ATLAS MATERIAL TESTING SOLUTIONS / AMETEK

PLASTICS WEATHERING – FROM BASIC PRINCIPLES TO RECENT DEVELOPMENTS IN TECHNOLOGY AND STANDARDIZATION

FLORIAN FEIL

AOWA - ATLAS ONLINE WEATHERING ACADEMY

ATLAS-MTS.COM

TODAY'S PRESENTER

Dr. Florian Feil

- Global Manager Client Education
- Senior Consultant – Weathering Technology

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Background:

- Expert in weathering and photo-degradation of materials and products.
- Representing Atlas in Standards Committees (ISO, CEN, DIN, ASTM)
- Chair of ISO/TC 35/SC 9
  General test methods for paints and varnishes
- Research on corrosion and corrosion protection at the DECHEMA Research Institute in Frankfurt (2005 - 2011).
- Postdoc on conducting polymers and electrochemistry at the Ohio State University (2003 - 2004).
- PhD degree in chemistry on the polymerization of polystyrene block-copolymers at the University of Constance, Germany (2002).

OUTLINE

- Introduction of Atlas
- Factors of Weathering
  - Solar Radiation
  - Heat
  - Moisture
- Weathering testing
  - Natural Weathering
  - Accelerated Laboratory Weathering
- Acceleration and Correlation
- Summary
- Question and answers (time permitting)

ATLAS MATERIAL TESTING TECHNOLOGY

Over 100 years of weathering testing innovation

Outdoor & Lab Weathering Services

Outdoor & Lab Weathering Services

Atlas Custom Systems

Larger scale solar simulation

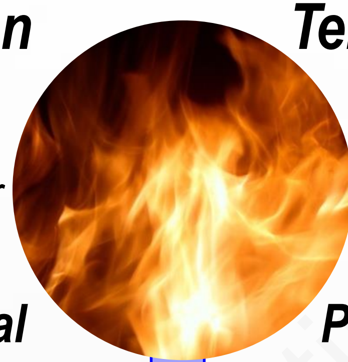
Consulting, Client Education and Standards

THE PRIMARY WEATHERING FACTORS

ATLAS MATERIAL TESTING SOLUTIONS AMETEK

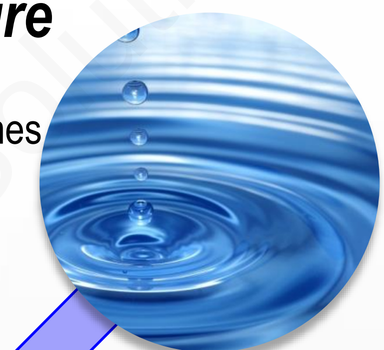
Solar Radiation

- Radiation
- Irradiance
- Spectral power distribution



Temperature

- Min/Max
- Dwell times
- Cycles



Water

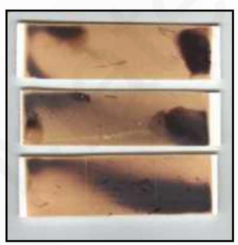
- Quantity
- Duration
- Phase
- Cycles

Chemical stresses

Physical stresses

O_2

+ secondary factors (urban pollutants, acid rain, etc. …)

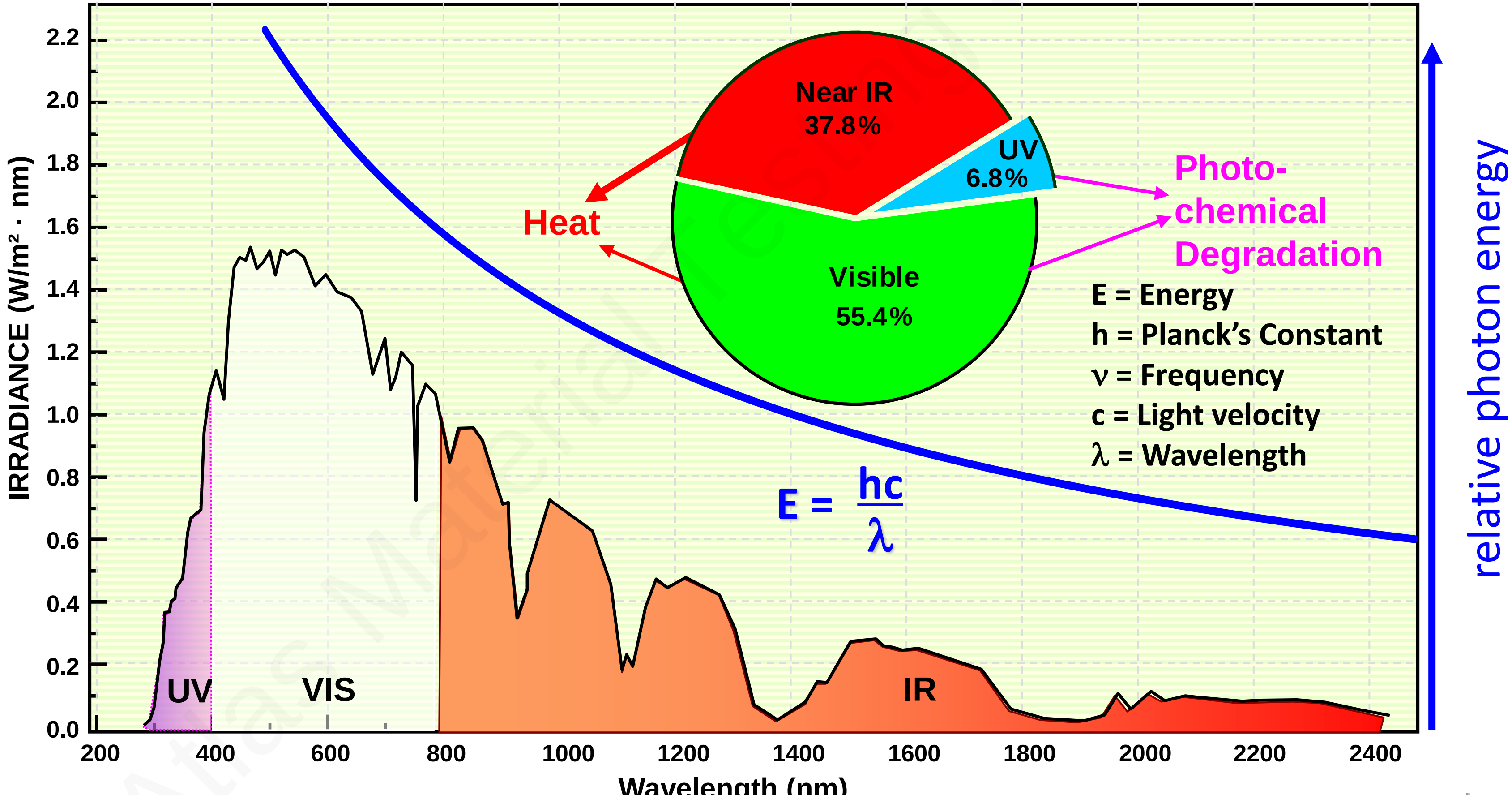


1. **Chemical microscopic damage**
2. **Visual macroscopic damage**

Synergy: “The combined effects are greater than the sum of the parts”

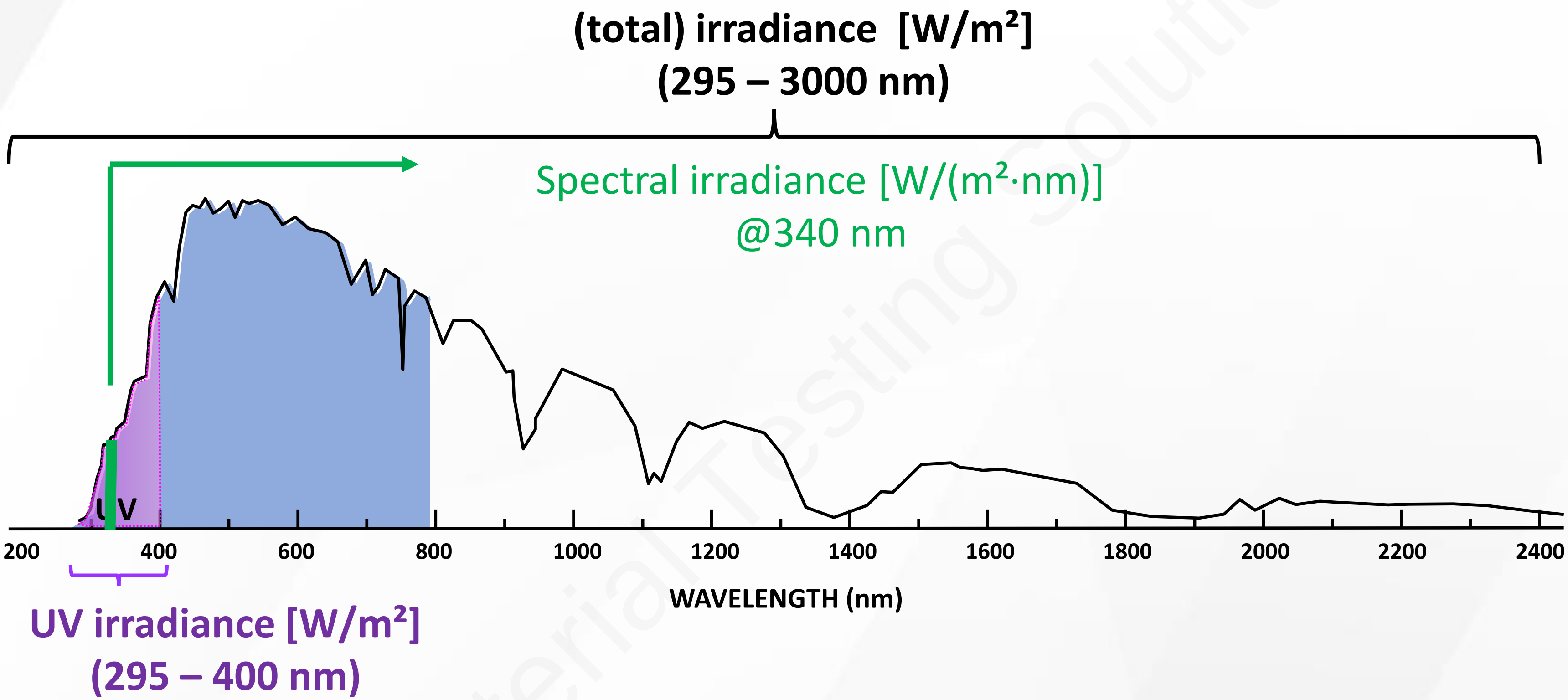
SPECTRAL IRRADIANCE DISTRIBUTION

Reference sun in weathering:
CIE (Commission International de L'Éclairage) CIE 241 (2020) CIE-H-1 (replaces CIE N°85; Table 4); AM1: spectral irradiance when the sun is filtered exactly by one atmosphere.



Atlas MTT CED 2023, Atlas-mts.com

RADIOMETRIC QUANTITIES



	total (295 – 3000 nm)	UV/Vis (300 – 800 nm)	UV range (295 – 400 nm)	spectral @340 nm
Typical **irradiance** Values (1-sun level)[a]	1000 W/m²	550 W/m²	60 W/m²	0.51 W/(m²·nm)
Annual **radiant exposure** in Miami (Ø)[b]	6665 MJ/m²	3637 MJ/m²	396 MJ/m²	3.3 MJ/(m²·nm)

a) Typical ratios in Xenon instruments; b) Average values (2000-2019) 24 °South.

WORLD RADIATION MAP (PUBLISHED 1998)

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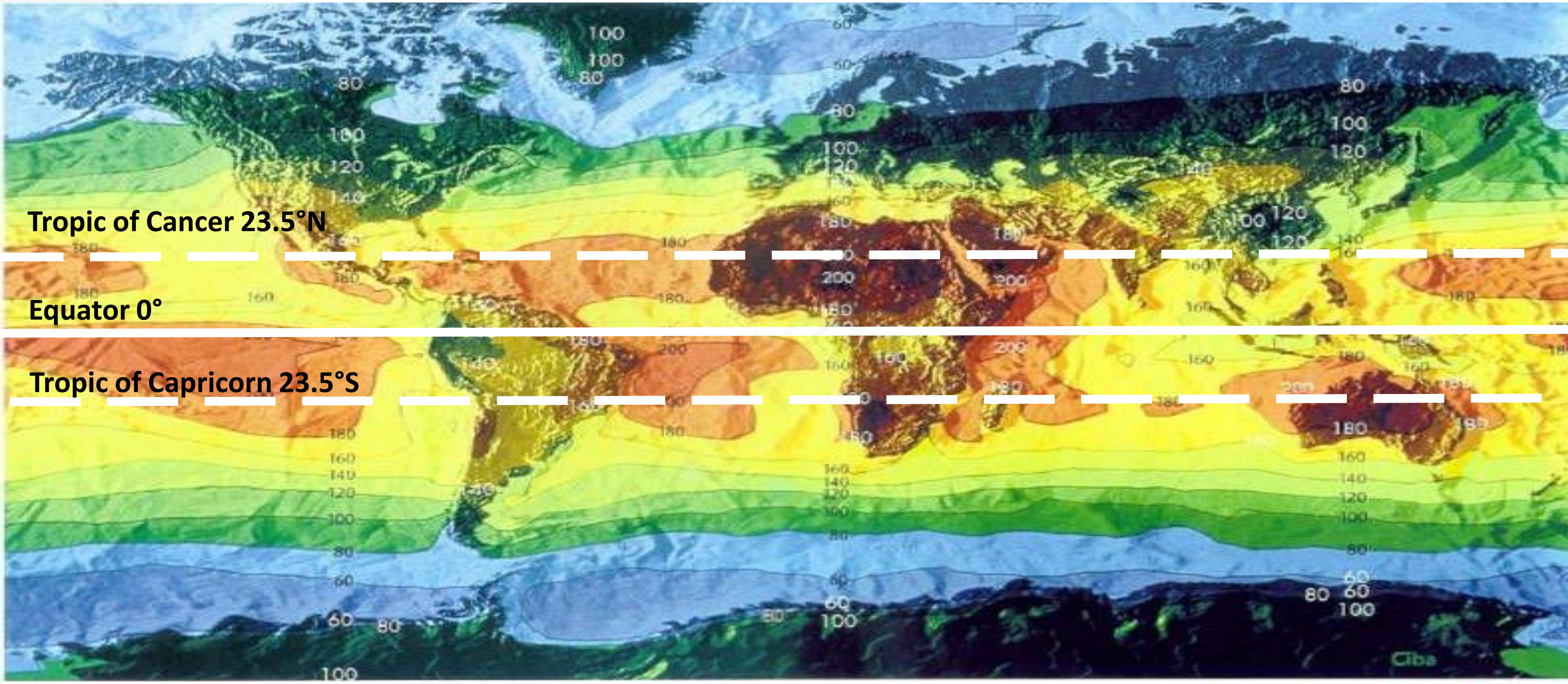

Updated and refined by BASF:
Gregor Huber, *SKZ Symposium – Weathering in the Automotive Industry; Würzburg 2015-04-15* and *7th European Weathering Symposium EWS, Naples,2015-09-17*.

Data provided by the Surface Radiation Budget Project at NASA Langley Research Center.

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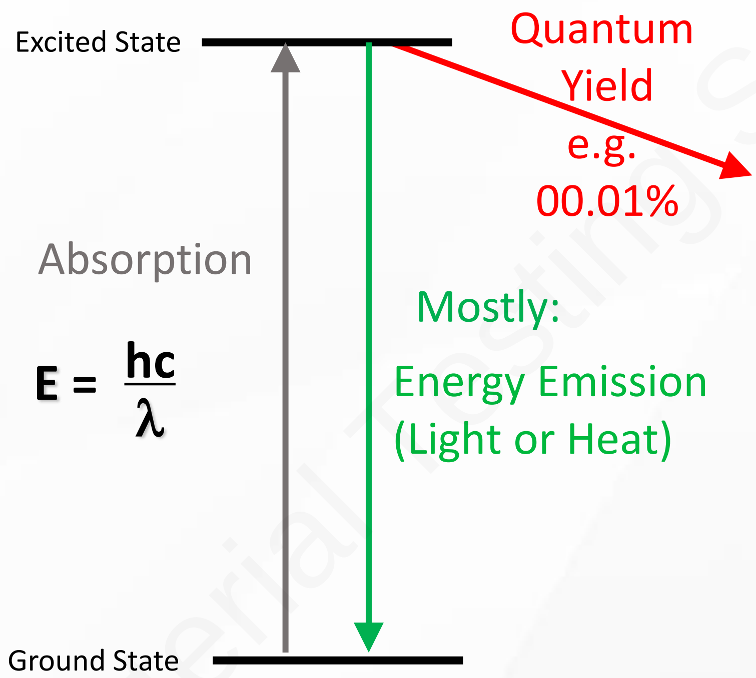
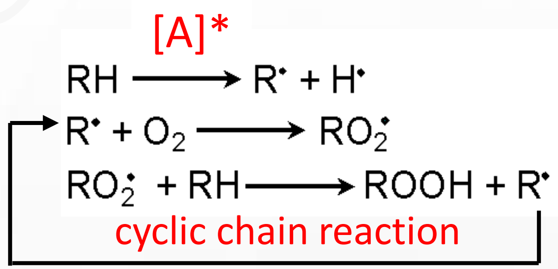
Simplified energy profile of a photochemical reaction



Photodegradation:
Photo-oxidation



→ Mechanical damage (chain scission, cross linking)
→ Appearance change (e.g. gloss loss, whitening, discoloration, bleaching)
→ Altered functionality, (Degradation of additives)

Photo-active group (Chromophore):
Polymer, Additive, Impurity

Weathering (photochemical) degradation starts by the absorption of a photon and the formation of an electronically excited molecule

SUMMARY: EFFECTS OF HEAT

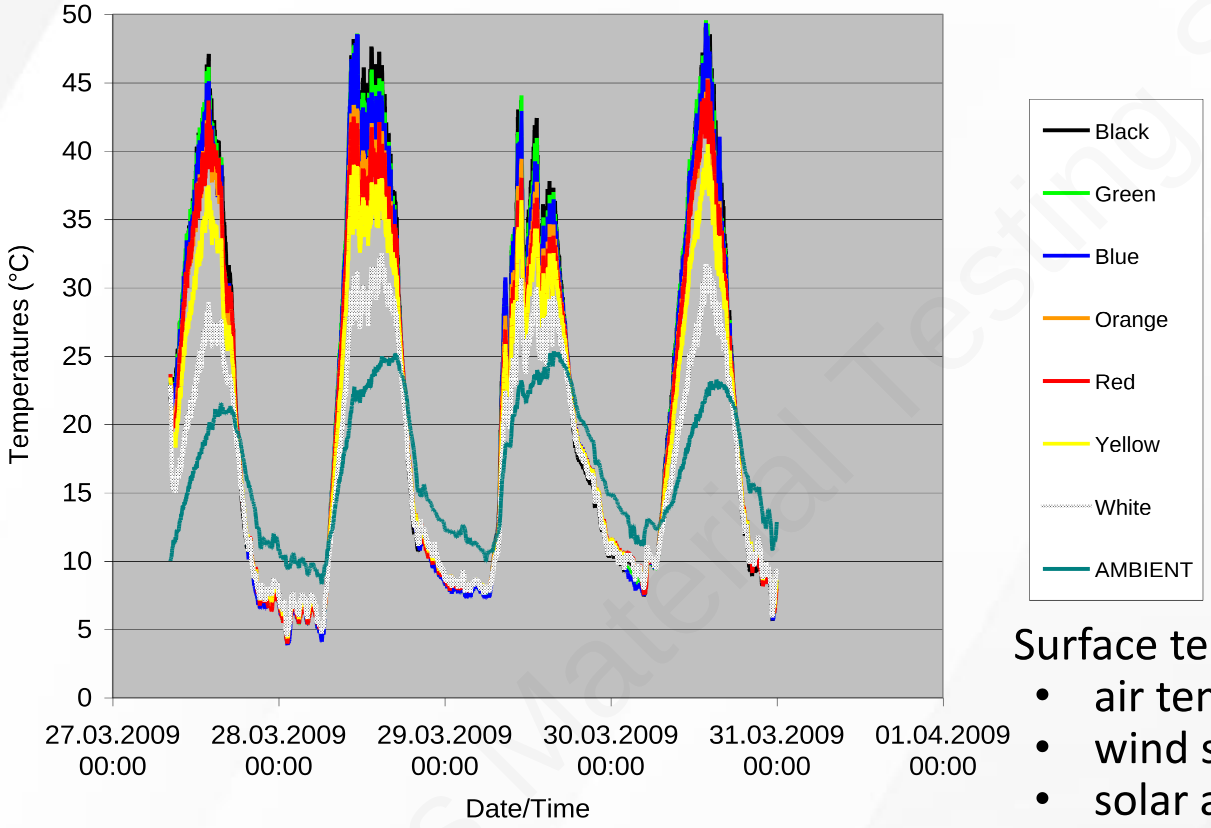
Elevated Sample Temperatures
(higher diffusion rate and reaction speed, phase transitions, TG)

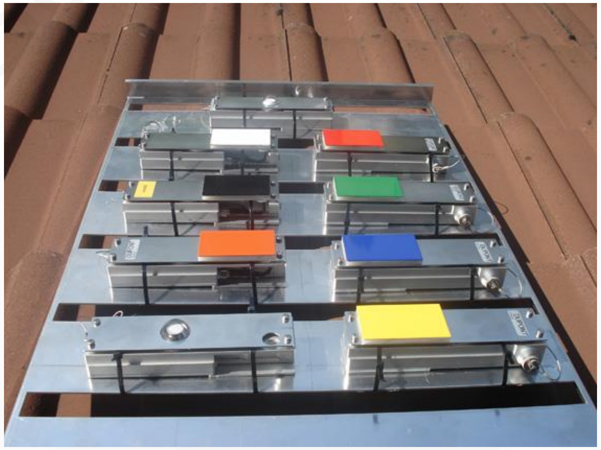
Expansion/Contraction
(mechanical tension and compressive stress, migration)

Evaporation/Condensation
(mechanical tension and compressive stress, loss of additives, content of moisture)

Thermal Ageing
(additional ageing process)

Surface temperatures of colored PVC-coated aluminum plates and ambient temperatures in Phoenix, Arizona:

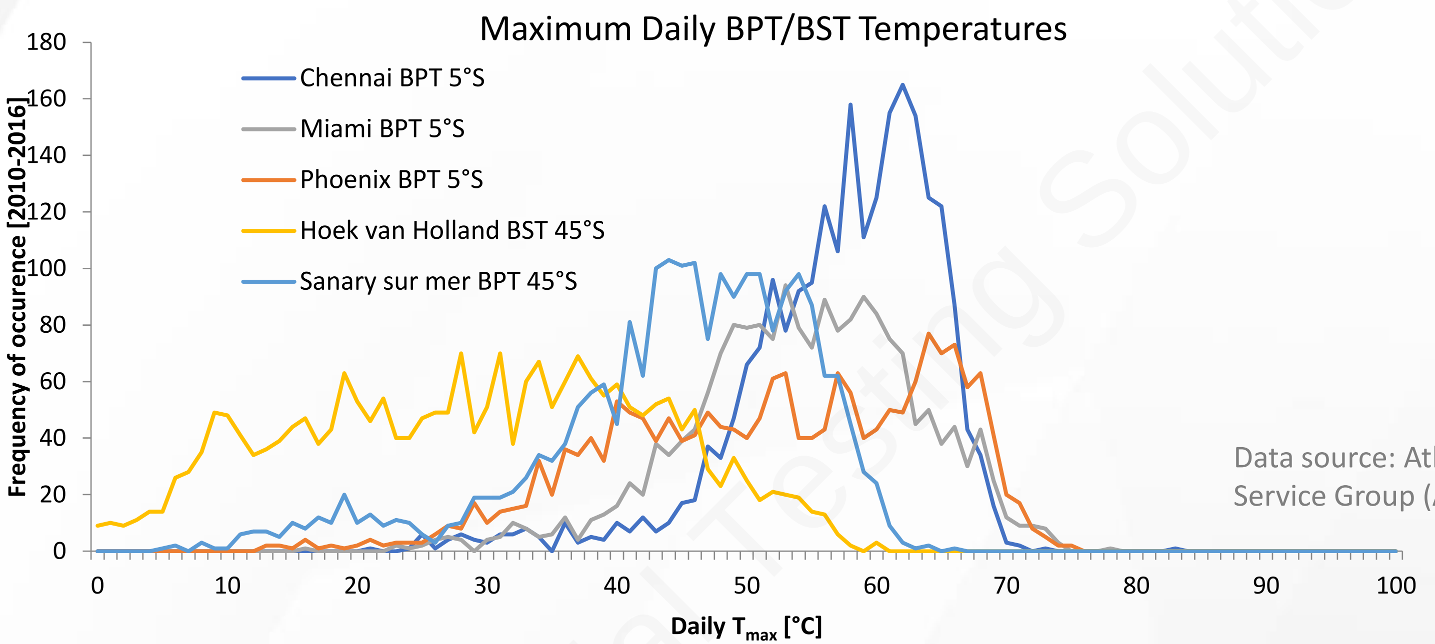




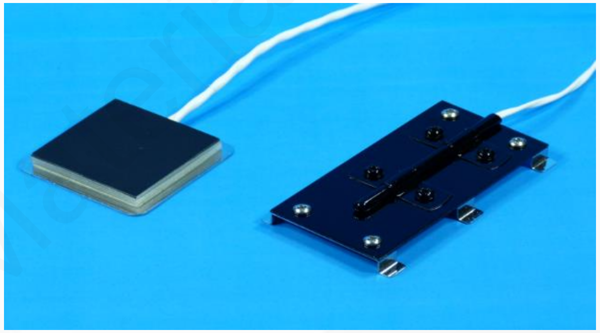
Surface temperature mainly depends on:

- air temperature
- wind speed
- solar and thermal radiation heat (surface color!)
- thermal conductivity of the sample

MAXIMUM DAILY TEMPERATURES



Data source: Atlas Weathering Service Group (AWSG) 2010-2015.



Black standard sensor (BST):

- Black coated stainless-steel plate with insulated back

Black panel sensor (PBT):

- Black coated stainless-steel plate without insulated back

EFFECTS OF MOISTURE

- Diurnal and seasonal variation of air humidity [%RH] and surface wetness:
  Absorption/Desorption (mechanical tension and compressive stress, wash out)
- Freeze-thaw cycles (mechanical tension)
- Thermal shock (mechanical tension)
- Erosion (loss of substance)
- Impact (loss of material)
- Chemical (hydrolysis)

QUANTIFYING MOISTURE

Absolute Humidity [g/m³]:
The density of water vapor.
It is the mass of the water vapor divided by the volume that it occupies

AH

Relative Humidity [%]:
The amount of water vapor in the air, compared to the amount the air could hold if it was totally saturated.

RH

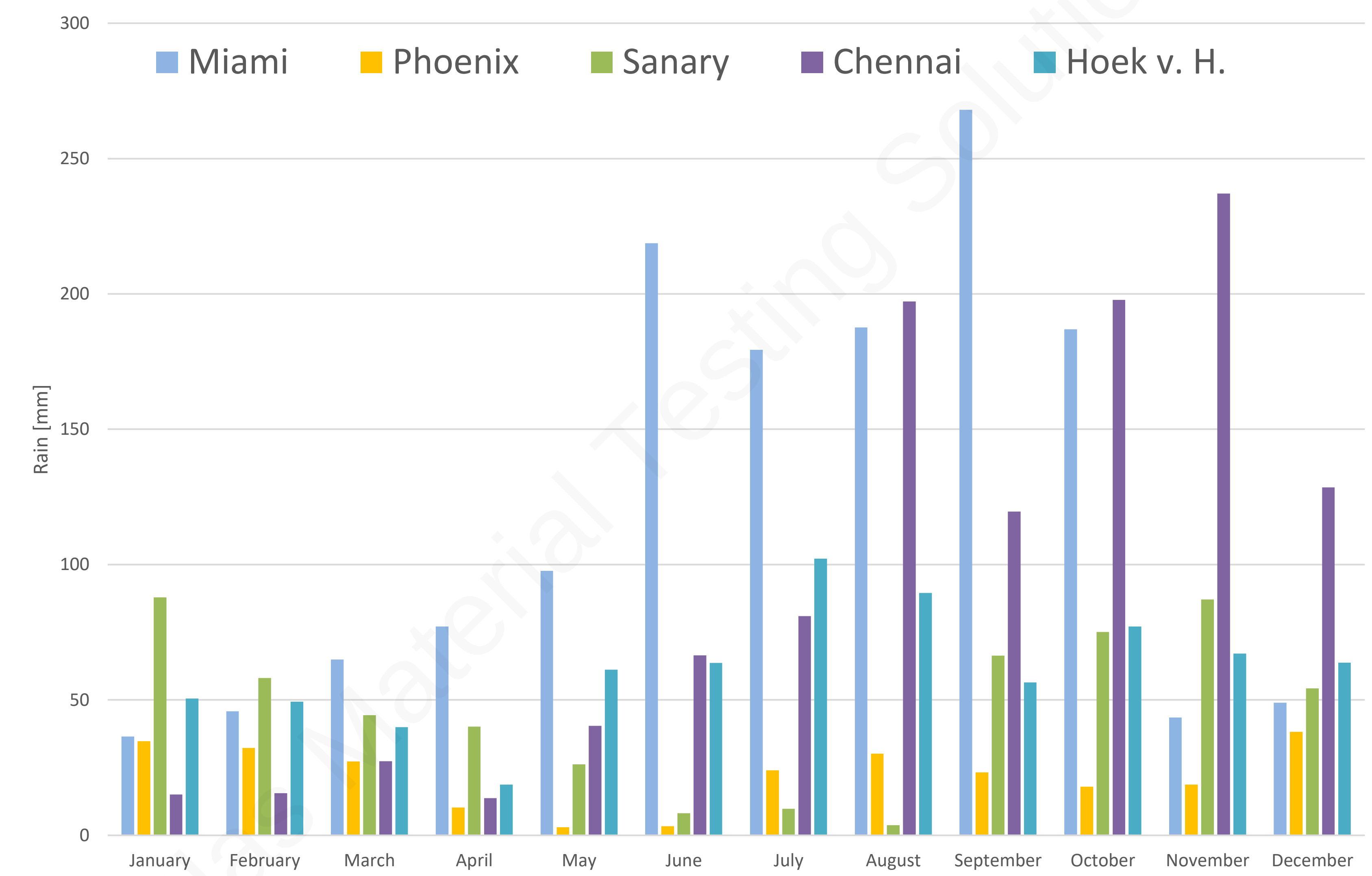
Dew Point [K]:
The temperature to which the air must be cooled for water vapor to condense and form fog or clouds (i.e. the temperature where the relative humidity is 100%).

T_D

Time of Wetness [%]:
The amount of time an exposed surface is wet by the effects of dew, rain, snow or mist.

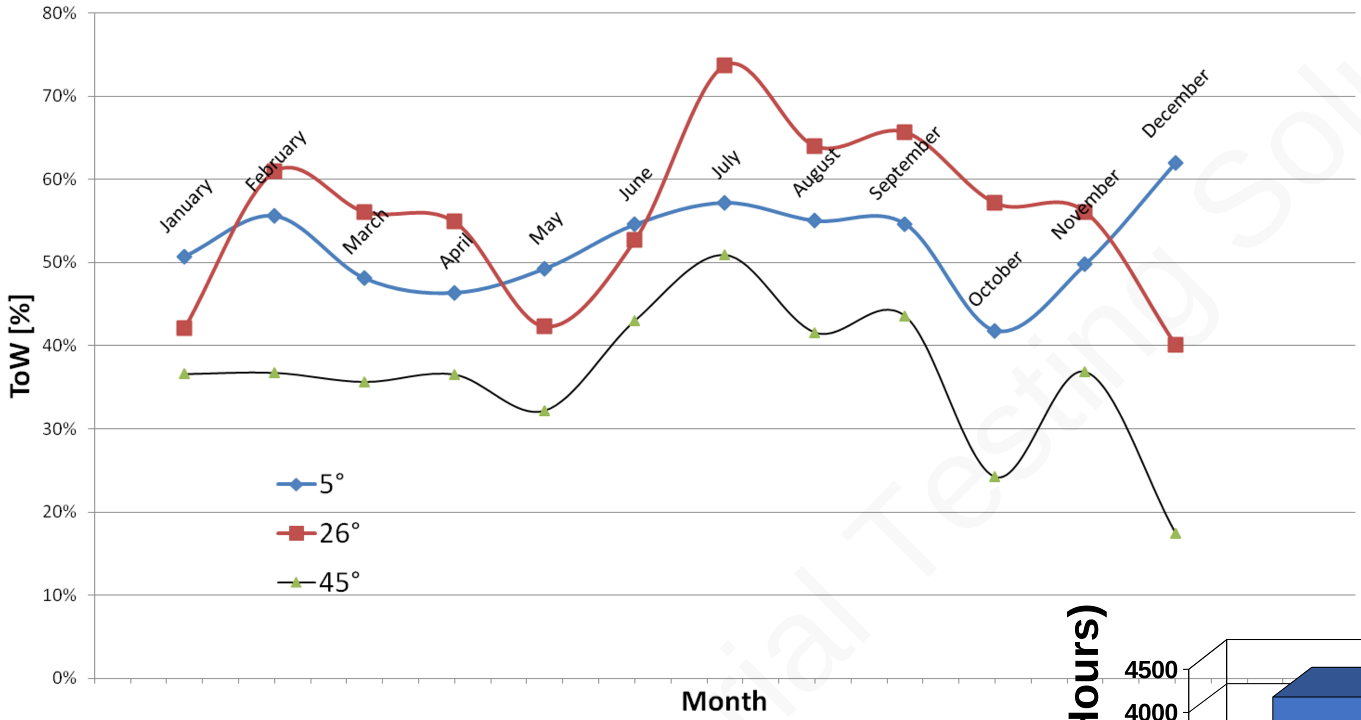
ToW

MONTHLY RAIN AT REFERENCE LOCATIONS



Data source: Atlas Weathering Service Group (AWSG): most data 2000-2019.

TIME OF WETNESS (TOW)

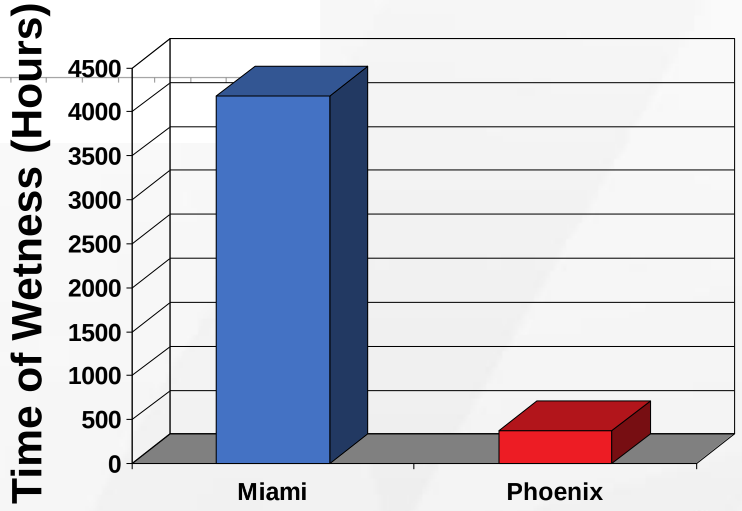


Data source: Atlas Weathering Service Group (AWSG) 2010-2012.

Measured ToW: highly dependent on orientation

ISO 9223 (2012): Corrosion of metals and alloys - Corrosivity of atmospheres - Classification, determination and estimation

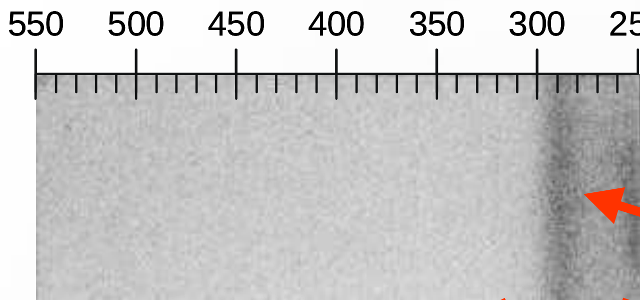
Estimating the time of wetness:
TOW; RH > 80%, T > 0°C



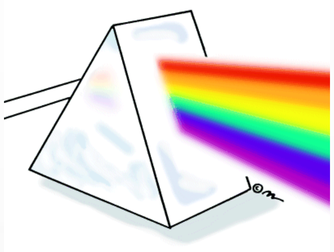
EFFECT OF RADIATION AND WATER

1. Photochemical 2. Mechanical

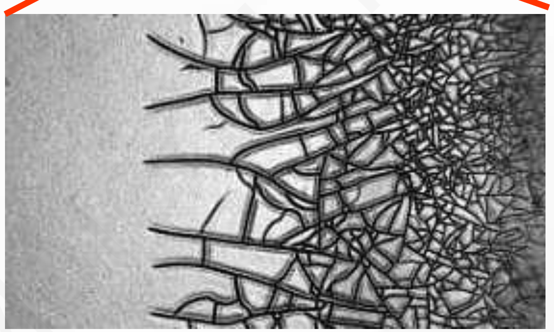
Acrylic-Melamine clear coat; Water revealing the physical damage



Irradiation wavelength (nm)



After 1000 hours, yellowing ONLY



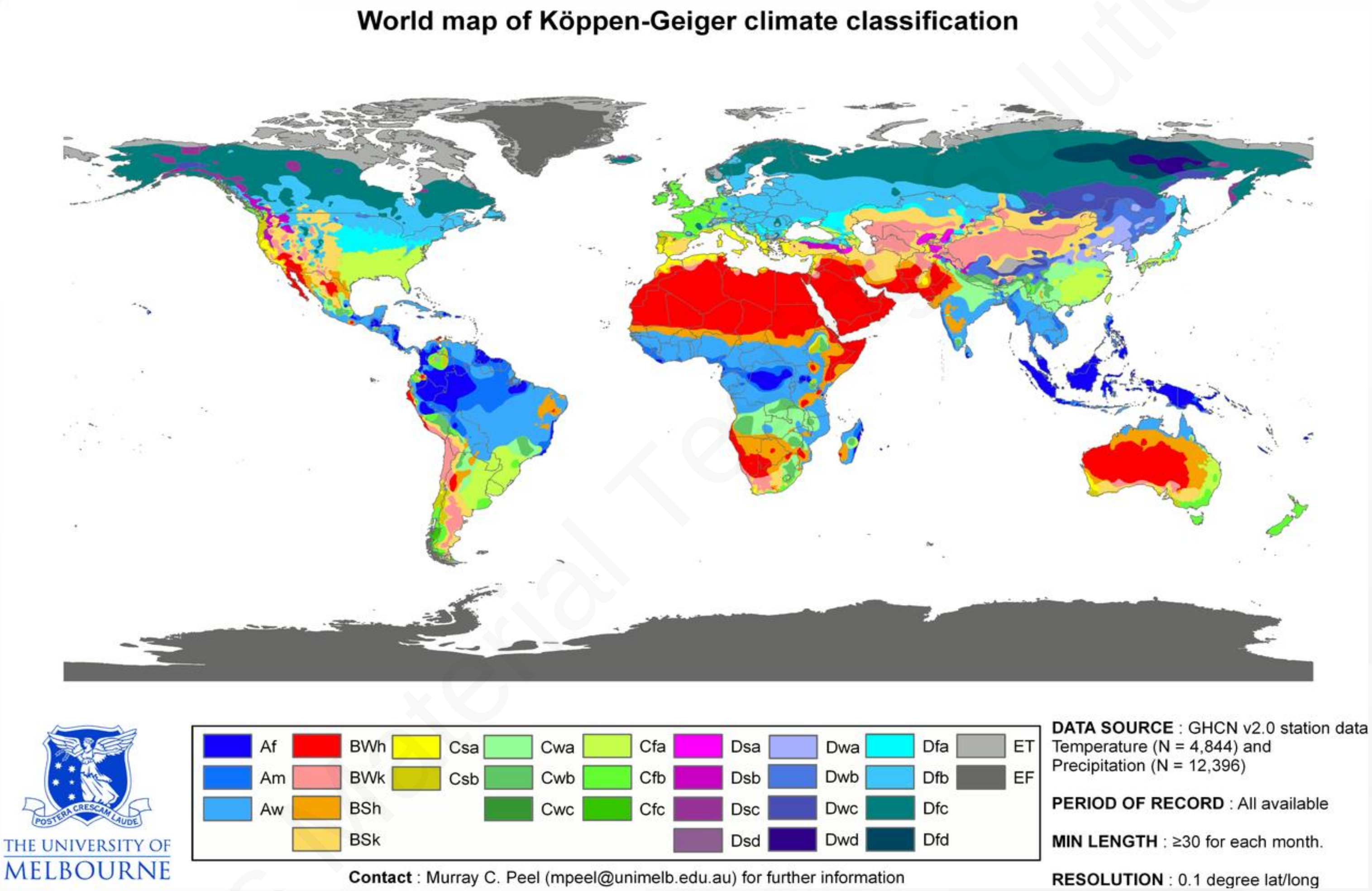
+ 24 hours wet/dry cycles

Cracks

According to A. Geburtig

Especially the weathering of coatings is influenced by moisture cycles.

CLIMATE REGIONS OF THE WORLD



Köppen-Geiger: Classification of climate zones upon their seasonal weather patterns.

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REFERENCE CLIMATE ZONES

South Florida

- *History: Weathering in subtropical climate*
- *Extreme conditions (high UV radiation, warm, humid)*
- *Inland – no coastal influence*
- *Minimal pollution – clean environment*

Arizona

- *History: Weathering in desert climate*
- *Extreme conditions (high UV radiation – hot - dry)*
- *Higher maximum temperatures compared to Florida*
- *Minimal pollution – clean environment*

Recognized benchmark weathering sites.

Atlas - SFTS

Atlas - DSET

ATLAS' WORLDWIDE EXPOSURE NETWORK

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Atlas operated sites | WEN affiliated sites | Accelerated Weathering Testing Lab

Prescott, AZ, USA
High Altitude Test Site

Alberta, MI, USA
Cold Climate Test Site

Mt. Prospect, IL, USA & Linsergericht-Altenaßlau, Germany
Weathering Service Labs

Medina, OH, USA
Northern Industrial Temperate Climate

Moscow, RU
Humid Continental Climate
Novorossiysk, RU
Black Sea Corrosion Site
Gelendzhik, RU
Warm Temperate Maritime

Phoenix, AZ, USA
High Desert Benchmark,
Accelerated Concentrated Solar Weathering,
Atlas Solar Test Center (STC)

Seosan, KR
Light Industrial Marine
Choshi, JP
Subtropical Climate
Kirishima, JP
Volcanic Marine
Miyakojima, Okinawa
Tropical /Subtropical Humid
Guangzhou, CN
Subtropical Climate
Hainan, CN
Tropical Climate
Turpan, CN
Desert Climate
Singapore, SG
Tropical Climate

Jacksonville, FL, USA
Automotive Acid Etch
Long Key, FL, USA
Corrosion Test Site

Miami , FL, USA
Subtropical Benchmark

Sanary-Sur-Mer, Bandol, FR
Mediterranean Benchmark

Hoek van Holland, NL
North Sea Corrosion Test Center

Chennai, IN
Tropical Benchmark

Townsville, AU
Tropical Climate
Melbourne, AU
Temperate Climate

NATURAL WEATHERING: PLASTICS

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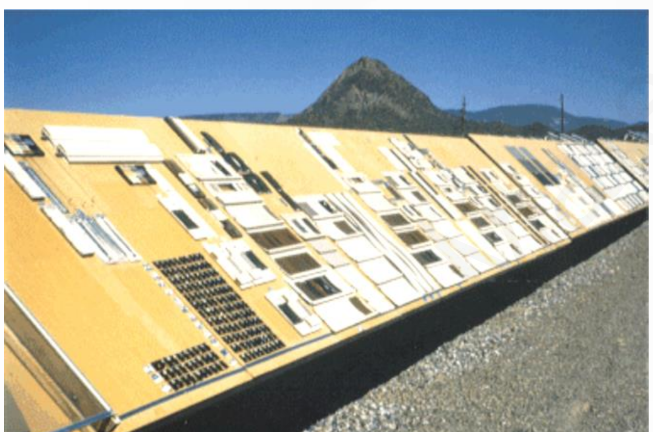
ISO 877-2 – Plastics: Methods of exposure to solar radiation – Part 2: Direct weathering and weathering using glass-filtered solar radiation

Method A: Direct - Open backed

- **Apparatus:** specimen rack
  Method A: design, frame, Materials (inert; Aluminum Alloys, stainless steel, untreated wood in dry climates); adjustable solar altitude (i.e. tilt) and azimuth;
  Method B: additionally framed cover of window, windscreen or other glass types
- **Conditions of exposure:** aspect and site
- **Exposure stages**: duration or radiant exposure



Method A: Direct - Backed

Method B: Under-glass

Also:

ASTM G7 - Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials

ASTM G24 - Standard Practice for Conducting Exposures to Daylight Filtered Through Glass

DIRECT WEATHERING

90° South Exposure Rack 45° South Exposure Rack 34° South Exposure Rack

Standards:

ASTM G7—Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials

ISO 877-1—Plastics: Methods of Exposure to Solar Radiation—Part 1: General Guidance

ISO 2810—Paints and Varnishes: Natural Weathering of Coatings—Exposure and Assessment

TYPICAL EXPOSURE CONDITIONS

ASTM G7, ISO 877-1/2, ISO 2810

Variations:

- by sample orientation (5°, 45°, at latitude, 90°; N/S)
- by sample backing
- by test specimen (flat material panel or component)

Exposure Type	Unbacked	Backed
5° South	Exterior Materials	Roofing Membranes and other Roofing Materials
At Latitude	Any Material	
45° South	Powder/Coil Coating, Corrosion Tests	PVC Siding, General Building Materials, Thermoplastics
90° South	Window Profiles, Trade Sales Panels, Wind Screens	PVC Siding
90° North	Mildew/Algae/Biofilm Studies	
5° or 45° Underglass	Interior materials, Foam Backed Vinyl, Carpets, Window Coverings, Indoor Flooring, etc.	

EXAMPLES OF ANNUAL RADIANT EXPOSURES

Typical climates: average radiant exposure per year	Orientation	Total 295 - 2450 nm MJ/m²	UV 295 - 385 nm MJ/m²	UV 300 - 400 nm MJ/m²
Miami, Florida/US (2000 - 2022) (90°: 2009 - 2013)	5° S	6337	309	402
	26° S	6675	313	407
	45 °S	6313	288	374
	90 °S	3630	166	215
Phoenix, Arizona/US (2000 - 2022)	5° S	7553	348	452
	34° S	8377	351	456
	45 °S	8235	333	433
Sanary-sur-Mer, France (2006 - 2022)	0°	5774	232	301
	45 °S	6896	257	334
Hoek van Holland, The Netherlands (2007 - 2022)	0°	3963	159	207
	45 °S	4587	171	222
Chennai, India (2008 - 2022)	5° S	6876	304	380

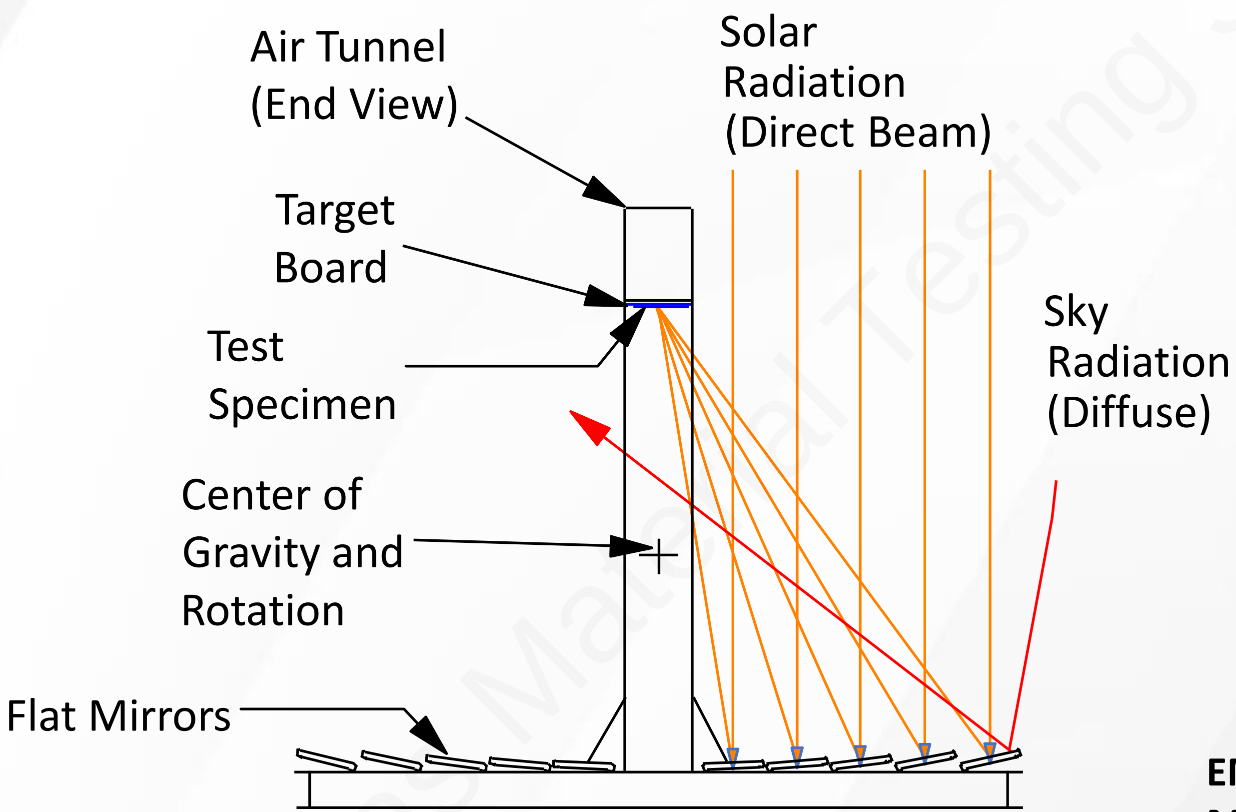
Data source: Atlas Weathering Service Group (AWSG)

Note 1: old unit „Langley": 1 Ly = 41,84 kJ/m²

Note 2: red and green values calculated based on H(300 – 400 nm) ~ 1.3 x H(295-385 nm)

ACCELERATED OUTDOOR WEATHERING

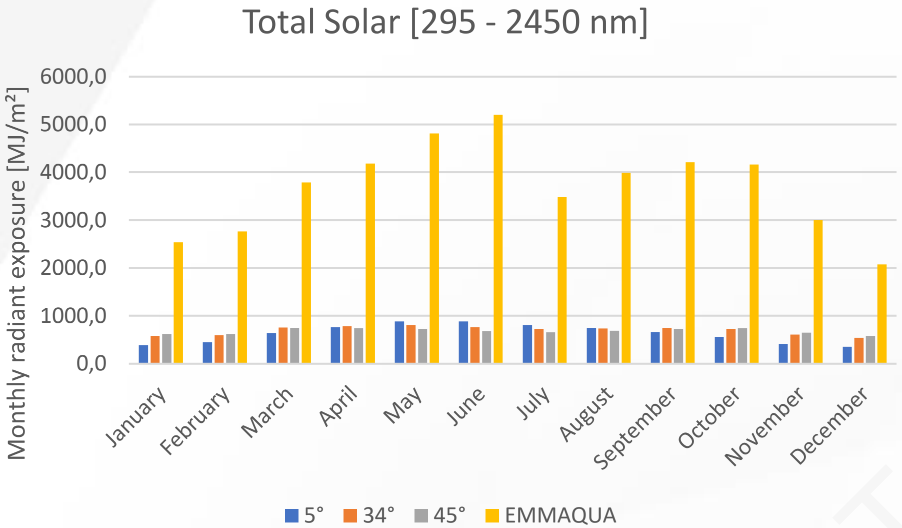
- **ISO 877-3 -** Plastics – Methods of exposure to solar radiation – Part 3: Intensified weathering using Fresnel mirrors
- **ASTM G90 -** Standard Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight

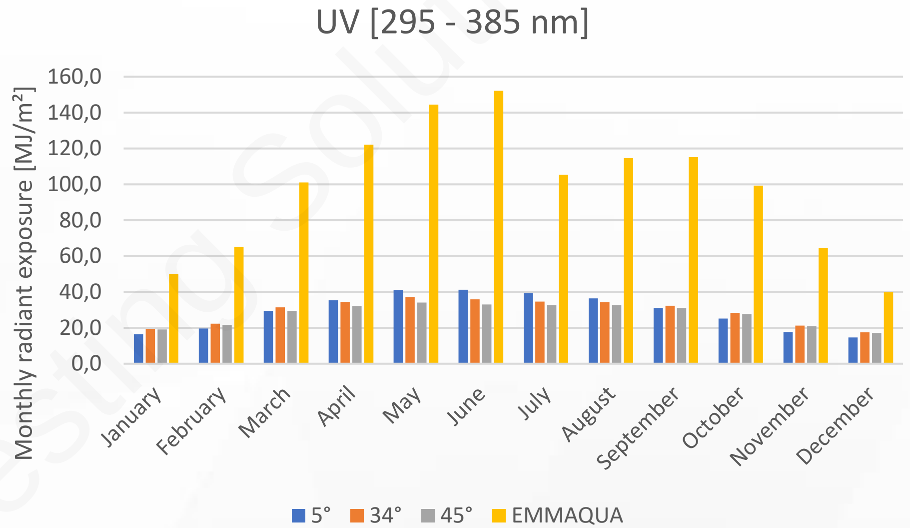


Temperature control: by air flow or cool mirrors (LT-EMMA)

EMMA®/**EMMAQUA**® **E**quatorial **M**ount with **M**irrors for **A**cceleration (*AQUA* – with water spray)

EMMA/EMMAQUA® RADIANT ENERGY





Average Phoenix (2000-2022)	Intensification factor vs. 34°	
	Total	**UV**
January	4.28	2.56
February	4.68	3.02
March	4.88	3.15
April	5.33	3.62
May	5.93	3.88
June	6.69	4.21
July	4.62	2.96
August	5.27	3.32
September	5.48	3.49
October	5.67	3.48
November	4.79	2.98
December	3.80	2.26

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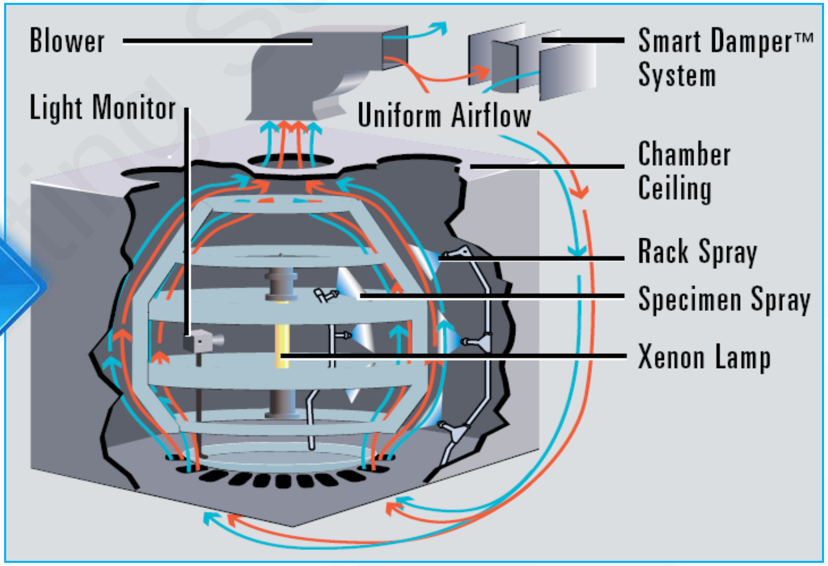
BRINGING THE OUTDOORS INTO THE LABORATORY

Main weather factors: ***Heat*** ***Light*** ***Moisture***



Laboratory weathering instruments deliver simulated solar radiation, heat and moisture in a controlled, reproducible way to both eliminate natural outdoor weather variability and provide test acceleration through increased stress levels.

How well this is accomplished differentiates instruments and manufacturers.

REQUIREMENTS OF REALISTIC LABORATORY WEATHERING

Correlation

- same stress as in outdoor conditions results in:
- same macroscopic ageing/appearance change

Relevance

- same degradation pathway, same degradation mechanism

Acceleration

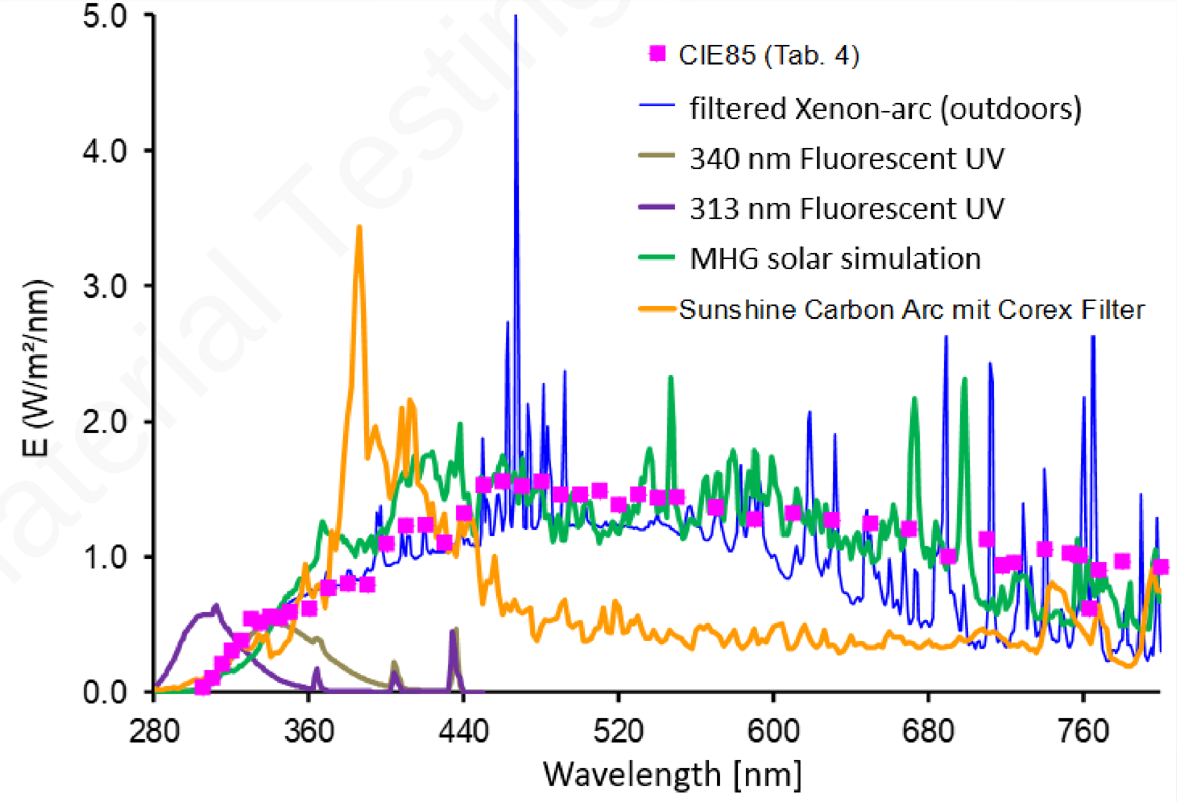
- over field exposures

Precision

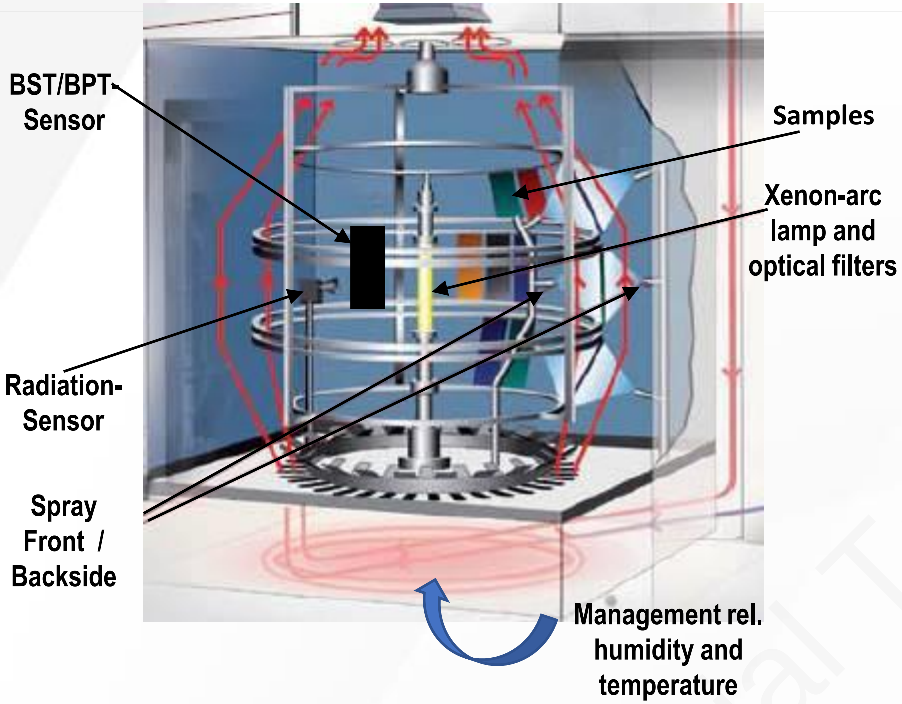
- Repeatable and reproducible test results
- Independent control over stress factors

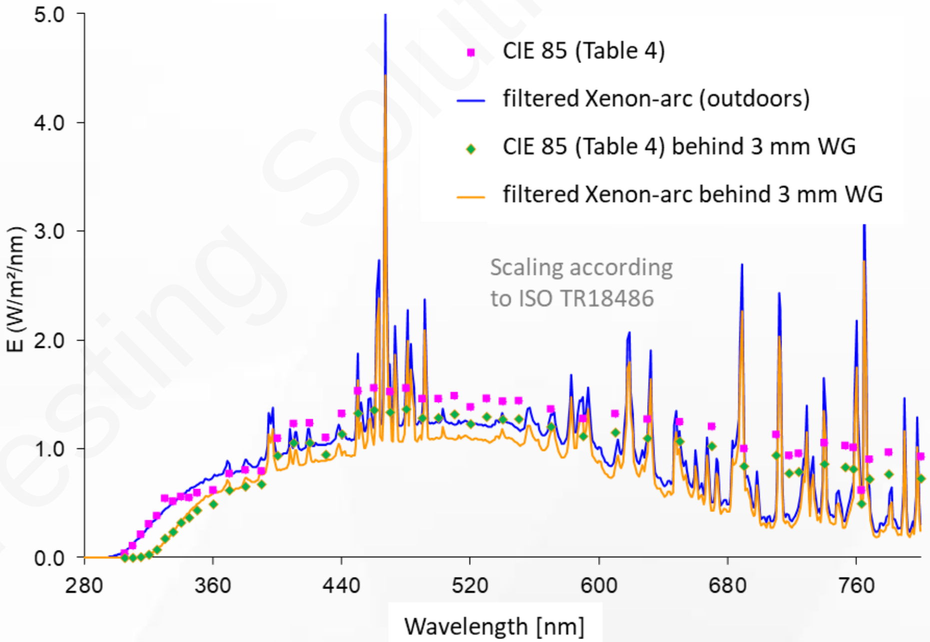
LIGHT SOURCES FOR LABORATORY WEATHERING

- **Xenon Arc** instruments
  - Weather-Ometer®, Xenotest®, SUNTEST®
- **Fluorescent UV** instruments
  - UVTest®
- **Carbon Arc** instruments
- **Metal Halide** systems
- **Mercury** Vapor instruments
  - SEPAP (not included)



XENON-ARC WEATHERING





Weathering with full spectrum Xenon-arc radiation:

- Monitoring and control of all test variables (Irradiance, CHT, BPT, RH)
- Cycles (dry/rain phase and/or light/dark phase)

General Standards:

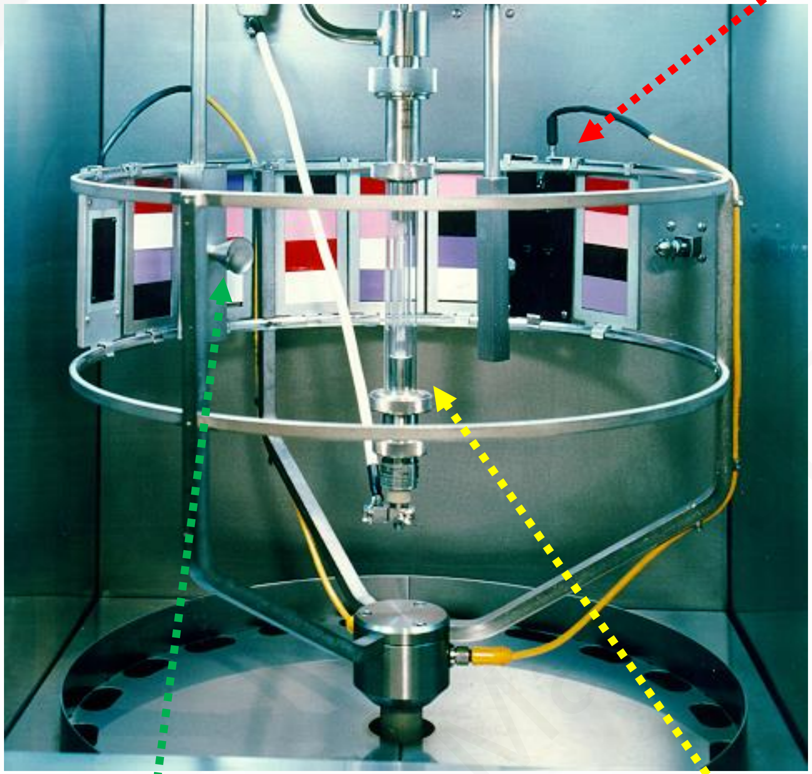
ASTM G155 Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials

ISO 16474-2 Paints and varnishes - Methods of exposure to laboratory light sources - Part 2: Xenon-arc lamps

ISO 4892-2 Plastics - Methods of exposure to laboratory light sources - Part 2: Xenon-arc sources

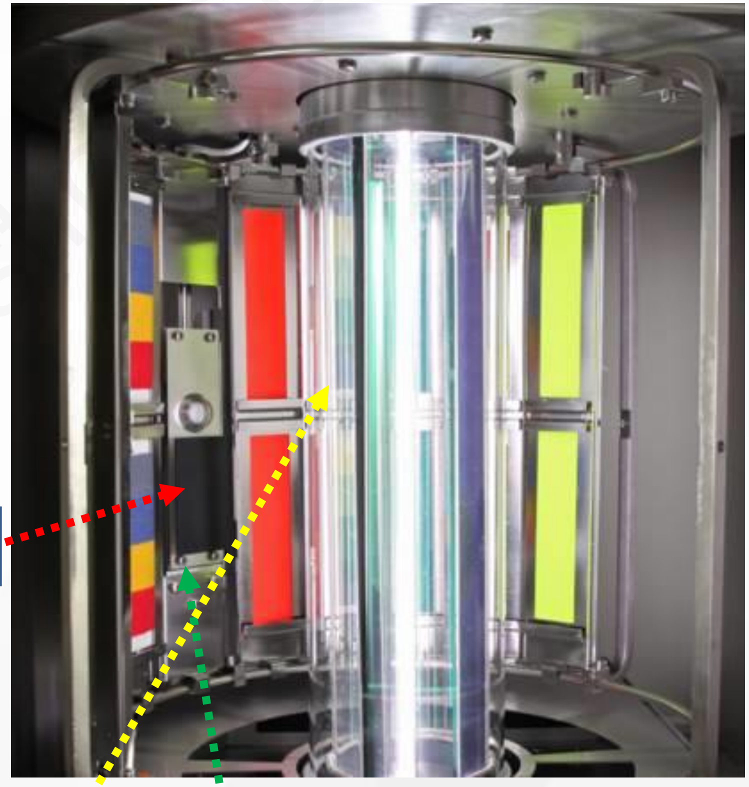
Test Chamber: Water-cooled

Ci3000 Weather-Ometer®



Test Chamber: Air-cooled

Xenotest® 220+



BPT

BST

Radiation monitor

Xenon Lamp & Filter Assembly

Irradiance sensor (according to ISO 9370) and BST on sample level

BENEFITS AND APPLICATIONS

Rotating-rack type:

- **“Full weathering instrument”**
  - Monitoring and control of irradiance, surface temperature and chamber air temperature
  - Water spray
- **Strengths and application**
  - Flat test specimen
  - Irradiance and temperature uniformity
  - High capacity
  - Backing options
- **Limitations**
  - Specimen size (flat)
  - Specimen dimensions (3D)

Ci4400

Flat-bed type:

- **“Full weathering instrument”**
  - Monitoring and control of irradiance, surface temperature and chamber air temperature
  - Water spray
- **Strengths and Application**
  - Component (3D) testing
  - Cooling option
- **Limitations**
  - Irradiance and temperature uniformity

SUNTEST® XXL / XXL+

GENERAL TEST METHODS

Weathering

Materials for exterior applications

- Parameters:
  - Radiation: Outdoor „Daylight“
  - Heat: Normal Temperature
  - Humidity: Rain, Dew, Relative Humidity

Outdoor exposure: direct
Instrument: Xenon-arc, Fluorescent UV, Carbon-arc
Climate types: Moderate, Humid, Arid…
Application: Plastics, Coatings, Technical Textiles, …
Test Phases: Spray, Condensation, Dry, Dark, Light
Examples: ISO 4892-2 Cycle 1, ASTM G155 Cycle 1
SAE J2527, ISO 105-B10, ASTM D7869, ISO 16474-2 Cycle 1

Lightfastness

Materials for interior applications

- Parameters:
  - Radiation: „Daylight“ behind window glass
  - Heat: Normal Temperature
  - Humidity: Relative Humidity

Outdoor exposure: behind window glass
Instrument: Xenon-arc, (Fluorescent UV), Carbon-arc
Climate type: interior climate
Application: Apparel, Furniture, Packaging, Paper, …
Test Phases: Dry, (Dark), Light
Examples: ISO 4892-2 Cycle 2, ASTM G155 Cycle 4, ISO 105-B02, ISO 12040, ISO 16474-2 Cycle 2

Hot-Lightfastness

Materials for automotive interior applications

- Parameters:
  - Radiation: „Daylight“ behind window glass
  - Heat: High Temperature
  - Humidity: Relative Humidity

Outdoor exposure: behind window glass, IP/DP-Box, Black Box
Instrument: Xenon-arc, Carbon-arc
Climate type: automotive interior climate
Application: Plastics, Coatings, Leather, Textiles, …
Test Phases: Dry, (Dark), Light
Examples: ISO 4892-2 Cycle 3, ASTM G155 C.8, SAE J2412, ISO 105-B06

EXAMPLE: ISO 4892-2 (2013) CYCLES 1,2,3

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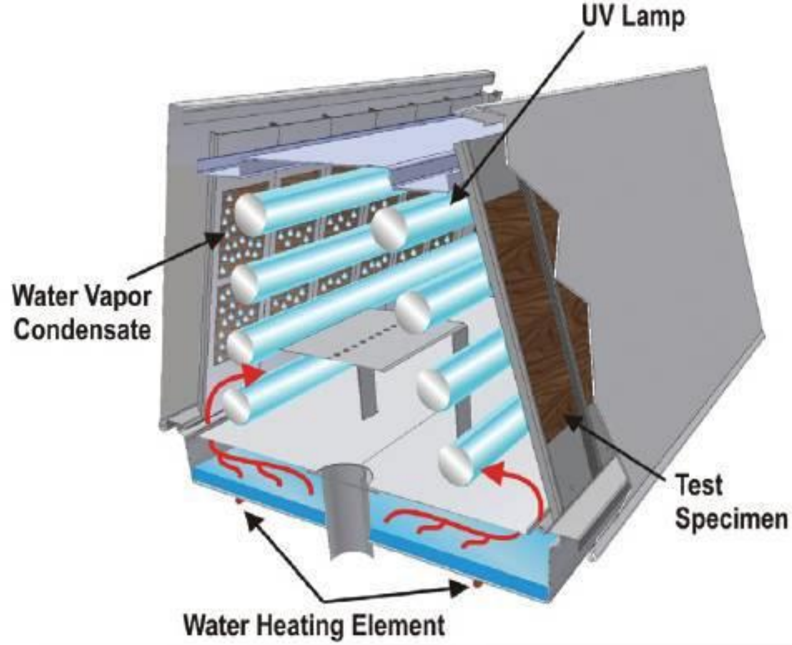
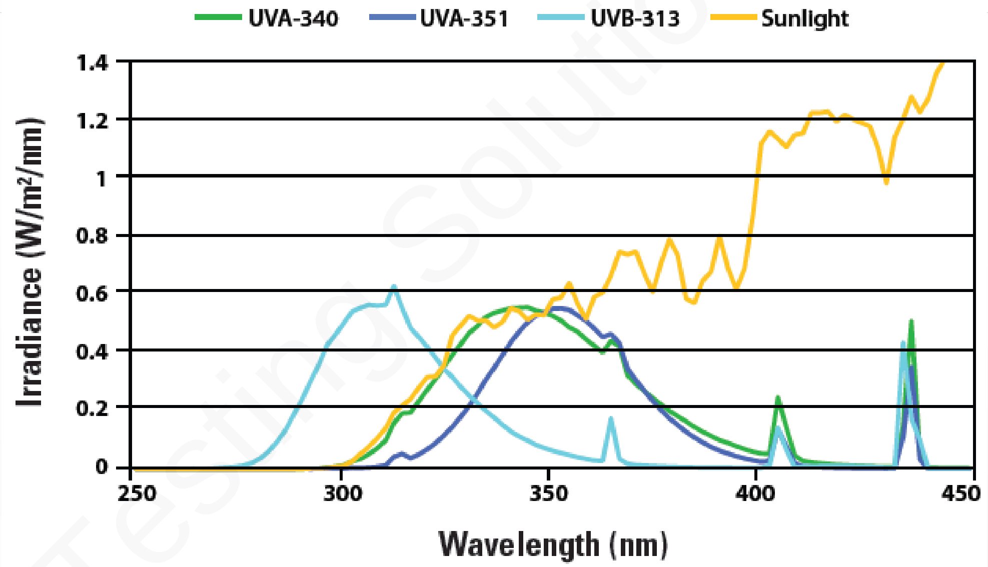
Xenon-arc instruments:

Method A — Exposures using daylight filters (artificial weathering)						
Cycle No	Exposure period	Irradiance		Black-**standard** temperature [°C]	Chamber temperature [°C]	Relative humidity %
		Broadband UV300-400 [W/m²]	Narrowband [W/(m²·nm)]			
1	102 min dry	60 ± 2	0.51 ± 0,02 (@340 nm)	65 ± 3	38 ± 3	50 ± 10
	18 min water spray	60 ± 2	0.51 ± 0,02 (@340 nm)	----------	-----------	-----------
Method B — Exposures using window glass filters						
2	Continuously dry	50 ± 2	1.10 ± 0,02 (@420 nm)	65 ± 3	38 ± 3	50 ± 10
3	Continuously dry	50 ± 2	1.10 ± 0,02 (@420 nm)	100 ± 3	65 ± 3	20 ± 10

→ typical weathering cycle
→ harmonized with
ISO 16474-2 (coatings)
ISO 105-B10 (textiles)
→ lightfastness cycle

→ hot-lightfastness cycle
→ Cycles 4,5,6 are similar, but with BPT control





Typical control parameters:

- SPD by lamp type (UVB-313, UVA-340, UVA-351)
- Irradiance control
- BPT control
- Water sprays
- Condensation (dark cycle)
- Light/Dark Cycling
- No RH control

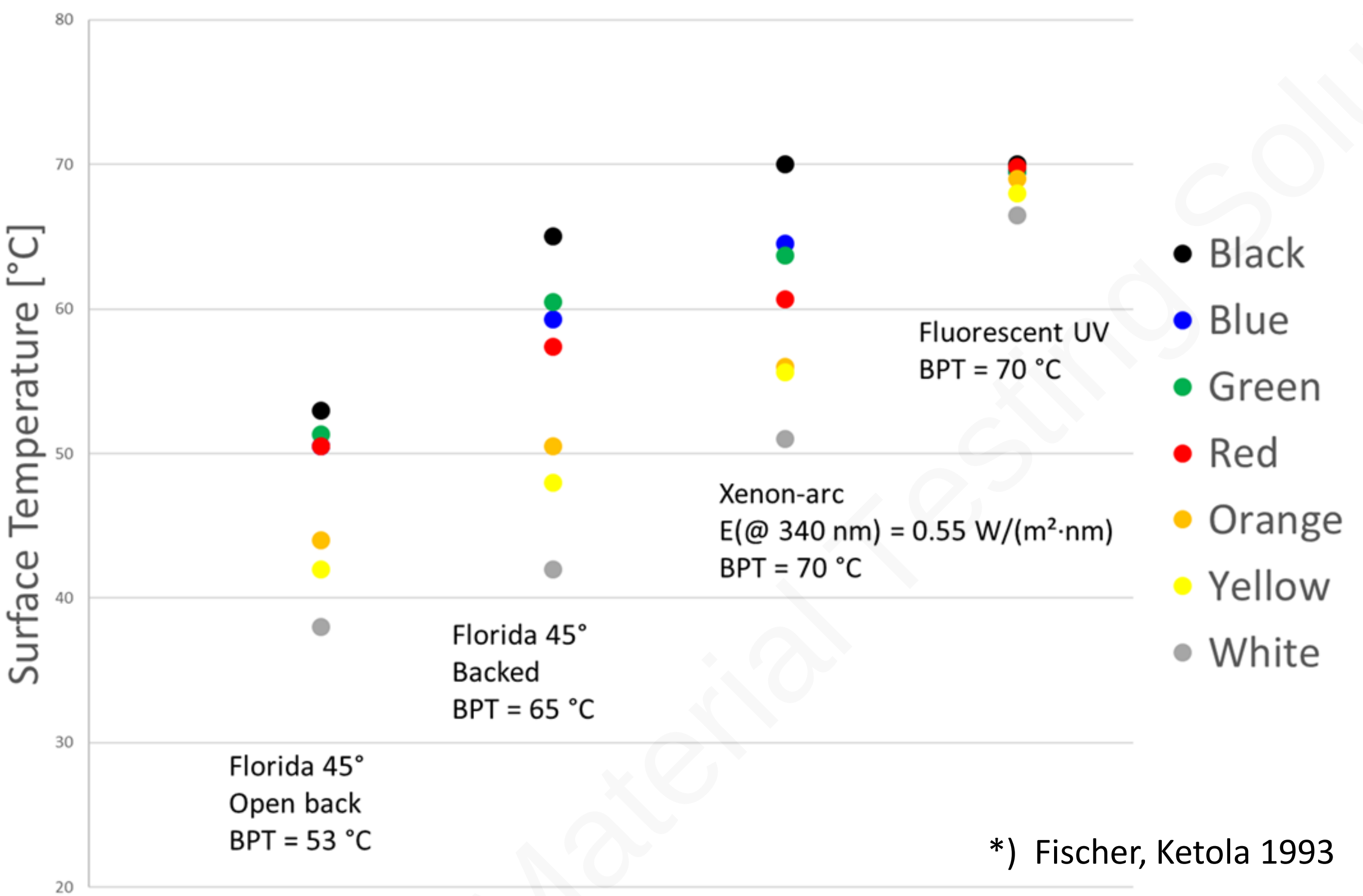
General Standards:

ASTM G154 Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials

ISO 16474-3 Paints and varnishes - Methods of exposure to laboratory light sources - Part 3: Fluorescent UV lamps

ISO 4892-3 Plastics - Methods of exposure to laboratory light sources - Part 3: Fluorescent UV lamps

FLUORESCENT UV DEVICES: TEMPERATURE EFFECTS



Fluorescent UV:
Temperature Control by an external heater

→ different colored samples absorb different wavelength regions and heat up differently in outdoor exposures

→ fluorescent UV lamps don't heat up the samples by IR and visible radiation

→ all samples will have almost the same temperature by external heaters

EXAMPLE: ISO 4892-3 (2016) PLASTICS

Fluorescent-UV instruments:

Cycle No.	Exposure period	Irradiance	Black-panel temperature
Method A: Artificial accelerated weathering with UVA-340 lamps			
1	8 h dry 4 h condensation	0.76 W·m^{-2}·nm^{-1} at 340 nm UV lamp off	60 °C ± 3 °C 50 °C ± 3 °C
2	8 h dry 0.25 h water spray 3.75 h condensation	0.76 W·m^{-2}·nm–1 at 340 nm UV lamp off UV lamp off	50 °C ± 3 °C Not controlled 50 °C ± 3 °C
3*)	5 h dry 1 h water spray	0.83 W·m^{-2}·nm^{-1} at 340 nm UV lamp off	50 °C ± 3 °C Not controlled
4	5 h dry 1 h water spray	0.83 W·m^{-2}·nm–1 at 340 nm UV lamp off	70 °C ± 3 °C Not controlled
Method B: Artificial accelerated weathering with UVA-351 lamps (daylight behind window glass)			
5**)	24 h dry (no moisture)	0.76 W·m^{-2}·nm^{-1} at 340 nm	50 °C ± 3 °C
Method C: Artificial accelerated weathering with UVB-313 lamps			
6	8 h dry 4 h condensation	0.48 W·m^{-2}·nm^{-1} at 310 nm UV lamp off	70 °C ± 3 °C 50 °C ± 3 °C

*) identical to ISO 16474-3 Cycle 2; **) identical to ISO 16474-3 Cycle 3;

Notes:
- Relative humidity not controlled
- Methods not harmonized with ISO 16474-3
- for coatings, the typical weathering cycle is 4 h dry with radiation / 4 h condensation

SPECTRAL SENSITIVITIES AND RADIATION SOURCES

Aliphatic Systems

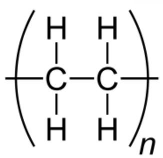
small π-Systems

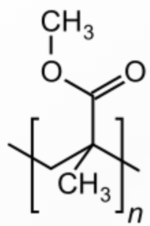
(double bonds, ketones and aromatics)

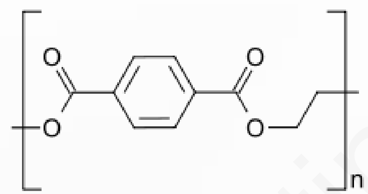
large π-Systems

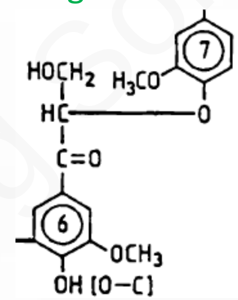
(Chromophores)

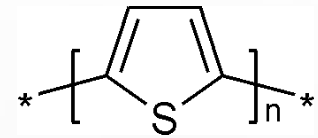
Polyolefins (PE/PP) → PMMA, PS → PC, PET, ABS → Lignin → colors and dyes, conducting polymers

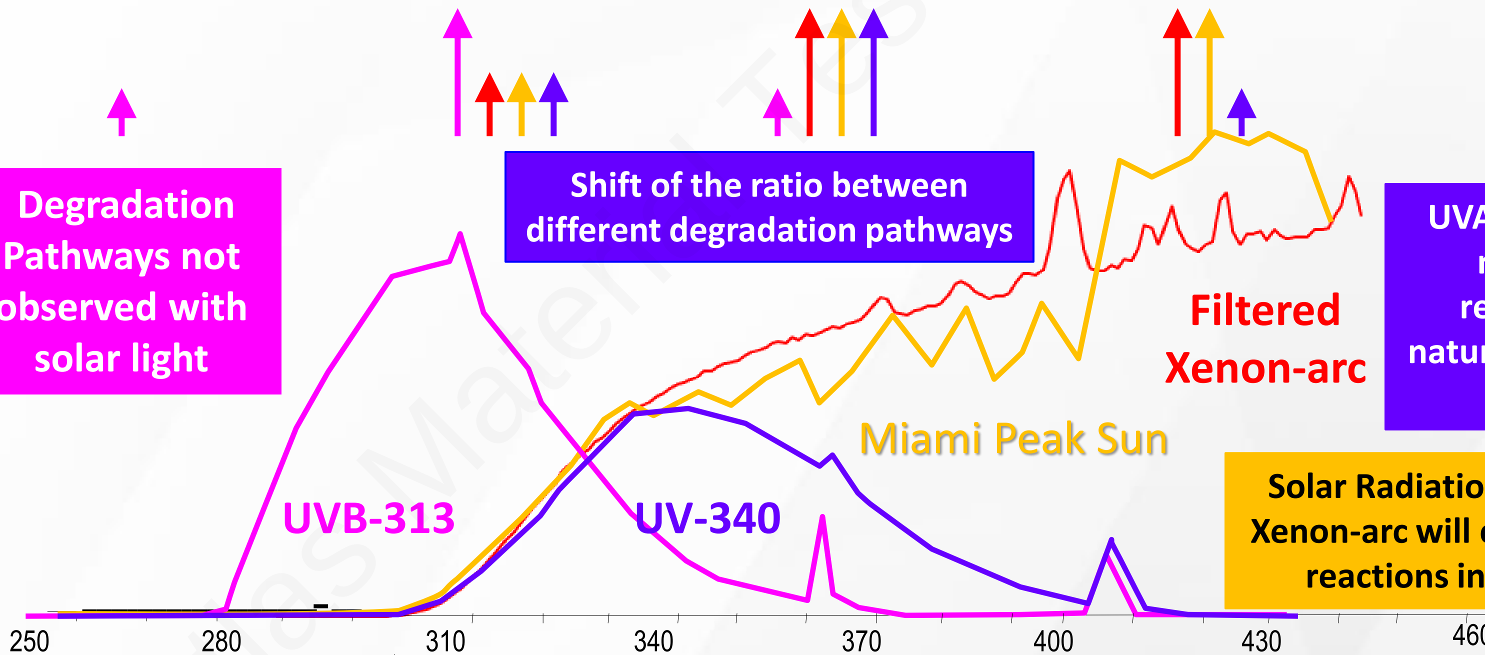












Degradation Pathways not observed with solar light

Shift of the ratio between different degradation pathways

UVA and UVB are not able to reproduce all natural degradation pathways

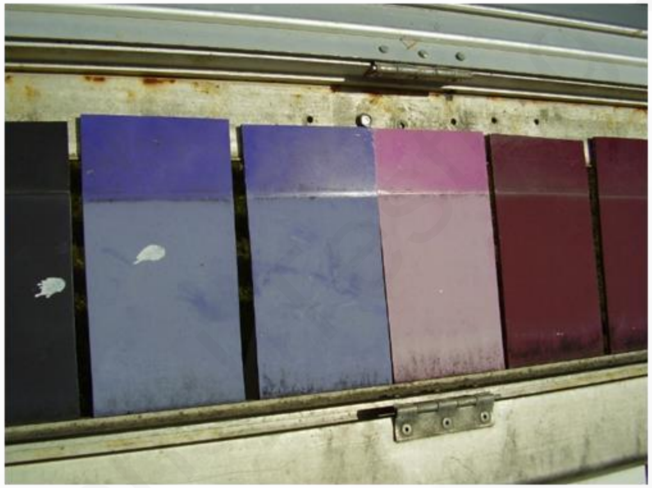
Solar Radiation and Filtered-Xenon-arc will cause the same reactions in the same ratio

OUTLINE

- Introduction of Atlas
- Factors of Weathering
  - Solar Radiation
  - Heat
- MoistureWeathering testing
  - Natural Weathering
  - Accelerated Laboratory Weathering
- Acceleration and Correlation
- Summary
- Question and answers (time permitting)

THE TWO QUESTIONS OF TESTING

How fast is my test?



How good is my test?

A QUICK CALCULATION

- **What do I know?**
  - Annual Radiant Exposure in Florida: H(300 nm – 400 nm) = 402 MJ/m^2
  - Laboratory test: ISO 4892-2. Irradiance: E(300 nm – 400 nm) = 60 W/m^2
- **Question:** How long does it take a **weathering instrument** to reach the solar radiant exposure of **1 year Miami** (at 5° South orientation)?
- **Formula:** Radiant Exposure H = Irradiance E x Time t

$H = E \times t$

$t = H / E$

$= 402\ MJ/m^2 \ / \ 60\ W/m^2$

$= 402/60 \ 10^6\ J/W$

$= 6.7 \ 10^6\ s$

= 1861 h = 78 days = 11 weeks

1 W = 1 J/s

1 J/W = 1 s

1 h = 3600 s

$AF_E = 52/11 = 4.7$

ACCELERATION FACTOR VARIABILITY

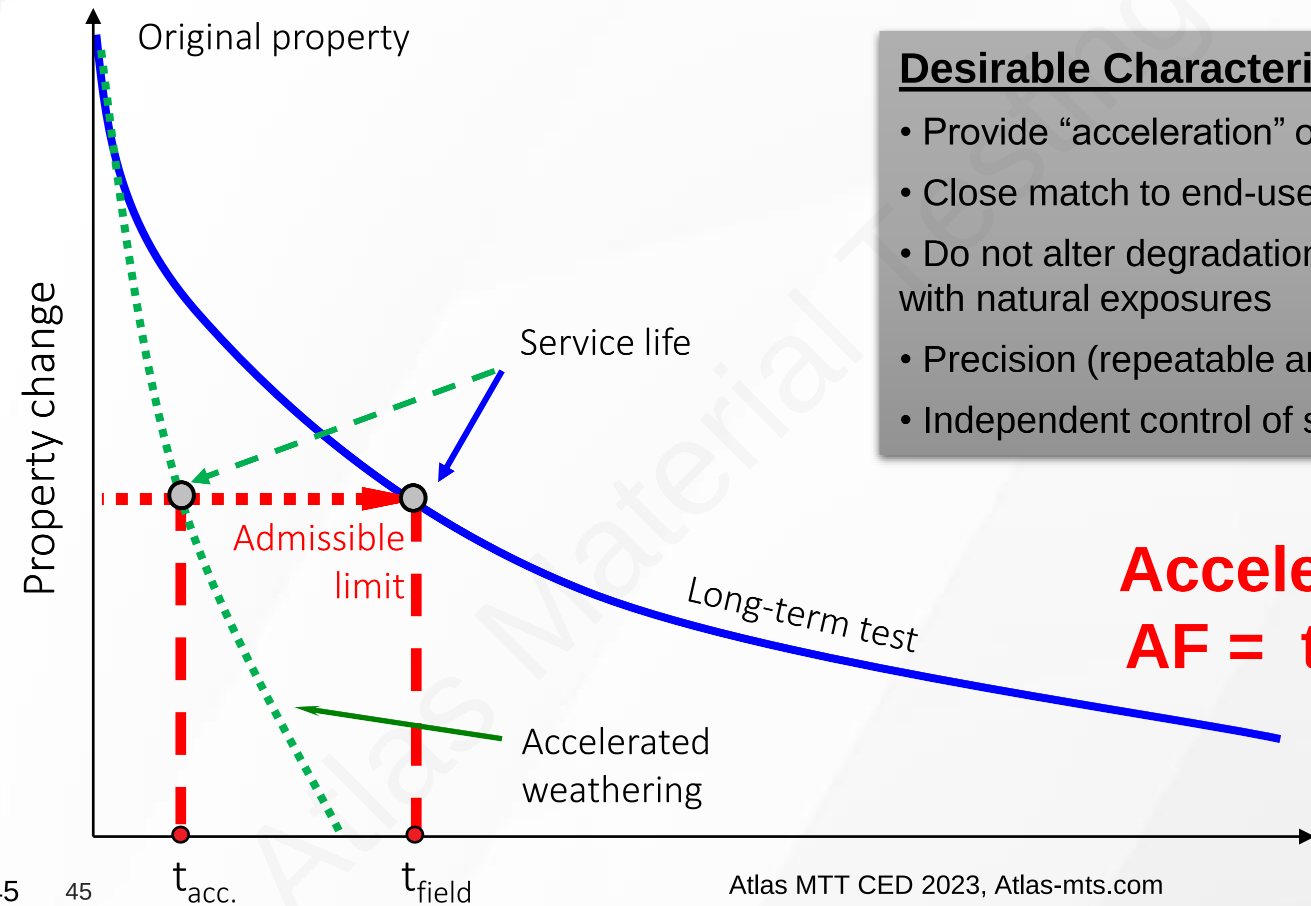
Region	Accelerated Xenon-arc Weathering						
	Calculated factors (based on annual radiation)	Experimental acceleration factors – reported values					
Central Europe	8.8	27	20		13 – 23	9	
Sanary (South France)	6.4						
Florida	4.7	4	6	9	5 – 7	4	3.5
Arizona	4.3						
Kalahari	4.8	9					

Deviation from calculated and measured factors →

"Real acceleration factors" depend on reference location, test conditions (temperature, moisture) and the **material**!

WEATHERING TESTS – ACCELERATION FACTOR

The time required in a **specific outdoor weathering test** to induce a certain specific property change in a specific specimen, divided by the time needed for the same change in a replicate specimen in a **specific accelerated laboratory (or outdoor) weathering test:**



Desirable Characteristics:

- Provide "acceleration" over real time
- Close match to end-use conditions
- Do not alter degradation mechanisms ➔ "correlates" with natural exposures
- Precision (repeatable and reproducible)
- Independent control of stress factors (E, T, RH)

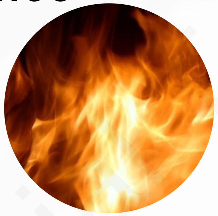
Acceleration factor:

$$AF = t_{field} / t_{accelerated}$$

ATLAS MATERIAL TESTING SOLUTIONS
AMETEK

Factors used to achieve acceleration:

- **Radiation**
  - Short wavelength radiation (below natural UV-cut on)
  - Level of spectral irradiance



- **Temperature**
  - Level of temperature
  - Temperature cycles
- **Moisture**
  - dry/wet cycles (amplitude/frequency)

Factors that may decrease correlation (ISO 4892-1 and ASTM G151):

- Short wavelength exposure
- Spectral distribution with high deviation from sun radiation
- High intensity exposure
- Continuous exposure to light
- Unrealistic specimen temperatures
- Unrealistic or non-existent temperature cycling
- Unrealistic or non-existent moisture delivery

… and others

Balance between correlation and acceleration

OBJECTIVES OF WEATHERING TESTING

Comparable Methods

Aging under more or less realistic but easily controllable and reproducible conditions

Test conditions:

- *General*
- *Regardless of material/location*

Objective:
Ranking, repeatability, reproducibility

Examples:

ASTM G155 (2021) Standard Practice for Operating Xenon Arc Lamp Apparatus for Exposure of Materials

ISO 4892-2 (2021) Plastics - Methods of exposure to laboratory light sources - Part 2: Xenon-arc lamps

ISO 105-B02 (2013) Textiles - Tests for colour fastness - Part B02: Colour fastness to artificial light: Xenon arc fading lamp test

General

Realistic/Predictive Methods

Simulation of the climatic conditions and ideally the aging processes that prevail in use

Test conditions dependent on:

- *Place of use/climate zone*
- *material*
- *application*

Objective:
Reproduction of damage mechanisms, lifetime prediction

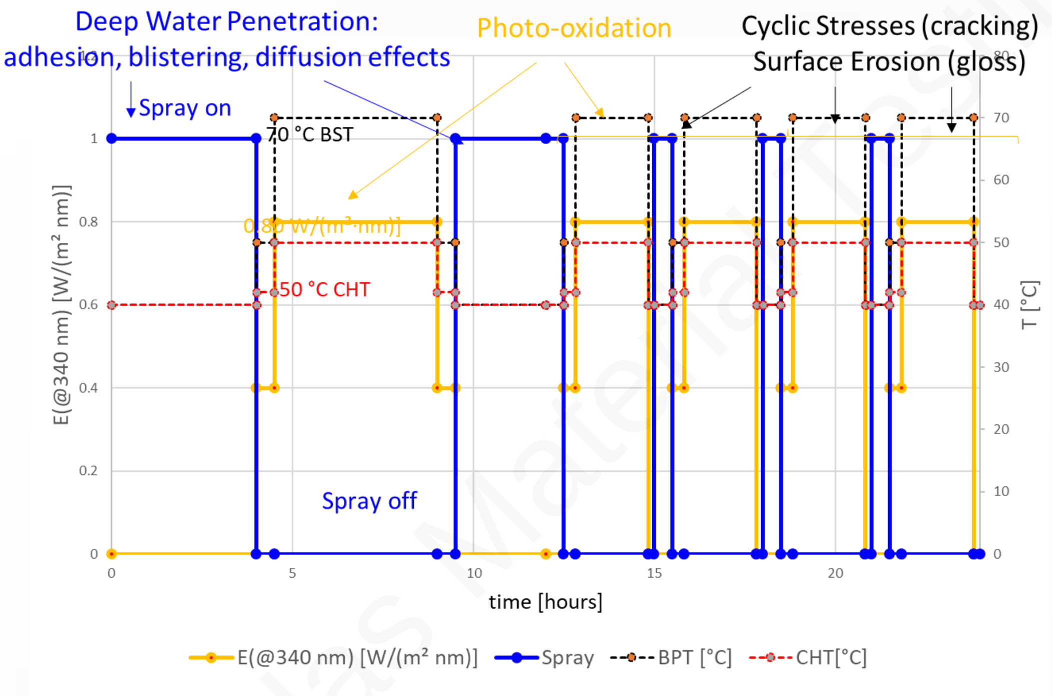
Example:

ASTM D7869 (2017) Standard Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings

Material Specific

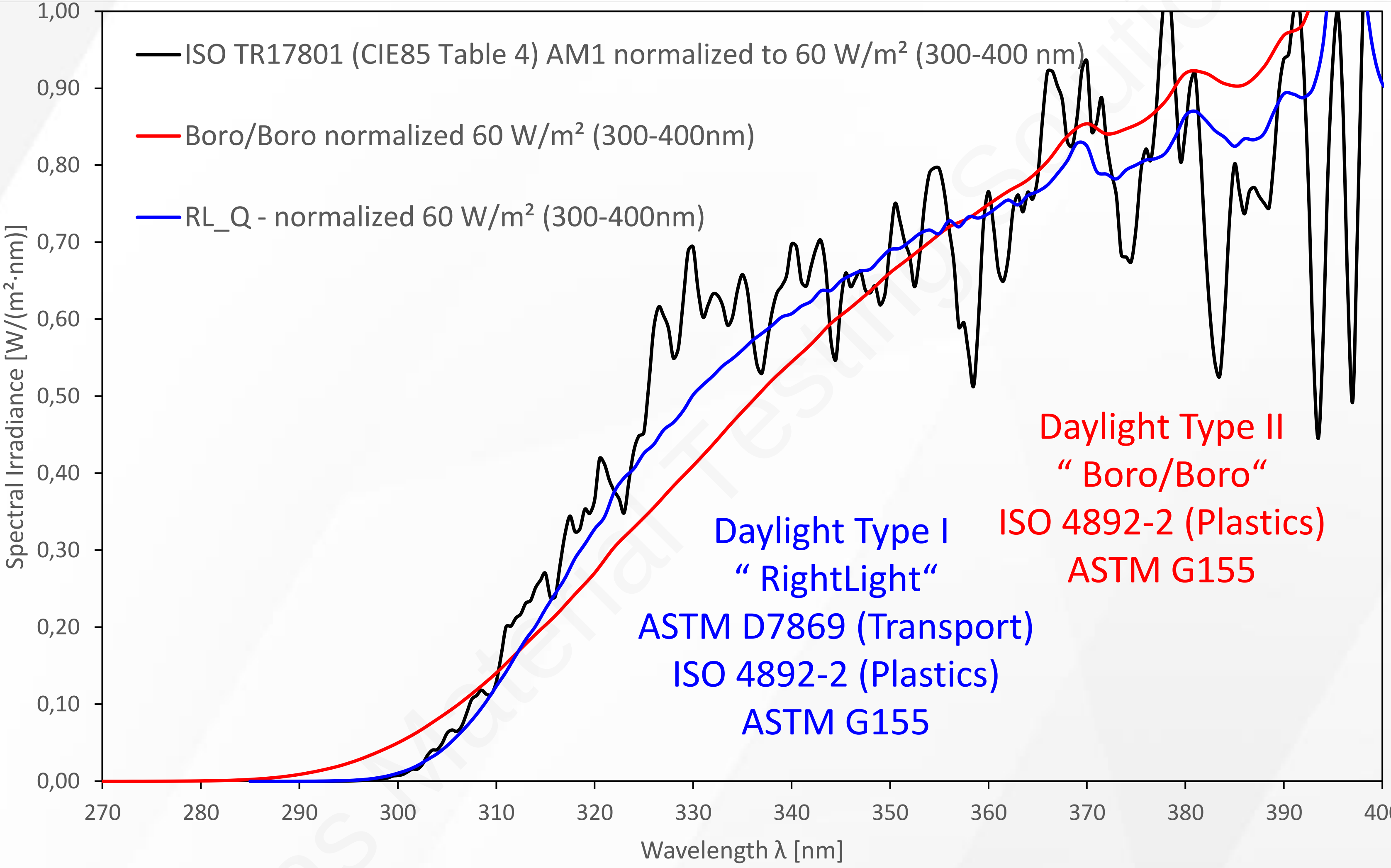
Motivation: Realistisc Test Method

ASTM D7869 (2017) Standard Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings



Wavelength band (nm)	Total Irradiance Over Indicated Wavelength Band (W/m²) Minimum Irradiance (W/m²/nm)	Maximum Irradiance (W/m²/nm)
λ < 290	0.00	0.005
290 ≤ λ < 295	0.00	0.01
295 ≤ λ < 300	0.01	0.04
300 ≤ λ < 305	0.10	0.20
305 ≤ λ < 310	0.38	0.56
310 ≤ λ < 320	2.29	3.10
320 ≤ λ < 330	4.76	5.82
330 ≤ λ < 340	6.84	7.56
340 ≤ λ < 350	7.69	9.40
350 ≤ λ < 360	8.13	11.00
360 ≤ λ < 370	8.32	12.47
370 ≤ λ < 380	8.30	13.83
380 ≤ λ < 390	8.64	14.40
390 ≤ λ < 400	9.23	17.15

DEVELOPMENT OF NEW FILTER COMBINATIONS



Note: Extended-UV Filters are not included in ISO 4982-2/ISO 16474-2, but in ASTM G155.

TESTING RECOMMENDATIONS

General Testing Recommendations for Material Development:

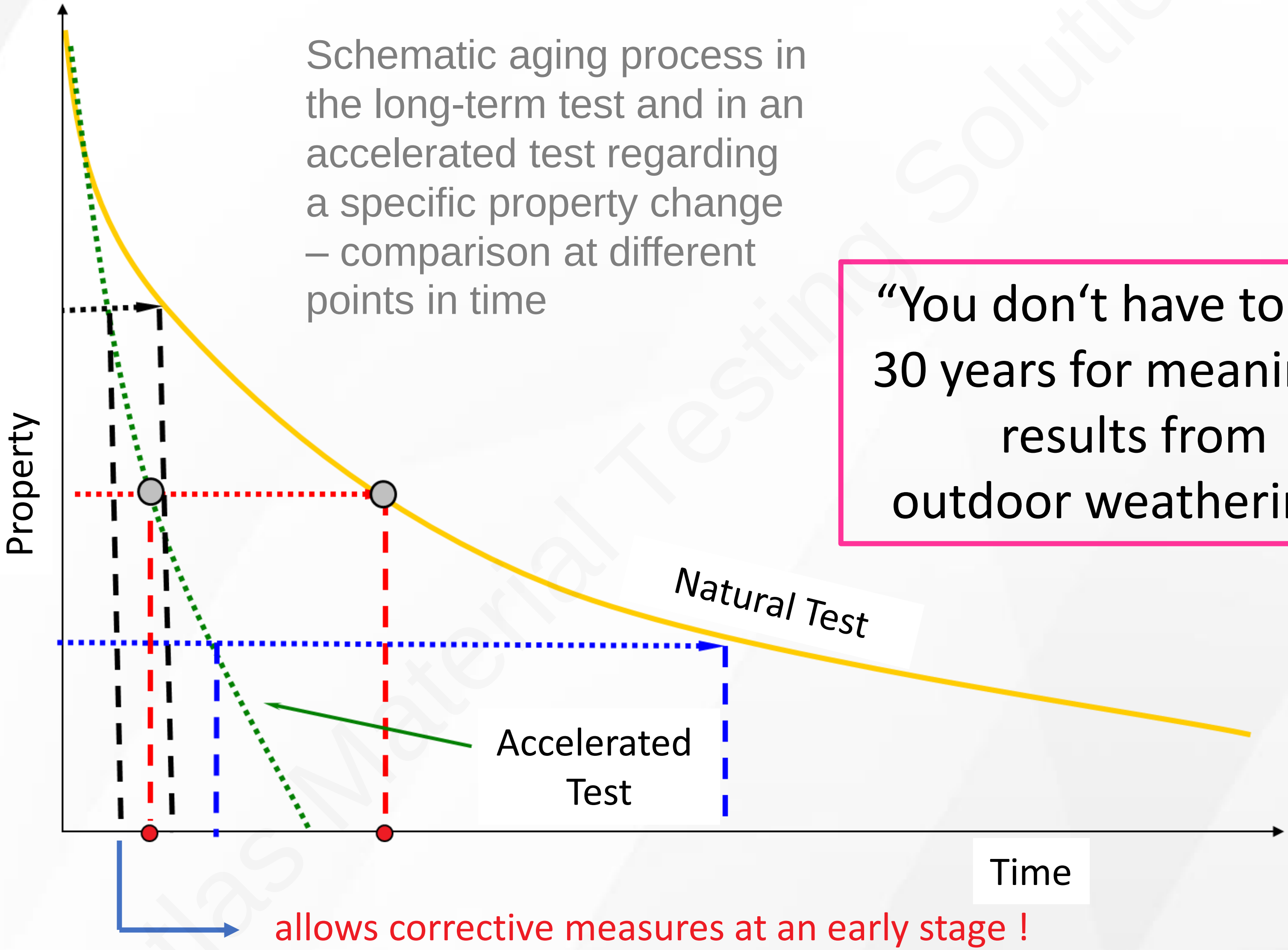
- always include materials you know (control)
- always include materials which will fail
- use different degrees of acceleration
  e.g. standard testing (ISO 4892-2, 60 W/m² + high irradiance)
  and static outdoor and accelerated outdoor (EMMAQUA)
- for planning of test time, especially for long lasting products (10 years or longer), consider radiant exposure and temperature (Arrhenius)
- always include **outdoor validation** and **start it now!**

→ highly accelerated tests allow early extrapolation and prediction

→ continuous validation and corrective measures will give increasing confidence in product performance

POINT OF TIME FOR COMPARISON

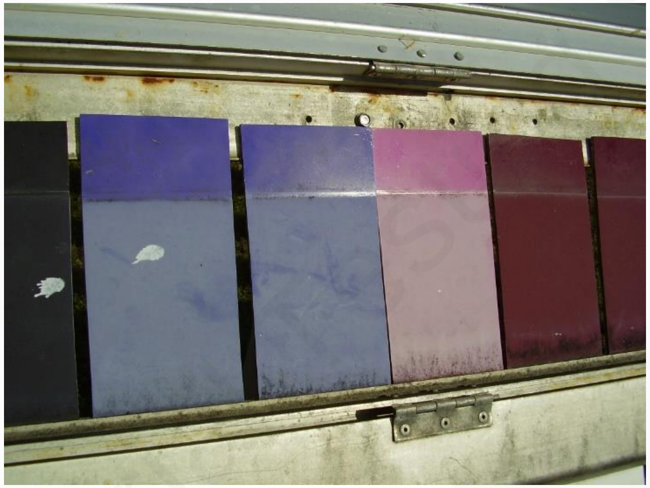
Schematic aging process in the long-term test and in an accelerated test regarding a specific property change – comparison at different points in time



“You don‘t have to wait 30 years for meaningful results from outdoor weathering!”

allows corrective measures at an early stage !

Acceleration (factor) is material dependent!


A good test is based on SLP models and provides the right balance between acceleration and empirical realism!

A good method found for one material is not necessarily working similarly well for another!

THANK YOU!

Questions?

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