathering chamber covered with automotive side window glass. This glass cover is interchangeable with various windshield types to provide flexibility in product development. An automatic **two-axis tracking system** maintains the chamber at normal incidence to the sun for maximum solar irradiance.

CTH Glas-Trac

The exposure cabinet maintains a 70°C air temperature during daylight hours and a 38°C air temperature/75% relative humidity during night time hours (other test conditions are also available). The method simulates the conditions associated with automotive interiors and tracks the sun for acceleration, combining to produce the fading of sensitive materials in relatively short test times. Exposures are timed in MJ/m^2 of total UV (295–385 nm).

Full-Car Component and Vehicle Testing

The final test for material durability is the satisfaction of customers. Customers care about the total package. In some cases, materials that appear to perform within specification do not meet customers expectations when the finished product is in end use. A final test using the actual glass is an important part of any material approval process. This may involve exposures using an actual vehicle as the test cabinet. Full vehicle testing gives the experimenter two advantages: test conditions that match the exact end-use conditions, and most importantly, full confidence that the customer will be satisfied with the material's weathering performance.

Special Outdoor Environments

While it is understood that radiation, temperature, and moisture are the three main factors of weathering, some materials are more susceptible to the secondary effects, such as pollution or corrosive salt air. Some of these climates and their associated weathering sites are described on pages 21–22.

Racks at corrosion test sites are often placed at specific distances (25 m and 75 m, for example) from the mean sea-sand interface. Tidal immersion sites test marine coatings with specially designed racks that expose specimens above water during low tide, then immerse the specimens in seawater during high tide. Exposures in high-pollution environments commonly use rack angles such as 5° or 45° and may be either backed or open-backed.

Test Conditions, SAE J2230

Parameters	Day Conditions	Night Conditions
Temperature	70±5°C air	38±5°C air
Humidity	Not controlled	75±10%
Hours	8AM to 6PM	6AM to 8PM

Variability of Outdoor Exposures

Outdoor weathering tests are generally agreed to be the most reliable tests in terms of correlation to end-use service life, but many variables exist that do not guarantee repeatable results.

Variability Due to Climate

Climate at the test site can significantly affect the material failure rates and modes. Different climates obviously have different amounts of radiant energy, temperature, moisture, and pollutants, which will undoubtedly lead to different test results. Also, Acts of Nature may result in long-term variations in the climate. Volcanoes can eject incredible amounts of ash and pollutants into the air that can lower maximum air temperatures and radiant exposure levels. The warming and cooling of the Eastern Pacific Ocean, creating the El Niño and La Niña conditions, cause two- to three-year variations in temperatures, moisture, and wind currents in many affected areas of the world. Hurricanes can cause severe damage to specimens exposed in the subtropical climate of south Florida if weathering laboratories do not take precautions to protect specimens. Variations in the concentration of ozone in the atmosphere can cause higher or lower amounts of UV radiant energy to reach the earth's surface.

Pollutants from volcanic eruptions can lower maximum air temperatures and radiant exposure levels.

Variability Due to Time of Year

Solar radiant energy, temperature, and moisture vary considerably with time of year. These seasonal variations can cause significant differences in the rate of degradation in many materials and must be considered in comparing results of short-term (less than one or more full years) exposures.

Variability Due to Year-to-Year Climatological Variations

Because average temperature, hours of sunshine, and moisture can vary considerably from year to year at any given location, comparisons of test results of even full-year exposures can be difficult. Therefore, results from a single exposure test cannot be used to predict the absolute rate at which a material degrades. Several years of repeat exposures are needed to get an "average" test result for any given site.

Hurricanes can cause significant damage to unprotected specimens.

Variability Due to Test Design

Every exposure test has some variability inherent in its design. Specimen placement on an exposure rack, location in the test field, and specimen mounting configurations can all lead to test variability.

While the variability of outdoor exposures cannot be denied, weathering tests performed by trained, experienced experts should ALWAYS be included in any R&D program. These test methods provide baseline information on the durability of new materials. **ASTM G141**, *Addressing Variability in Exposure Testing on Nonmetallic Materials* is a good reference which further addresses the variability that is common to weathering test methods.

Laboratory Weathering

Laboratory Weathering

Laboratory Weathering

Because there is a need for more rapid evaluations of the resistance of materials to weathering than can be obtained by outdoor exposure tests, devices with artificial light sources are generally used to **accelerate** the degradation. These sources include **filtered long arc xenon, fluorescent, metal halide lamps** and **carbon arc.** Less commonly used light sources include mercury vapor and tungsten lamps. These **laboratory accelerated weathering** tests are sometimes, and perhaps more appropriately, referred to as **artificial weathering.**

The acceleration over natural weathering occurs for several reasons. Principally, the tests can run continuously at naturally occurring or higher irradiance than solar radiation, uninterrupted by the natural day/night cycle, seasonal variations, and weather conditions. Temperatures, thermal cycles, humidity, and water exposure also can be manipulated to maximum, but not unrealistic, stress levels. Specimens can be exposed to spectral energies at or beyond the limits of their intended service exposures, although caution must be exercised so as not to cause unnatural degradation mechanisms.

In addition to the ability to manipulate and accelerate weathering conditions on demand, a fundamental benefit of a laboratory test is the **reproducibility** and **repeatability** over what is essentially an uncontrolled and variable phenomena, the actual weather. Research can be conducted to study the specific response of materials to various weathering factors. Each of the weathering factors can be controlled independently.

Each light source has its own inherent benefits (and pitfalls) of which a weathering experimenter must be aware. Since the radiant energy received by an exposed material is considered to be most important, we will focus our attention on the quality of the light source, referring to how well each light source resembles natural sunlight and simulates other outdoor factors.

DETOUR

Repeatability and Reproducibility

These are two commonly used terms that always pop up when discussing the capabilities of laboratory weathering instruments. Repeatability is the ability of a single weathering instrument to replicate test results. Reproducibility is the ability of several weathering instruments to replicate results if they all run the same tests. Obviously, all weathering instrument manufacturers attempt to make their devices as repeatable and reproducible as possible. There is a certain amount of variability that will exist in any instrument, but there are several other factors that may lead to non-repeatable tests, including: improper calibration and/or operation, variability of water spray, maintenance of the equipment, variability in specimens, variability of the evaluation equipment used to measure the change of a specimen's property, and negligence in specimen handling and preparation.

Xenon Arc Instruments

The first weathering machine to use a **xenon arc lamp** was developed in 1954 (XENOTEST® 150). The xenon long arc, when properly filtered, simulates UV and visible solar radiation more closely than any other artificial light source. Xenon arc is a precision gas discharge lamp in a sealed quartz tube. The spectral power distribution is altered through filtering to simulate solar radiation. It is widely preferred as a light source when the material to be tested will be exposed to natural sunlight. Xenon arc instruments are widely used by the textile, polymer, paint, and automotive industries.

XENOTEST 150,
circa 1954

In the course of xenon arc development, two instrument systems have emerged: water-cooled and air-cooled xenon lamp devices. The type of cooling has only a negligible effect on the spectral output of the lamp but does have an influence on the overall design and on the optical filtering system. Atlas Fade-Ometers® and Weather-Ometers® use water-cooled xenon arc exclusively. The Atlas XENOTEST® Alpha, Beta, 150S+ and the smaller Atlas SUNTEST CPS+ and XLS+ table top exposure units use air-cooled xenon lamps. ISO 4892-2, *Plastics — Methods of Exposure to Laboratory Light Sources — Part 2: Xenon-arc Sources;* ISO 11341, *Paints and Varnishes — Artificial Weathering and Exposure to Artificial Radiation — Exposure to Filtered Xenon-arc Radiation;* ISO 105-B02, *Textiles — Tests for Colourfastness — Colourfastness to Artificial Light: Xenon Arc Fading Lamp Test;* and ASTM G155, *Practice for Operating Xenon Arc Light Apparatus for Exposure of Nonmetallic Materials* are the primary standards regarding performance requirements of these instruments.

Water-cooled xenon instruments

Ci5000
Weather-Ometer

Ci65A
Weather-Ometer

Air-cooled xenon instruments

SUNTEST XLS+

XENOTEST Beta

DETOUR

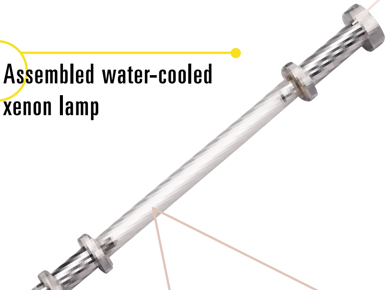
Does the Cooling of the Lamp Influence the Test Results?

A xenon lamp, similar to the sun, not only emits light but also produces a large amount of heat energy. While heating up the samples may be intended, the filters, the lamp itself, and surrounding components have to be cooled to avoid over-heating, damage, and aging. Like the motor of a car can be cooled by water or by air, both techniques can also be applied for weathering instruments and are used according to the requirements of the different types of xenon lamps. Instruments using water (like the Ci-series Weather-Ometers) are generally called “water-cooled xenon instruments.” The SUNTEST and XENOTEST Alpha and Beta are examples of “air-cooled instruments.” The technology of lamp cooling does not affect the spectral power distribution in the UV and VIS, or the cut-on of radiant energy. If the SPD (by using appropriate filter systems) and irradiance on the sample level are identical, the type of lamp cooling has no influence on the test results.

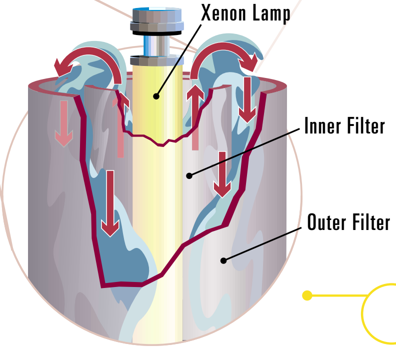
Depending on the design of the weathering instrument, specimens may be exposed in the vertical or in the horizontal position. For large-scale equipment, two-tier and three-tier inclined specimen racks help to provide uniform irradiance to all samples. The entire rack rotates around the xenon lamp for even better uniformity of the irradiance, temperature, and humidity at the sample level and when additional functions are required, such as spraying.

Ci5000 Weather-Ometer®
three-tier specimen rack

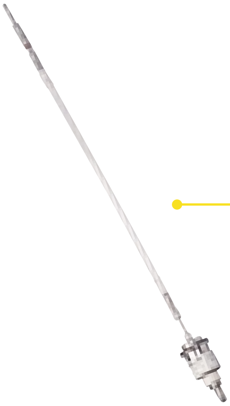
Xenon lamps are sealed quartz tubes. The spectral output of the xenon lamp already closely matches the spectral distribution of solar radiation in the UV- and visible-wavelength range, but contains a considerable amount of infrared and radiation below the cut-on of solar radiation. Therefore, the xenon lamp(s) is (are) surrounded by an optical filter system. The design of the filter system and the type of filter depends on the type of xenon lamp. The water-cooled xenon lamp is surrounded by two cylindrical optical filters. Cooling water flows in between the lamp, the inner filter and the outer filter. In addition to its cooling function, the water absorbs some of the unwanted infrared radiation. Water absorbs much of the radiation beyond 1200 nm, which is normally sufficient to obtain an acceptable sample temperature. More infrared radiation can be removed with special infrared absorbing/reflecting filters. Except for the table top units with horizontally positioned radiation systems, one or more air-cooled xenon lamps are surrounded by a flat-filter lantern and an outer cylindrical filter. Lamp(s) and filters are cooled by an air stream.



Assembled water-cooled
xenon lamp



Schematic of water—
cooled xenon lamp



Xenon lamp

The filters help to obtain the desired spectral distribution that simulates various conditions of natural weathering and special testing requirements. By combining different types of glass in the two cylindrical filters of the water-cooled system, it is possible to produce different spectral power distributions. Types of cylindrical filters available include **quartz, borosilicate glass, high borate borosilicate Type-S glass, soda lime glass,** and **Coated InfraRed Absorbing (CIRA) quartz** for water-cooled instruments *(see Figure 3.1)*. Additional filtering is possible using a special lantern to hold a wide variety of filters that are available in flat form. Air-cooled XENOTEST® instruments use optical interference filters called **Xenochrome® 300** or **320** and other specific absorption filters; each of these filter lanterns combine with a special quartz **(Suprax)** filter. Apart from normal filters for air-cooled SUNTEST instruments, special filters for pharmaceutical or cosmetics testing are available. *(see Figure 3.2)*. The spectral power distributions for the most common xenon filter combinations in the UV region and between 250-800 nm are shown on pages 45-46.

Fig 3.1

Atlas Water-cooled Xenon Filter Combinations

Filter Combinations Inner Filter Glass	Filter Combinations Outer Filter Glass	Test Conditions
Type “S” Borosilicate	Type “S” Borosilicate	Most common combination for weathering tests
Type “S” Borosilicate	Soda Lime	Most common combination for lightfastness tests behind window glass
Quartz	Type “S” Borosilicate	Weathering tests with somewhat more UV and shorter wavelengths of UV than sunlight
CIRA	Type “S” Borosilicate	Weathering tests requiring full spectrum match and/or cooler test temperatures
CIRA	Soda Lime	Weathering tests requiring precise match for solar cut-on, full spectrum match, and/or cooler test temperatures

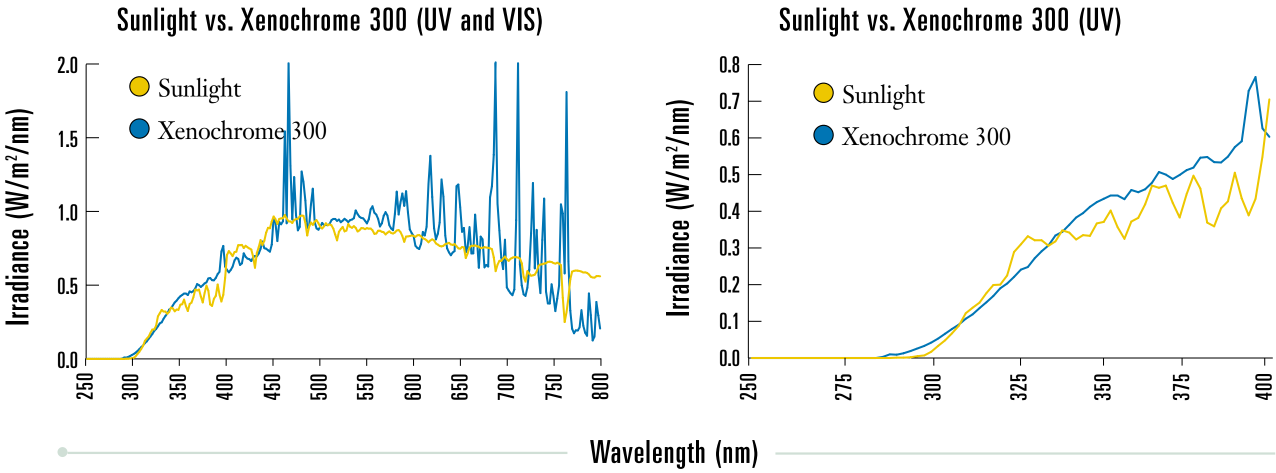
Fig 3.2

Atlas Air-cooled Xenon Filter Combinations

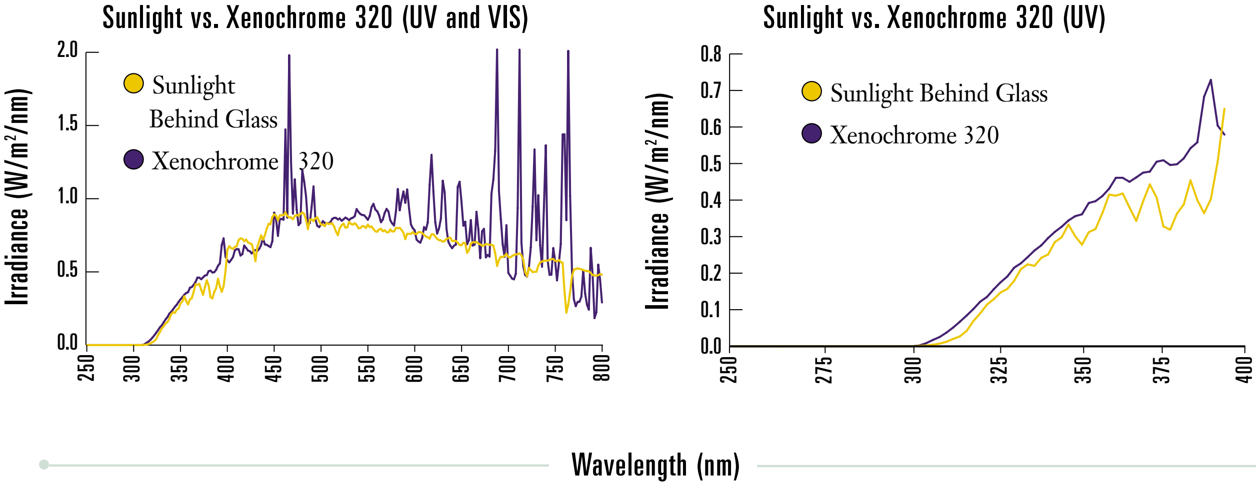
Type of Filter	Test Conditions
Xenochrome 320	Simulation of solar radiation behind window glass
Xenochrome 300	Simulation of outdoor solar radiation according to CIE Pub. 85, Table 4
Window Glass	Simulation of solar radiation behind window glass for testing materials at higher temperatures (such as automotive interior trim materials)
Infrared Absorption Filters	Simulation of solar radiation behind window glass
Infrared Absorption Filters w/UV-window	Simulation of outdoor solar radiation needed for older standard requirements
Infrared Absorption Filters w/Window Glass	Simulation of solar radiation behind window glass at high temperatures

Spectral Power Distribution of Various Glass Filters Compared to Sunlight

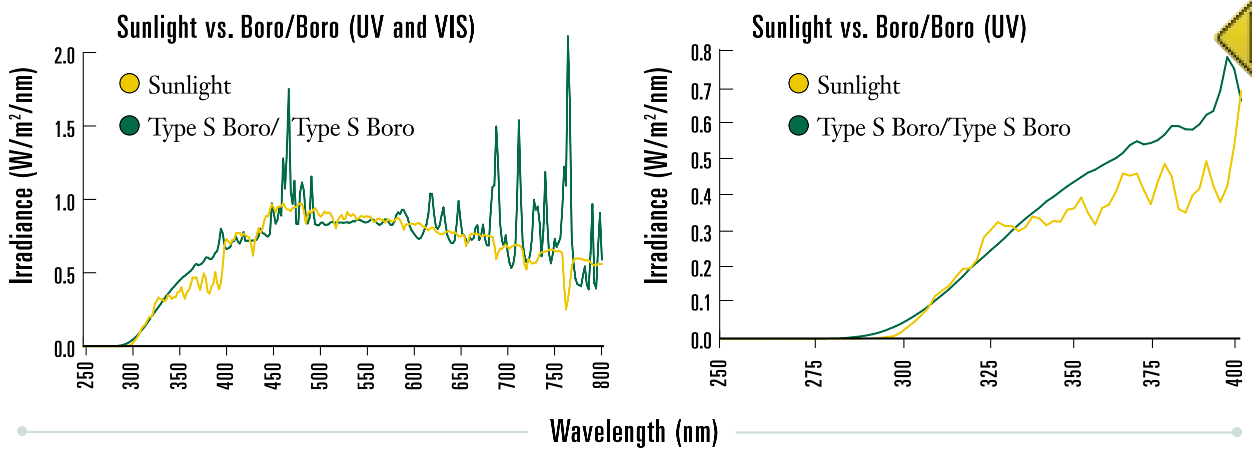
Xenochrome 300 Filter Compared to Sunlight



Xenochrome 320 Filter Compared to Sunlight Behind Glass

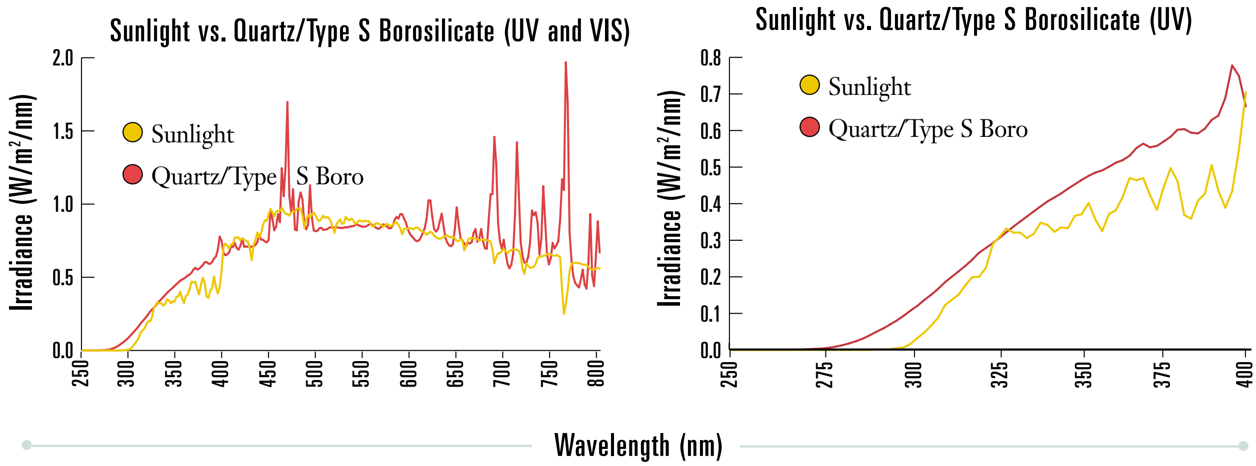


High Borate Borosilicate Type-S Filters Compared to Sunlight


Sunlight vs. Boro/Boro (UV and VIS)

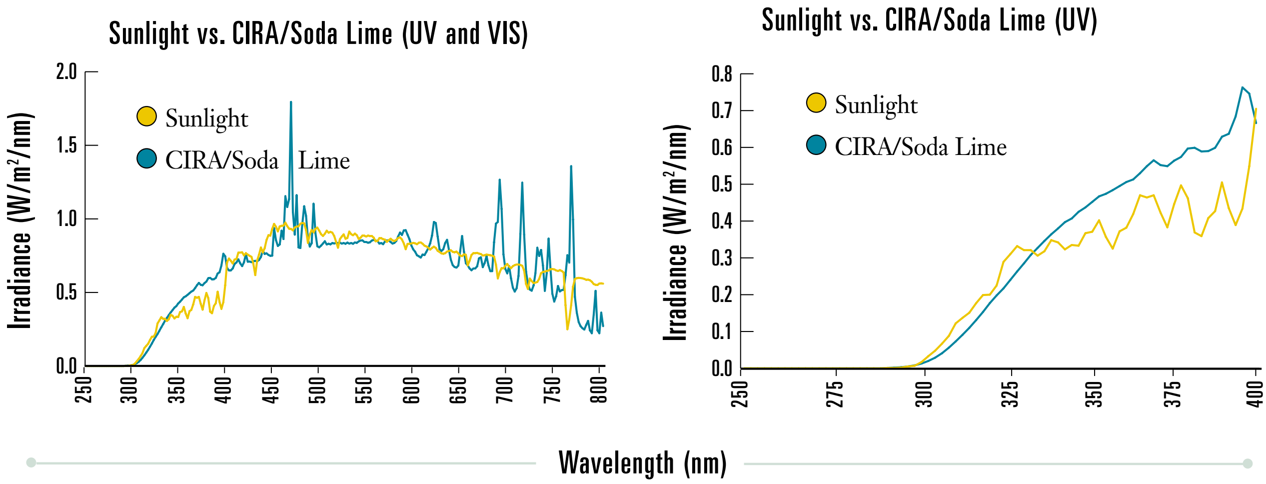
Sunlight vs. Boro/Boro (UV)

Quartz/Type S Borosilicate Filters Compared to Sunlight


Sunlight vs. Quartz/Type S Borosilicate (UV and VIS)

Sunlight vs. Quartz/Type S Borosilicate (UV)

Coated InfraRed Absorbing (CIRA) Quartz/Soda Lime Filters Compared to Sunlight


Sunlight vs. CIRA/Soda Lime (UV and VIS)

Sunlight vs. CIRA/Soda Lime (UV)

Modern xenon weathering instruments have precise control over both the spectral distribution of energy through optical filtering, as well as the irradiance. Radiant exposure is controlled by a **microprocessor.** Water-cooled instruments typically control the irradiance at a very narrow wavelength band (either **340 nm** or **420 nm**). A sample of the light from the xenon lamp is directed by a quartz light rod and filtered with a special device called a **narrow band interference filter.**

A **photodetector** then sends a signal to a **wattage regulator** to raise or lower the power to the lamp *(see Figure 3.4)*. Air-cooled instruments typically control the **broad band UV irradiance** (300 nm to 400 nm) directly at the sample level using the multi-sensor Xenosensiv for irradiance and black standard temperature *(see Figure 3.3)*. The irradiance measuring devices meet **ISO 9370**, *Plastics — Instrumental Determination of Radiant Exposure in Weathering Tests— General Guidance and Basic Test Method.* The irradiance in xenon instruments can be controlled at levels which approximate natural conditions or at increased levels for even more acceleration.

Fig 3.3

Irradiance control— air-cooled instruments

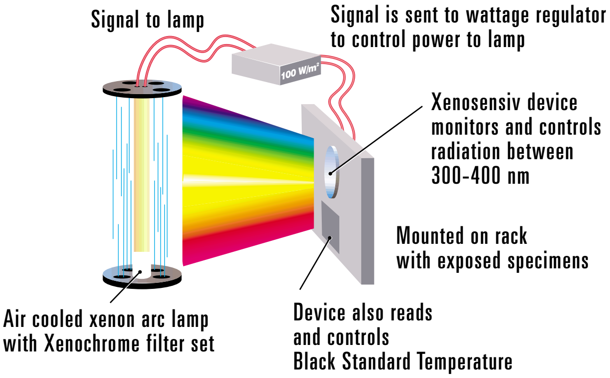
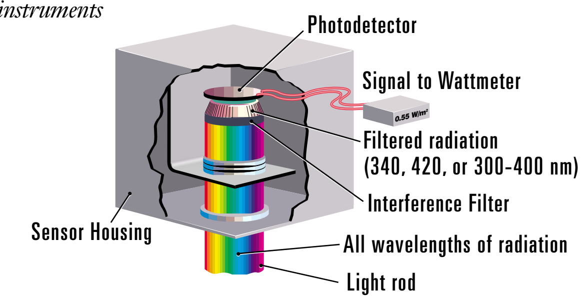
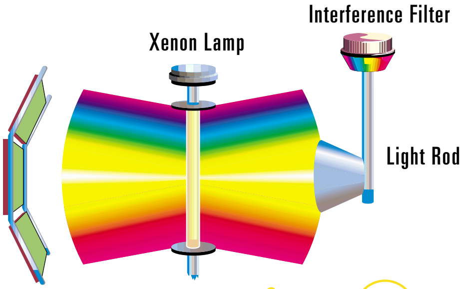


Fig 3.4

Irradiance control— water-cooled instruments





In both air-cooled and water-cooled instruments, specimens on exposure see all wavelengths of radiation from the xenon lamp.

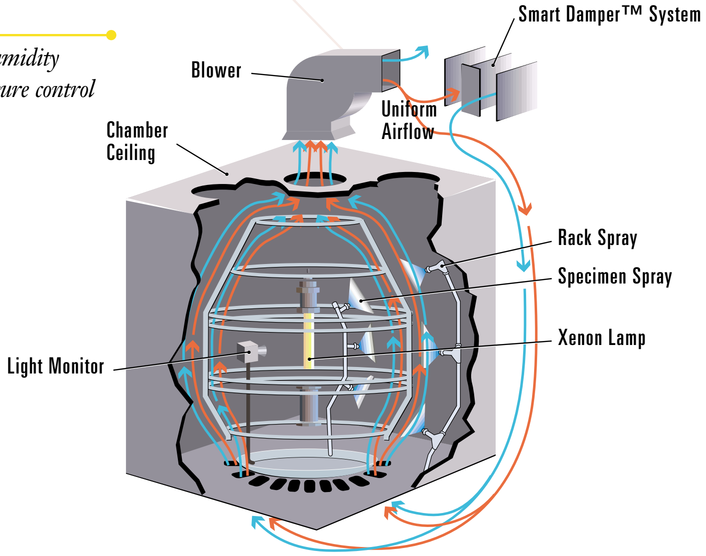
Narrow Band vs. Broad Band Control

Aging of materials is mainly a result of the UV and VIS radiation. Therefore, test methods specify either the irradiance within the UV region (for example, 50 W/m^2 between 300 and 400 nm), or the spectral irradiance at a certain wavelength in the UV or near VIS (for example, 0.55 W/m^2 at 340 nm). Some standards give values for both. The use of these two different concepts has mainly historical reasons. Some weathering instruments use broad band, others use narrow band measurement and control of the irradiance. Both technologies are equivalent regarding technical and economical aspects. If the spectral power distribution of the lamp/filter system is known, the broad band and narrow band values can be converted into each other. The manufacturer of the instrument is able to supply information to the user for each individual case.

In addition to the controlled irradiance, large scale water-cooled and air-cooled xenon instruments also provide for adjustment and control of temperature and humidity in a wide range. Digital proportional control of damper and heater systems maintains tight control of test chamber temperature and humidity. Automatic or manual adjustment of blower speed maintains simultaneous or independent control of chamber and black panel (standard) temperatures *(see Figure 3.5)*. Various humidity levels in the chamber air can be realized by the use of ultrasonic fogging systems. The instruments also provide for water spray or formation of condensate on the surface of exposed specimens, or for immersion of test specimens in water (table top units). Test cycles with light and dark phases can be programmed.

Fig 3.5

Xenon arc humidity and temperature control



DETOUR

Why Do We Have to Use Highly Purified Water for Specimen Spraying?

Sometimes the use of purified water for spraying the specimens is explained by the need to avoid corrosion inside the instrument. But this is not the most important reason. Ultra-pure water is necessary to ensure clear and reproducible test conditions. Additionally, without proper treatment of the water to remove cations, anions, organics, and, in particular, silica, exposed specimens might develop spots or stains that do not occur in natural exposures. Therefore, it is strongly recommended that water for the spray system contains a maximum of 1 µg/g of solids and 0.2 µg/g of silica. Distillation, or a combination of deionization and reverse osmosis is usually used to achieve the desired purity.

DETOUR

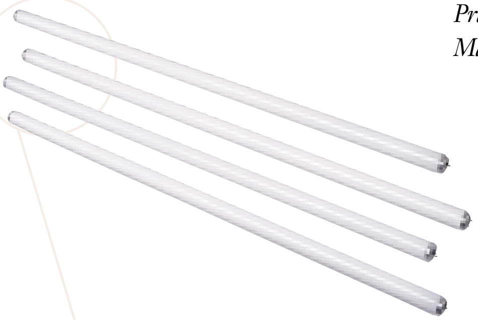
What is Better: Black Standard or Black Panel Thermometer?

Besides radiation, the temperature of the sample surface is the most critical factor in weathering tests. Online measurement of the real sample temperature is very expensive, technically difficult, and sensitive to errors in measurement. Therefore, the temperature on the sample surface is characterized by measuring the temperature of a standardized metal panel. A black coated panel indicates the maximum possible surface temperature of a specimen. For historical reasons, two different types of black panel thermometers (BPT) are used. A panel mounted on an insulating plastic baseplate has been used mainly in European countries and by ISO, the International Standards Organization, and is also called the Black Standard Thermometer (BST). The uninsulated type was introduced by ASTM. The temperature indicated by a BST is higher than that indicated by a BPT, depending upon the exposure conditions. Both types have their advantages and disadvantages. Because different types of BST and BPT are available, a test report should always specify which type was used.

Fluorescent UV Devices

Fluorescent UV lamps, similar in mechanical and electrical characteristics to those used for residential and commercial lighting, have been developed with specific spectral distributions. These sources are incorporated into fluorescent UV condensation devices such as the **Atlas UV2000**. These devices may be used in tests that vary **light/dark cycles**, temperature, condensing humidity, water sprays, and irradiance control. Their functional design and use is primarily governed by **ISO 4892-3**, *Plastics—Methods of Exposure to Laboratory Light Sources—Fluorescent UV-Lamps;* **ISO 11507**, *Paints and Varnishes—Exposure of Coatings to Artificial Weathering—Exposure to Fluorescent UV and Water;* and **ASTM G154**, *Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials.*

Fluorescent lamps come with different spectral characteristics



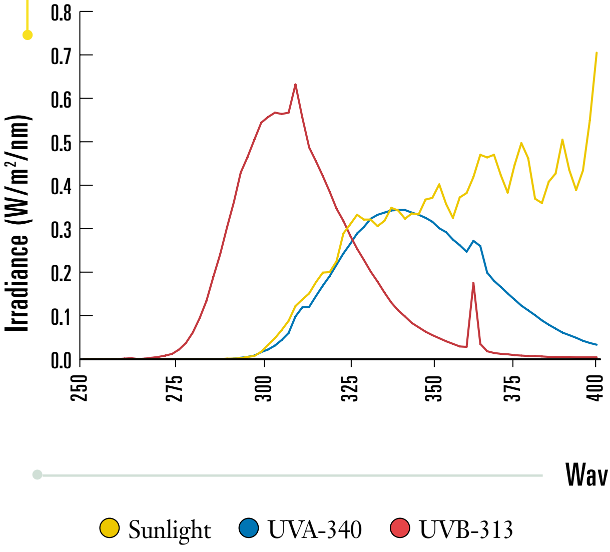
There are several different types of fluorescent UV lamps that have unique spectral characteristics. Fluorescent **UV-B lamps** (**F40** and **UVB-313**), with a peak around 313 nm, have nearly all of their energy concentrated between 280 nm and 360 nm. A large percentage is at wavelengths shorter than what is present in natural sunlight. There is very little radiation with wavelengths longer than 360 nm. Reversals in the stability ranking of materials have often been reported between laboratory accelerated and outdoor tests when the accelerated test uses UV-B lamps. This occurs because of the large amount of short wavelength UV and the lack of long wavelength UV and visible radiation; the mechanisms of degradation may be significantly different from those of the “natural” tests.

Fluorescent black lights, referred to as **UV-A lamps**, are available with peak emissions of 340 nm – 370 nm (e.g., **UVA-340** and **UVA-351**). In the UVA-340 lamp, developed in 1987, the short wavelength irradiance simulates that of direct solar radiation below 325 nm.

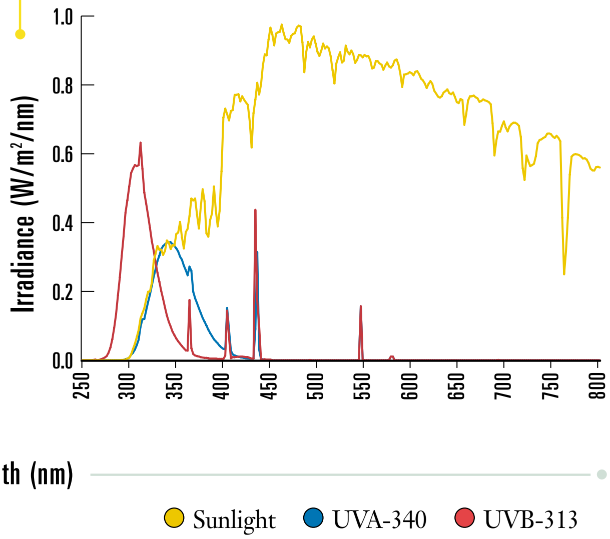
UV2000

Because UV-A lamps do not emit radiation below the cut-on of natural sunlight, correlation with outdoor weathering is somewhat improved, but test times are longer than with UV-B lamps. It may be noted, however, that tests using fluorescent lamps are widely practiced. These tests are useful for **relative rank comparisons** between materials under specific conditions, but the comparison to service lifetime performance or correlation to outdoor exposures may not be valid. The best use of the UV lamps is for general **screening tests**, such as checking for gross formulation errors with an artificially harsh exposure.

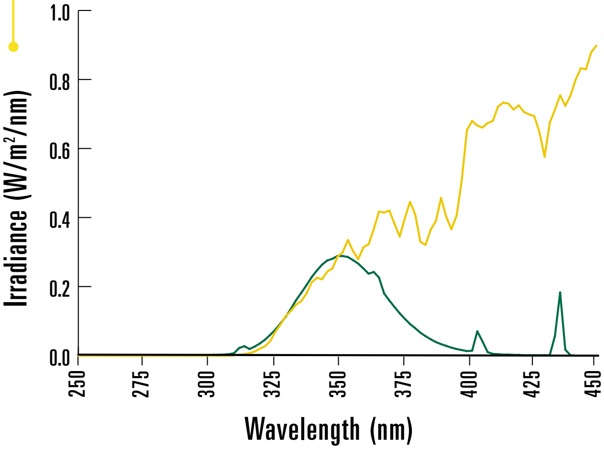
Fluorescent UV Lamps vs. Sunlight (UV)



Fluorescent UV Lamps vs. Sunlight (UV and VIS)



Fluorescent UV Lamps vs. Sunlight Behind Glass



The UVA-351 spectral distribution at lower wavelengths is similar to that of sunlight filtered through window glass.

● Sunlight Behind Glass ● UVA-351

In general, fluorescent UV devices offer a condensation cycle (during a lights-off period) to produce moisture *(see Figure 3.6)*. The test surface is exposed to a heated, saturated mixture of air and water vapor. The relative humidity inside the chamber is approximately 100% during the dark cycle. The reverse side of the panel is exposed to room air that drops the panel temperature below the dewpoint, causing condensation (dew) on the exposed surface. The sequence and time intervals for both the ultraviolet cycle and the condensation cycle are programmable and automatic. Likewise, temperatures can be controlled (within limits) during both the UV and condensation cycles.

Though fluorescent UV light sources are widely used in materials testing, knowledge of their limitations will serve the tester well. Until recently, the UV-B bulbs have been the most popular sources. However, their use has declined due to their poor record in accurately predicting a materials' outdoor performance. The UVA-340 source is more viable as it provides a good match for the terrestrial solar spectrum between 300 and 400 nm, but is very deficient thereafter, having virtually no output in the visible and infrared. This deficiency is important because it will tend to expose materials of different colors to the same surface temperature, contrary to what they would actually experience in a full spectrum source like sunlight and xenon. As we have already seen, temperature will affect degradation rates and processes. Some users of fluorescent UV testing devices like the fact that the condensation simulates dew very closely. Others state that the temperature of this condensing water is higher than any material would see in natural conditions, resulting in unrealistic water spotting on the surface.

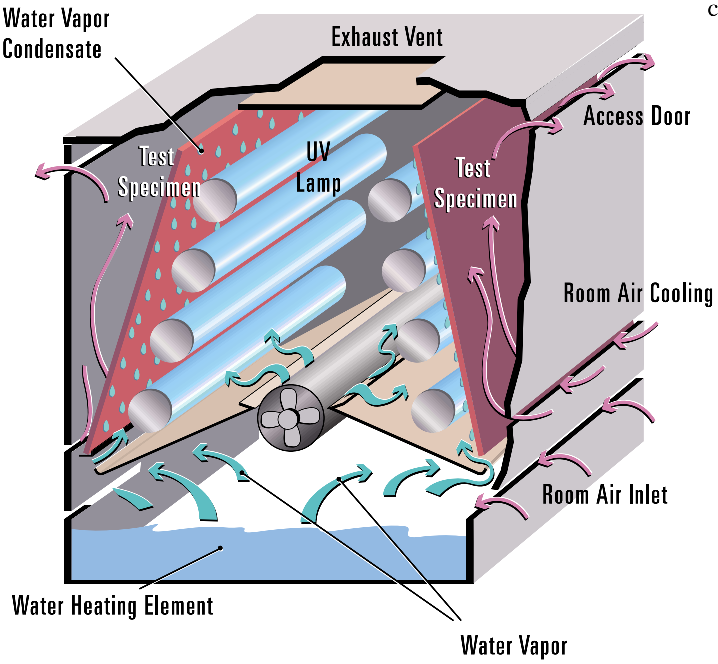


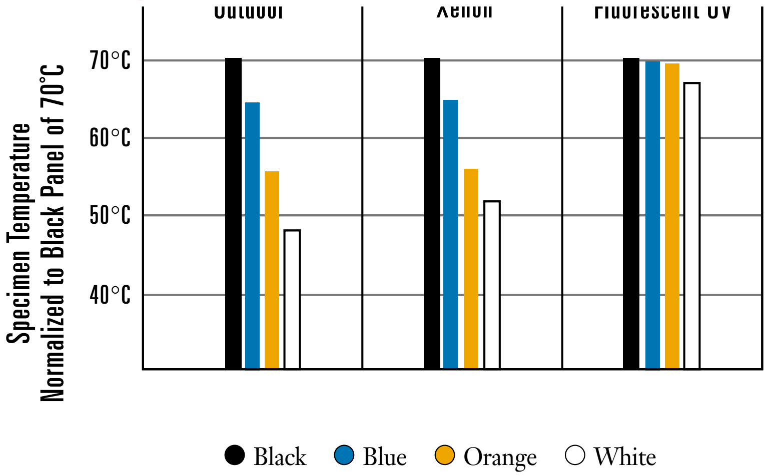
Fig 3.6

Condensation cycle for fluorescent UV devices

Temperatures of Specimens Exposed in a Fluorescent UV Weathering Device.

Temperature differences of various colors seen in natural weathering exposures are a result of the difference in the absorption of radiant energy, especially in the infrared region of the spectrum. In artificial accelerated testing, only those devices that emit this infrared radiation will give similar temperature separations. In a study conducted by the 3M Weathering Resource Center, seven different colored specimens were exposed outdoors and in several types of artificial instruments. The graph to the right illustrates the (lack of) temperature differences in fluorescent UV weathering devices. Despite this fact, fluorescent UV testers can be a useful type of artificial testing, because the spectral intensities of the UVA-340 bulbs are very similar to natural sunlight in the shorter wavelength UV region .

Temperature of Exposed Colored Panels



Note: Black Panel temperature in the fluorescent UV device is achieved by heating the chamber air. Thus, all specimens are heated equally, without regard to color.

Fischer, R. M. and Ketola, W. D. , "*Surface Temperature of Materials in Exterior Exposures and Artificial Accelerated Tests,*" Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202, Warren D. Ketola and Douglas Grossman, Eds., American Society for Testing and Materials, Philadelphia, 1994

Metal Halide Systems

The automotive manufacturers and their suppliers continue to experiment with new technology and testing approaches. This is shown by efforts to expose large components such as **instrument panels**, **door assemblies** and **bumper fascia** systems to test the effects of mounting stresses and formed parts that are made from several components or materials. The natural weathering example of these efforts is the IP/DP Box® shown earlier. But there are light sources available that make it practical to expose these large components (or even entire vehicles) artificially.

For more than 20 years, special metal halide lamps (such as the SolarModul 4000) have been an accepted radiation source for "full-spectrum" solar simulation systems. Mainly used by automotive manufacturers and their suppliers, these systems are gaining importance and have two main applications:

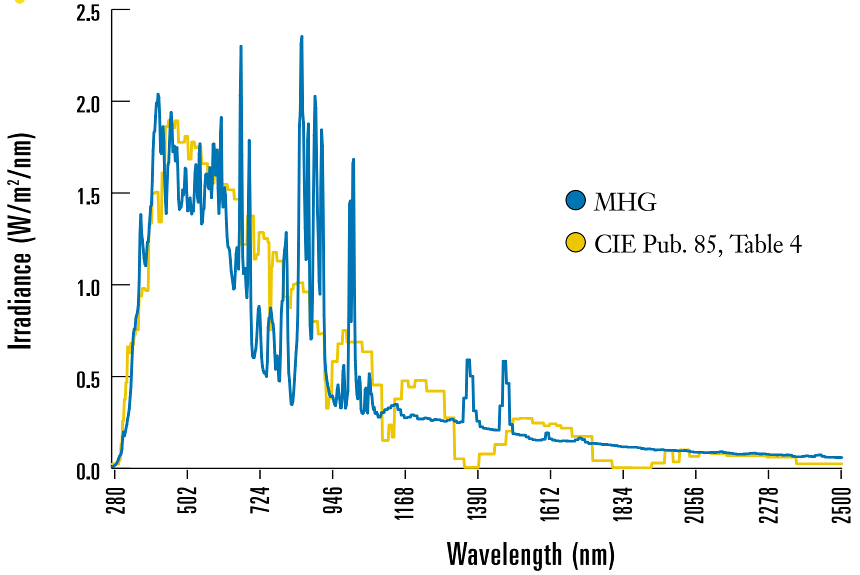
- Aging tests (weathering and thermal stress) are mainly used for components made from several materials.
- Solar heat load tests are mainly used for research and development of air-conditioning systems.

DETOUR

Recipe for Metal Halide

Different from thermal radiators (e.g. tungsten-halogen lamps) metal halide lamps do not have a continuous spectrum. They produce a so-called quasi-continuous spectrum consisting of a large number of individual spectrum lines and a major continuum over a wide spectral range. This quasi-continuum radiation is generated by a large number of different chemical components in the arc plasma. Most important here are the Rare Earths. These metals (e.g. Dysprosium, Thulium, Holmium) form halides with the existing halogens. Additionally, the recipe for the MHG lamps offers a spectrum very similar to that of the sun. It has to be seen as very sensitive due to its multiple line characteristic. Only stabilized, "true output" controlled power supplies and well designed lamp fixtures can offer appropriate operating conditions to maintain a constant spectral power distribution. Any unintentional variation of lamp intensity must be avoided, and any intentional variation needs to be supported by detailed knowledge of the changes in the lamp spectral properties and the effect on the application for which the source is used.

MHG vs. Sunlight



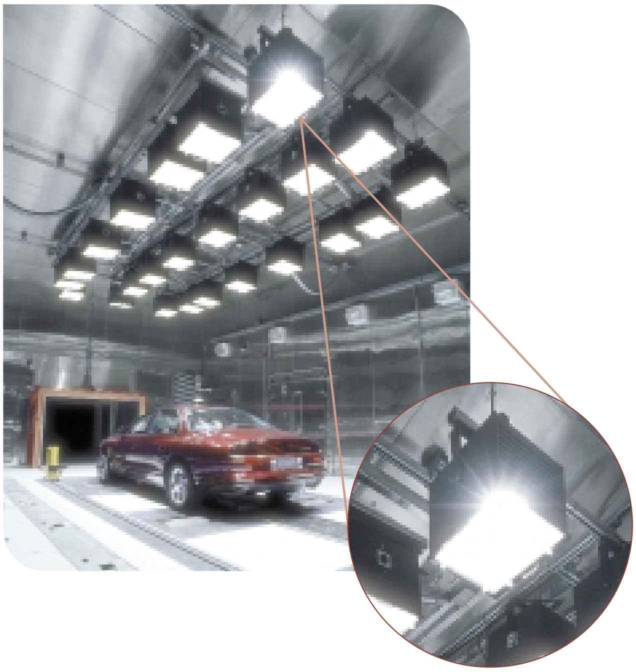
Metal halide lamps belong to the larger family of **discharged** lamps. They are manufactured in various versions and for different applications. Even if they are all characterized as “daylight” sources, only a few of them are suitable for solar simulation. So, in this respect, the use of the general term “metal halide” is critical.

Based on the technology of metal halide lamps used for general lighting purposes, high-quality versions were introduced in the late 1960s for the photo optics field. Today’s lamps offer a high **luminous efficacy** (about 100 lm/W), a **color temperature** of 5500 to 6000 K, a high **luminance** (up to 30 kcd/cm^2) and a **color rendering** (95), which almost matches the “natural” rendering of non-luminous colors (100). These are all important features and indicate high quality, but are not enough to make the lamps an acceptable source for solar simulation. Full-spectrum match and uniform, stabilized irradiance are the main requirements for a solar simulation system.

To fulfill those demands for solar simulation, metal halide lamps are carefully checked for their electrical and optical characteristics and individually measured for their spectral power distribution to become **MHG (Metal Halide Global)** lamps for solar simulation use. In combination with suitable filters, optical systems, and electronic power supplies, they provide a spectral power distribution that closely matches solar radiation.

Because of their high efficiency, these sources are ideally suited for use in large-scale chambers, using several radiation units strategically placed to provide uniform exposures. The special features that are associated with some of the metal halide chambers are quite remarkable. Solar simulation systems, such as the SolarConstant shown to the right, have been designed to simulate day cycles (sunrise through sunset) and drive cycles by mechanically moving the system along the walls and ceiling of the chamber.

SolarConstant drive-in solar simulation chamber



Radiation Unit

Full vehicle tests include:

- *Material performance (interior/exterior)*
- *Fit and finish*
- *Squeak and rattle*
- *Occupant comfort (thermal/AC)*
- *Occupant safety (Front/Rear/Side airbag aging performance)*
- *Emission evaluations*

SolarConstant systems equipped with MHG lamps match the requirements of many test methods (such as DIN 75 220, *Aging of Automotive Components in Solar Simulation Units*; IEC 68-2-5; MIL STD 810; SFTP). The DIN 75 220 specification describes cycles that closely simulate natural, worst-case, irradiance, temperature, and humidity parameters. Conditions have been written to simulate the subtropical and desert benchmark climates of natural weathering.

Smaller MHG exposure chambers, such as the SolarClimatic™ series instruments, are used to test small to mid-size components. These devices have irradiance, humidity, ambient, and black panel (black standard) temperature control. They also meet the DIN 75 220 specification.

SolarClimatic 2000

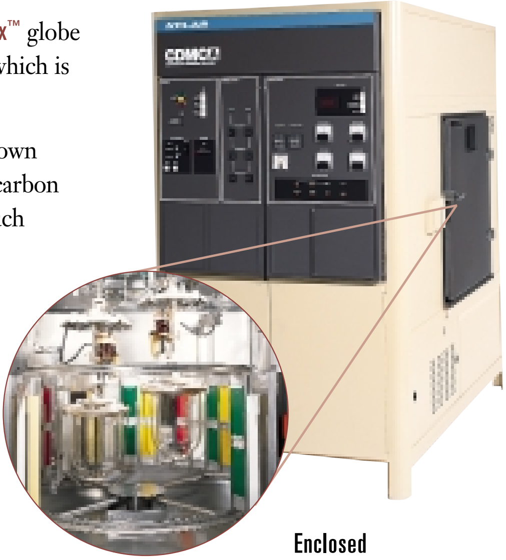
DIN 75 220 Test Specifications

		Exterior	Interior	
Irradiance (280-3000 nm)		1000 W/m² ± 100 W/m²	830 W/m² ± 80 W/m²	
Test Chamber Temperature				
Day		42°C ± 3°C	80°C ± 3°C 65°C ± 3°C	Exposure Zone 1 Exposure Zone 2
Night		10°C	10°C	
Frost Climate		-10°C	-10°C	
Relative Humidity				
Day	Dry	< 30%	< 30%	
	Humid	> 60%	> 40% > 50%	Exposure Zone 1 Exposure Zone 2
Night	Dry	> 55%	> 55%	
	Humid	condensation permissible	condensation permissible	

Carbon Arc Instruments

The **carbon arc instrument** was first used by German synthetic dye chemists to evaluate the effect of light on the color of dyed textiles. The first Atlas Color Fade-Ometer,® introduced in 1919, used an **enclosed carbon arc (ECA)** light source. These instruments work by igniting paired **carbon rods**, which then burn continuously as the light source. The carbon rods are enclosed in a **Pyrex™** globe to provide some optical filtering and an oxygen-deficient atmosphere, which is necessary for proper burning rates of the carbon rods.

The **spectral emission** in the UV bears little resemblance to sunlight, as shown by the spectral power distribution graph on page 57. For the enclosed carbon arc, two strong emission bands, peaking at 358 nm and 386 nm, are much more intense than natural sunlight. This type of light source can be expected to have a weaker effect than solar radiation on materials that absorb only short wavelength UV radiation, because there is very little irradiance below 310 nm. But because of the strong emission bands, ECA exposures will have a stronger effect on materials that also absorb long wavelength UV and visible light.


Enclosed
Carbon Arc Weather-Ometer

The first **open-flame carbon arc** device, the Atlas **Sunshine Carbon Arc Weather-Ometer®** with **Corex®** filters, was introduced in the 1930s. The Sunshine Carbon Arc uses three pairs of **carbon rods** and operates in a free flow of air. The arc is rotated among the pairs to provide approximately one day's operation per set. The radiant energy is usually filtered by flat Corex filters, which are mounted around the arc.

The light produced by the Sunshine Carbon Arc provides more UV at wavelengths below 300 nm than sunlight but gives a much better match than the enclosed carbon arc. Compared to solar radiation, the Sunshine Carbon Arc is more like sunlight than the enclosed carbon arc at longer wavelengths. When used without filters for faster testing, stability rankings of some materials may be distorted when compared with outdoor testing.

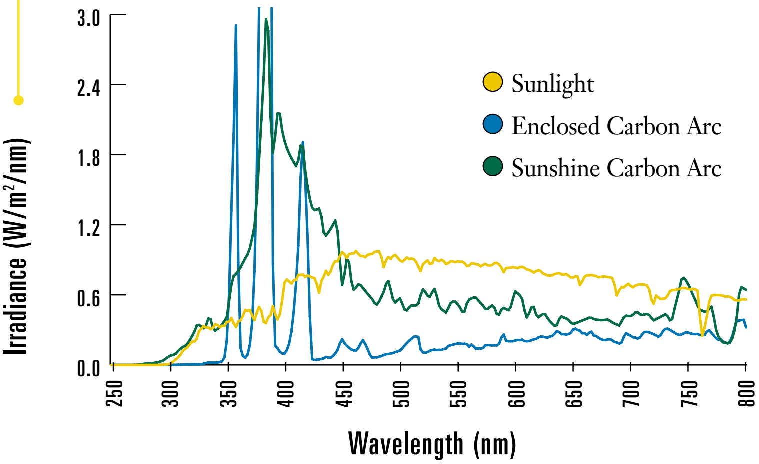

Various Carbon Rods


Sunshine Carbon Arc
Weather-Ometer

Therefore, in trying to evaluate the relative light stability of materials, some of which absorb only short wavelength UV and others that also absorb long wavelength UV, the carbon arc light source could distort the rankings when compared with samples exposed to solar radiation.

Both carbon arc technologies require daily replacement of the carbon rods and cleaning of the filters or globes. Filters and globes degrade and must be periodically replaced; accumulated carbon soot also must be removed. There is a vast amount of historical data on the use of carbon arcs, and a number of test methods still specify their use. While good correlation with outdoor exposures has been reported for some materials whose weathering mechanisms are appropriate for these limited spectrum sources, this technology has largely been replaced with fluorescent UV or xenon arc systems. **ISO 4892-4,** *Plastics — Methods of Exposure to Laboratory Light Sources — Part 4: Open-flame Carbon arc Lamps;* **ASTM G152,** *Standard Practice for Operating Open-Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials;* and **ASTM G153,** *Standard Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials* are the primary documents describing performance characteristics of devices that use a carbon arc light source.

Filtered Carbon Arc vs. Sunlight



Corrosion Cabinets

Although the effects of corrosion of metal substrates does not necessarily require a light source, **corrosion** testing has traditionally been considered a "weathering test." Outdoor weathering sites that test a material's resistance to corrosive environments can be found throughout the world. These include industrial locations, where NO_X, CO_2, and SO_2 combine with moisture in the atmosphere to create acid rain, or marine environments that contain high levels of sea salts.

DETOUR

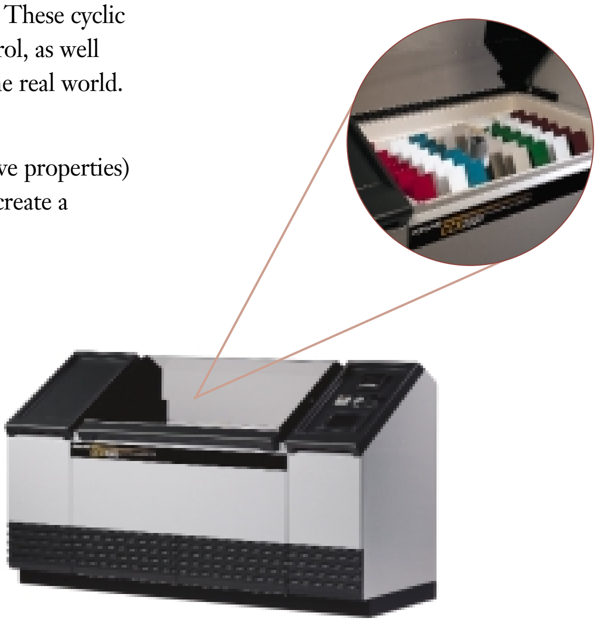
Why Would Anyone Use a Carbon Arc Source if the SPD Doesn't Look Anything Like Natural Sunlight?

For over 40 years, carbon arc technology was essentially the only artificial light source commercially available. As a result, manufacturers accumulated extensive amounts of historical information pertaining to the performance of their material to this source. As new formulations are developed, the first question one might ask is, "Is it better than our old formulation in terms of weatherability?" The only way to compare is to expose it to the same light source. Also, many standards and material specifications were written that require the use of carbon arc testing. Even though newer artificial weathering instruments have been developed to better simulate natural sunlight, the historical data collected, specifications, and the desire to avoid comparing "apples to oranges" has resulted in the limited, but continued, use of carbon arc devices for material durability testing.

Corrosion cabinets have been developed to accelerate the effects of corrosive environments. One of the original specifications for corrosion testing is **ASTM B117,** *Standard Practice for Operating Salt Spray (Fog) Apparatus.* This traditional type of testing exposes specimens to a single test condition, usually 35-40°C, with 100% relative humidity created from a water soluble chemical such as sodium chloride. It has been proved that this method is not a realistic test and rarely predicts the service life of a material.

Since the real corrosive environment changes from day to day (or faster), labs began exposing samples to various environmental stresses that promoted corrosion. Lab technicians spent countless hours transferring specimens from one environment to another; a salt fog cabinet for corrosion, an oven for dry heat, a sink for direct spray, etc. New technology in corrosion exposure equipment now creates these desired environments within one cabinet, which significantly reduces the need to move or otherwise touch test specimens. These cyclic corrosion tests incorporate variable temperature and humidity control, as well as different corrosive chemicals that better simulate conditions in the real world. Test conditions may also include:

- Salt or chemical fog— Salts (or solutions with other corrosive properties) are atomized with heated, humidified air under pressure to create a relative humidity of 95-100%, often called "saturation."
- Water fog — Saturation cycle similar to the salt or chemical fog cycle, except that DI water fog condenses in the exposure area instead of a soluble chemical.
- Dry-off— Heated air is circulated throughout the exposure chamber to reduce humidity.
- Dwell— No action taken inside the chamber, returning conditions to the ambient state.
- Direct spray— Samples are sprayed directly with salt or chemical solution, a process similar to spray washing of a car with low-pressure water through a hose and nozzle.
- Immersion— Samples are immersed in a salt or chemical solution that is usually heated, typically the same concentration that is used for the fogging cycle.
- Gas injection— A natural or industrial pollutant, most commonly SO_2, is injected into the exposure area during an episode of fogging.



Advanced cyclic corrosion cabinet, CCX Corrosive Fog Exposure System

One advanced cyclic corrosion standard is **SAE J2334,** *Cosmetic Corrosion Lab Test.* This method has shown excellent correlation with end-use conditions in studies performed by the Society of Automotive Engineers, the American Iron and Steel Institute, and the Auto/Steel Partnership. An important parameter of this test is the requirement for 50% relative humidity during the long dry-off cycle. This is critical, because corrosion is more likely to occur during transition periods from wet to dry and dry to wet than during wet conditions only.

Practical Applications

Practical Applications

Practical A

The information in the first three sections of this guidebook gives much of the theoretical knowledge needed for conducting standardized weathering programs. However, it would be difficult to take only this information and be able to conduct efficient, appropriate tests. Questions regarding the correlation of natural weathering to accelerated weathering, the use of standard reference materials, and test program development should be understood to help bridge the gap between theory and the practicality of real-world testing.

Fig 4.1

Testing Myths and Mistakes Exposed

Be careful not to fall into these bad habits when conducting accelerated tests. Taking these shortcuts will inevitably lead to poor correlation.

Reasons for Poor Correlation	The Myth	What Really Happens
Short wavelength light sources (outside of the solar spectrum)	Shorter wavelengths of radiation have more energy which will degrade my material faster.	The high energy contained in shorter wavelengths of radiation causes unnatural photochemical changes.
Continuous exposure to light	Maximizing the amount of time a material is exposed will shorten my test time.	Some materials need a "rest period" for certain chemical reactions to take place. Since natural outdoor exposures will always have a "dark cycle," it makes sense to simulate this in artificial weathering instruments.
High irradiance levels (especially with artificial light sources)	Blasting my samples with high irradiance is the only way to get the acceleration I need.	Some photochemical changes during exposure may be induced at high irradiance levels that do not occur at normal levels.
Abnormally high specimen temperatures	I'll get faster acceleration since higher temperatures result in faster degradation rates.	Unrealistic temperatures during exposure often cause different types of degradation, which do not correlate with outdoor exposures.
Unrealistic temperature differences between light and dark materials	Since UV radiation is the most important factor of weathering, that's all I really care about.	Radiation sources with only UV radiation will cause unrealistic or a lack of temperature differences between materials of different color or structure.
No temperature cycling	If I keep my temperatures high, I will get faster acceleration.	Natural temperature cycling often causes physical changes to materials as a result of the expansion and contraction of materials.
Unnatural levels of moisture	I'll soak my specimens to increase degradation.	The absorption/desorption cycle of water causes physical stresses that can actually cause more degradation than a saturated environment.
Absence of pollutants or other biological agents	Since these are "secondary" factors, I'm not concerned about these factors or what they do to my material.	Laboratory weathering instruments are rarely, if ever, used to replicate the effects of pollutants or other biological factors, but they are an inherent part of the natural weathering process, and we must remember that they may result in less-than-expected correlation.

Correlation and Acceleration

In the context of materials durability, **correlation** can be defined as the ability of an artificial weathering method to produce results that agree with real-time outdoor or service environment exposures. **Acceleration** is a measure of how rapidly a test can be conducted using a natural accelerated or artificial laboratory method, compared with conventional, natural outdoor weathering. The foundation of whether or not an artificial test correlates with natural weathering is based on the changes that have occurred to the materials on exposure. These might be mechanical or appearance changes, such as **gloss loss, color change, tensile strength**, etc., or they may be chemical changes, which can be detected with **infrared spectrophotometry, electron spin resonance**, **chemiluminescence,** or **thermal analysis**. Figure 4.1 shows several factors that will certainly decrease correlation.

How Many Hours in an Artificial Test Instrument Equal One Year of Natural Exposure?

Without a doubt, this is probably the most often-asked question during any discussion on weathering. If someone stated, “The answer to this question is exactly 1200 hours,” you would probably question their technical capabilities and common sense, knowing all the variables that exist in our environment. By contrast, if someone answers this question “I don’t know,” you might think they are foolish to spend money and time performing artificial weathering tests in the first place. If this question were posed to the most knowledgeable, experienced researchers in weathering, they would probably say, “It depends.” Surprisingly, this would be the correct answer. However, by making some assumptions and understanding some basic concepts, we can formulate answers that are more specific than “It depends.”

For this example, an Atlas Ci-series Weather-Ometer® will be used.
Other important facts are:

- The annual mean UV radiant exposure (295 – 385 nm) at the site latitude angle of 26° south for one year in Florida is 280 MJ/m^2.
- The irradiance is controlled at a narrow wavelength range in a Weather-Ometer. For this example, assume that a test is being conducted at 0.35 W/m^2 at 340 nm.
- How is irradiance converted from a narrow wavelength band (340 nm) to a wider wavelength range (295 – 385 nm)? Before this can be answered, the equations on page 63 must be understood.

A Correlation/Acceleration Example

Probably the best way to graphically show what can happen when trying to over-accelerate a weathering test is with the chicken and the egg story. But this is not the traditional question of, “Which came first?” If we consider a fertilized egg, we know that after approximately 21 days at 35°C, the result will be a chick hatched from the egg. This could be analogous to testing materials under natural conditions. Of course, most materials engineers are always stressing that, “I can’t wait that long for my results!” But if we try to accelerate the birth of this chick by exposing it for five minutes at 180°C, we get the result of a fried egg instead of a little chick! While we know the results of acceleration in our chicken-egg story, we sometimes forget that the same type of thing might happen with our accelerated weathering test.

Radiant exposure is irradiance integrated over time. Therefore, the following equation applies:

$$\mathrm{W/m^2} \bullet \text{time (seconds)} = \mathrm{J/m^2}$$

In a Weather-Ometer® radiant exposure is normally measured in kJ/m^2, so joules (J) must be converted to kilojoules (kJ):

$$1\ \mathrm{J/m^2} = 0.001\ \mathrm{kJ/m^2}$$

Artificial weathering tests are timed in hours:

$$3600 \text{ seconds} = 1 \text{ hour}$$

Next, all of these conversions can be combined to obtain the following equation:

$$\mathrm{kJ/m^2} = \mathrm{W/m^2} \times 3.6 \times \text{hours}$$

If irradiance is controlled in the Weather-Ometer at 340 nm, radiant exposure at this wavelength band must be converted to that UV range measured at outdoor exposure sites. For general purposes, the energy contained in the 340 nm wavelength range is approximately one percent of this UV range. Knowing this, the following conversion can be made:

$$10\ \mathrm{kJ/m^2} \text{ at } 340\ \mathrm{nm} \cong 1\ \mathrm{MJ/m^2}\ (295 - 385\ \mathrm{nm})^{*}$$

These numbers are now inserted into the equation shown above to get a general idea about radiant exposure levels at specific irradiance set points.

$$2800\ \mathrm{kJ/m^2} \text{ at } 340\ \mathrm{nm} = 0.35\ \mathrm{W/m^2} \text{ at } 340\ \mathrm{nm} \times 3.6 \times \text{hours}$$

After performing a few algebraic functions:

$$2222 \text{ (light) hours} = \frac{2800\ \mathrm{kJ/m^2} \text{ at } 340\ \mathrm{nm}}{0.35\ \mathrm{W/m^2} \text{ at } 340\ \mathrm{nm} \times 3.6}$$

Notice that the term "light hours" has been added to the final answer. Many Weather-Ometer cycles are programmed with a dark cycle. Obviously, this time should not be counted in the equation above.

Although a number has been given that everyone is looking for, a few points must be made clear that will affect this value:

- We are comparing radiation from a xenon light source to natural sunlight. While properly filtered xenon energy is a close match to natural sunlight, it is not an exact match and this will add to the variability.

DETOUR

Radiant Exposure Only Tells Half the Story

The ability to compare radiant exposure between natural weathering and xenon arc exposures can be a powerful tool when developing service life prediction models. But there are other factors that must be considered as well. The spectral sensitivity of the exposed material (see Figure 1.5 on page 13) may make these "equivalent" exposures useless. Temperature, moisture, and the secondary effects will play a role in material degradation. As we have already discussed, these factors work synergistically to degrade materials. Because of this, the study of weathering and degradation of materials has been described as "half science and half magic."

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* *A similar conversion could be accomplished by comparing instruments that control irradiance at 420 nm, 300-400 nm, or 300-800 nm. This would mean that one "average" year in Florida (based on radiant exposure measurements taken at the site latitude) would be approximately 2800 kJ/m^2 at 340 nm. Measurements taken with narrow band radiometers confirm this calculation.*

- The filters used will change the spectral power distribution slightly (especially in the short wavelength UV), which will add to the variability.
- There is very little consistency in terms of irradiance levels of natural sunlight, which will add to the variability.
- Time-of-day, seasonal, and long-term variations in the spectral power of sunlight will add to the variability.
- Geographic, latitudinal, and other atmospheric variations will contribute to the variability of natural sunlight.
- Optical filter and xenon lamp age will cause a slight variability in the spectral power distribution of the xenon test equipment used.

Because of these factors, the tolerance for the answer given in the equation on page 63 will be no more accurate than ± 10%.

As already shown, the wavelengths of energy that cause degradation to a material vary, depending on the formulation of the material. The other factors of weathering (temperature and moisture) will also contribute in some way to this degradation. It is highly unlikely that specimens exposed for 2222 light hours in a Weather-Ometer at an irradiance level of 0.35 W/m^2 (at 340 nm) will experience the same amount of degradation after one year in south Florida. However, one may be able to use these formulas as a starting point to generate some information on acceleration rates in a Weather-Ometer for their own material.

The Use of Standard Reference Materials

Historically, carmakers performed weathering tests for their suppliers. Today, budget cuts do not allow this indulgence. Suppliers must do their own testing and prove that the testing has been done correctly. But how do they do that? The best approach is through the use of a **standard reference material** (SRM). An SRM is a sample of a material that has known optical, appearance, or physical change properties when exposed to specific test conditions.

The concept of using SRMs is as follows:

1. A certificate is included with the lot of SRMs that defines the amount of property change (usually a color change) that corresponds to a specific amount of radiant energy, based on a given set of exposure conditions.
2. The SRM is measured for this property to establish initial, or unexposed values.
3. The SRM is exposed as one of the specimens on test.
4. At a pre-determined amount of radiant exposure (as stated on the certificate), the SRM is removed from exposure and re-evaluated.
5. The amount of property change is compared to the stated change on the certificate.

DETOUR

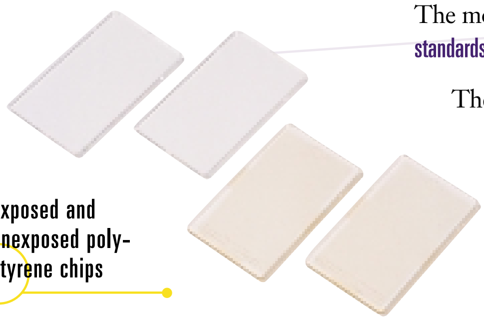
Getting "Control" of Our Definition of a "Control"

One of the ASTM definitions of a control is, "…a material which is of similar composition and construction to the test material used for comparison, exposed at the same time." Another ASTM definition is, "…a material that has known values in normal use." This is a good definition of a Standard Reference Material (SRM). In another context, a control is referenced to be, "…an evaluation to check, test, or verify." In the weathering context, a "control" is most commonly thought of as a portion of the tested material that is either cut from the original and stored in stable conditions, or a portion of the exposed specimen which is protected from light exposure by masking. This is a very different meaning than that of a reference material. For weathering applications, a true SRM must have properties that are sufficiently well established to be used for verification of the operation of a weathering instrument or the assessment of a measurement method.

6. If the property change of the SRM falls within the tolerance range on the certificate, the weathering instrument is considered to be "within specifications." Essentially, the result of the test indicates that the specified levels of irradiance, temperature, and moisture were correct.

7. If the property change falls outside the tolerance limits, the reasons for the discrepancy must be explained and resolved.

The most common types of reference materials are the **polystyrene lightfastness standards** and the **AATCC** and **ISO Blue Wool reference materials**.

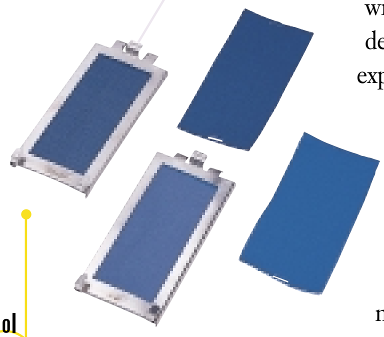


Exposed and unexposed polystyrene chips

The polystyrene chip is a clear plastic that was developed in the late 1980s by General Motors and Dow Chemical Company. The polystyrene chip is designed to be reproducible from one batch to the next and can be used as a reference for both interior and exterior automotive applications. Also, the color change of the chip (yellowing) is linear with increasing levels of radiant exposure. There is a limitation of this linear correlation as the yellowness approaches the saturation level.

AATCC Blue Wool is a textile colored with two unstable blue dyes in variable concentrations. There are several "grades" of Blue Wool **(L2** through **L9).** The color of each higher-numbered blue wool shows half the amount of fading when compared to the corresponding lower-numbered grade after simultaneous exposure. Initially, the material was used as a reference within AATCC standards as a **"dosimeter."** This was done by visually examining the fading of the material, from which a number of **AATCC Fading Units** could be determined. With the advent of controlled irradiance and improved monitoring devices in artificial weathering instruments, the blue wool is now used more often as an SRM, similar to the polystyrene chip. AATCC Blue Wool reference standards are used extensively in the textiles industry and for automotive interior test methods.

Another reference standard is the ISO Blue Wool Standard (1–8). It is similar to the AATCC Blue Wool in that one higher grade would show half the rate of fade as the lower grade. However, its purpose should not be confused with the AATCC Blue Wool. ISO Blue Wools are used as a reference to determine a classification for the lightfastness properties of a simultaneously exposed textile material. After exposure, the textile in question is compared to the exposed ISO Blue Wool Standard for colorfastness. A determination is made as to which ISO Blue Wool grade faded at the same rate as the textile specimen. The specimen is then given a colorfastness ranking that corresponds to that particular grade of ISO Blue Wool. The ISO Blue Wool Type 6 is extensively used in the automotive industry to define a test cycle when testing interior materials. Although similar in appearance, AATCC and ISO Blue Wool Standards are *not* interchangeable.



AATCC Blue Wool reference materials

Setting Up a Weathering Test

General Information

Understanding the important parameters of weather, the natural weathering methods, the laboratory weathering instruments, and the inherent strengths and weaknesses of each of these methods are important steps in developing a weathering test program. However, sending specimens to an independent testing service, or placing specimens in an artificial cabinet without careful thought and planning will lead to insufficient data collected, incorrect evaluation of the exposed specimens, and ultimately, poor decisions as a result of this analysis. There are many publications and educational courses available that deal with experimental design, but some of this information lacks a connection with an actual weathering test. **ASTM E632**, *Standard Practice for Developing Accelerated Tests to Aid Prediction of the Service Life of Building Components and Materials* is a beneficial tool for proper weathering test development. Although additional information is presented here, this section is roughly based on the ASTM E632 standard.

The first step in test development is defining the objective for the test. Is the testing to meet a standard or specification in order to sell the material? This may be one of the easier objectives because the tests to be performed are often specifically directed by the industry standards. Many times, these standards go so far as to define exact information pertaining to the test. This objective is often true in the automotive industry, where the auto manufacturer (OEM) has referenced a common automotive test specification that defines the test and/or instrument, the amount of time or radiant exposure, the evaluations to be performed, and the minimum acceptable property change of the material tested.

Sometimes the objectives are to compare a material with an older formulation, compare a new manufacturing process, or to compare a competitor's material. These types of objectives require much more thought because the parameters for testing may not be defined. Many variables may be analyzed that may relate to the material, the process, the stresses of weathering, or some combination of all these variables. For example, testing the material formulation may include analyzing the addition of specific stabilizers: how much stabilizer is most cost efficient, or which vendor has the superior stabilizer for your application or material? Processing questions may deal with the effects of increased extruder speeds, new thickness specification of a coating, or examining different surface preparation methods. Sophisticated research and development questions will attempt to collect information on these formulation or processing questions and to determine which particular weathering stresses cause degradation. This leads to true service life prediction tests.

Problem Definition

For service life prediction tests, it is first important to define the in-service performance requirements and criteria. Identifying the critical performance characteristics and properties are the first steps. Are appearance properties important, such as color, gloss, haze, or biological contamination? Are physical properties important, such as tensile strength, cracking, brittleness, impact strength, or abrasion resistance? Are there other properties, such as washability, electrical properties, dimensional stability, or adhesion? Once the proper performance criteria has been established, one must understand the evaluation methods available, and how the results of these evaluations can be related to your customers' expectations.

The next step in this characterization procedure is to understand the type and range of weathering degradation factors that may influence the property change that has been established to be important. We have already discussed the most common degradation factors, such as radiation, temperature, moisture, and corrosion. Understanding which of these are important may also lead to other degradation factors, such as chemical incompatibilities, wind load, installation procedures, or typical in-use wear and abuse. During the later phases of test development, it is also important to understand the extreme levels of these factors that will be experienced by the material in its final service environment. Computer programs are available that model these factors and their effects on materials.

The final step in this initial procedure is to put these performance criteria and degradation factors together by identifying the actual degradation mechanisms that induce changes in the properties of the material. If enough is known about the chemistry of the material, it may be possible to identify specific chemical reactions, such as hydrolysis and photo-oxidation. Limitations will always exist in this knowledge, but identifying all the mechanisms possible will reduce the chance for error in the ultimate service life prediction. Determinations made in this step lay the groundwork for designing preliminary accelerated aging tests and ultimately lead to better correlation from these accelerated methods.

Pre-testing

Pre-testing is the next step in service life prediction. These tests demonstrate that rapid changes in properties of the material can, in fact, be induced by exposure to extreme levels of the degradation factors. These changes support (or rule out) the determinations made during the problem-solving steps. Information from pre-tests may include property changes that are likely to be used as degradation indicators, the order of importance of these factors, mechanisms by which properties change, and the intensities of degradation factors needed to induce rapid property changes. Of course, the intensities of these factors should never go beyond the extremes that your material will experience in service, which are typically determined during the problem definition phase. Refer to Fig. 4.1, "Testing Myths and Mistakes Exposed," on page 61.

Testing

The purposes of this step are to:

1. Design and perform new or improved predictive, accelerated service life tests
2. Design and perform in-service tests that serve as a baseline for comparison
3. Measure the rates at which properties change in service
4. Compare measured changes that occur during the in-service methods to the accelerated tests

Long-term in-service tests should emphasize the important degradation factors for the material. These may include actual in-service tests of the complete system or exposure of selected materials at benchmark outdoor weathering sites. It is essential to design the tests so that all important factors are considered. The intensity or magnitude of the degradation factors should be measured during the test.

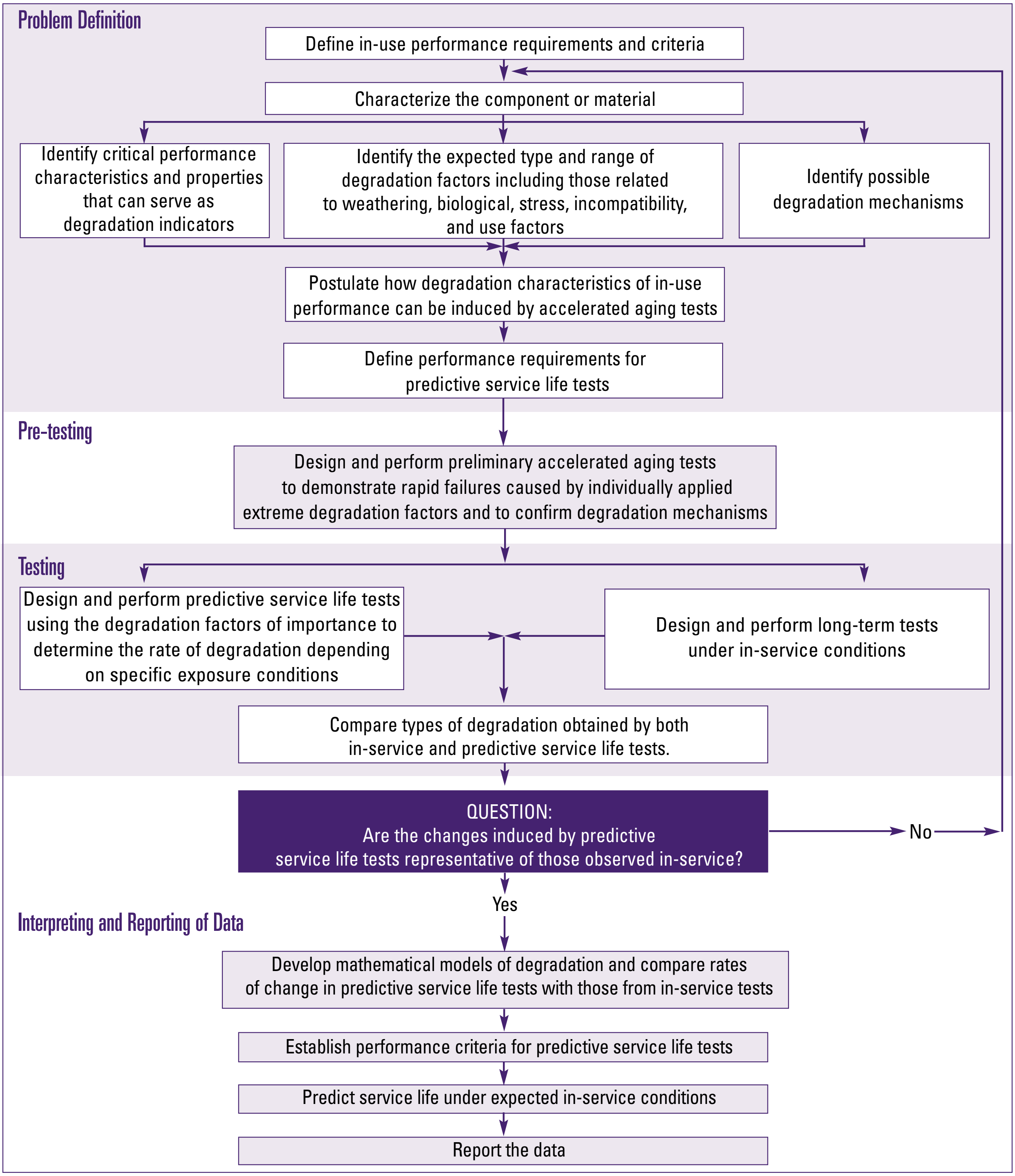
The goal of accelerated aging tests is to provide a relatively rapid means of measuring the rate of property changes typical of those that occur in the long-term tests. These tests are commonly designed from information obtained during the pre-tests. The intensity levels of the degradation factors during accelerated aging tests will normally be at or near worst case conditions as in the end use environment. These levels are below those used during pre-testing. As with the long-term tests, the degradation factors should be measured. The material properties deemed important during the problem definition phase should be evaluated using standard, qualitative methods.

If the initial accelerated methods do not induce mechanisms representative of in-service degradation, or if mechanisms *are* induced that are not seen in the long-term tests, the accelerated tests should be altered after reassessing the information obtained during the problem definition and pre-testing analyses.

Unfortunately, altering the levels of the degradation factors in the accelerated tests may not directly impact the property change of the material as expected. Even if proper analysis has been done in the problem definition step, changing the level of a particular degradation factor may or may not affect the property change. The synergy of degradation factors should always be considered when developing these accelerated tests. This leads to more difficult interpretation of the results of the tests, especially when comparing the results of the long-term tests with the results of the accelerated tests.

A graphical representation of this step-by-step process is shown on the following page.

Setting up a Weathering Test



Adapted from ASTM E632

Testing Examples

Rather than speaking generically about test design, it may be easier to understand how to properly set up a weathering test by using a few specific examples. Of course, there are so many different types of materials and applications that we cannot begin to cover all of them. Also, the types of decisions or problems that might be solved by a weathering test program are infinite. We will use an automotive instrument panel, a dyed cotton used for t-shirts, and an exterior house paint, which represent not only different types of materials but also different applications. Real-world applications will ultimately be much more complex, but this is a good introduction to weathering test development.

The Automotive Instrument Panel

Following the steps mentioned previously, we must first define the objective and/or problem to be solved. In this case, we will assume that our company is an approved supplier to an automotive manufacturer. For this test, we are going to attempt the following objectives:

1. Validate a material for use in a new car design
2. Use an accelerated aging test that we hope can quickly predict the in-service performance of the material
3. Determine correlation between long-term tests and accelerated aging tests

Ci5000
Weather-Ometer

Our material contains a new plasticizer that will have been pre-tested, and indications show that this new formulation will not volatize out of the plastic skin of the instrument panel after exposure.

Because this is an automotive application, it is very likely that there is a defined test that must be performed to be able to sell our instrument panel to our automotive manufacturer. This may include a specified duration of exposure following an automotive interior cycle using a Ci5000 Weather-Ometer.® Because we are interested in an accelerated test that matches the in-service environment, we may also consider a component test in a SolarClimatic 2000™ or place our IP in an actual vehicle and perform an accelerated test using a full-scale environmental chamber with a metal halide lighting system. For our long-term baseline test, we would consider using a device such as the IP/DP Box® in a desert environment.

SolarClimatic 2000

IP/DP Box

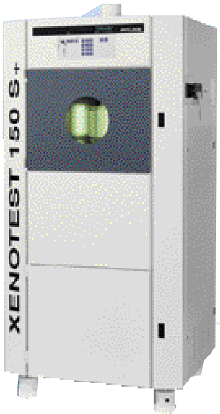
Ci3000F
Fade-Ometer®

Our criteria for evaluation would include color, gloss, and physical properties, such as cracking, blistering, etc. We would follow our recognized specification to properly measure these criteria, which may include both instrumental and visual assessments. We could examine the glass covering the IP/DP Box® and the windshield of the vehicle in our environmental chamber to examine plasticizer migration. For all of these evaluations, we would perform measurements initially, at specified intervals of exposure, and at the end of our exposure testing. Whether we perform the tests ourselves or send our specimens to an independent weathering laboratory, we will measure the degradation factors and compare the levels of these factors in each test.

After testing and evaluation, we would examine our results across all methods of exposure. We would report the data for all exposures and evaluations in accordance with the test specifications required. We should be able to make a determination of our first objective after all testing is complete. Using recognized statistical methods, we could determine the correlation of the accelerated tests to the long-term tests, satisfying our second objective. Results of this correlation comparison will tell us whether or not we have met objective number three, or if further testing will be required, altering some of the levels of the degradation factors.

Dyed Cotton Material

The primary objective is to determine the color stability of the dye after exposure. This property, sometimes referred to as colorfastness, is going to be most affected by radiation. While other degradation factors may exist in-service, our pre-testing has determined that factors such as moisture and temperature are less important than radiant exposure.



XENOTEST 150 S+

All exposure testing will most likely follow AATCC Test Method 16, *Colourfastness to Light: General Method* or ISO 105-B02, *Colourfastness of Textiles*. This would include exposure in instruments such as the Atlas XENOTEST Alpha, XENOTEST® 150 S+, or Ci3000-series Weather-Ometer®. Long-term, baseline tests, as well as the accelerated methods used, will follow one of the options specified in these methods. Our performance criteria will be color stability, so we will perform visual and/or instrumental color evaluations using prescribed methods from AATCC or ISO. Duration of exposure, measurement interval, and correlation determination will again be analyzed using industry specifications and recognized statistical techniques.

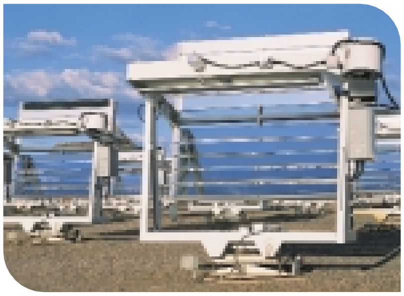
There are several tests that may need to be performed for washing, dimensional stability, or color transfer, but these evaluations fall outside this specific objective, not to mention the context of this manual.

XENOTEST Alpha

Exterior House Paint

Our objectives for this test may be to determine the viability of using our house paint on several different wood substrates. Our primary properties of concern would be color, gloss, physical effects that will be evaluated visually, mildew growth, and chalking. Because this application is subject to all degradation factors inherent of outdoor weathering, there are several weathering tests we can use to maximize these stresses. For example, we would want to expose our material to the benchmark subtropical and desert climates to examine how moisture (or a lack thereof) plays a role in the change in properties. Our outdoor exposure orientation would be 45° facing the equator. We might also choose to expose specimens vertically, which most closely matches the end use. By doing this, we could evaluate the acceleration obtained with the 45° orientation. Additionally, we would expose specimens at 90° facing north to evaluate the paint's resistance to mildew growth.

EMMAQUA



We recognize that the outdoor exposures would be long-term and an accelerated test would be useful. We could choose from natural accelerated exposures, such as EMMAQUA®, or xenon arc instruments such as a XENOTEST® Beta or Ci4000 Weather-Ometer®, using standard test cycles. For our pre-testing, we may use a SUNTEST XLS+ or a fluorescent UV testing device such as the Atlas UV2000.

XENOTEST Beta

Proper specimen preparation will have a great impact on the results we get from our exposure. We want to ensure that our surfaces have been prepared in a way similar to what exists in the end-use application. Thickness of the paint may be an important variable we would want to test, so we might apply our paint at a variety of thicknesses on each substrate and develop a full factorial matrix that addresses these variables. Because our wood substrate introduces an uncontrolled variable, we would want to submit several replicate test specimens and examine the variability between substrates, thickness ranges, exposure conditions, etc.

As always, our evaluation and statistical techniques will be performed in accordance with industry standards, using pictorial references for our visual assessments.

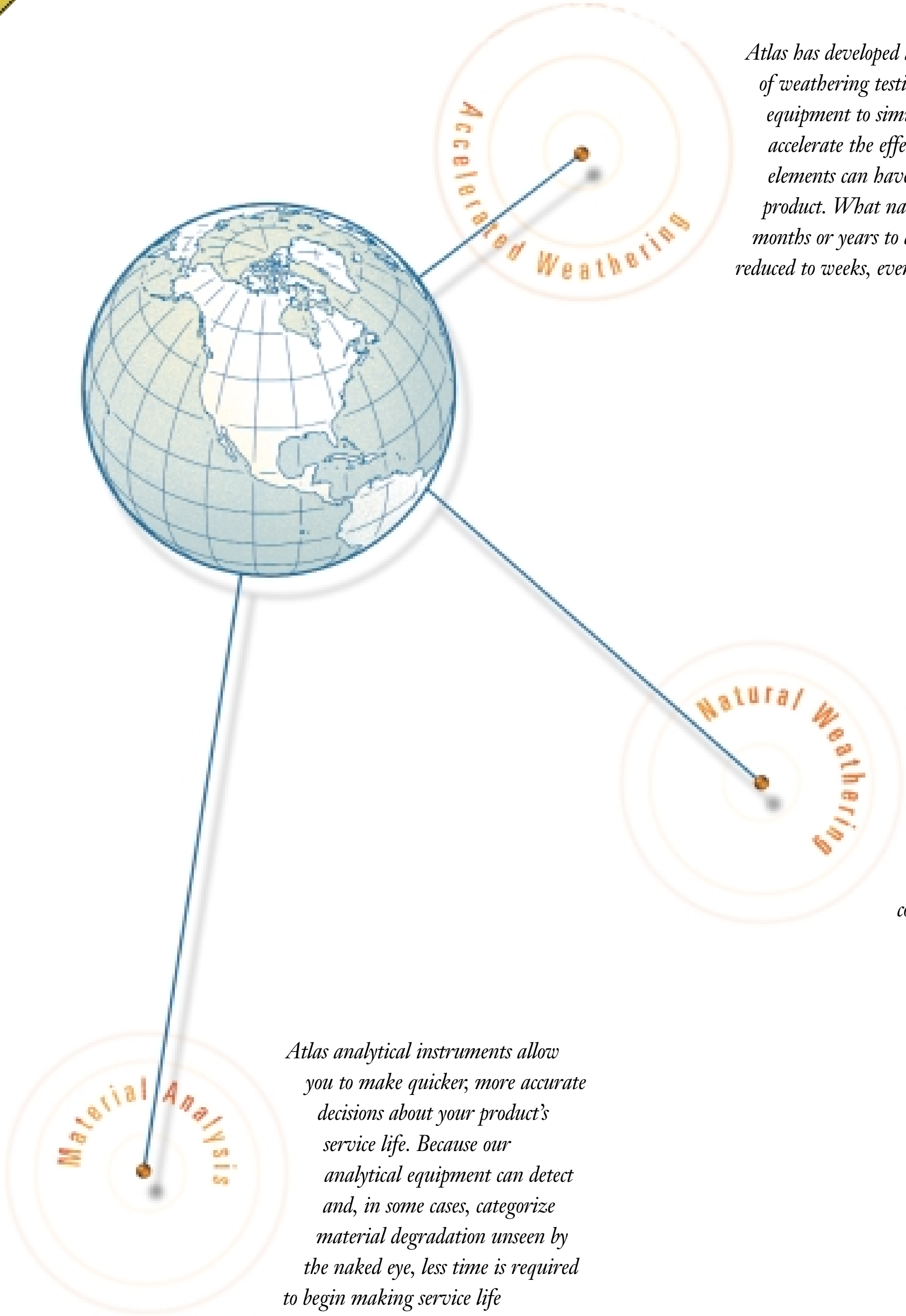
SUNTEST XLS+

Ci4000 Weather-Ometer

UV2000

Solutions

Solutions



Atlas has developed a variety of weathering testing equipment to simulate and accelerate the effects the elements can have on your product. What nature takes months or years to do can be reduced to weeks, even days.

No accelerated weathering program is complete without the confirmation from and correlation to natural weathering. Natural weathering services from Atlas provide the data you need to ensure your product is covered against costly liability issues.

Atlas analytical instruments allow you to make quicker, more accurate decisions about your product's service life. Because our analytical equipment can detect and, in some cases, categorize material degradation unseen by the naked eye, less time is required to begin making service life predictions.

The Network of Weathering

Many companies today have global operations, with their products being sold around the world. In addition, joint ventures and mergers have created intercontinental links that demand global testing methods and strategies. This means that providers of testing solutions and services need to provide tools that extend across the entire material process cycle — from research on raw materials, the design process, and the final product.

Atlas' network of weathering meets this challenge with material testing equipment and solar simulation systems for component and product testing — in other words, comprehensive testing solutions.

Weathering services are the heart of this network. They are the foundation for all subsequent laboratory testing and test equipment. Laboratory weathering instruments and solar simulation systems should provide results that correlate to natural weathering. The only way to confirm this correlation is to conduct outdoor exposures.

In regard to today's speed of development cycles, there is no question that both outdoor testing and laboratory testing must be used for reliable results. One method cannot be used without the other. Outdoor testing is the criterion, and laboratory testing gives the necessary acceleration and reproducibility. One of the main functions of the network of weathering is to strengthen and further develop this essential relationship.

Measuring devices are required for two reasons. The first is to verify that the specified requirements are achieved with the given tolerances. The second, and probably most important, is to clearly identify the differences between tests performed on material, components, and complete products. Data acquisition and detailed analysis of the relevant exposure conditions are essential for the evaluation and comparison of test results.

Atlas is involved in the working committees of many standards organizations, giving expertise and guidance for the interpretation and application of standards. Furthermore, Atlas offers consultation for the selection of adequate tools and services to fulfill standards, company specifications, and the development and/or improvement of new testing technologies and specifications. This standardization avoids both subjective evaluations and the difficulties in reproducibility.

Nobody can predict with 100% confidence the service life of any material to the environment, but using the Atlas network of weathering will get us all closer to the answer.

Services Offered

Atlas Weathering Services Group (AWSG) provides the widest range of climatic and environmental conditions for material durability tests. All outdoor testing methods mentioned in this manual are available from AWSG, and their laboratories are accredited following the latest standards of ISO/IEC. Their indoor exposure laboratories offer artificial accelerated weathering tests and a variety of other environmental test programs, all designed to accurately simulate true end-use conditions. For complete testing programs, AWSG also provides the evaluations listed below. All evaluation services are included in the scope of AWSG's accreditation.

Instrumental color measurements — AWSG uses benchtop and portable color measurement instruments, including all common color scales, geometries, indices, illuminants, and color change statistics.

Instrumental gloss measurements — All common angles of measurement (20,° 60,° 75,° and 85°) are available with a variety of portable and benchtop units.

Distinctness-of-image (DOI) — Defined as the sharpness with which object outlines are reflected by a surface, this measurement is predominantly used by automotive coatings manufacturers.

Visual assessment — A wide variety of visual evaluations is available for rating both physical and appearance degradation phenomena on specimens associated with the weathering process. Whenever possible, these assessments are performed using recognized industry standards and pictorial references.

Other visual evaluations — Chalking assessment, adhesion tests, edge penetration for glass laminates, etc.

Spectrophotometry — Absolute or relative spectral measurements as a function of incident angle are available that meet or exceed the requirements of primary spectrophotometric test standards. Spectral measurements can be made ranging from 250 to 2500 nm. Emittance measurements can be performed, which measure the photometric characteristics in the far infrared.

Other optical property measurements — Haze, total transmittance, clarity, and window energy analysis calculations.

Radiometer calibration — AWSG has a solar radiometer outdoor calibration service directly traceable to the World Radiometric Reference (WRR) and to the National Institute of Standards and Technology (NIST).

Lamp and Radiometer Calibration — Factory calibration of lamps and radiometers, whichever is needed to properly calibrate the light measuring/monitoring system of your water-cooled or air-cooled xenon arc instrument.

Technical Services — A comprehensive range of services are offered, from Preventative Maintenance Contracts to arrangements for the provision of routine on-site calibration and instrument preparation services.

XenoCal

Because accelerated weathering instruments have become more accurate, repeatable, and reproducible, there is a need to better understand the actual irradiance at the sample plane. While this monitoring is crucial, it is also very important for today's quality needs to have proper calibration of the irradiance measured at the sample surface. For calibration applications, it is preferred to have a device that is not connected to the apparatus in any way. The device itself also must be calibrated and have traceability to internationally recognized standards. The XenoCal is the answer to this need in xenon arc instruments.

The sensor is installed so that its measurement surface is in the specimen plane. The measured values are transmitted to a PC. Using the associated XenoSoft computer software, the data can be analyzed providing the user with actual irradiance, its time slope, and radiant exposure.

XenoCal and XenoSoft

Independent measurement of irradiance and radiant exposure at the sample plane.

KHS Custom-made Systems

Solarsimulation Systems

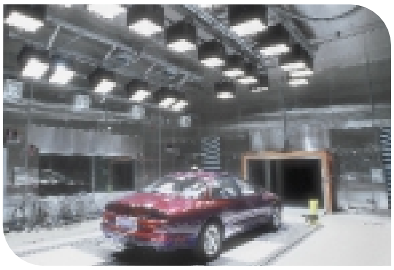
KHS SolarConstant systems provide effective simulation of solar radiation to meet the testing needs of the automotive industry. These systems are designed to meet the requirement of quantitatively (irradiance) and qualitatively (spectral distribution and uniformity) duplicating the characteristics of natural global radiation. With SolarConstant systems installed worldwide meeting the testing requirements of the automotive and many other industries, KHS has the experience to help you identify the parameters that play an important role in the design of an effective solar simulation system.

A critical part in the development of any solution for solar simulation systems is the detailed knowledge of the application and the related objectives. Consequently, interaction between KHS and their customers is essential for system design. This close cooperation to accurately define the test application assures that the final design of the system will satisfy test objectives. KHS does individual, tailor-made consulting on the problem, acquiring specifications and investigating alternative solutions and techniques.

KHS also provides systems specifically designed to comply with established test methods, such as **DIN 75 220,** *Aging of Automotive Components in Solar Simulation Units*, Society of Automotive Engineers (SAE) methods, MIL STD 810, EPA, and others. As leaders in the solar simulation field, KHS often acts as a consultant to standards organizations and specifying bodies. KHS offers guidance and support to assist with test method and specification development according to test objectives.

Some test specifications call for radiation within spectral ranges different from those defined for full-spectrum “global” radiation, such as concentrated ultraviolet or infrared radiation systems. KHS has experience with many types of power supplies and lamp types and can develop, design, and fabricate appropriate systems to meet your requirements.

The basic components of the SolarConstant systems are the Radiation Source, the Power Supply and the Control System.



SolarConstant in a solar morning configuration

The Radiation Source – A special metal halide (MHG) lamp is used as the radiation source. In combination with special glass filters, MHG lamp systems provide a spectral distribution very close to natural sunlight. Filters with different characteristics are available for applications other than the accelerated aging of materials test. The combination of lamp, reflector, and filter, all part of the enclosure, offers high irradiance efficiency and a superior spatial uniformity critical for component and vehicle testing.

The Power Supply – The electric power supply or EPS-Modul drives the lamp with square-wave current. This reduces the modulation of the radiation to less than ±1%, controls the intensity, and offers a stabilized power output even when incoming power varies. In addition, it provides the lamp optimal operation conditions, which results in extended MHG lamp life.

SolarConstant in a solar noon configuration

Control System – To allow the SolarConstant system to effectively simulate various natural solar conditions, a mechanical positioning system is used. This enables motorized movement of the solar array within all axes for easy adaptation to various test configurations or to simulate natural solar day or seasonal solar cycles. The control of the positioning can be manual pushbutton or integrated into the PC based SolarSoft system control program. SolarSoft provides automated control of radiation, along with effective simulation of various sun positions in the sky. Positioning systems are often unique to the application and test facility. KHS will work with you to define the SolarConstant mounting system that will work best for your application.

SolarConstant in a solar evening configuration

KHS SolarConstant systems are custom-made to meet your testing objectives. They are modular in nature and offer a large variety of configurations allowing for system design flexibility. With the use of various size Radiation Units, EPS-Modules, the Radiation Unit mounting system, and the flexibility of SolarSoft, KHS will design a cost-effective solution to fulfill your solar simulation requirements.

VIEEW™—Video Image Enhanced Evaluation of Weathering

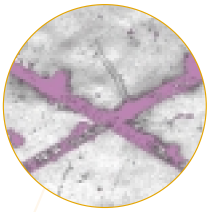
The human eye, coupled with the subjective judgment of a material inspector, has been used for visual evaluations of surface degradation due to weathering. Where visual perception is lacking in acuity, or conscious judgment is incapable of quantifying a large number of physical surface defects, pictorial references are employed for general comparison to allow a classification of the severity of a sample's defects. While this methodology has sufficed for many years, revolutionary advances in optical imaging and image processing/analysis technology have spawned precision tools for minimizing subjective, human influences and for automating inspection procedures.

The VIEEW Digital Image Analyzer, developed by Atlas Electric Devices Company, is the leading-edge integration of these technological advances. It is capable of capturing digital images of samples under various lighting schemes optimized for the sample surface, of digitally processing the images to highlight and enhance surface defects, and of measuring and counting defects so that each sample is defined by a comprehensive statistical profile. This process also may be applied to graded reference samples and stored on disk, ultimately allowing a classification of test samples by automatic, statistical comparison to the reference data. Thus the basic, historical evaluation method is preserved but is automatically performed by precision optics and special software at the press of a button.

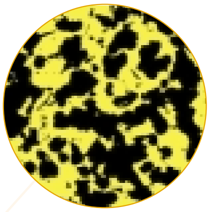
VIEEW provides a new and more accurate method for classifying samples according to the nature and severity of the surface degradation they incur. The instrument reliably determines quantitative values to define such degradation over a broader and more sophisticated range of deterioration mechanisms than have been possible with visual techniques. After the desired analyses have been performed, the important characteristics of each sample are resolved to a data set that can be numerically compared to other samples or to the data of reference samples or pictorial standards that have been captured and analyzed under the same conditions. Samples may then be graded or grouped according to the severity level with which they conform. Digital images and analysis data are stored in a custom image database and recorded on CD-ROM for long-term archiving. Custom paper reports may be generated using macro-enabled software.

VIEEW — Video Image Enhanced Evaluation of Weathering

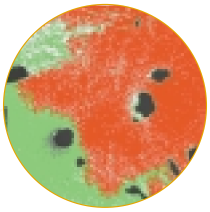
Typical defects that can be detected and evaluated



Scribe Corrosion



Stone Chipping: Clear Coat Layer

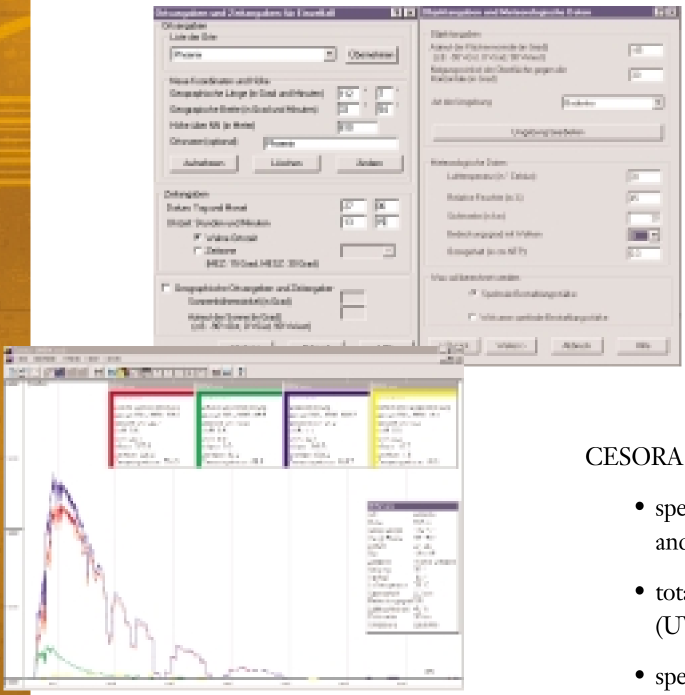


Stone Chipping: Below Clear Coat Layer

Filiform Corrosion

CESORA (Calculation of Effective Solar Radiation)

CESORA is a versatile calculation program developed in cooperation between Professor Dr. G. Manier, TH Darmstadt and Atlas Material Testing Technology.



Sample CESORA Screens

CESORA calculates the solar radiation on the earth's surface depending on the geographic location, the time of day, and the time of year. The result is also a function of several meteorological parameters, such as cloud cover, air temperature, relativehumidity, visibility, etc. The calculated solar spectrums can be evaluated with a number of action functions for biological objects and organic substances. CESORA offers a variety of applications. They extend from material testing (estimation of quality changes under the impact of solar radiation), the automotive industry (calculation of the irradiance at various parts of the car body and interiors), medicine (calculation of the erythema generating irradiance), and applications in agriculture and the building industry.

CESORA calculations include:

- spectral irradiance of direct solar radiation, diffused solar radiation, and radiation reflected by the ground for 200 – 3980 nm
- total irradiance as well as irradiance in specific wavelength regions (UV, VIS, and IR)
- spectral irradiance and irradiance in the UV, VIS, and IR after solar radiation has passed through filters (such as window glass of different qualities)
- effective irradiance for determined or user-defined action spectrums

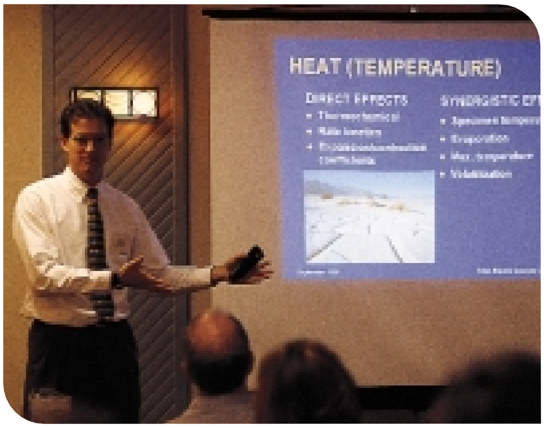
Client Education Services

Atlas offers several types of educational events to support the training needs of our customers.

The Fundamentals of Weathering is a basic, one-day seminar offered at various locations around the world that emphasizes lightfastness and weathering durability testing techniques. These techniques include natural and accelerated outdoor exposure testing as well as laboratory accelerated methods and instruments.

The seminar introduces the basics of how various factors of weather and climate, such as solar radiation, heat, and moisture, may affect materials and how to test the resistance of a formulation or product to them. Special attention is given to the testing techniques of paints and protective coatings, automotive materials, architectural products, and molded plastic materials. Textile and fiber lightfastness and weatherability are also discussed.

The Fundamentals of Weathering II further examines how various factors of weathering and climate, such as solar radiation, temperature, and moisture may affect materials and how to test the resistance of a formulation or product to those factors. Measuring devices for light, temperature, and moisture are identified, along with some of the common errors associated with their use. The course examines the way advanced laboratory instruments control irradiance, temperature, and humidity. Visual and instrumental evaluation methods are discussed for both physical and appearance attributes. Information is provided about the VIEEW™ system and full-scale testing programs such as those used by KHS.



The Atlas School for Natural and Accelerated Weathering (ASNAW) is an advanced-level symposium that presents the theories and practices needed to achieve materials durability through the use of weathering test methods. Considerable time is devoted to promoting individual and group interaction between course instructors and course participants. A half-day tour of an AWSG weathering laboratory provides a hands-on look at sample handling, exposure orientations, data acquisition, and interpretation of test results.

Atlas also provides hands-on training programs that deal with maintenance, calibration, and operation of their Weather-Ometer® and XENOTEST® instruments. These courses are designed for equipment operators, quality assurance personnel, and laboratory technicians who operate xenon arc weathering instruments.

The Atlas Client Education Division will also bring any of these courses to your facility for in-house training. In this format, lectures and demonstrations can focus on the specific needs of your laboratory's weathering programs.

Client Education Services

Atlas offers several seminars in weathering testing, from beginning to advanced training. The seminars are offered in locations around the world or in your own laboratory.

Consultant Services

The educational programs Atlas has conducted over the years provide general knowledge of weathering theory and practices. These classes cannot resolve every issue you may have as you are developing your weathering test programs. Atlas' consulting services can help guide you through every step of the process — from selection of appropriate weathering exposures and instruments to the development of test cycles to suit your needs. Atlas can conduct exposures to determine the spectral sensitivity or activation spectrum. We can also help you coordinate the data collected during and after weathering tests to calculate correlation and acceleration statistics or service life prediction models. We will work closely with your materials experts to resolve weathering problems related to chemistry, compatibility, or processing.

Corporate History

Corporate History

Corporate History

History of Atlas Electric Devices Company

Back when Hollywood didn't exist and Chicago was the motion picture capital of the world, Atlas' main business was supplying high-intensity stage lighting, using a carbon arc light source. It became apparent to the users of this stage lighting that certain textile materials and garments worn by the actors faded after extended lengths of time. The Solar Determinator, developed around 1915, was an instrument developed as an outgrowth of the stage lighting business, and in 1919, the first Atlas Color Fade-Ometer® was introduced, which was a redesign of the earlier Solar Determinator unit.

In 1934, Atlas introduced the Sunshine Carbon Arc Weather-Ometer®, which remained the standard laboratory accelerated testing device for over 30 years. In 1954, Heraeus developed the first xenon arc weathering machine (the XENOTEST® 150). As additional light sources were adapted for weathering tests, the company developed more advanced instruments with vastly improved controls. Today's Ci-Series and XENOTEST-series Weather-Ometers® represent the latest technology in laboratory weathering systems.

Stage Lighting for the Motion Picture Industry

Color Fade-Ometer

Sunshine Carbon Arc Weather-Ometer

Ci-Series Weather-Ometer

1919 *Atlas develops the Fade-Ometer*

1931 *South Florida Test Service opens*

1934 *Atlas develops the Sunshine Carbon Arc Weather-Ometer*

1948 *DSET Laboratories opens*

History of Atlas Weathering Services Group

The Atlas Weathering Services Group (AWSG) consists of three main weathering test locations:

- Miami, Florida, where South Florida Test Service (SFTS) is located
- Phoenix, Arizona, home of DSET Laboratories
- Atlas Material Testing Technology (AMTT) in The Netherlands

The first documented outdoor weathering testing was performed by the ASTM D-1 Subcommittee near Atlantic City, New Jersey in the early 1900s. It was soon realized that the hot, humid subtropical environment of south Florida degraded paints quickly, and SFTS, which opened in 1931, became the first commercial exposure site to open in this area. DSET Laboratories was founded in 1948 in the hot, dry desert climate of central Arizona. Atlas Material Testing Technology opened in Lochem, The Netherlands, in 1982. In 1995, the merger of SFTS, DSET, and AMTT created the Atlas Weathering Services Group. With 20 affiliated sites around the globe, AWSG has become the largest network of independent outdoor weathering laboratories in the world.

AWSG in south Florida

is located approximately 33 km (20 miles) northwest of downtown Miami in an unpolluted, subtropical environment. This has long been the benchmark for outdoor weathering tests because of the high temperature, moisture, and total UV content.

AWSG in central Arizona

is located approximately 50 km (30 miles) north of metropolitan Phoenix in an unpolluted, desert environment. This climate is well suited for many material weathering tests because of the wide daily temperature fluctuations, low moisture, and high solar radiation.

1954 *The XENOTEST® 150 xenon arc weathering instrument is introduced*

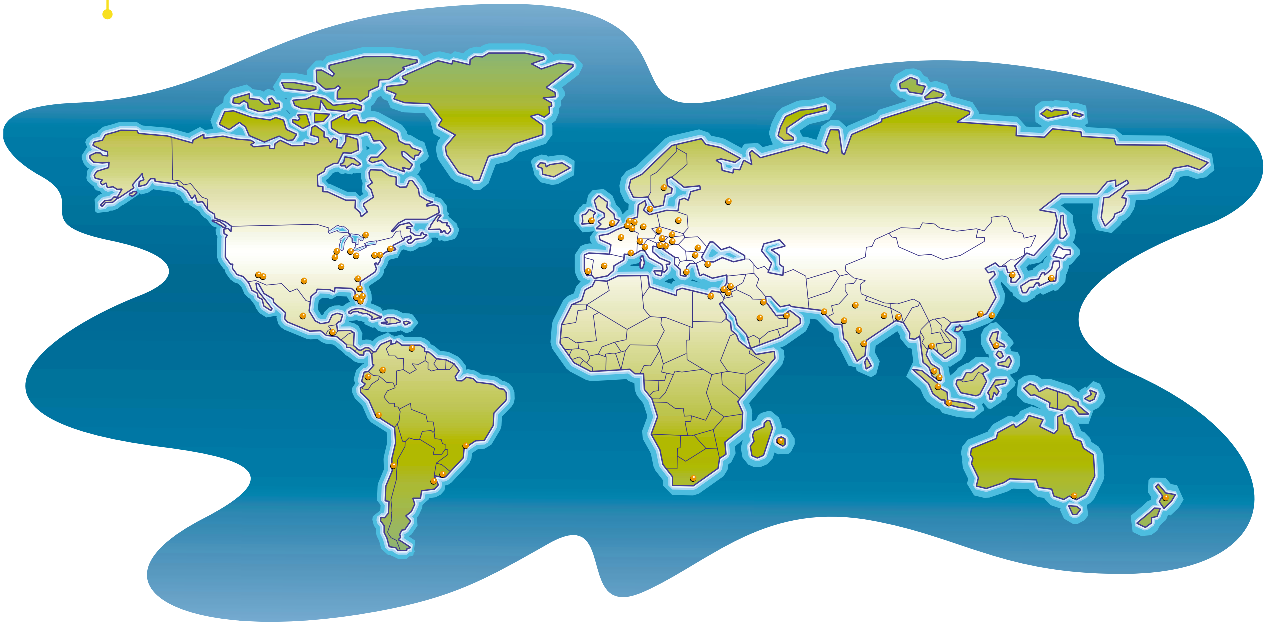
1960s *EMMA® (Equatorial Mount with Mirrors for Acceleration) is developed*

1974 *K.H. Steuernagel is founded*

1976 *Atlas Electric Devices Company acquires South Florida Test Service*

Atlas Material Testing Solutions Worldwide

Atlas' global network of service and support personnel ensures a clear understanding of international test standards, which is critical in today's global economy.



1978 *The Ci-Series of Weather-Ometers® is introduced*

1980 *KHS introduces the SolarModul series*

1982 *Atlas/SFTS BV European sales office opens in Lochem, The Netherlands*

1989-91 *KHS introduces the SolarConstant and SolarClimatic series*

1992 *Atlas acquires a 50% share of K.H. Steuernagel Lichttechnik GmbH*

1992 *Atlas/SFTS BV Weathering site opens*

History of K.H. Steuernagel

Since its foundation in 1974, K.H. Steuernagel Lichttechnik GmbH (KHS) has taken on the challenge of developing application-based solutions for technical lighting to meet the testing needs of the user. Similar to Atlas, KHS first started in the field of lighting systems for the motion picture and television industry. In 1977, the first lighting system for high-speed photography was installed at GM Opel in Rüsselsheim, Germany. This marked the first step toward KHS becoming a well-known specialist for technical lighting and radiation systems, serving the high-speed photography and solar simulation testing community.

History of Heraeus – XENOTEST

The roots of the first xenon lamp are linked to the traditional "Original Hanau Quarzlampengesellschaft," a German company owned by the former AEG and W.C. Heraeus GmbH, with its headquarters in Hanau, Germany. The cooperation between chemists and colorists from the German dyestuff manufacturer Cassella in Frankfurt and physicists of Original Hanau led to the development of the first xenon exposure device in 1954, the traditional XENOTEST® 150 System Cassella Equipment, using an air-cooled lamp. This was the basis for development of the textile standard ISO 105-B02, *Colourfastness to Artificial Light — Xenon Arc Fading Test.*

Original Hanau eventually became a division of the W.C. Heraeus Group in Hanau, and xenon arc testing equipment became the leading technology in Europe to test light and weatherfastness of materials. The Heraeus product division manufactured the XENOTEST and later the SUNTEST tabletop exposure systems before the acquisition by Atlas in 1995.

The first xenon exposure instrument, the XENOTEST 150, was developed in 1954.

1995 *Atlas acquires DSET Laboratories, creating Atlas Weathering Services Group (AWSG)*

1996 *KHS opens US Sales Office, Atlas/SFTS BV changes name to Atlas Material Testing Technology*

1995 *Atlas acquires the XENOTEST product line from Heraeus*

2000 *The Atlas Network of Weathering concept is adopted*

Appendices

Appendices

Appendix A – Terminology and Definitions

The following is not intended to be an all-inclusive list of terms. It is a basic glossary that will aid in understanding weathering and other related principles.

1. Solar Radiation

Air Mass	The ratio of the optical thickness of the atmosphere through which beam radiation passes to the optical thickness if the sun were at the zenith. Thus, at sea level, AM1 when the sun is at the zenith, and AM2 for a zenith angle Φz, of 60°. For zenith angles from 0° to 70° at sea level, $m = (\cos\Phi z)^{-1}$ For higher zenith angles, the effect of the earth's curvature becomes significant and must be taken into account.
Albedo	The ratio of the amount of radiation reflected by a surface to the amount incident upon it.
Azimuth Angle	An angle of a plane to the horizon measured clockwise to the object.
Collimated Beam	A light beam in which all rays are parallel.
Emissive Power or Radiant Self Exitance, W/m^2	The rate at which radiant energy leaves a surface per unit area, by emission only.
Intensity	Luminous or radiant flux radiated by a source.
Irradiance, Infrared	Radiation per unit area for which the wavelengths of the monochromatic components are greater than those for visible radiation, and less than about 1 mm. Note: The limits of the spectral range of infrared radiation may vary according to the user. Committee E-2.1.2 of the CIE distinguishes in the spectral range between 780 nm and 1 mm: IR-A 780 to 1400 nm, IR-B 1.4 to 3 µm, IR-C 3 µm to 1 mm.
Irradiance, Ultraviolet	Radiation per unit area for which the wavelengths of the monochromatic components are shorter than those for visible radiation. Note: The limits of the spectral range of ultraviolet radiation may vary according to the user. Committee E-2.1.2 of the CIE distinguishes in the spectral range between 100 and 400 nm: UVA 315 to 400 nm, UVB 280 to 315 nm, UVC 100 to 280 nm.
Irradiance, Visible	Any radiation per unit area capable of causing a visual sensation. Note: The limits of the spectral range of visible radiation may vary according to the user. The lower limit is generally taken between 380 and 400 nm and the upper limit between 700 and 780 nm.
Irradiance	The rate at which radiant energy is incident on a surface per unit area (W/m^2).
Luminous Flux	A measure of the visibility of brightness-producing capacity of radiant energy consisting in the ratio of photometric quantity to corresponding radiometric quantity in standard units (lumens per watt).

Light	The part of solar radiation that the human eye can detect (photopic vision, V_λ).
Pyranometer	An instrument for measuring total hemispherical solar beam + diffuse radiation, usually on a horizontal surface. If shaded from the beam radiation by a shade ring or disc, a pyranometer measures diffuse radiation.
Pyrheliometer	An instrument using a collimated detector for measuring solar radiation from the sun and from a small portion of the sky around the sun (i.e., beam radiation) at normal incidence.
Radiant Energy	Energy traveling through space in the form of photons or electromagnetic waves of various lengths.
Radiation, Actinic	The spectral region(s) of a light source responsible for the photodegradation of a particular material.
Radiation, Direct	The solar radiation received from the sun without having been scattered by the atmosphere. (Direct radiation is often referred to as beam radiation).
Radiation, Diffuse	The solar radiation received from the sun after its direction has been changed by scattering in the atmosphere. (Diffuse radiation is referred to in some meteorological literature as sky radiation or solar sky radiation; the definition used here will distinguish the diffuse solar radiation from radiation emitted by the atmosphere).
Radiation, Long Wave	Radiation originating from sources at temperatures near ordinary ambient temperatures and, thus, substantially all at wavelengths greater than 3µm. Long-wave radiation is emitted by the atmosphere or by any other body at ordinary temperatures.
Radiation, Solar or Short Wave	Radiation originating from the sun, in the wavelength range of 0.3 to 3.0µm. In the terminology used throughout this book, solar radiation includes both direct and diffuse components unless otherwise specified.
Radiation, Total Solar	The sum of the direct and the diffuse radiation on a surface. Total solar radiation is sometimes used to indicate quantities integrated over all wavelengths of the solar spectrum. (The most common measurement of solar radiation is total radiation on a horizontal surface, often referred to as global radiation).
Radiometer	A general class of instruments designed to detect and measure radiant energy.
Radiosity or Radiant Exitance, W/m^2	The rate at which radiant energy leaves a surface, per unit area, by combined emission, reflection, and transmission.
Solar Radiant Exposure	The incident energy per unit area on a surface, found by integration of irradiance over a specified time period (J/m^2).
Spectral Power Distribution	The variation of energy due to the source over the wavelength span of the emitted radiation.

Spectrum	Spatial arrangement of electromagnetic energy in order of wavelength.
Wavelength	The distance, measured along the line of propagation, between two points that are in phase on adjacent waves. Wavelength determines the color of light. Wavelengths of visible light range from about 400 to about 800 nm.
Zenith Angle	Φz The angle subtended by a vertical line to the zenith (i.e., the point directly overhead) and the line of sight to the sun.

2. Material Properties (Appearance Attributes)

Absorption	A process by which light or other electromagnetic radiation is converted into heat or other radiation when incident on or passing through material.
Absorption, Selective	The process of absorption which varies with wavelength.
Appearance	The aspect of visual experience by which differences are recognized. An example is the visual evaluation of exposed materials to identical unexposed materials. This is a criteria of visual inspection reports.
Artificial Illuminants	A synthetic light source of spectral distribution as close as possible to that of the natural illuminant (usually daylight) to be duplicated.
Attribute	Distinguishing characteristic of a sensation, perception or mode of appearance.
Bleaching	A phenomenon usually associated with the weathering of paint coatings in which some light-colored coatings become whiter in their appearance.
Blemish	An irregularity visible at the surface of a specimen and not attributed to the natural weathering process.
Bloom	The scattering of light in directions near the specular direction by a deposit or excretion on a specimen. Bloom can be removed by rubbing or polishing.
Brightness	*In optics and appearance measurements* -- the attribute of visual sensation by which an observer is aware of differences in luminance; *in pigments, dyes and colored products* -- the attribute of color that corresponds to its perceived difference from the color of dirt; *in metals* -- freedom of metallic surfaces from reflection haze and texture; *in lighting* -- the luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction; *in dyeing* -- the color quality, a decrease in which corresponds to the effect of the addition of a small quantity of neutral gray dye to the dyestuff, whereby a match cannot be made by adjusting the strength.
Chroma (Munsell)	Departure of color from gray having the same Munsell value, expressed on a scale extending from zero by steps of approximately equal visual importance, to a maximum of about 20. Corresponds to saturation.

Chromatic	Perceived as having a hue; not white, gray, or black.
Chromatic Attributes	Those attributes associated with the spectral distribution of light, specifically hue and saturation.
Chromaticity	That part of a color specification that does not involve luminance. Chromaticity is two dimensional and is given by pairs of numbers, such as dominant wavelength and purity.
CIE Chromaticity Coordinates	(Trichromatic coefficients or trilinear coordinates) The ratios of each of the tristimulus values of a color to the sum of the tristimulus values.
CIE, Commission Internationale de l'Eclairage	The main international organization concerned with problems of color and color measurement.
CIE Standard Sources	Standard sources for which the CIE in 1931 specified the spectral power distribution as follows: **Illuminant A:** a tungsten filament lamp operated at a color temperature of 2854K; it approximates a blackbody operating at that temperature. **Illuminate B:** an approximation of noon sunlight having a correlated color temperature of approximately 4870K. It is obtained by a combination of Illuminant A and a special filter. **Illuminate C:** an approximation of overcast daylight having a correlated color temperature of approximately 6770K. It is obtained by a combination of Source A and a special filter. In 1965, CIE recommended new illuminants to supplement Illuminants A, B, and C, the most important of which was D6500, with a correlated color temperature of 6500K. D65 is especially used in the evaluation of fluorescing or brightened materials where the spectral energy distributions of the light source in the 300-400 nm ultraviolet range contribute to color appearance.
CIE Tristimulus Values	The amounts of the three reference or matching stimuli required to give a match with the color stimulus considered, in a given trichromatic system. The symbols recommended for the tristimulus values are X, Y, Z in the CIE (1931) Standard Colorimetric System and X^{10}, Y^{10}, Z^{10} in the CIE (1964) Supplementary Colorimetric System.
Clarity	The characteristic of a transparent material whereby distinct images may be observed through it.
Color	The visual sensation produced by light of different wavelengths throughout the visible region of the spectrum. By such perception, an observer may distinguish between objects of the same size, shape, and structure.

Color Attribute	A three-dimensional characteristic of the appearance of an object, light source or aperture. One dimension usually defines the lightness, and the other two together define the chromaticity.
Color Difference	The magnitude and character of the difference between two object colors under specified conditions.
Colorimetry	The science of the quantitative measurement of color.
Color Matching	Procedure of adjusting a color mixture until all visually apparent differences from a target color are eliminated.
Color Measurement Scale	A system of specifying numerically the perceived attributes of color.
Color Temperature	The temperature at which the walls of a uniformly heated furnace must be maintained so that light from a small hole in it shall yield the chromacity of the source whose color temperature is to be specified.
Directionality of Surface	The extent to which the appearance of a surface, particularly its glossiness, changes with rotation of the surface in its own plane.
Distinctness-of-Image	The sharpness with which outlines are reflected by the surface gloss of an object.
Dominant Wavelength	The wavelength of spectrally pure energy that, if mixed with white light, would match a color.
Fading	A color change in a material that involves a weakening or lightening with time, usually as a result of exposure to light, weather, etc.
Fluorescence	The process by which electromagnetic radiation of one spectral region is absorbed and reradiated at other, usually longer, wavelengths.
Gloss	(1) Subjective term used to describe the relative amount and nature of mirror-like (specular) reflection or (2) numerical value for the amount of specular reflection relative to that of a standard surface under the same geometric conditions.
Gloss Measurement Scales	Systems of specifying numerically the perceived gloss of an object.
Gray Scale for Color Difference	A system for evaluating visually the color difference between two specimens by comparison with differences between two grays.
Haze	See “transmission haze” and “reflection haze.”
Hue	The attribute of color perception by means of which an object is judged to be red, yellow, green, blue, purple, etc.
Hunter L,a,b Scales	A uniform color scale devised by Hunter in 1958 for use on a color difference meter, based on Hering’s opponent color theory of vision.

Hunter L',a',b' Scales (Rh Scale)	A uniform color scale proposed by Hunter for use with dark colors and with transparent and metallic objects, which uses Y instead of Y1/2 as the lightness factor.
Hunter Rd,a,b Scales	A uniform opponent-color scale devised by Hunter in 1948, used for the analog scales of the color difference meter; the forerunner of the Hunter L,a,b scale.
ICI	International Commission on Illumination.
Illuminant	Incident luminous energy specified by its spectral distribution.
Lightfastness	The resistance to color change when exposed to a light source.
Lightness	Perception by which white objects are distinguished from gray, and light from dark-colored objects.
Luster (contrast gloss)	A highlight or glossiness perception in which shifty bright areas are seen on the surface of an object. Luster increases with increased ratio between light reflected in the specular direction and that reflected in diffuse directions adjacent to the specular direction.
Opacity	The degree to which a sheet or film obscures a pattern beneath it.
Reflection	Process by which incident light leaves a surface or medium from the side on which it is incident.
Reflection, Diffuse	Process by which incident light is redirected over a range of angles from the surface on which it is incident.
Reflection Haze	The scattering of reflected light in directions near that of specular reflection by a specimen having a glossy surface. Surface haze cannot be removed by rubbing or polishing.
Reflection, Specular	Process by which incident light is redirected at the specular angle, as from a mirror, without diffusion.
Saturation	The attribute of color perception that expresses the degree of departure from the gray of the same lightness.
Sheen	Specular gloss at a large angle of incidence for an otherwise matte specimen; the usual angle of measurement is 85°.
Translucency	The property of a material by which a major portion of the transmitted light undergoes scattering.
Transmission, Diffuse	Process by which incident light, while being transmitted through an object, is redirected, or scattered over a range of angles.

Transmission, Specular	Process by which incident light is transmitted through an object in a rectilinear, straight-through manner, without diffusion.
Transmission	Process by which incident light is transmitted through an object.
Transmission Haze	The scattering of light within or at the surface of a nearly clear specimen; responsible for cloudy appearance of specimen.
Transparency	The property of a material by which a major portion of the transmitted light undergoes scattering.
Turbidity	Loss of transparency due to diffusion caused by presence of particulate matter.
Value	The quality which tells us whether a color is light or dark.
Weighted Ordinate Method	A method of arriving at XYZ tristimulus values by multiplication of integrating XYZ values at equal wavelength intervals, of values of spectral reflectance (transmittance) by weighing factors that are products of spectral energy values and spectral tristimulus values, followed by addition of these products.
Whiteness	Perception of high lightness, high diffusion, and absence of hue.
Yellowness	The attribute by which an object color is judged to depart from a preferred white toward yellow.

3. Material Properties (Physical Attributes)

Adhesion	A material property associated with the molecular attraction exerted between the surfaces of bodies in contact, characterized by constant and firm attachment.
Blister	An enclosed elevated area (as in paint) resembling a blister on human skin.
Chalking	The formation on a pigmented coating of a friable powder evolved from the film itself, or just beneath the surface.
Checking	Fractures at the surface of coatings which do not expose the substrate.
Cracking	Fractures that expose previous coatings or substrates.
Crazing	A system of cracking or checking visible at the surface of materials.
Defect	Any irregularity occurring in or on a material as a result of degradation.
Delamination	A separation of distinct layers of materials in a laminate.
Elongation	The increase in gauge length of a tension test specimen, usually expressed as percentage of the original gauge length.

Flaking	Detachment of paint film from previous coating or substrate.
Hardness	The resistance of a material to deformation, particularly permanent deformation, indentation, or scratching.
Pinholes	Small, pore-like flaws in a material extending entirely through an applied film and which have the appearance of pin pricks when viewed by reflected light.
Scaling	See “flaking.”
Shear Strength	The maximum shear stress that a material is capable of sustaining. Shear strength is calculated from the maximum load during a shear or torsion test and is based on the original dimensions of the cross section of the specimen.
Spectrophotometry	Use of a spectrophotometer, an instrument for measuring the transmittance and reflectance of surfaces and media as a function of wavelength.
Surface Uniformity	Freedom of a surface from texture or markings.
Tensile Strength	The maximum tensile stress that a material is capable of sustaining. Tensile strength is calculated from the maximum load during a tension test carried to rupture and the original cross-sectional area of the specimen.
Texture	Structural quality of a surface determined by the interrelation of its elements.
Yield Strength	The stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. The deviation is expressed in terms of strain.

4. Weathering

Accelerated Outdoor Weathering	Outdoor weathering using the sun as the source of irradiance, and where the rate of deterioration is accelerated over that of the in-service exposure position, increasing one or more of the influencing parameters.
Ambient Air Temperature	The existing temperature of the air or of an object in thermal equilibrium with the surrounding atmosphere.
AATCC Blue Wool	Standard dyed-wool samples of seven grades, each step in the series representing a doubling of lightfastness. Used as a calibration and verification tool in AATCC Test Methods.
Black Box	A black-painted aluminum box with an open top where the flat test specimens to be exposed constitute the top surface of the box. The box is equipped with mounting strips to hold the test specimens firmly in place. The top surface of the box must be completely filled at all times; any blank spaces on the top surface must be occupied by black “dummy” panels to maintain correct operating conditions.

Black Box Under Glass	A glass-covered enclosure or cabinet of any convenient size. It shall be constructed of corrosion-resistant metal and be enclosed to prevent ambient air from circulating over the samples. Exterior non-glass surfaces shall be painted black. The interior shall remain unpainted.
Black Panel Thermometer	A temperature measuring device consisting of a metal panel, having a black coating that absorbs all wavelengths uniformly, with a thermally sensitive element firmly attached to the center of the exposed surface. The black panel thermometer is used to control a laboratory weathering device and to provide an estimate of the maximum temperature of samples exposed to a radiant energy source.
Black Standard Thermometer	A temperature measuring device consisting of an insulated black plastic which absorbs all wavelengths of radiation uniformly, with a thermally sensitive element firmly attached on the center of the unexposed surface. The black standard thermometer is used to control specimen temperature in air-cooled xenon arc devices.
Climatological types	Major regions of significantly different recurring weather patterns. In weathering, several distinct climatological types are used to evaluate the atmospheric durability of materials within any single climatological variation, at a specific geographic location.
Control	The term "control" has three current widespread uses: 1. A material of similar composition and construction to the test material used for comparison, exposed at the same time. 2. A portion of the material to be tested that is stored under conditions in which it is stable, and is used for comparison between exposed and original state. 3. A portion of the exposed specimen that is protected from light exposure by masking.
Corrosion	Chemical or electrochemical oxidation of a surface of metal which can result in loss of material or accumulation of deposits.
Dewpoint	The temperature at which moisture in the air begins to condense. The temperature below which condensation of water vapor begins to take place when the atmosphere is cooled.
Durability	In weathering, a measure of the retention of original condition and function of a material after exposure to a specified set of conditions.
Enclosed Carbon Arc	A light source in which an arc is produced across a pair of carbon rods by a high-energy electrical source, such that a high-intensity light is emitted. The carbons are enclosed in an inverted glass dome, which acts to prolong the life of the carbons, and to modify the spectral power distribution received by the specimens.

Exposure	The act of subjecting a test specimen to test conditions.
Exposure Angle	The tilt from horizontal of the test specimen or any other exposed material, or both.
Exposure, Backed	A technique of weathering in which test specimens being exposed are mounted onto a solid backing material, of sufficient strength to hold the specimen. When the specimen and the backing are in direct contact, the backing material must be of a type that will not contaminate the specimen. When two materials are intimately joined to form one composite, the materials below the top surface are not considered as a backing.
Exposure, Open-Backed	A technique of weathering in which the test specimens are exposed such that the portion of the specimen being evaluated is open to the effects of the weather on all sides.
Fluorescent Ultraviolet Lamp	A lamp in which the irradiance from a low-pressure mercury arc is transformed to a higher-wavelength UV by a phosphor. The spectral power distribution of a fluorescent lamp is determined by the emission spectrum of the phosphor and the UV transmittance of the glass tube.
Fresnel-Reflector System	Flat mirrors arranged in an array such that they reflect onto a target, the illuminated area of which simulates the size and shape of the flat mirror. Such an array simulates the ray-tracing of a parabolic trough of the same aperture angle.
ISO Blue Wool Reference Standard Materials	Standard dyed wool samples, each step in the series representing a doubling of lightfastness. Used to classify the colorfastness of textile materials.
Laminate	A composite material made by adhering two or more layers of the same or different materials.
Light	Electromagnetic radiation in a spectral range visible to the human eye (approximately 400-800 nm).
Masked Area	A portion of the exposed specimen that is protected from light exposure by covering with the exposure rack or other means.
Metal Halide Lamps	Lamps that emit radiation generated by a large number of different chemical components in the arc plasma. The most important components are the Rare Earths (i.e. Dysprosium, Thulium and Holmium) which form halides with the existing halogens. Metal Halide Lamps offer a close match to sunlight. They are an efficient light source with low infrared heating effects.
Nanometer	Unit of length equal to 10^{-9} m.

Open Flame Sunshine Carbon Arc	A light source in which an arc is produced across a pair of copper coated carbon rods filled with rare earth elements intended to produce a specific spectral power distribution. The carbons are open to the atmosphere and may be surrounded by a glass lantern arrangement, which acts to modify the spectral power distribution received by the specimens.
Photodegradation	Photochemically induced changes in the condition of the material.
Photodetectors	Devices for converting radiant or luminous flux into an electric current proportional to it.
Primary Standard	A standard whose calibration is determined by the measurement of parameters usually different from the parameter for which it will be used as a standard.
Reference Material	A material with known performance.
Reference Specimen	A portion of the reference material that is to be exposed.
Relative Humidity	The ratio of the actual pressure of existing water vapor to the maximum possible (saturation) pressure of water vapor in the atmosphere at the same temperature, expressed as a percentage.
Sample	A group of units or portion of material taken from a larger collection of units or quantity of material that serves to provide information that can be used as a basis for action on the larger quantity.
Secondary Standards	All standards other than primary standards.
Solarization	Change in transmittance, reflectance, or absorptance property of a material, such as glass, as a result of exposure to sunlight or other light sources.
Standard Reference Material (SRM)	A weathering reference material having well documented weathering degradation properties that have been certified by a recognized standards agency or group and that are identical when exposed to identical test conditions.
Temperature, Dry-Bulb	The temperature of the ambient air; for example, the temperature that is measured by the dry-bulb thermometer of a psychrometer.
Temperature, Wet Bulb	The equilibrium temperature of a liquid vaporizing into a gas.
Test Specimen	A specific portion of the samples upon which the testing is to be performed.
Tilt Angle	The angle between the horizontal and the plane of the test fixture, glass frame, or sensory instrumentation.

Time-Of-Wetness	The total amount of time that a surface is wet. This is typically reported in hours.
Weathering Behind Glass	A technique of weathering in which the test specimens are exposed in a glass-covered frame constructed of wood, metal, or other satisfactory material that protects the specimen from the effects of rain and weather. The frame shall be open at the back or sides to allow ambient air to circulate over the specimens.
Weathering Reference Material	A reference material whose weathering degradation properties are well-documented and repeatable when exposed to identical test conditions. A WRM differs from an SRM in that its weathering history has not been certified by a recognized agency.
White Panel Temperature	White Panel Temperature is the temperature measured on a metal panel with a white low-heat conducting coating and a thermal sensitive element firmly attached to the center of the exposed surface.
White Standard Thermometer	The White Standard Thermometer measures the White Standard Temperature at the sample plane. The White Standard Temperature provides information on the surface temperature of white, low-heat conducting samples during exposure.
Visual Evaluation	The evaluation by an experienced observer of the visual interpretation of the properties of object or material evaluated.
Weathering, Direct	A technique of weathering in which the test specimens are exposed to all prevailing elements of the atmosphere.
Weathering, Natural	Outdoor exposure of materials to unconcentrated sunlight, the purpose of which is to assess the effects of environmental factors on various functional and decorative parameters of interest.
Xenon Arc	A light source produced by a high-intensity electrical current through a tube containing low pressure xenon gas. The spectral energy distribution of this light source is generated by the electrical current arcing through the xenon gas plasma between the electrodes, and is modified by filters.

Appendix B - Selected Basic Weathering Standards

1. Natural Weathering

Standard No.	Title
ISO 877	Plastics—Methods of Exposure to Direct Weathering, Indirect Weathering Using Glass-filtered Daylight, and to Intensified Weathering by Daylight Using Fresnel Mirrors
ISO 2810	Paints and Varnishes—Natural Weathering of Coatings—Exposure and Assessment
ISO 105-B03	Textiles—Tests for Colourfastness—Part B03: Colourfastness to Weathering: Outdoor Exposure
ASTM G7	Recommended Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials
ASTM G24	Standard Practice for Conducting Exposures to Daylight Filtered Through Glass
ASTM D4141	Standard Practice for Conducting Accelerated Outdoor Exposure Tests of Coatings
ASTM G90	Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight
ASTM D4364	Standard Practice for Performing Accelerated Outdoor Weathering of Plastic Materials Using Concentrated Natural Sunlight (EMMA®, EMMAQUA®, or EMMAQUA®– NTW)
ASTM D1435	Recommended Practice for Outdoor Weathering of Plastics
ASTM G147	Standard Practice for Conditioning and Handling of Nonmetallic Materials for Natural and Artificial Weathering Tests
AATCC TM16	Colourfastness to Light—General Method
AATCC TM111	Weather Resistance: Exposure to Natural Light and Weather Through Glass
SAE J576	Plastic Materials for Use in Optical Parts such as Lenses and Reflex Reflectors of Motor Vehicle Lighting Devices
SAE J951	Florida Exposure of Automotive Finishes
SAE J1961	Accelerated Exposure of Automotive Exterior Materials using a Solar Fresnel-Reflective Apparatus
SAE J1976	Outdoor Weathering of Exterior Materials
Ford BI 160-01	Florida and Arizona Outdoor Exposure Test

GM9163P	Field Weathering Tests
GM9538P	Weathering Exposure Tests for Interior Trims

2. Artificial

Standard No.	**Title**
ISO 4892-1,2,3,4	Plastics—Methods of Exposure to Laboratory Light Sources - **Part 1:** General guidance **Part 2:** Xenon Arc sources **Part 3:** Fluorescent UV-lamps **Part 4:** Open-flame Carbon Arc lamps
ISO 11341	Paints and varnishes —Artificial Weathering and Exposure to Artificial Radiation — Exposure to Filtered Xenon Arc Radiation
ISO 105-B02	Textiles —Tests for Colourfastness — Part B02: Colourfastness to Artificial Light: Xenon Arc Fading Lamp Test
ISO 105-B04 (B10)	Textiles —Tests for Colourfastness— Part B04: Colourfastness to Weathering: Xenon Arc
ISO 105-B06	Textiles —Tests for Colourfastness— Part B06: Colourfastness and Aging to Artificial Light at High Temperatures: Xenon Arc Fading Lamp Test
ISO 3917	Road Vehicles — Safety Glazing Materials—Test Methods for Resistance to Radiation, High Temperature, Humidity, Fire, and Simulated Weathering
ISO 9227	Corrosion Tests in Artificial Atmospheres — Salt Spray Tests
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus
ASTM G23	Practice for Operating Light-Exposure Apparatus (Carbon Arc Type) With and Without Water for Exposure of Nonmetallic Materials.
ASTM G26	Standard Practice for Operating Light–Exposure Apparatus (Xenon Arc Type) With and Without Water for Exposure of Nonmetallic Material
ASTM G53	Recommended Practice for Operating Light– and Water–Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials
ASTM G151	Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources
ASTM G152	Standard Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials

ASTM G153	Standard Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials
ASTM G154	Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials
ASTM G155	Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Nonmetallic Materials
AATCC TM16	Colourfastness to Light — General Method
AATCC TM169	Weather Resistance of Textiles—Xenon Lamp Exposure
AATCC TM177	Colourfastness to Light at High Temperature and Humidity
SAE J1885	Accelerated Exposure of Automotive Interior Trim Using a Controlled Irradiance Water-Cooled Xenon Arc Apparatus
SAE J1960	Accelerated Exposure of Automotive Exterior Materials Using a Controlled Irradiance Water-Cooled Xenon Arc Apparatus
SAE J2019	Accelerated Exposure of Automotive Exterior Materials Using a Controlled Irradiance Air-Cooled Xenon Arc Apparatus
SAE J2020	Accelerated Exposure of Automotive Exterior Materials Using a Fluorescent UV and Condensation Apparatus
SAE J2212	Accelerated Exposure of Automotive Interior Trim Components Using a Controlled Irradiance Air-Cooled Xenon Arc Apparatus
SAE J2334	Cosmetic Corrosion Lab Test
DIN 75 220	Ageing of Automotive Components in Solar Simulation Units
VDA 75 202	Testing the Colourfastness of Automotive Interior Materials with Xenon Arc Apparatus
VDA 621-429	Anstrichtechnische Prüfungen - Bewitterungsprüfung zur Farbtonbeständigkeit
VDA 621-430	Anstrichtechnische Prüfungen - Prüfung der Rißbeständigkeit von Klarlacken bei 2-Schicht-Metallic-Lackierungen
JASO M 346	Light Exposure Test Method by Xenon Arc Lamp for Automotive Interior Parts
JASO M J09	Corrosion Test Method for Automotive Materials

3. Miscellaneous

Standard No.	Title
ASTM E632	Developing Accelerated Tests to Aid Prediction of the Service Life of Building Components and Materials
ASTM E891	Tables for Terrestrial Direct Normal Solar Spectral Irradiance for Air Mass
ASTM G113	Standard Terminology Relating to Natural and Artificial Weathering Test of Nonmetallic Materials
ASTM G156	Standard Practice for Selecting and Characterizing Weathering Reference Materials Used to Monitor Consistency of Conditions in an Exposure Test

Appendix C - Primary Standards Organizations

ISO (International Organization for Standardization)

1, rue de Varembé
Case postale 56
CH-1211 Genève 20, Switzerland

www.iso.ch

+41 22 749 01 11 phone
+41 22 734 10 79 fax (Sales Dept.)

ANSI (American National Standards Institute)

11 West 42nd Street
New York, NY 10036 USA

www.ansi.org

(212) 642-4980 phone
(212) 302-1286 fax

ASTM (American Society for Testing and Materials)

100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

www.astm.org

(610) 832-9585 phone
(610) 832-9555 fax

AAMA (American Architectural Manufacturers Association)

1827 Walden Office Square, Suite 104
Schaumburg, IL 60173-4628

www.aamanet.org

(847) 303-5664 phone
(847) 303-5774 fax

AAMVA (American Association of Motor Vehicle Administrators)

4301 Wilson Blvd. Suite 400
Arlington, VA 22203

http://w4.pragmatix.com/aamva/

(703) 522-4200 phone
(703) 522-1553 fax

AATCC (American Association of Textile Chemists and Colorists)

P.O. Box 12215
Research Triangle Park, NC 27709

www.aatcc.org

(919) 549-8141 phone
(919) 549-8933 fax

AFNOR (Association Française de Normalisation)

92049 Paris la Défense
Cedex. France

www.afnor.fr/english/welcome.htm

+33 1 42 91 55 55 phone
+33 1 42 91 56 56 fax

BSI (British Standards Institute)

www.bsi.org.uk/bsi

+44 (0) 181 996 9000 phone
+44 (0) 181 996 7400 fax

CENELEC (European Committee for Electrotechnical Standardization)

www.cenelec.be/

CEN (European Committee for Standardization)

36, rue de Stassart
B-1050 Brussels

www.cenorm.be

+ 32 2 550 08 19 fax

CGSB (Canadian General Standards Board)

CGSB Sales Centre
Ottawa, Canada
K1A 1G6

http://w3.pwgsc.gc.ca/cgsb/

(819) 956-0425 phone
(819) 956-5644 fax

CSA (Canadian Standards Organization)

78 Rexdale Boulevard,
Rexdale (Toronto), Ontario, Canada
M9W 1R3

www.csa.ca

(416) 747-4000 phone
(416) 747-4149 fax

DIN (Deutsches Institut für Normung e. V.)

www.din.de/

ETSI (European Telecommunications Standard Institute)

www.etsi.fr/

IEC (International Standardization Institute)

www.iec.ch/

JASO (Japanese Automotive Standards Organization)

Japanese Society of Automotive Engineers
10-2 Goban-Cho, Chiyoda-ku
Tokyo 102, Japan
www.jsae.or.jp/US/index_e.html

JISC (Japanese Industrial Standards Committee)

Japanese Standards Association
1-24 Akasaka 4, Minato-ku
Tokyo 107, Japan
www.aist.go.jp/LJIS/e-index.html

NIST (National Institute of Standards and Technology)

100 Bureau Drive
Gaithersburg, MD 20899 USA
www.nist.gov

NSF International (National Sanitation Foundation)

PO Box 130140
3475 Plymouth Road
Ann Arbor, MI 48113 -0140, USA

www.nsf.org

(800) 699-9277 phone
(734) 930-9088 fax

SAE (Society of Automotive Engineers)

400 Commonwealth Drive
Warrendale, PA 15096-0001

www.sae.org

(412) 776-4970 phone
(412) 776-0790 fax

Additional Sources for Standards

NSSN (National Resource for Global Standards)

www.nssn.org

For a small fee, one can set up a user profile, and this organization tracks all pertinent standards selected. They also have an extensive document search engine that is useful and up to date. The site provides a way to purchase the standard. For “uncommon” standards organizations, the site refers you to Global Engineering Documents.

GLOBAL ENGINEERING DOCUMENTS

http://global.ihs.com

This organization provides standards developed by hundreds of international standards organizations. It has locations around the world. You can click on the appropriate location nearest you for the phone, fax, and address to order standards.

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A word about the Architect of the Guidebook

Matthew McGreer

Matthew McGreer has been involved with weathering or the degradation of materials for the last twelve years. Nine of those years were spent at DSET Laboratories in Phoenix, Arizona where Mr. McGreer gained most of his vast knowledge regarding weathering while serving as the Manager of Evaluation Services. While at DSET, Mr. McGreer served on various ASTM standards committees involving appearance, visual methods and lighting.

Currently as General Manager of Client Education at Atlas, Mr. McGreer develops and directs courses related to material degradation. His seminars range from the popular "Fundamentals of Weathering" held in various cities across the U.S., to "ASNAW," a twice a year symposium that brings together weathering leaders from industries found throughout the world. Mr. McGreer received a Bachelor of Science degree in Geology from the University of Nebraska.

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Weathering Testing Guidebook

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