



PRACTICAL GUIDE TO UV TESTING



MICOM LABORATORIES INC.

Founded in 1999, Micom Laboratories Inc. is an established third party independent laboratory offering products and material testing services. With a proven track record of helping customers succeed, we specialize in providing complete test services and expertise for today's complex offerings.

With years of specialized technology testing expertise, in-depth experience and absolute commitment to customer care, our team of experts does more than simply test your products. Micom Laboratories Inc. strives to deliver outstanding value to our diverse customer base.

Our philosophy is to provide the highest quality services at value-based costs.

Our measure of success is our long-term client partnerships.

Micom Laboratories Inc. is committed to providing rapid turn-around time, value based pricing, technical assistance, key account management and accurate timely reporting. We are partners with our clients to improve the quality of their products and brand image.

Using proven processes and quality procedures in its specialized lab, Micom Laboratories staff delivers the end results our customers need – products that meet all necessary requirements to ship in order to ship them around the globe. This frees them from costly and time-consuming testing and allows them to focus on their essential engineering and business issues.

Today Micom Laboratories has a 15 000 square feet test facility, in Montreal, Canada. We offer a wide range of test services all related to material and product testing.



If you have any questions about UV Testing and would like to speak to one of our material testing specialists, we invite you to [contact us](#) today at 1 (888) 996-4266. It will be our pleasure to answer your questions.



CHAPTER 1

ACCELERATED AGING

Accelerated aging is a broad type of testing that uses amplified adverse conditions to increase the rate of aging of materials and products. Amplified adverse conditions can be environmental in nature (such as sun, heat, cold, salted water, vibrations, etc.) or simulate accelerated wear and tear or a combination thereof. The goal is to estimate quickly the products and materials' expected service life or to understand unexpected field failures.

The process of accelerated aging of products and materials can be accomplished in various ways depending on the type of material or product being tested, the intended use as well as the ambient conditions present while using the material or product.

Among the most popular types of accelerated aging tests are:

- [UV testing](#)
- [Corrosion testing](#)
- Heat aging testing
- Temperature and humidity testing
- Thermal shock testing
- Functional cycling

When performing this type of testing it is important to have a good understanding of the product characteristics, the normal use conditions, what constitutes a foreseeable abuse and what is the product's life expectancy. To have a good assessment of the product's performance and be able to predict how it will fare in the future, we need to be careful not to expose a product to conditions that could cause abnormal aging processes to occur (i.e. avoiding supplying our sample with an activation energy for a specific aging reaction that would not occur naturally in real life conditions). Accelerated aging is as much a science as an art.

Field exposure can lead to many failure types such as:

- Discoloration (fading) and color change
- Cracking
- Corrosion
- Flaking
- Wear

Accelerated aging is often a combination of various environmental stresses such as UV exposure, corrosion, temperature and relative humidity variations as well as numerous pollutants (such as Ozone, NO_x, S_xO, etc.). Since these aging mechanisms will often compound themselves synergistically, we will also combine some test methods at our [Testing Lab](#). For example the [ASTM D5894](#), also known as Cyclic Salt Fog/UV Exposure of Painted Metal Test, combines cyclic corrosion and UV exposure in one test. The fact that applications can be so diverse, it is often impossible, even given today's technology, to simulate all aging parameters with all their intricacies at once. From a development standpoint it can also be better to simulate a limited amount of parameters at once so that each aging mechanism can be isolated and evaluated by itself.

REAL WORLD APPLICATION

Accelerated aging is just like cooking a turkey

You forgot the “In laws” are coming tonight for Thanksgiving. You have a 20 pounds frozen turkey in your hands, you look at the clock on the wall and realize you have 3 hours until dinner. While you would have let the turkey thaw overnight and would have left it in the oven for about 5 hours you now have to cook it on an “accelerated basis” to make up for your error. How about setting your oven at “self cleaning” and cook the turkey for some time at that temperature? Simply because you will end up with a charred turkey on the outside still frozen on the inside.

Accelerated aging, including corrosion and UV testing are just the same. If your aging process is too aggressive, you will get results that are just like that frozen turkey; not what you wanted. This is because you gave your material an activation energy that is not realistic compared to what it will experience in real life.



BASIC RULES

TEMPERATURE

There are basic rules to be followed in all aging testing procedures. With the exception of freeze-thaw cycles that assess the impact of phase changes, all aging processes increase as a function of the ambient temperature. This acceleration process is governed by **Arrhenius's law**:

$$k \text{ (rate of change)} = A \exp (-E/RT)$$

where E = activation energy

A = pre-exponential factor

T = absolute temperature

R = gas constant

In layman's terms; any chemical reaction will double its rate with each 10 °C increase. This is why corrosion and UV aging, for example, are both done at temperatures above room temperature. Conversely excessive temperature exposure is not recommended. Beyond a certain temperature point, high levels of activation energy will cause molecules in the tested material to respond and cause chemical reactions to take place that would not naturally occur even over long periods of time or extremely adverse conditions.

In addition in many accelerated aging processes, organic molecules experience asymptotic behavior (i.e. beyond a certain temperature there is no significant gain; only risk).

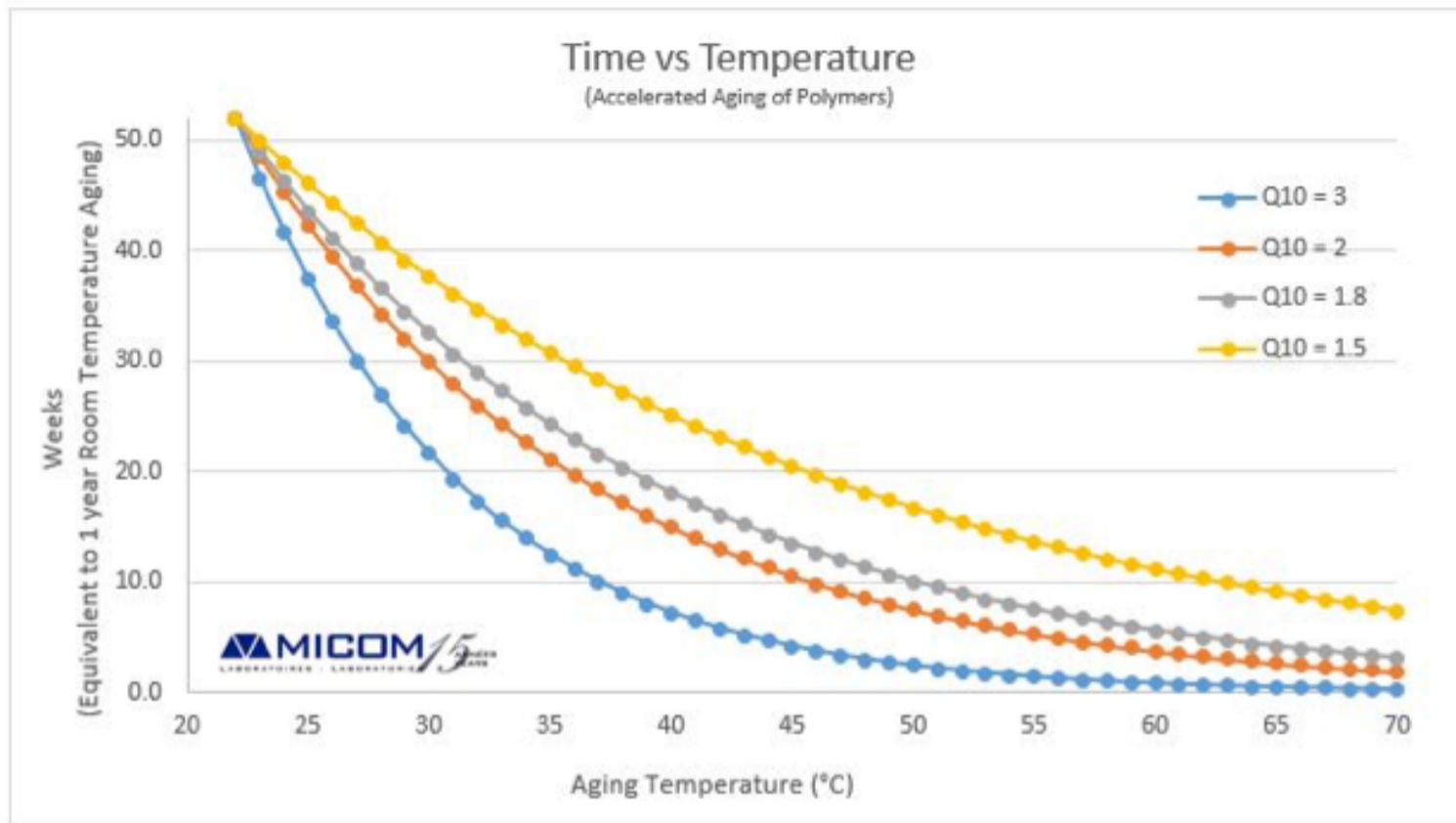


Figure #1a: Arrhenius's law – accelerated aging curves

Arrhenius's law is general in nature and it assumes the general case where the aging rate doubles every 10°C increase. This ideal case would correspond to curve Q10=2 above. If you want to age your products at a temperature of 45 °C, for example, you would need a 10 weeks aging process to simulate one year of real life aging.

The accelerated aging factor is not always "2". If the aging factor is known then the simulation can be adjusted accordingly. For example should it turn out that the material being tested has an accelerated aging factor of 3 (q10=3 above); for the same aging temperature of 45 °C, the number of normal weeks of aging would be 4 instead of 10.

DARK CYCLES

In some instances of aging processes there is one of multiple primary reactions that can compete or promote each other. There are also secondary reactions that can have a significant bearing on the final results. In some cases both reaction types can occur simultaneously. Also sometimes the secondary reaction can only occur in the absence of the primary reaction. This secondary reaction can generate intermediates that will react once the primary reaction resumes. It is important to provide a “dark” cycle that stops the primary aging process to leave room for secondary process. For example, in many UV aging test methods there is a portion of the exposure that occurs without any UV bombardment. The same is true for corrosion testing where the most evolved test methods are cyclic in nature with a “dark cycle” (i.e. for a certain period of time there is no corrosive agent at the materials being tested). Most advanced aging test procedures include dark cycles of some sort.

WATER

Water is often used in synergistic aging. In some cases water is directly involved in the chemical reaction occurring in the aging process. In other cases water can have a mechanical contribution such as erosion or cooling. Furthermore, it can sometimes act as a lens locally concentrating the incident light or it can simply be used to wash off the samples substrate to allow for a dark cycle (e.g. cyclic corrosion or rain cycle in weathering testing).

ONCE THE AGING PROCESS IS OVER

Once the aging process is completed physical/mechanical measurements need to be made on the samples to assess whether or not product properties were modified or adversely compromised compared to the unexposed product. Taking measurements while the aging process is occurring can be extremely helpful:

- Saves time if early failures are observed
- Provides a better understanding of material behavior
- Allows for a better comparison and final test results interpretation when tested side-by-side to a reference product with known characteristics

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CHAPTER 2

WHY TEST FOR ACCELERATED AGING?

Ultraviolet (UV) testing from an accelerated aging perspective finds its roots in photochemistry. This part of chemistry studies light as an energy source to induce chemical reactions (i.e. light is used to provide the required activation energy so that one or more chemical reaction start occurring). Photochemistry deals almost exclusively with organic molecules (i.e.: carbon based molecules). Typical examples of organic molecules include polymers and coatings that are all susceptible to sun degradation over a certain period of time, as well as most of all living tissues: plants, trees, human' skin, etc.,

Figure #1, below, shows the complete spectrometric spectrum. Of this spectrum only minuscule portion is visible to the human eye: from 390 to 700 nanometers (nm). The UV spectrum goes from 10 to 400 nm. Most spectrophotchemical reactions are promoted with wavelength between 200 nm and 400nm as well as in the visible from 400 to 700nm.

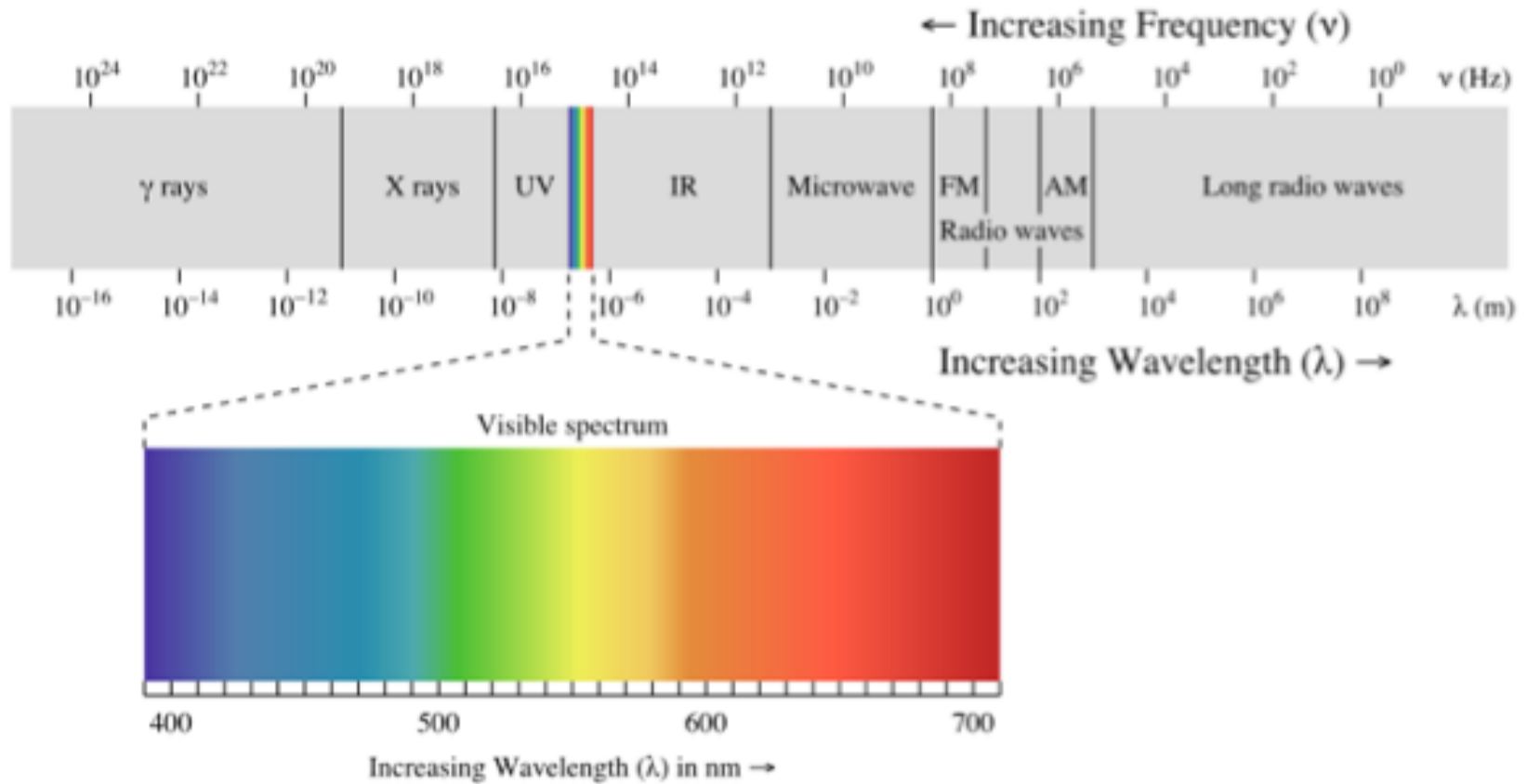


Figure #1 Spectrophotometric spectrum. Source: www.austincc.edu

Only specific functional “sites” of organic molecules will react at very specific wavelength corresponding to site’s specific resonance energy levels. These sites are called “Chromophores”. If available, the chromophores will absorb radiant energy corresponding to the vibration levels of their valence electrons. These excited electrons will then be promoted to specific higher energy levels (orbitals) where they become much more reactive (activated complex) and are likely to get involved in chemical reactions that would not occur under normal conditions. These reactions could involve a mixture of the following:

- Bond to other molecules close by (isomerization)
- Bond to other active sites on the same molecule (rearrangement)
- Breakage of the molecular chain (photolysis).

Most typical photochemical sequences occur in phases:

- Absorption of light energy exciting one or more chromophore on a molecule
- Primary photochemical reaction of the excited Chromophore



Secondary chemical reactions occurring as a result of the presence of the activated complexes generated by the primary reaction. These secondary reactions do not require light as activation energy (Dark cycle).

REAL WORLD APPLICATION

Why do Fireflies shine?

Despite its scary technical name; everybody has witnessed naturally occurring photochemistry phenomenon. A common example is the firefly. Fireflies produce an electronically excited enzyme called “luciferin” emitting light as a result of a peroxide function decomposition through an enzymatic reaction.

This “bioluminescence” phenomena is actually essential to the fireflies mating process. While the male is flying it emits flashes of light at a given frequency. The females, while they remain stationary, flash a response which orients the males in the proper direction and the signaling process keeps iterating until the mates are united. Different firefly species will differentiate from each other because of the signal frequencies used by each species.

Photosynthesis is another important photochemistry based process; no light, no plants.

Source: www.farmersalmanac.com

UV EXPOSURE AND SUNLIGHT

Everybody is familiar with terms such as “Ozone layer hole” (figure #2), “SPF”, “Skin Cancer” and the importance of protecting our skin when being outdoors for some period of time. What is the technical explanation behind all this? The sun emits light and a significant portion of this light is in the ultraviolet domain.

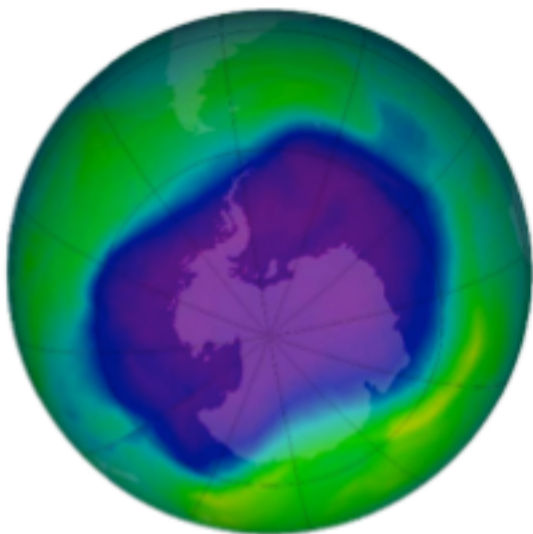


Figure 2. Image of the largest Antarctic ozone hole ever recorded (September 2006), over the Southern pole

The spectrum of solar radiation on Earth is shown on the next page in figure #3. The spectrum’s yellow and red portion added together amount to the total solar emissions. The part in yellow never makes it to the Earth’s surface as it gets filtered by the ozone layer, hence the importance of NOT having an “Ozone Hole”.

The CO₂ and water present in the atmosphere also absorb a portion of the U.V. Emission’s spectrum (see figure #3 for absorption bands). As the Ozone Layer becomes thinner, higher amounts of ultraviolet radiations and shorter, higher energy wavelengths, are not filtered out anymore thus having a more deleterious and faster effect not only on us but on everything outdoors or exposed to sun through a window. The shorter, more energetic wavelengths, will also attach chromophores that would not have reacted years ago as those short wavelengths were not present either at all or were only present in negligible quantities. This also explains why you need more skin protection if you travel to very high altitudes areas: there is less atmosphere to filter the UV radiations.

On the next page, Figure #3 shows the difference between the emission solar spectrum and what effectively gets to the planet’s surface. Infrared radiations that get to the earth’s surface are felt as heat and do not have any deleterious effects on organic molecules. In other terms these radiations are not harmful. As discussed earlier, most spectrophotocatalytic reactions will be stimulated with wavelength between 200 nm and to 700nm. Because of their shorter wavelengths and higher energy; the ultraviolet radiations will break down stronger chemical bonds. The UV spectrum is split in four wavelength ranges:

UV A	UV B	UV C	Vacuum UV
320-400 nm	290 -320 nm	200-290 nm	10-200 nm

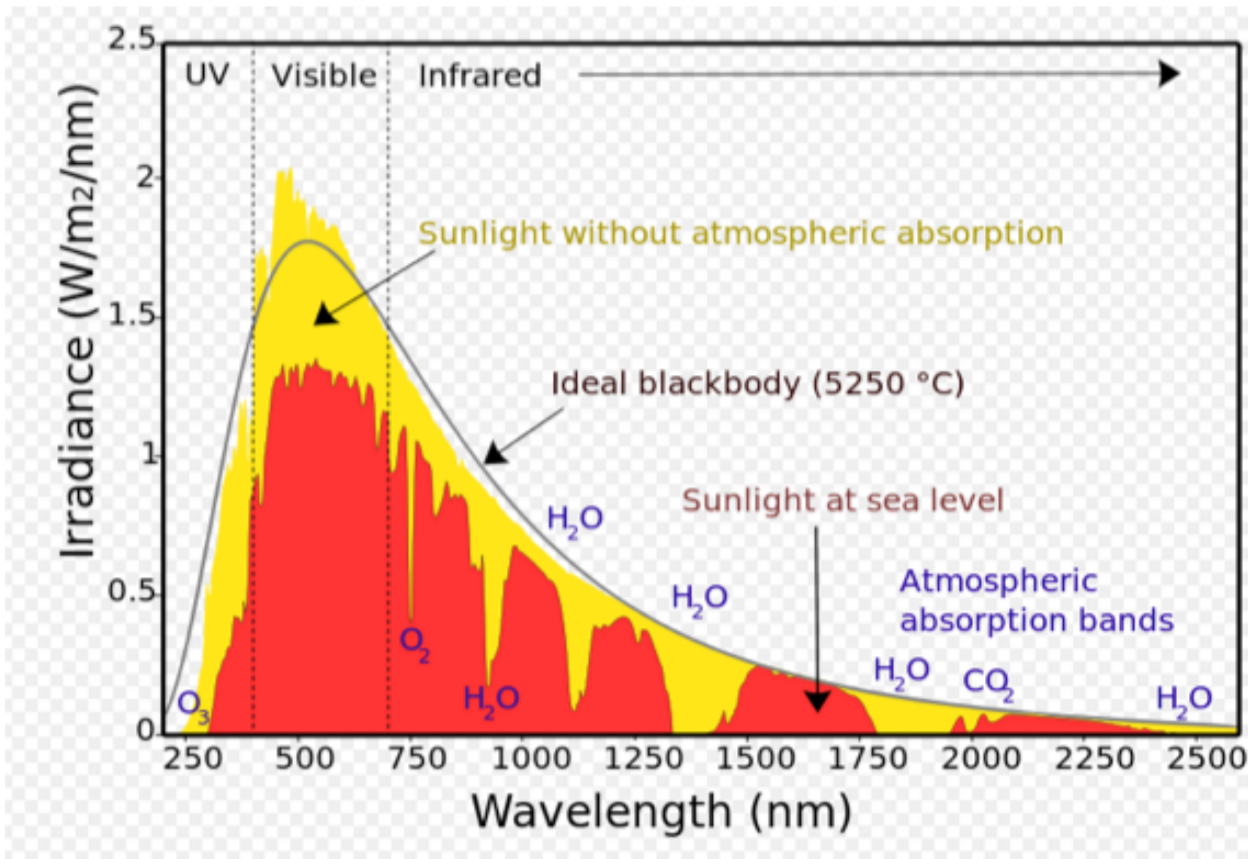


Figure #3: Spectrum of Solar Radiation on Earth
 (source: www.Wikipedia.org)

As can be seen in figure #4 below, UVc radiations (200-290 nm) are strongly absorbed by earth's ozone layer. There is very little UVb (290-320 nm) and the bulk of the UV radiations is in the UVA region. It is important to understand the UV distribution on earth since it will help you decipher what is the best simulation possible for your application.

It should be noted that despite the small amount of UVbs present at Earth's surface, because of their higher energy, their presence should not be neglected.

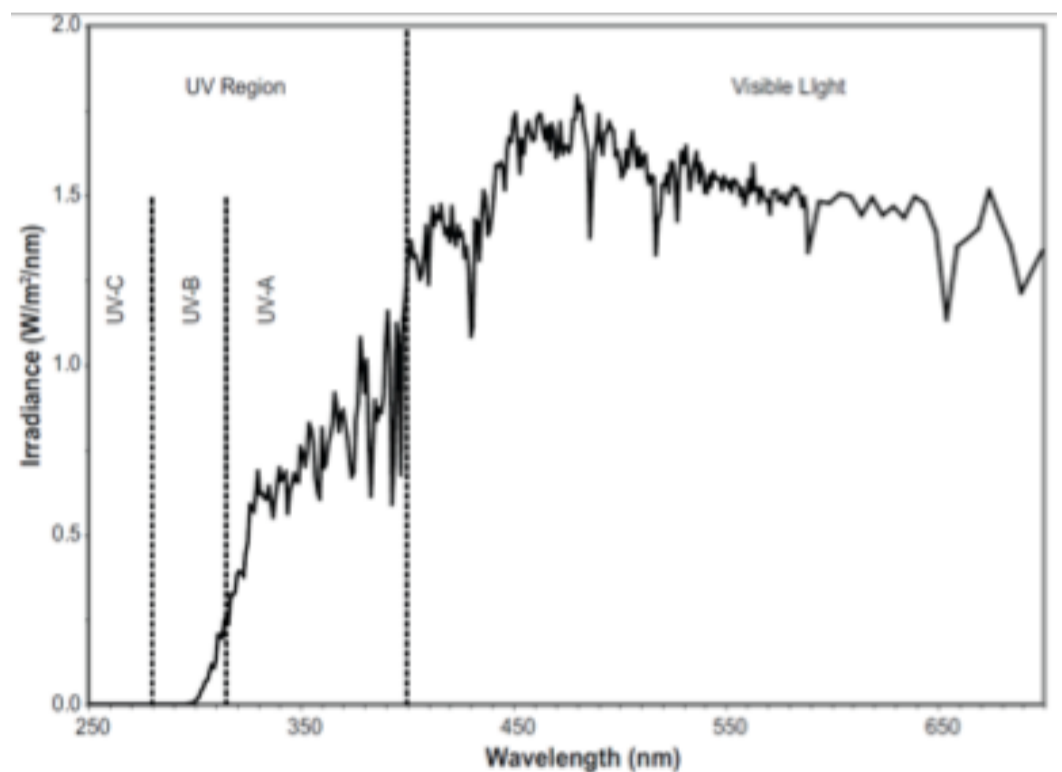


Figure #4: UV and Visible sun spectrum on earth.
 (Source: Sunlight, Weathering & Light Stability Testing.
 Q-Lab, Technical Bulletin LU-0822)

Typically, saturated and mono-unsaturated molecules (e.g.: waxes, some oils) will be excited at wavelengths below 190 nm. Poly-unsaturated molecules and aromatic compounds will react at wavelengths between 190-380 nm (most polymers, most living tissues). Colors in colored materials will react with light exposure within a range of 380- 780 nm.

Chromophore An example of compound	max (nm)
H ₂ O	183
C-Ca C-H. CH ₄	CCA 170, 173
C-X, CH ₃ OH, CH ₃ NH ₂ , CH ₃ I	180-260, 187, 215, 258
C=C, H ₂ C=CH ₂	160-190, 162
H ₂ C=CH-CH=CH ₂	217
C=O, H-CH=O	270, 170-200, 270, 185
H ₂ C=CH-CH=O	328, 208
C-N	190, 300
N=N	340
C=S	500
NO ₂	420-450
N=O	630-700

Table 1: Chromophores examples and their resonance wavelengths.

On the next page, Figure #5 shows the difference between the UV intensity of direct sunlight and sunlight exposure through glass. A quick look at the two curves might give the impression there is not much difference between direct sunlight and sunlight through glass. Did you ever catch a sunburn behind a window glass? Obviously not! Should you take a closer look you would note that the overall light intensity is about 15% higher for outdoor exposure.

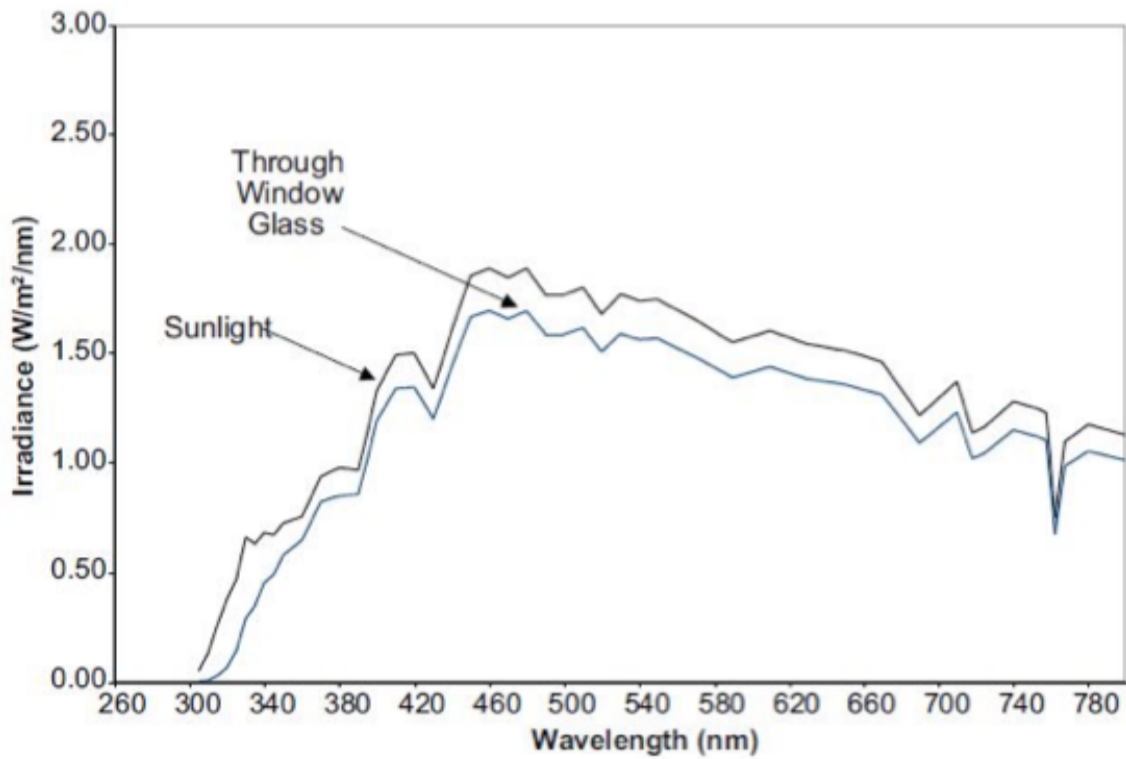


Figure #5: Direct sunlight and sunlight through glass
(Source: Sunlight, Weathering & Light Stability Testing. Q-Lab, Technical Bulletin LU-0822)

However this known fact and the lower light intensity does not explain why one cannot get a sunburn behind a window glass. The reason lies in the spectrum's UV segment. First of all because these wavelengths being shorter are much higher in energy. Furthermore, in that portion of the emission spectrum, the direct sunlight curve shows light intensities that are many times the light intensity of the sunlight through window glass curve. We will come back to the importance of the curve differences later on when we discuss which test conditions should be used.

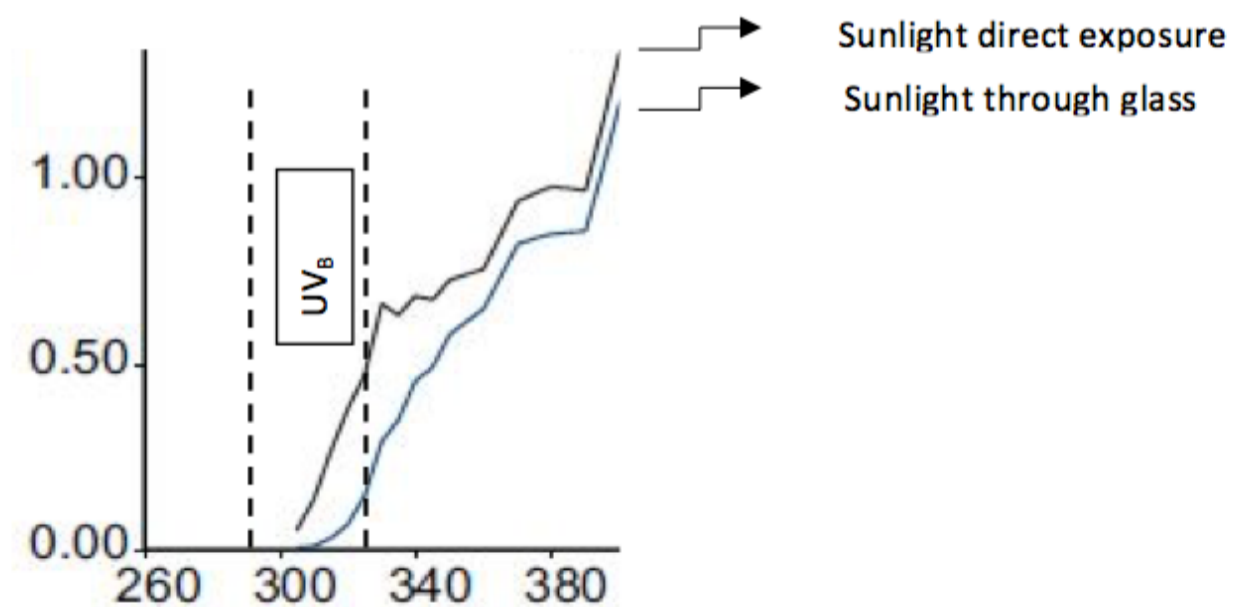


Figure #5a: Direct sunlight and sunlight through glass; UV region.
(Source: Sunlight, Weathering & Light Stability Testing. Q-Lab, Technical Bulletin LU-0822)



REAL WORLD APPLICATION

Can someone get a sunburn through a vehicle window while driving?

According to [Huffington Post Canada](http://www.huffingtonpost.ca/2012/06/06/bill-mcelligott-sun-damage_n_1573546.html), "Truck driver Bill McElligott, 69, has unilateral dermatoheliosis, according to The New England Journal of Medicine. Essentially, ultraviolet A (UVA) rays transmitted through the window of his delivery truck have severely damaged the skin on the left side of his face during the 28 years he has spent driving on the job."

If you look at Figure #5 on the previous page, it shows there is a difference between a direct sun exposure and an exposure to sun through glass. The intensity difference when you are behind a window is probably sufficient so that we don't get a "standard" sunburn. However, figure #5 clearly shows there is still a significant amount of UVAs and some, higher energy – more detrimental, UVBs.

Source: http://www.huffingtonpost.ca/2012/06/06/bill-mcelligott-sun-damage_n_1573546.html

SOLAR EXPOSURE VARIATIONS

CHEMISTRY OF THE ENVIRONMENT

The actual environment where a product is used is often difficult to completely simulate as there are too many aging processes happening simultaneously. Parameters such as ambient relative humidity, rain, pollution, altitude and geographical position, average temperature, hours of exposure and many others will impact the extent and specific aging mode. We also have to consider additional aging processes that synergistically compound their aging impacts such as corrosion, freeze-thaw cycles, abrasion, etc.,

Atmospheric pollution can also be a contributing factor. For instance, in principle, a dense smog should limit the amount of sunlight that gets to the materials surface. Conversely if the chemicals present in the smog are photo sensitive, their activated complexes might react with the materials surfaces and initiate a degradation process that would not have occurred otherwise. Ozone exposure can also damage significantly materials surfaces.

LOCATION

Solar radiations can vary significantly from year to year and from location to location. Below is a map of the yearly regional sum of irradiance. The spread can be as wide as five folds.

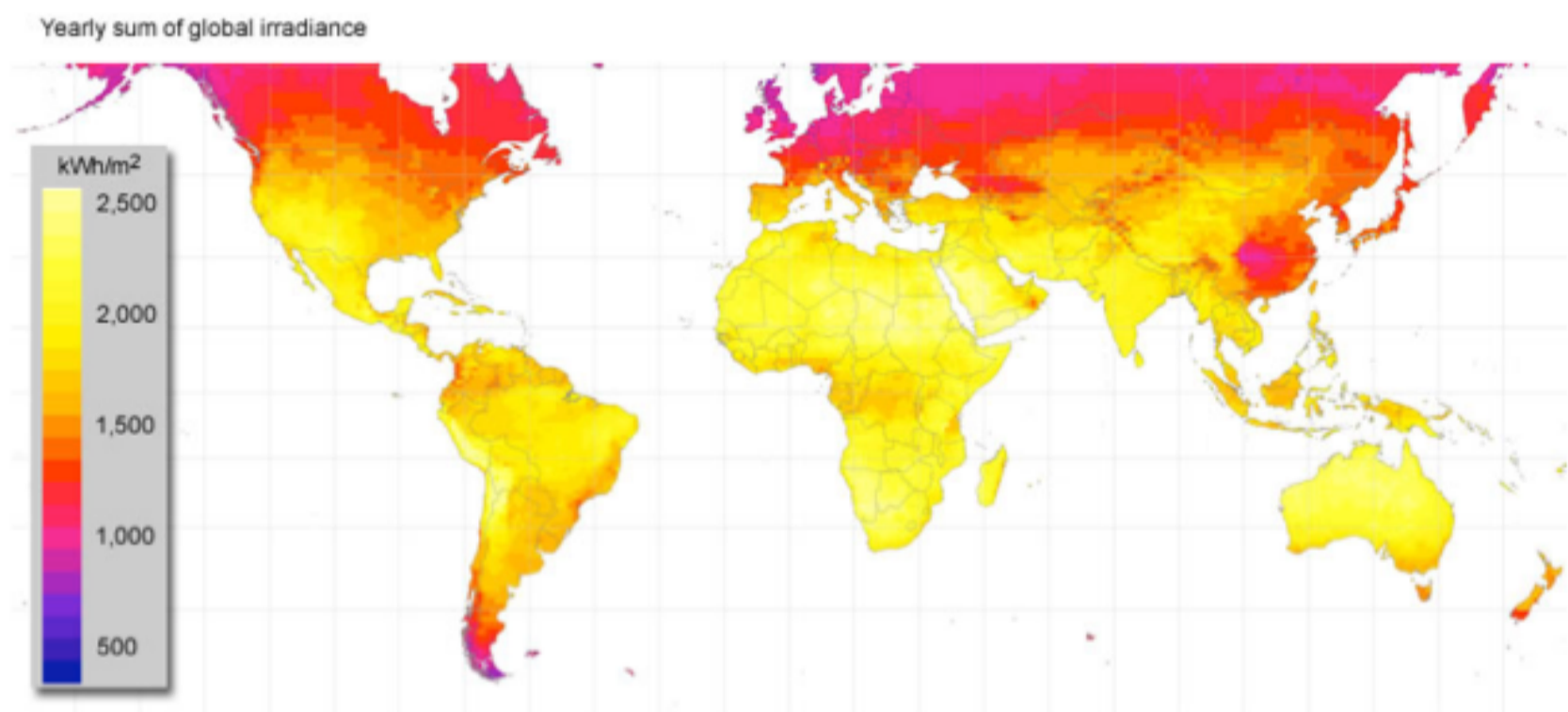


Figure #6: Yearly sum of global irradiance

SO WHY UV TESTING?

In summary, Sunlight exposure either direct or through glass can have deleterious impacts on carbon based materials such as coatings, polymers, textiles and many others. The damages vary and can include among others:

- Chalking
- Cracking
- Loss of physical properties
- Peeling
- Blistering
- Fading
- Color Change

Laboratory UV testing allows for faster, more reproducible, systematic and reliable results. As outlined above, there are no techniques that can take all of the potentially contributing factors. Most techniques will compound UV exposure with temperature and water (spray, dew, relative humidity).

Because the amount of light per hours per surface unit is controlled (irradiance) it is possible to calculate, for a given region, the approximate amount of years of real life exposure an actual test sample is being exposed too. This process is called the “time compression factor”.

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CHAPTER 3

HOW TO TEST ACCELERATED AGING?

HOW IS LABORATORY UV TESTING DONE?

There are three main types of laboratory UV test equipment. The main difference between them is the light source used to generate the UV Visible emission spectrum. The three light source types are:

- Carbon arc
- Xenon arc
- Fluorescent lighting

CARBON ARC

Carbon arc was actually the first light source to be used for UV exposure testing. This light source is based on an older technology: an electric arc between two carbon electrodes that were being progressively consumed and producing a light spectra. Despite the fact that equipment manufacturers don't support carbon arc equipment anymore, it is still used namely by the Japanese automotive industry for legacy reasons; they have a lot of historical data based on that technique so they want to keep comparing apples to apples.

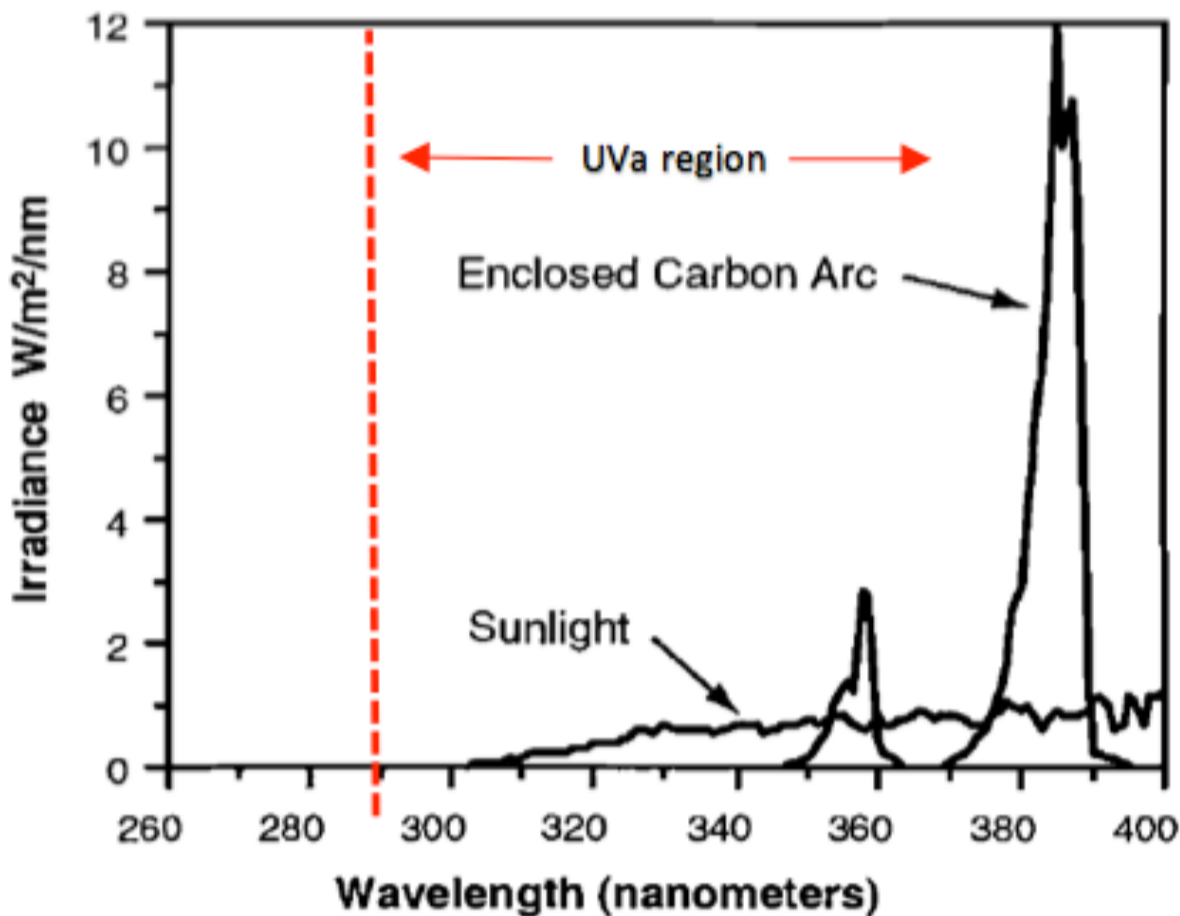


Figure #8: Carbon arc emission spectrum
(Source: From : Sunlight, Weathering & Light Stability Testing. Q-Lab, Technical Bulletin LU-0822)

Figure #8 above compares the enclosed arc to the sun emission spectrum. It can easily be seen that for the carbon arc a large portion of the spectrum is missing while the emission intensity is extremely high in some specific areas. Depending of the specific chromophore(s) a given material has and its overall molecular structure the product might “over react” if one of its bond happens to have an absorption frequency that coincides with the emission peaks or it might not react at all if its resonance frequencies do not coincide with the carbon arc emission bands . So one could get a “false” positive or a “false” negative which leads to a poor simulation and consequently to the wrong conclusions.

Sunshine carbon arc, another carbon arc type, also has a really high intensity peak around 385 nm and has an emission spectra that goes well within the UVc realm that will only be present in outer space. As the higher energy frequencies are not present on earth it could degrade products using certain chemical reactions that would not realistically occur on earth even if the material was exposed for a century.

XENON ARC

Xenon, a noble gas, is a chemical element (Xe). It is a colorless, heavy gas (66 times the molecular weight of hydrogen, H₂). Xenon has numerous very specific chemical characteristics, namely its chemical “inertness”. Xenon is used in photographic flashes, in high pressure arc lamps for motion picture projection, and in high pressure arc lamps to produce ultraviolet light.

Xenon arc units use a xenon in a precision gas discharge lamp in a sealed quartz tube. To obtain a better match with the sun emission spectrum, the xenon arc must be filtered using specific filter combinations. Depending on whether one wishes to simulate indoor or outdoor conditions, different filters will be used.

Figure #9 below compares the sun’s emission spectra against a Xenon arc emission pattern using daylight filter combination

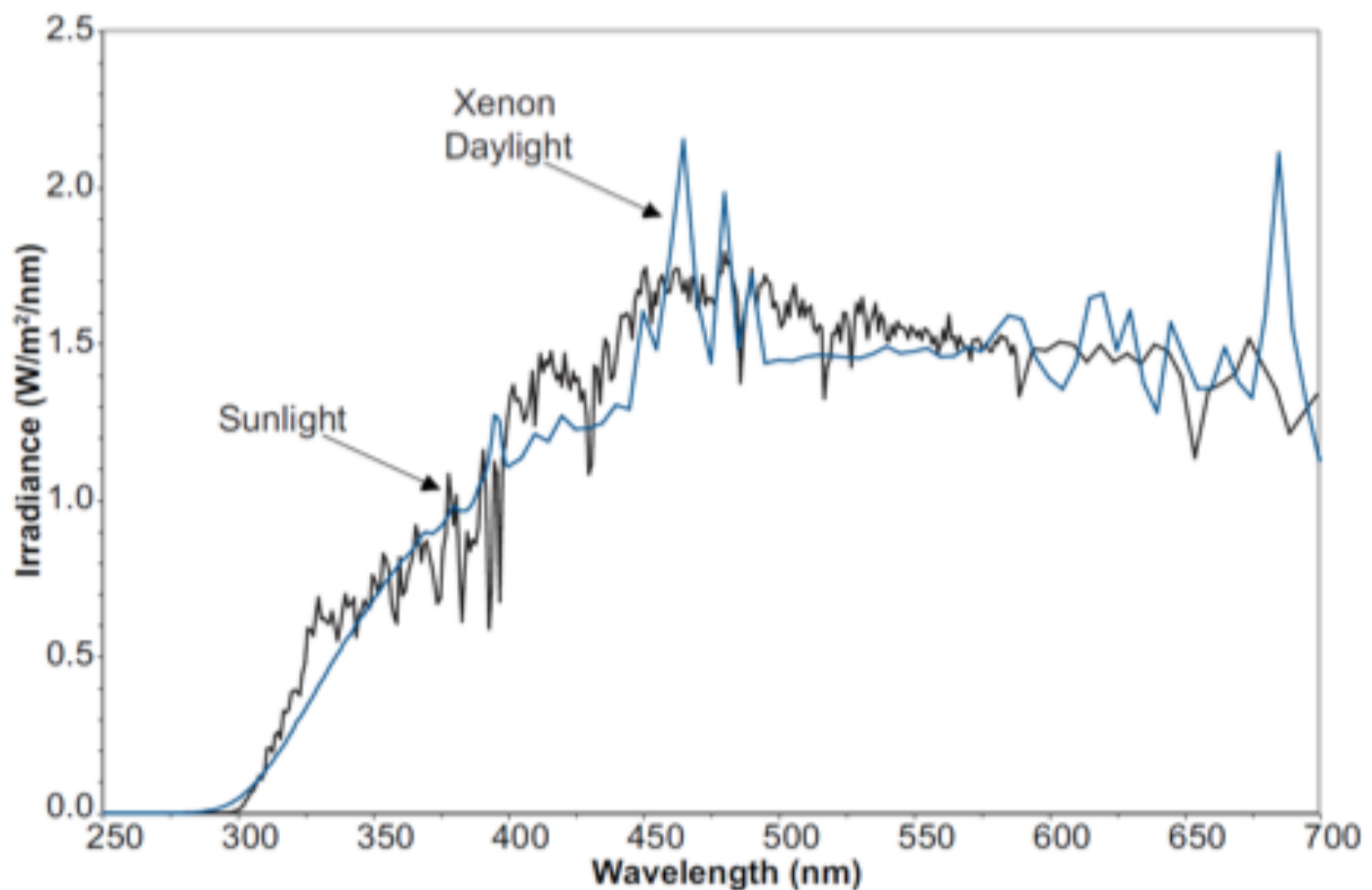


Figure #9 – Sunlight (outdoor) vs Xenon arc unit with daylight filter
(Source: From : Sunlight, Weathering & Light Stability Testing. Q-Lab, Technical Bulletin LU-0822)

Xenon arc UV exposure is used across many industries. There are many standards and specifications requiring Xenon arc exposure as can be seen in [Appendix 1](#).

Over the years Xenon arc and Fluorescent light units (discussed later on) have replaced carbon arc as a light source for ultraviolet aging to a very large extent. Xenon arc units offer the following advantages over carbon arc units:

- Steadier emission pattern
- Simulates more closely sun's own emission spectrum both in relative intensity and spectral distribution
- Allows to distinguish and simulate both direct sun exposure (outdoor conditions) and sun exposure through glass (indoor conditions)
- Xenon is a relatively good time predictor thus allowing for more accurate accelerated aging

TIME COMPRESSION FACTOR

Experience demonstrates that the time compression factor concept (i.e. the rate of accelerated aging induced by the exposure), is often poorly understood. How does test chamber exposure time compare to outdoor exposure time? What is the acceleration factor? How long do I have to test my product to simulate 5 years of outdoor exposure?

For decades, weathering experts have tried to find that magic number. The truth however is that there is no such magic number. No matter how the question is formulated, the answer is always the same: "It depends!"

It depends for one simple reason: Mother Nature is not as reliable as lab equipment and different materials will react differently. In some cases, even the same material available in different colors will react differently, depending of the color being used.

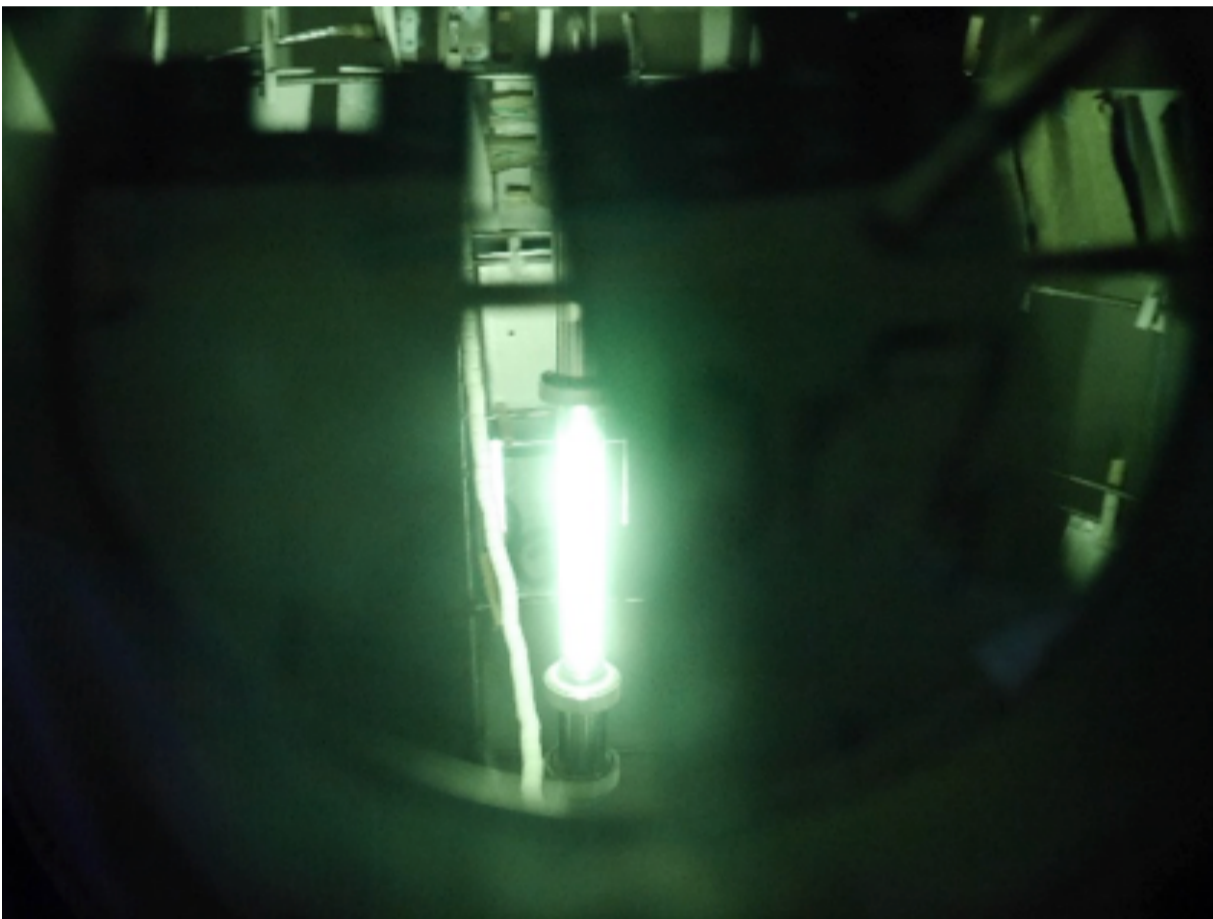
Xenon arc testing requires the use of calibrated lamps, specific filters, very accurately monitored irradiance, purified (demineralized) water, controlled atmosphere (humidity and temperature) and pre-defined light, dark and rain cycles durations. On the other hand, natural outdoor exposure depends on when and where you are: Latitude, altitude, cloudiness, humidity, smog, rain, temperature, orientation, season, time of day, and many more. All those parameters have a major influence on the "efficiency" of outdoor exposure.

In other words, if you were to spend 5 minutes in a weathering chamber, no matter when or where you do it, you would always get the same "tan". On the other hand, we cannot say that 5 minutes of

outdoor exposure in downtown London in December is equivalent to 5 minutes of outdoor exposure in Miami in June. Presented this way, the answer is obviously “No”. That is exactly why it is impossible to have an ABSOLUTE acceleration factor for accelerated weathering testing.

SO, WHY IS XENON ARC UV AGING SO POPULAR AND USEFUL?

Xenon arc testing is actually a very powerful tool for comparative purposes. Testing simultaneously multiple formulas can quickly give vital information. Instead of waiting years to get the data from outdoor exposure or feedback from customers, accelerated weathering gives you the data you need in days or weeks.



Photograph #3: 6500 Watts Xenon arc as seen through a safety lens

How fast is fast?

Even if the absolute acceleration factor cannot be determined for the reasons explained above, experience shows that using accelerated weathering, conclusions can usually be drawn after weeks (sometimes days) while natural outdoor exposure takes months or years.

In a world where time is money and where technologies and trends are constantly moving, Xenon arc testing has become a key asset for decision makers in many industries.

PREVALENT PRACTICE

The most prevalent practice in North America for xenon arc UV testing is [ASTM G155](#) - Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials. This practice is the basis of all of the other standards for accelerated weathering using Xenon Arc UV light sources to simulate exposure to natural sunlight on an accelerated basis. Many standards call up this practice; for a list by product category please review [Appendix 1](#).

ASTM G155 is used to perform accelerated aging on a wide range of products and industries including products for the automotive industry, surface coatings, pharmaceutical light stability tests, printing inks, roofing, rubber, adhesives, textiles, geotextiles and many others.

When testing your products using this practice, the samples are exposed to repetitive cycles of light and moisture under controlled environmental conditions. Moisture is usually produced by spraying the test specimen with demineralized water or by the condensation of water vapor onto the specimen.

XENON ARC TESTING – EXPERIMENTAL PARAMETERS TO SPECIFY

To perform an [accelerated weathering test](#) that is relevant for your application the following test parameters need to be defined carefully:

- **Lamp filters**

- The choice of boro-silicate - Soda Lime filters is to be used should you wish to expose your samples to indoor conditions. The choice of boro-silicate (inner and outer filters) will yield outdoor sun exposure conditions.

- **The lamp irradiance level**

- Irradiance is the light intensity you wish to use to expose your sample to UV light. It is normally expressed in units of Watts/square-meter/nanometer. The light intensity is measured at 340 nm for exterior conditions or at 420 nm for indoor exposure. The irradiance can also be measured over a wavelength range e.g.: 300-400 nm.

- **The type and duration of moisture exposure**

- Water spray at the back of the front of the samples or only one of them. Usually spraying the samples back will be for generating condensation at the specimen's surface. Spraying the sample's front, or UV exposed part, will be for simulating surface erosion that allows to remove surface residues that might be generated upon testing and that could act as a self-protecting phenomena, example: chalking

- **The timing of the light and moisture exposure**

- **The temperature of light exposure**

- Also known as “black panel temperature”. As discussed above, the sample’s surface temperature will control to a large extent the rate of the aging process. An instrumented metal panel painted black is set on the samples rack and sends a signal to the control system to accurately maintain the sample’s surface temperature

- **The temperature of moisture exposure**

- **The light/dark cycle timing.**

- We discussed above of the importance of having a “dark” cycle within the overall cycle to allow for secondary reaction to take place.

There are twelve predefined cycles in table X3.1 of ASTM G-155 that can be used when doing xenon arc testing. Other standards may also alter the cycle for specific purposes.



Photograph #4: sample set up in a Xenon arc unit

FLUORESCENT LIGHT EXPOSURE

Fluorescents are also used as a source of ultra-violet radiations for accelerated aging. Whereas Xenon arc emission units have an emission spectrum that reproduces the complete solar spectrum in the UV, visible and infra-red region, fluorescents by nature, have a much narrower emission spectrum. However, fluorescents happen to emit in an area of the UV spectrum that corresponds to the resonance frequencies of chromophores (see table #1) pertaining to the mechanical resistance of polymers.

The two most popular lamps are UVA-340 and UVB-313. There is also a UV-351 lamp that simulates sun through glass. The UVA-340's emission spectra offers a very good fit with the solar spectrum between 300 and 360-370 nanometers. The UVB-313 does not have a good fit with the sun's emission spectra albeit there is some overlapping between the two in the region between 310-340 nm. UV-B is not used so much for its good fit with the solar spectrum; it emits in a lower frequency, higher energy part of the spectrum. This yields a very aggressive environment that turns up fast test results that can be used for development purposes but should not be used to try predicting field performance. For this reason, even if we can do it when we get requests, we never suggest to our clients to use the UVB-313 in our day-to-day practice.

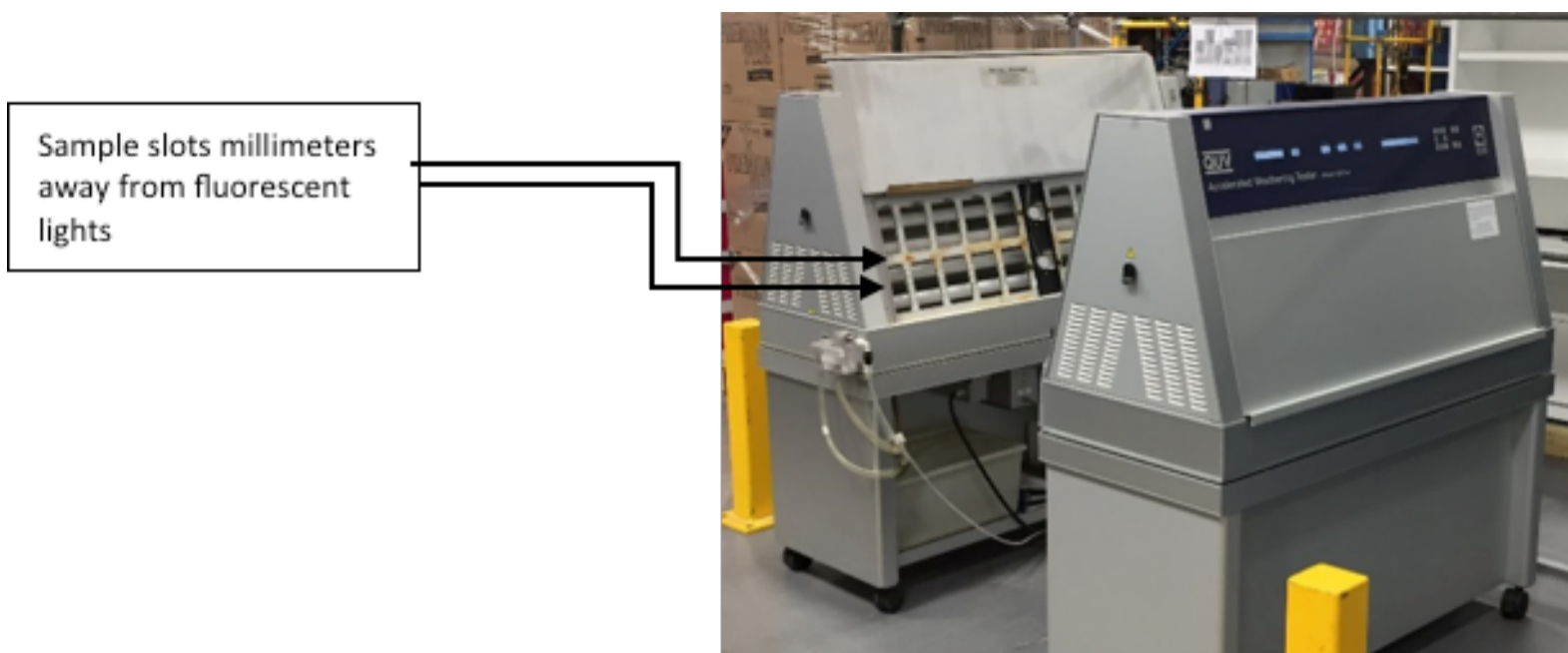
Time compression factor

Because of the narrow emission spectra each type of fluorescent lamp can provide, UV aging using fluorescent light exposure is generally not a good time predictor. We most often recommend using this practice on a comparative basis with materials of known performance so that conclusions can be drawn.

Prevalent Practice

[ASTM G154](#) - Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials and ISO 4892-3 – Methods of Exposure to Laboratory Light Sources – Fluorescent UV-lamps are the most prevalent practices dictating how Fluorescent light exposure equipment should perform including what should be the spectral irradiance characteristics of the most common lamps and suggests common light exposure cycles (Table X2.1).

Photograph #5 on the next page shows a typical Fluorescent light tester. Typically the cabinet's bottom is covered with a pan holding water and a heating element for generating moisture to the required level. There is a total of 8 fluorescents working all at the same time to expose the specimen.



Photograph #5: Fluorescent light exposure testers

EXPERIMENTAL PARAMETERS TO SPECIFY

The following test parameters need to be defined so that we can properly run a Fluorescent light exposure test based on practice [ASTM G154](#):

- **The fluorescent lamp**
 - Specifying the lamp to be used will dictate the emission spectrum used for the exposure.
- **The lamp's irradiance level**
 - In watts per meter square per nanometer; this is the amount of light your samples will be receiving per unit of area
- **The type of moisture exposure**
 - Options are: condensation or % relative humidity. The most common exposure conditions in ASTM G-154 require condensation
- **The timing of the light and moisture exposure**
- **The temperature of light exposure**
- **The temperature of moisture exposure**
- **The timing of a light/dark cycle**
- **The number of cycles to be run**

Just as in [ASTM G155](#), there are predefined cycles that can be used when doing ASTM G154 testing. You will find these cycles in table X2.1 of the test method.

ASTM G-155 OR ASTM G-154; WHAT SHOULD BE USED?

The absolute answer is: “it depends”. Both techniques have pros and cons. [ASTM G155](#) offers overall a better emulation of the solar spectrum and is a better time predictor. However [ASTM G-154](#), albeit it is a poor “time predictor”, it is deemed to be better and faster than ASTM G-155 at causing accelerated aging causing loss of mechanical properties. Ultimately the answer lies in what you are concerned with; aesthetics or loss of mechanical properties, what are the chromophores on your product’s material and which aging technique offers the best aging characteristics for the resonance frequencies associated with these chromophores?

For example we did a comparison study between ASTM G-155 (cycle #1), ASTM G-154 with a UVA 340 set of lamps, indoor and outdoor exposures on polystyrene chips that are used as control material for [UV testing](#). The figure #10 below shows polystyrene’s molecular structure. This material is used as a standard for UV testing quality control purposes.

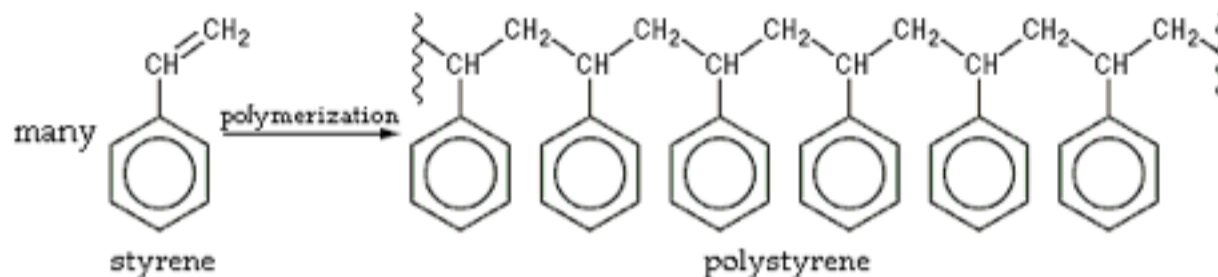


Figure #10: Polystyrene molecular structure

Source: Wikipedia : H Padleckas created this image file on November 17, 2005 for use in articles like "Polystyrene" in Wikimedia. H Padleckas 06:49, 18 November 2005 (UTC)

On the next page, figure #11 shows that both ASTM G-155 (cycle 1) and ASTM G154 (cycle 1) polystyrene (PS) offers a very similar color change (Delta E) as a function of the number of hours of exposure. This can be explained by the fact that the wavelengths absorbed by PS are emitted by both UV source. Had we used a different molecule with chromophores absorbing closer to or in the visible range; the outcome might have been completely different between the two techniques even though the same material was used in both cases.

Purpose of the study

To establish a correlation between the fading (change in color) of samples exposed to “natural” light and samples exposed to accelerated aging in lab conditions.

Study conditions

Coupons were exposed to direct outdoor sunlight (facing North and South) and also exposed behind window glass (facing SouthEast). Identical coupons were exposed to accelerated aging using common ASTM G155 daylight, ASTM G155 Window glass and ASTM G154 UVA340 cycles.

Color measurements were taken over the course of 1 full year. The numbers presented in the graph below are the Delta E values (calculated as per [ASTM D2244](#)) as a function of the number of hours of exposure.

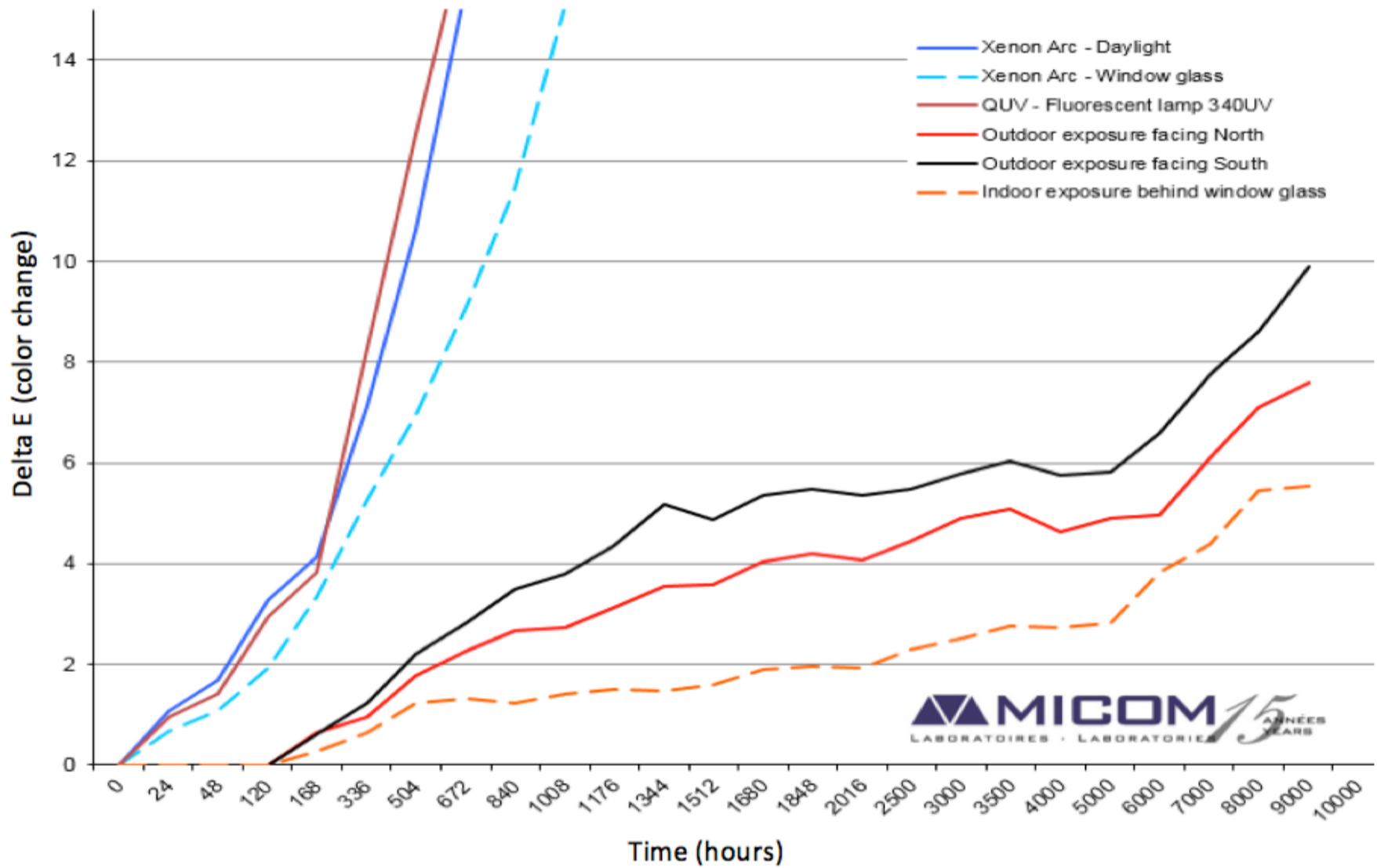


Figure #11: Accelerated Aging of polystyrene chips using different aging techniques. The acceleration Factor is from right to left.

OBSERVATIONS

Coupons exposed to “natural” light:

As expected, we measured a faster fading for the coupons exposed outdoor and a slower fading for the coupons exposed behind a window glass.

Facing Exposure South > Facing Exposure North > Facing Exposure Window Glass

Coupons exposed to accelerated aging (Xenon-Arc and Fluorescent UV light)

As anticipated, we measured a faster fading for the coupons exposed to ASTM G155 daylight compared to the coupons exposed to ASTM G155 window glass conditions.

Fading Daylight cycle > Fading Window Glass cycle

Coupons exposed to ASTM G155 daylight conditions and ASTM G154 (Fluorescent 340 UV lamps) showed an identical fading rate (Delta E).

Fading Xenon Arc (Daylight) = Fading Fluorescent

So, the various conditions can be ranked as follows:

Xenon Arc (Daylight) = Fluorescent > Window Glass cycle > Exp. South > Exp. North > Exp. Window Glass

Correlation between accelerated aging and “natural” exposure:

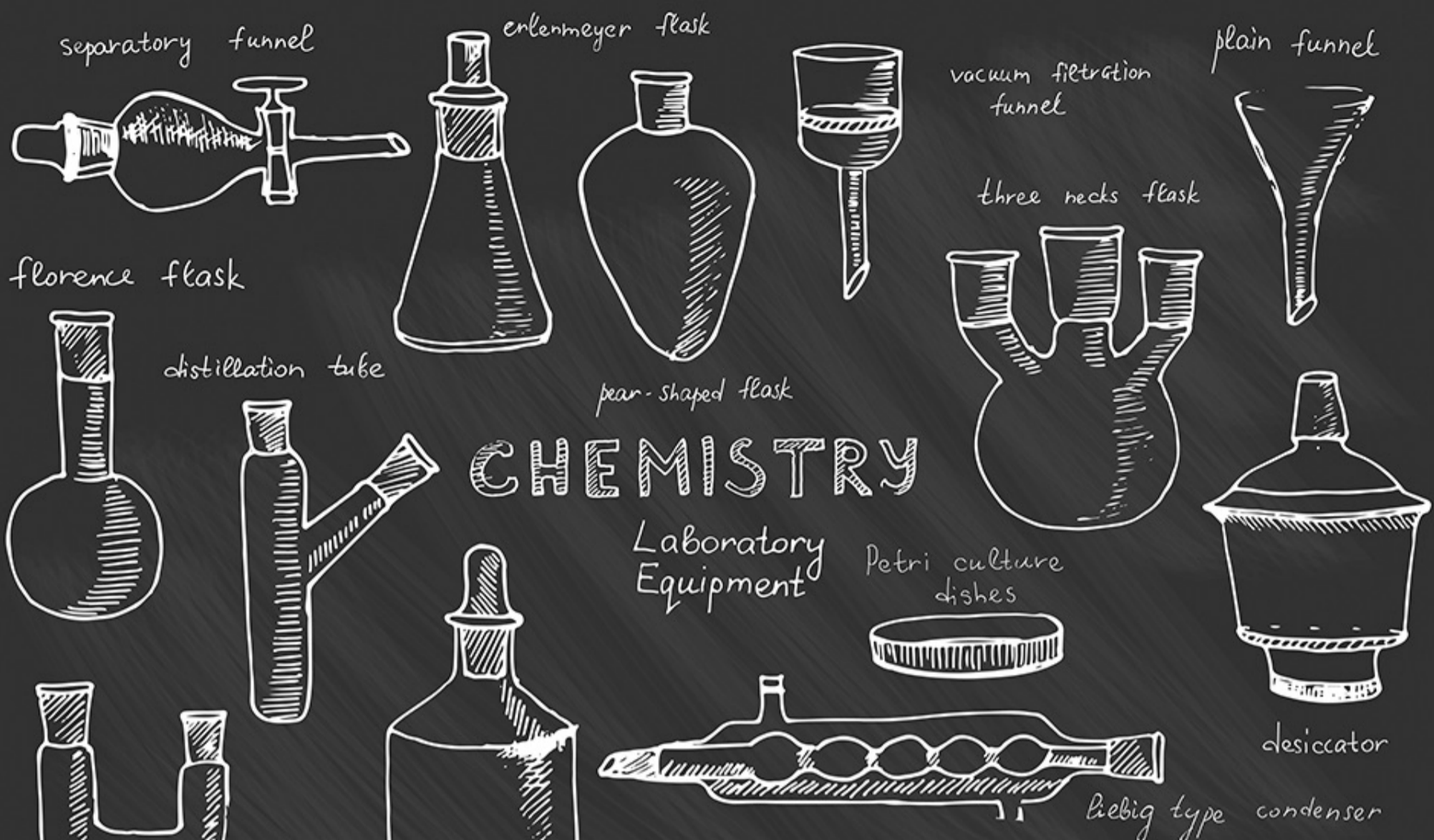
Outdoor exposure vs. Daylight test conditions: the average acceleration factor was found to be: 21.5

Indoor exposure vs. Window Glass cycle: the acceleration factor was found to be: 23.8

“Rule of Thumb”

With a compression factors found above, a rough estimate would be: 2,000 hrs of accelerated aging simulate 5 years of natural exposure.

Keep in mind that the acceleration factor is highly material and environmentally dependent. The study presented here was performed in Montreal from May 2014 to May 2015 on Polystyrene coupons.



PREPARING A TEST PLAN

When you need to evaluate your materials for UV exposure resistance it is therefore important to identify clearly what are your goals and from this point to consider what are the relevant parameters and from them to elaborate a proper test plan. Factors to consider should include:

1. Which undesirable impacts do you expect and are you trying to prevent? Color change or loss of mechanical properties might dictate the use of a different test protocol starting with a different UV source.
2. Indoor or outdoor exposure?
3. Ambient temperature? Aggravating factor?
4. Ambient relative humidity? Aggravating factor?
5. Rain cycle? Erosion & cooling effect promoting aging.
6. Dark cycle? In some cases this will promote chemical reactions that would not happen otherwise.
7. Sample size; shape, thickness
8. Duration of the predictable real life exposure.

9. Do you need progressive sampling/measurements on your samples? This will limit your testing costs should the materials you are testing are not performing as expected.
10. What are the measurable parameters that matter in your specific application?

UV AGING AND QUALITY CONTROL

Nowadays all serious laboratories will offer UV testing test services within a quality control environment. What should you be looking for? You send your samples to the lab, they come back; how can you know that the right test was done on your products?

Even if you have a good track record with your laboratory services supplier you might want to look out for some of the following pieces of evidence:

- Is the lab [ISO 17025 accredited](#)? ISO 17025 is more or less the equivalent of ISO 9001 with specific performance requirements that have to be met. Make sure they are accredited by a nationally recognized laboratory.
- Not only should the laboratory be accredited, you should insure the specific test you are requiring is part of their scope of testing which is readily available on their registrar's website.
- Your lab should have calibration and verification records for all of the operational parameters required by each aging method.
- Finally you should ask your lab service supplier to show you data where he ran control materials such as polystyrene chips or blue wool and assess whether he performs within acceptable limits.

On the next page, figure #12 summarizes the appropriate workflow visually via a decision tree.

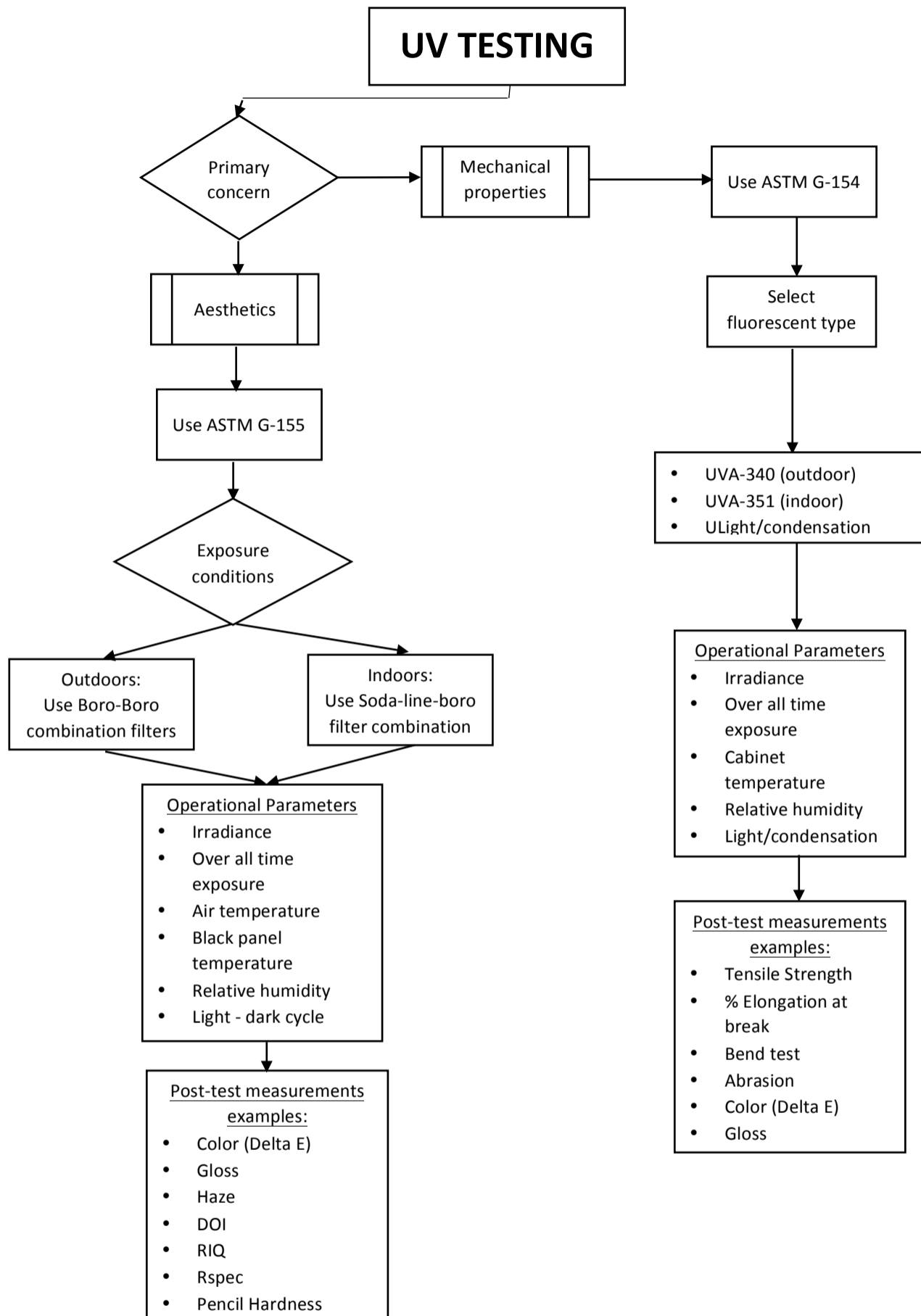


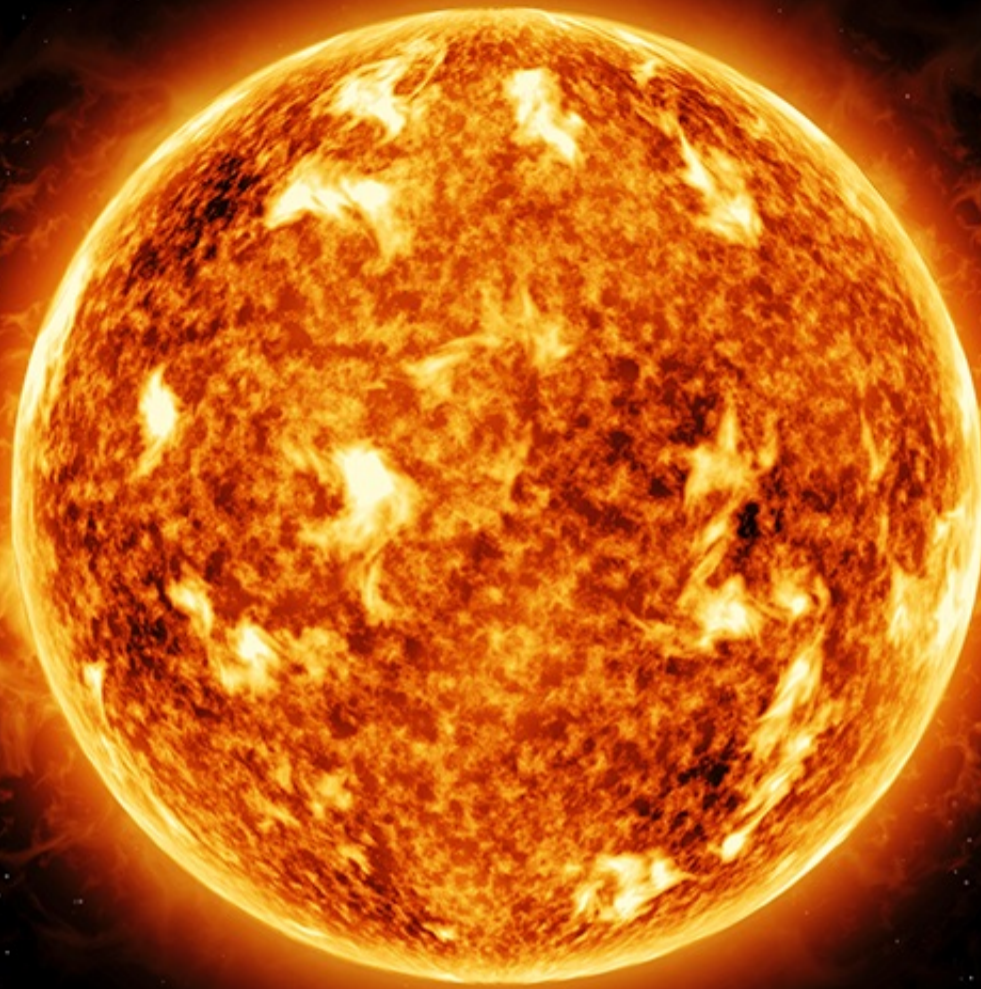
Figure #12: Preparing a test plan

WHEN SHOULD A RE-TEST BE REQUESTED?

As discussed above accelerated aging is a complex mix of contributing environmental factors that cannot all be taken into consideration. Most materials used in manufacturing are rarely pure products; they will contain UV stabilizers, colorants, plasticizers, curing agents, molding agents, fire retardants, recycled materials.

Many of these products come from various suppliers over whom you have little control. Even pure resins are likely to vary from supplier to supplier. Small changes to some of these parameters including process related parameters such as molding temperature or curing time can alter the UV resistance of your products. All of these factors, combined with the product value and how critical is your applications need to be factored in your decision of when re-testing should be required.

Micom Laboratories Inc. is an established third party independent laboratory offering products and material testing services. If you have any questions about UV Testing and would like to speak to one of our material testing specialists, we invite you to [contact us](#) today at 1 (888) 996-4266. It will be our pleasure to answer your questions.



CHAPTER 4

WHAT TO AVOID WITH UV TESTING

Being optimists we don't like focusing on negatives. However we believe the following should be avoided at all costs. Some of these points might appear trivial. However over the last 25 years of doing material testing, we've seen many people do these mistakes:

1. When you need to do UV testing don't start from the results to try to figure out what will be the product's future field behavior; consider carefully all of the parameters required to get to your goal. Make sure your test plan is well aligned with your needs (figure #12 is a good start). If you feel you don't know enough about UV testing; get your lab to make suggestions; a serious laboratory should have well versed staff in this type of testing. If you don't get decent feedback from your current lab, change your testing lab! Better have no test than a misleading test.

2. Don't expect to be able to simulate years of outdoor field exposure with a few hundred hours of testing. Some labs however claim to get results in short period of time. Make sure you ask questions and verify the the basis for their claims?
3. There is a big difference between outdoors and indoors exposures. Make sure you get the right exposure for your test.
4. Don't be shy to ask the lab to include its quality control documentation in attachment of their test report. You might pay extra for this documentation, but it might be well worth it at the end. For example, keep in mind that a calibration lamp for a weather-o-meter has to be calibrated externally every 50 hours of use or every two years whichever comes first. Some labs might not do the proper and regular lamp calibrations. Make sure you verify how the labs maintains their equipments before sending your test samples.
5. Don't try to save money by skipping intermediate measurements during the aging process. If your formulation is not right you will be able to catch them early based on the test results. Your initial investment in intermediate measurements, can save you a lot of money down the road if you need to end the test sooner and avoid wasting your time. If your formulations are right, intermediate measurements will show you a trend for your product as a function of the exposure duration and it will allow you to assess if your product was borderline OK or if you can extrapolate a longer life expectancy.

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CHAPTER 5

APPENDIX #1

XENON ARC UV AGING:

TEST METHODS, PRACTICES AND SPECIFICATIONS

Xenon arc testing is used to simulate outdoor and indoor sun exposure on surface finishes and coatings and polymers. ASTM G155 is a practice used to do xenon arc testing. This practice is called up in most of the test methods requiring Xenon arc testing.

Below is a partial list of these test methods which we can all test to:

General

- IEC 68-2-9 Basic Environmental Testing Procedures-Part 2: Guidance for Solar Radiation Testing
- ISO 4892-1 Plastics-Methods of Exposure to Laboratory Light Sources-Part 1: General Guidance
- ASTM G151 General Guidelines for Exposure of Nonmetallic Materials
- ASTM G155 Xenon-Arc Test Apparatus for Exposure of Nonmetallic Materials Assemblies (Solar Radiation)
- MIL-STD-810G Environmental Engineering Considerations and Laboratory Tests (Solar Radiation)
- GB/T 16259 Test Method for Accelerated Weathering Building Materials

Automotive

- SAE J2412 Accelerated Exposure of Automotive Interior Trim Components Using a Controlled Irradiance Xenon-Arc Apparatus
- SAE J2527 Accelerated Exposure of Automotive Exterior Materials Using a Controlled Irradiance Xenon-Arc Apparatus
- PV 1306 Lightfastness Test for Determination of Tackiness of Polypropylene Plastics
- PV 3929 Weather Aging in Dry, Hot Climate
- PV 3930 Weathering in Moist, Hot Climate
- ASTM D7356 Accelerated Acid Etch Weathering of Automotive Clearcoats Using a Xenon-Arc Exposure Device

Coatings

- ISO 11341 Paints and Varnishes — Artificial Weathering and Exposure to Artificial Radiation — Exposure to Filtered Xenon-Arc Radiation
- ASTM D3451 Testing Coating Powders and Powder Coatings
- ASTM D3794 Testing Coil Coatings
- ASTM D6577 Standard Guide for Testing Industrial Protective Coatings
- ASTM D6695 Xenon-Arc Exposures of Paints and Related Coatings
- GB 1865 Paints and Varnishes - Artificial Weathering and Exposure to Artificial Radiation-Filtered Xenon Arc Radiation
- JIS K 5600-7-7 Testing Methods for Paints - Part 7: Long-Period Performance of Film - Section 7: Accelerated Weathering (Exposure to Filtered Xenon Arc)
- MPI: #113 Exterior, Waterborne, Pigmented Elastomeric Coating
- MS 133: Part F14 Methods of Test for Paints & Varnishes: Part F14: Artificial Weathering & Exposure to Artificial Radiation – Exposure to Filtered Xenon Arc Radiation (ISO 11341)
- GB/T 5237.4 Wrought Aluminum Alloy Extruded Profiles for Architecture – Part 4: Powder Coating Profiles
- IRAM 1109 – B14:2008 Paints - Methods for Testing Part B14 – Accelerated Weathering Exposure to Radiation Using a Xenon Arc Lamp

Pharmaceutical

- ICH Guideline Stability Testing: Photostability Testing of New Drug Substances and Products

Plastics

- ISO 4892-2 Plastics-Methods of Exposure to Laboratory Light Sources-Part 2: Xenon-Arc Sources
- JIS K 7350-2 Plastics-Methods of Exposure to Laboratory Light Sources-Part 2: Xenon-Arc Sources
- DIN EN 513 Unplasticized Polyvinylchloride (PVC-U) Profiles for Fabrication of Windows & Doors
- ASTM D1248 Polyethylene Plastic Extrusion Materials for Wire and Cable
- ASTM D2565 Xenon-Arc – Plastics for Outdoor Applications
- ASTM D4101 Polypropylene Plastic Injection and Extrusion Materials

- ASTM D4459 Xenon-Arc – Plastics for Indoor Applications
- ASTM D5071 Xenon-Arc Exposure of Photodegradable Plastics
- ASTM D6662 Plastic Lumber Decking Boards
- UL 1581 Reference Standard for Electrical Wires, Cables & Flexible Cords
- GB/T 16422.2 Plastics – Methods of Exposure to Laboratory Light Sources Part 2: Xenon-Arc Sources
- GB/T 15102 Surface Decorated Wood-Based Panels with Paper Impregnated Thermosetting Resins

Geotextiles

- ASTM D4355 Deterioration of Geotextiles to UV Light

Textiles

- AATCC TM 16 Color Fastness to Light
- AATCC TM 169 Weather Resistance of Textiles: Xenon Lamp Exposure
- GB/T 8427 Textiles – Tests for Color Fastness – Color Fastness to Artificial Light: Xenon Arc Fading Lamp Test
- GB/T 8430 Textiles - Tests for Color Fastness – Color Fastness to Artificial Weathering: Xenon Arc Fading Lamp Test
- GB/T 14576 Textiles – Tests for Color Fastness – Color Fastness to Light of Textiles Wetted with Artificial Perspiration
- IS: 2454 Indian Standard- Method for Determination of Colour Fastness of Textile Materials to Artificial Light Xenon Lamp)
- ISO 105-B02 Textiles – Tests for Color Fastness – Color Fastness to Artificial Weathering: Xenon Arc Fading Lamp Test
- ISO 105-B04 Textiles – Tests for Color Fastness – Color Fastness to Artificial Weathering: Xenon Arc Fading Lamp Test
- ISO 105-B06 Color Fastness and Ageing to Artificial Light at High Temperatures: Xenon Arc Fading Lamp Test
- M & S C9 Color Fastness to Light
- M & S C9A Color Fastness to Wet Light in the Presence of Alkaline or other Chemical Residues

CPAI-84 Specification for Flame Resistant Materials used in Camping Tentage

Printing Inks/Artists' Materials/Paper

ISO 11798	Information and Documentation – Permanence of writing, printing & copying on paper
ISO 12040	Graphic Technology - Prints and Printing Inks
ISO 18909	Imaging Materials – Processed Photographic Colour Films and Paper Prints
ASTM D3424	Lightfastness of Printed Matter
ASTM D4303	Lightfastness of Artists' Pigments
ASTM D5010	Testing Printing Inks & Related Materials
ASTM D6901	Standard Specification for Artists' Colored Pencils
ASTM F2366	Lightfastness of Ink Jet Prints Exposed to Window Filtered Daylight
GB/T 22771	Graphic Technology – Prints and Printing Inks – Assessment of Lightfastness using Filtered Xenon Arc Light

Roofing

ASTM D4434	Poly Vinyl Chloride Sheet Roofing
ASTM D4637	EPDM Sheet Used in Single-Ply Roof Membrane
ASTM D4798	Xenon-Arc – Bituminous Materials
ASTM D4811	Non-Vulcanized Rubber Sheet Used as Roof Flashing
ASTM D5019	Reinforced Non-Vulcanized Polymeric Sheet
ASTM D6083	Liquid Applied Acrylic Coatings Used in Roofing

Rubber

ISO 3865	Rubber, Vulcanized or Thermoplastic – Methods of Test for Staining on Contact with Organic Materials
ISO 4665	Rubber, Vulcanized or Thermoplastic – Resistance to Weathering
GB/T 3511	Rubber, Vulcanized or Thermoplastic – Resistance to Weathering

Adhesives

- ASTM D904 Exposure of Adhesive Specimens to Artificial Light
- ASTM C1442 Conducting Tests on Sealants Using Artificial Weathering Apparatus
- ASTM C1501 Standard Test Method for Color Stability of Building Construction Sealants

Packaging

- ASTM D6551 Accelerated Weathering of Pressure-Sensitive Tapes by Xenon Arc

Sealants

- ASTM C1442 Conducting Tests on Sealants Using Artificial Weathering Apparatus
- ASTM C1501 Color Stability of Sealants



CHAPTER 6

APPENDIX #2

FLUORESCENT UV LIGHT EXPOSURE TEST METHODS

General

ASTM G-151, Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources

ASTM G154 testing, Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Non-Metallic Materials

British Standard BS 2782: Part 5, Method 540B (Methods of Exposure to Lab Light Sources)

Colts Standard Test – UV Dye Resistance to Fade - QUV

GB/T 14522 – Artificial Weathering Test Method for Plastics, Coatings, and Rubber Materials used for Machinery Industrial Products – Fluorescent UV Lamps

SAE J2020, Accelerated Exp. of Automotive Exterior Matls Using a Fluorescent UV/Condensation Apparatus

Plastics

ISO 4892 Plastics - Methods of Exposure to Laboratory Light Sources-Part 3: Fluorescent UV Lamps

ASTM D-1248, Standard Specification for Polyethylene Plastics Extrusion Materials for Wire and Cable

ASTM D-4329, Standard Practice for Light/Water Exposure of Plastics

ASTM D-4674, Test Method for Accelerated Testing for Color Stability of Plastics Exposed to Indoor Fluorescent Lighting and Window-Filtered Daylight

ASTM D-5208, Standard Practice for Exposure of Photodegradable Plastics

ASTM D-6662, Standard Specification for Plastic Lumber Decking Boards

Adhesives & Sealants

ASTM C 1501, Standard Test Method for Color Stability of Building Construction Sealants as Determined by Laboratory Accelerated Weathering Procedures

ASTM C-1184, Specification for Structural Silicone Sealants

ASTM C-1442, Standard Practice for Conducting Tests on Sealants Using Artificial Weathering Apparatus

ASTM D-904, Standard Practice for Exposure of Adhesive Specimens to Artificial Light

ASTM D-5215, Standard Test Method for Instrumental Evaluation of Staining of Vinyl Flooring by Adhesives

Printing Inks

ASTM F1945, Lightfastness of Ink Jet Prints Exposed to Indoor Fluorescent Lighting

Coatings

ASTM D-4587, Std. Practice for Light/Water Exposure of Paint

GM 4367M Topcoat Materials - Exterior

GM 9125P Laboratory Accelerated Exposure of Automotive Material

ISO 11507, Exposure of Coatings to Artificial Weathering-Exposure to Fluorescent UV and water

ISO 20340, Performance Requirements for Protective Paint Systems for Offshore and Related Structures

NISSAN M0007, Fluorescent UV/Condensation Test

prEN 927-6– Pt. 6: Exposure of Wood Coatings to Artificial Weathering Using Fluorescent UV and Water

US Government, FED-STD-141B

Roofing

CGSB-37.54-M, Canadian General Standards Board Spec. for PVC Roofing & Waterproofing Membrane

ASTM D-4799, Test Method for Accelerated Weathering of Bituminous Roofing Materials

ASTM D-4811, Std. Specification for Nonvulcanized Rubber Sheet Used as Roof Flashing

ASTM D-3105, List of Test Methods for Elastomeric and Plastomeric Roofing & Waterproofing

ASTM D-4434, Std. Specification for PVC Sheet Roofing

ASTM D-5019, Std. Specification for Reinforced Non-Vulcanized Polymeric Sheet Used in Roofing Membrane

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