WEATHERING AND CORROSION TESTING IN THE AUTOMOTIVE INDUSTRY: AN OVERVIEW OF TODAY'S REQUIREMENTS

Andy Francis, Q-Lab Corporation

Weathering and Corrosion



Weathering

Changes in material properties resulting from exposure to the radiant energy present in sunlight in combination with heat (including temperature cycling) and water in its various states, predominately as humidity, dew, and rain.


(Atmospheric) Corrosion

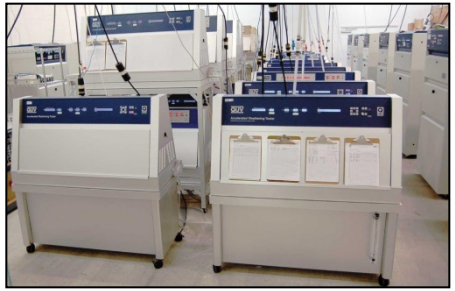
Deterioration and destruction of a material and its vital properties due to electrochemical reactions on the surface of a metal in an atmospheric environment. It occurs when the surface is wet by moisture formed due to rain, fog and condensation.

Weathering and Corrosion Testing

Weathering

Outdoor

Accelerated



Corrosion

Outdoor

Accelerated

Types of Accelerated Tests

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification

Types of Accelerated Tests

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification

Types of Accelerated Tests

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification
Correlative	Rank-ordered data	• Open-ended • Medium	Natural exposure (Benchmark site)

Types of Accelerated Tests

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification
Correlative	Rank-ordered data	• Open-ended • Medium	Natural exposure (Benchmark site)
Predictive	Service life Acceleration factor	• Open-ended • Long	Natural exposure (Service environment)

Types of Accelerated Tests

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification
Correlative	Rank-ordered data	• Open-ended • Medium	Natural exposure (Benchmark site)
Predictive	Service life Acceleration factor	• Open-ended • Long	Natural exposure (Service environment)

Types of Accelerated Tests

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification
Correlative	Rank-ordered data	• Open-ended • Medium	Natural exposure (Benchmark site)
Predictive	Service life Acceleration factor	• Open-ended • Long	Natural exposure (Service environment)

Types of Accelerated Tests

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification
Correlative	Rank-ordered data	• Open-ended • Medium	Natural exposure (Benchmark site)
Predictive	Service life Acceleration factor	• Open-ended • Long	Natural exposure (Service environment)

Weathering Testing

Historical Accelerated Weathering Test Standards

- **Several different tester architectures for light delivery**
  - Xenon arc
  - Fluorescent UV
  - Others (carbon arc, metal halide)
- **Xenon arc light sources reproduce full-spectrum sunlight**
- **Hardware-based “102/18” light/light+spray standards were the first widely-used weathering standard tests**
  - Almost 100 years old but still in use
  - Common examples: ISO 4892-2, ASTM G155 Cycle 1, ISO 113
  - OK for pass/fail, but not realistic!

SAE J2527: Significant improvement … but still a ways to go

- **SAE J2527 (J1960) became the “state of the art” in 1980’s**
  - Research into primary stressors (light, water, heat)
  - Replicated gloss loss seen in Florida exposures
- **This SAE weathering standard was well-researched and a leap forward but did not match real-world weathering factors**
  - Light spectra
  - Moisture delivery
- **As a result, it did not adequately predict Florida outdoor field failures for very durable coatings**
  - Chemical change (Photo-oxidation, water-based effects)
  - Physical change (Cracking, Blistering, Delaminating)

Modern Weathering Test Standard Development

- Outdoor weather data collected to understand real-world weather conditions: **sunlight**, **heat**, and **water**
- Outdoor weathering test dataset collected to provide basis for **correlation**
- Accelerated **test cycles** developed to match those real-world conditions and degradation mechanisms
- Variety of materials and failure modes evaluated with accelerated testing to verify **validity** of test

Collect outdoor weather data

Approach: collect outdoor weather data to better understanding the forces of natural weathering:

Sunlight

Heat

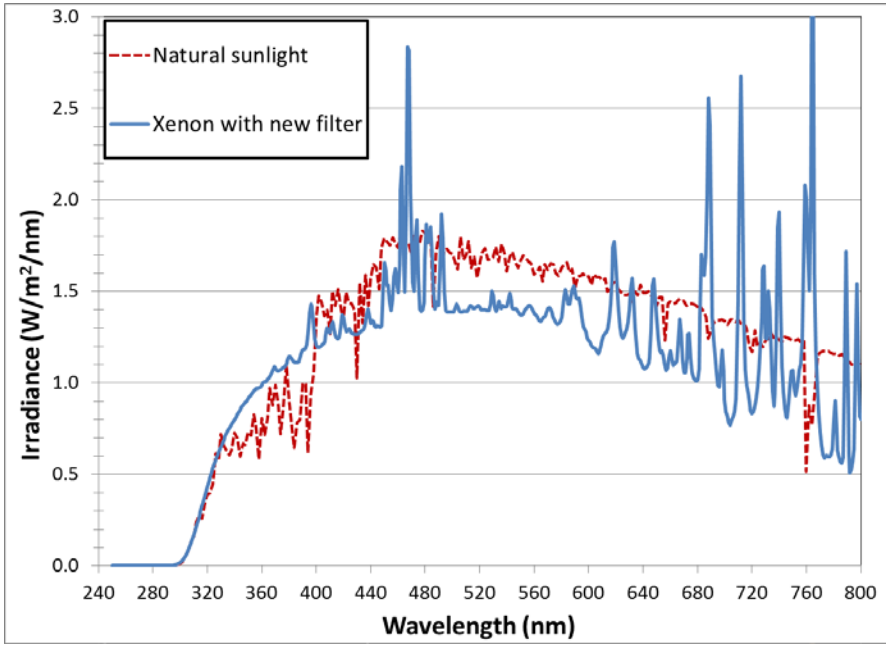
Water

Goal: Obtain suitable body of field data to develop realistic Accelerated laboratory tests

Perform Outdoor Testing

- Include both common field failures & control materials
- Use multiple replicates and lots of different materials systems
- Prepare specimens in a consistent fashion to minimize variability
- Test according to standards
- Conduct multiple exposure sets and evaluate frequently

Deliver Realistic Forces of Weathering: Light



A xenon light source with proper optical filters correlates better to outdoor exposure

Deliver Realistic Forces of Weathering: Heat

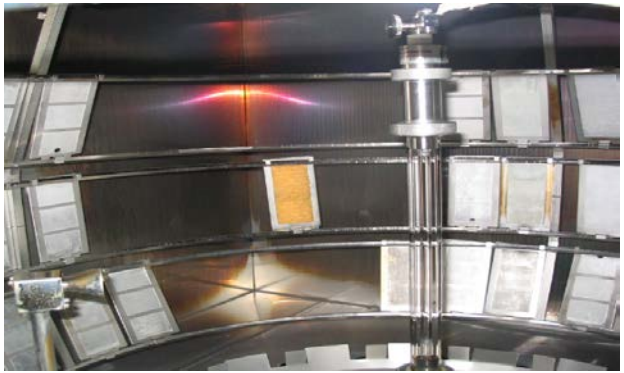
High temperature serves primarily to accelerate water uptake. Two key guiding principles:

1. Do not exceed maximum service temperature

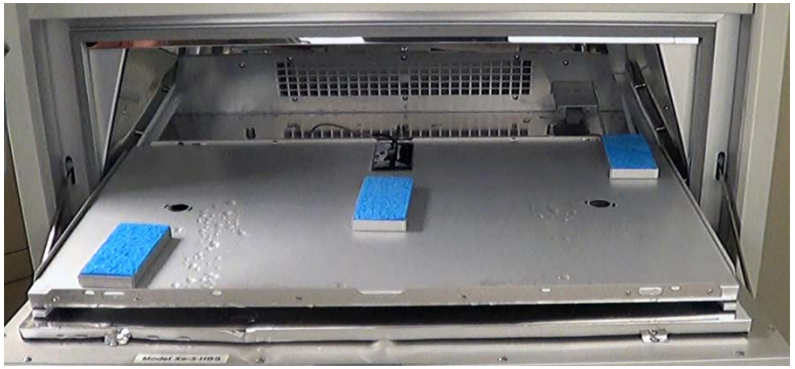
2. Use realistic temperatures to increase correlation

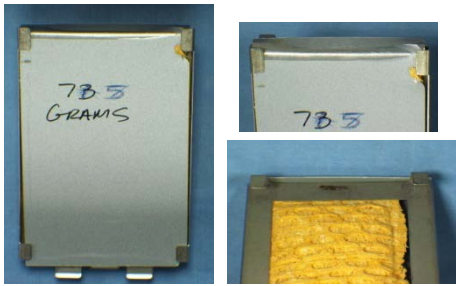
Deliver Realistic Forces of Weathering: Water

Rotating Drum



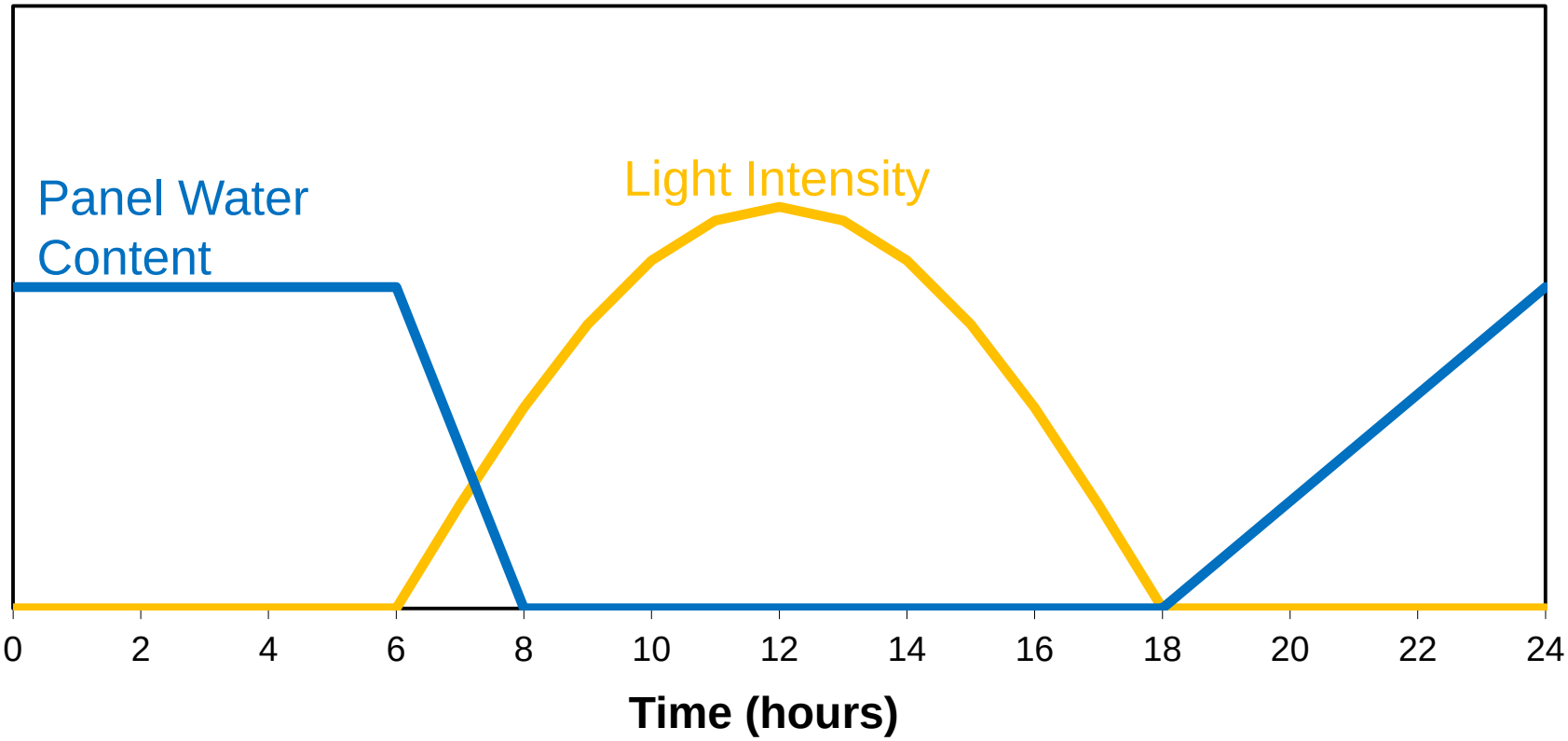
Flat Array



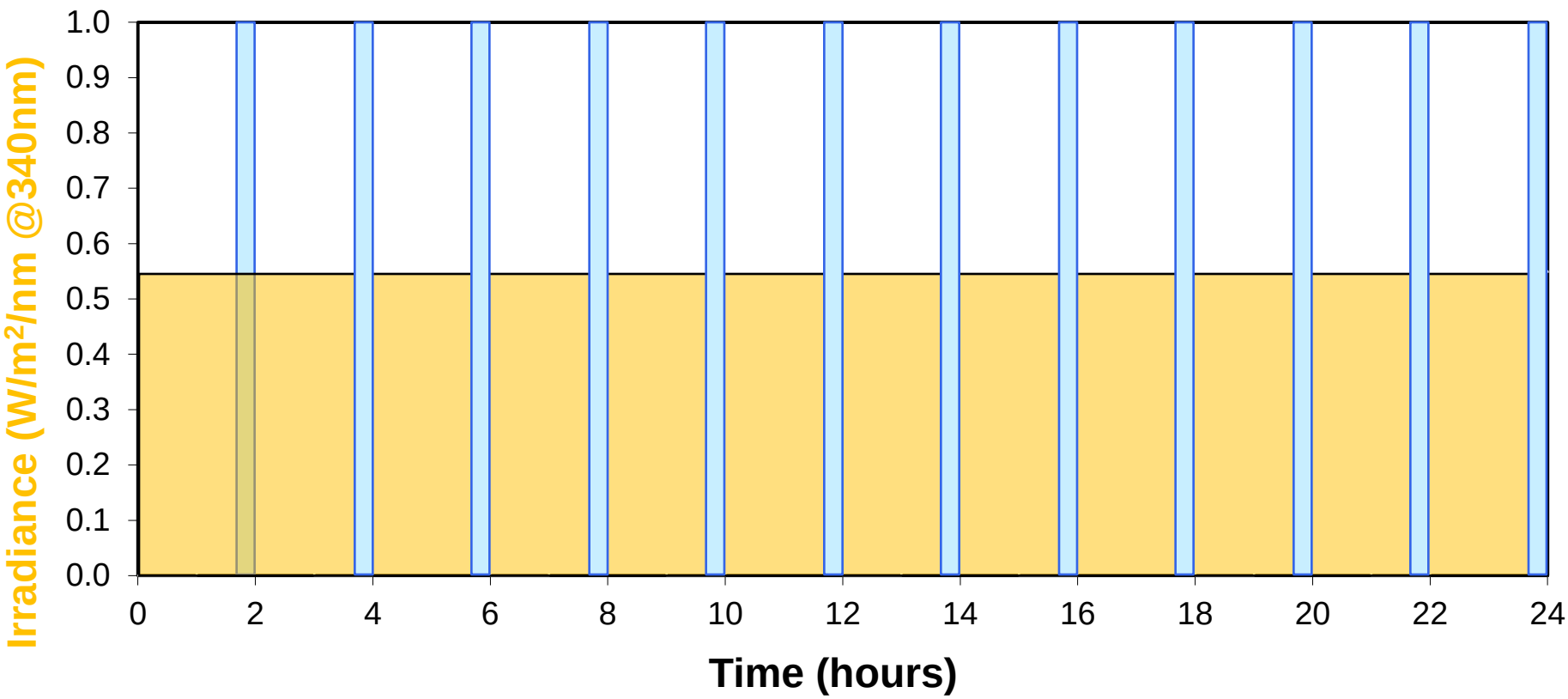


Shielded sponge holder

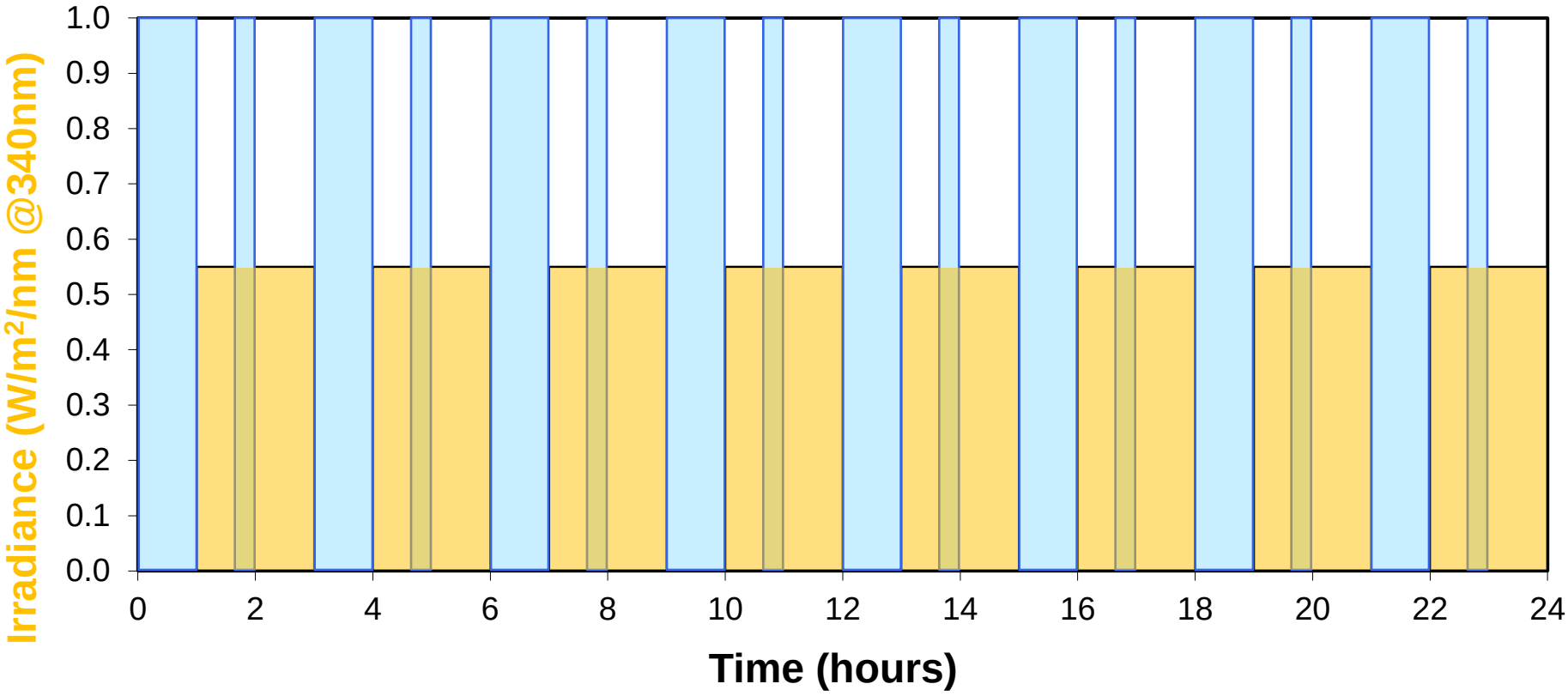
Develop a cycle that mimics a typical Florida outdoor daily cycle



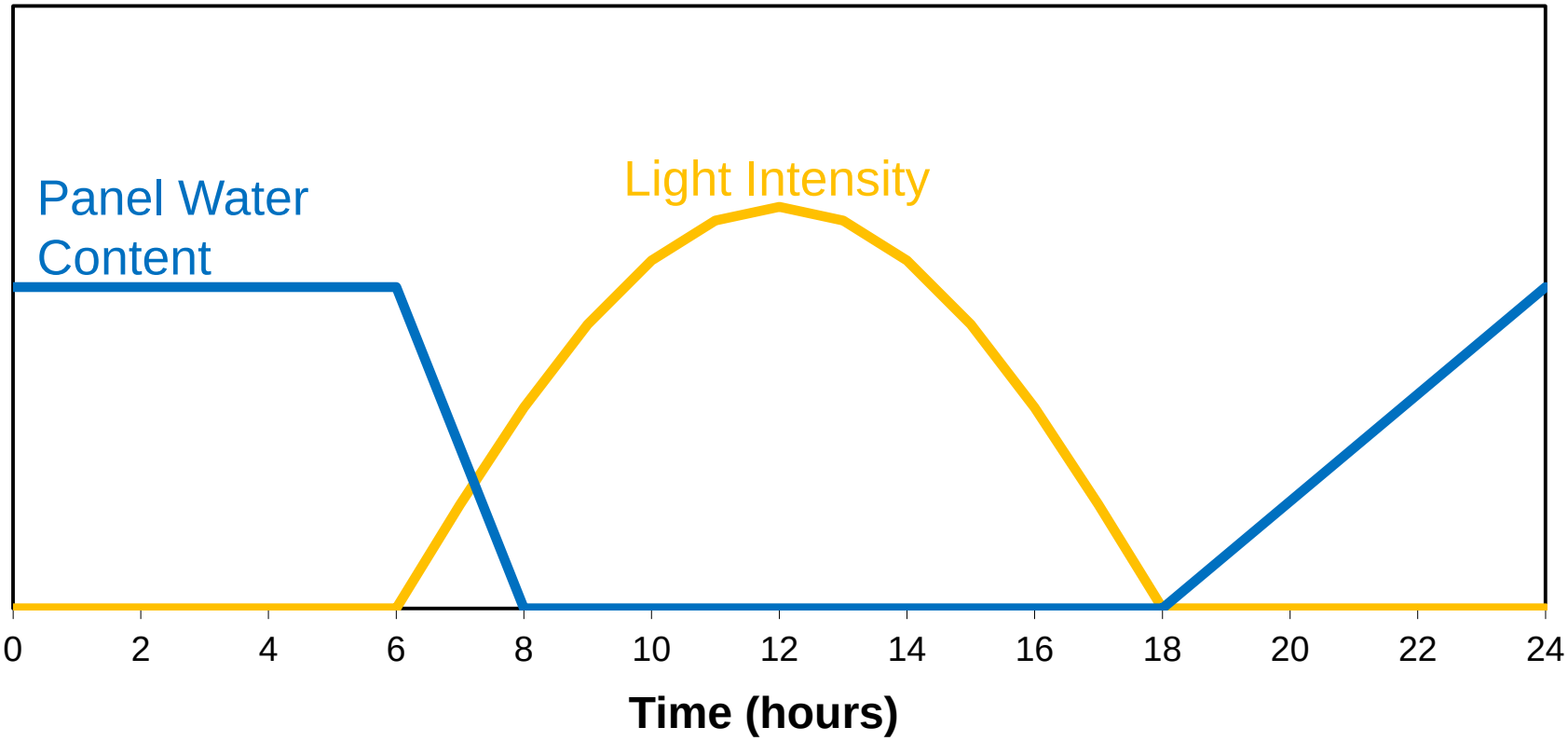
102/18
Not a Good Match with Outdoor Weather



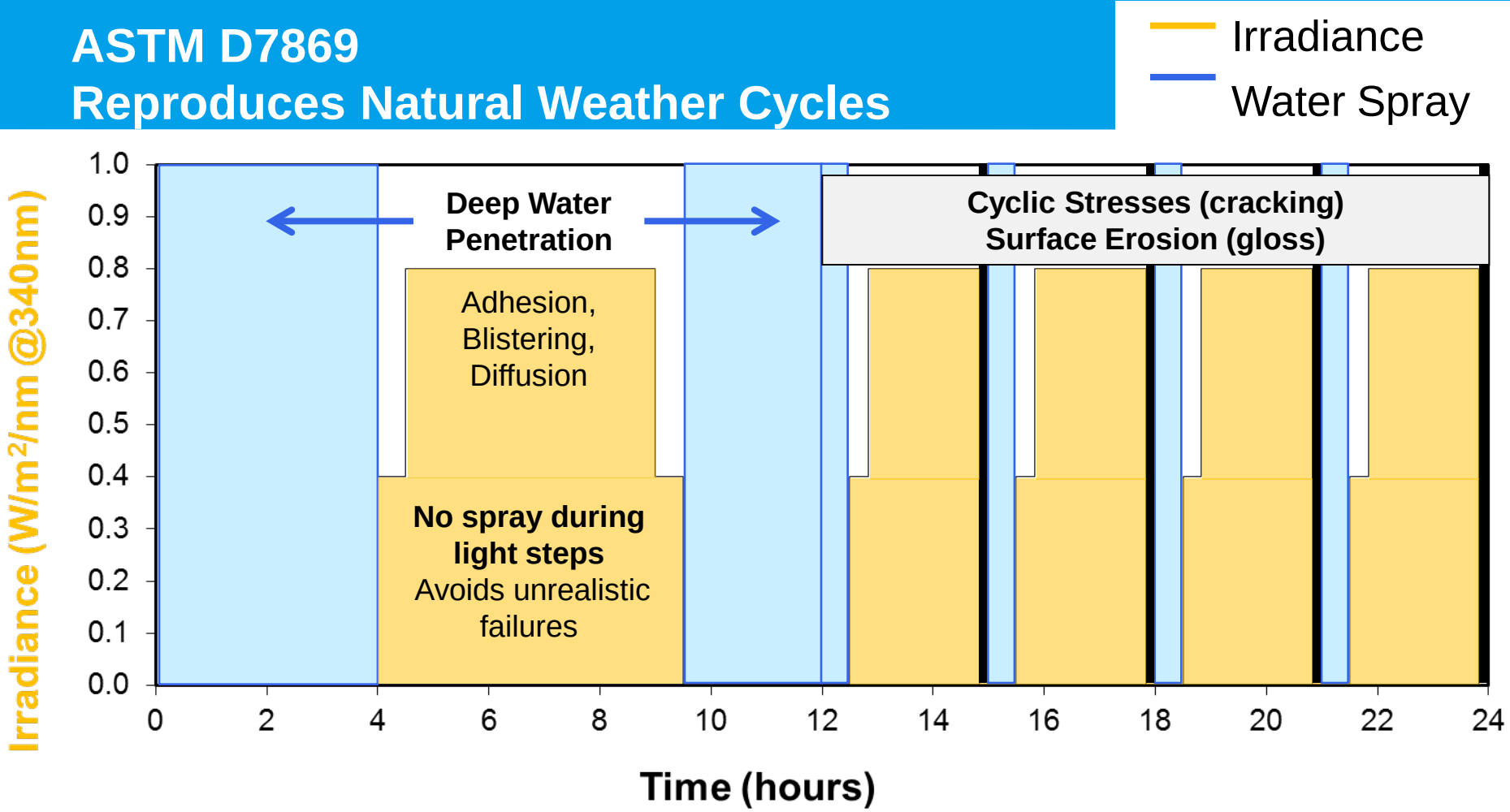
SAE J2527
Not a Good Match with Outdoor Weather



Develop a cycle that mimics a typical Florida outdoors daily cycle



ASTM D7869
Reproduces Natural Weather Cycles



Validate Test Methods
Multiple failure modes reproduced by accelerated test

- **Chemical change**
- **Cracking**
- **Blistering**
- **Adhesion loss**
- **Color**
- **Gloss loss**

Conclusions
Weathering Testing

- Modern accelerated lab weathering test cycles are thoroughly **researched** - developed using scientific understanding of outdoor weather phenomena – light, heat, and water

- Test cycles must be **validated** by comparison of results to long-term outdoor weathering data of a variety of coatings systems

- A good test standard for correlation must be **realistic**. The example here reproduces faithfully *almost all* physical failure mechanisms and as a bonus is 40% faster than current test method.

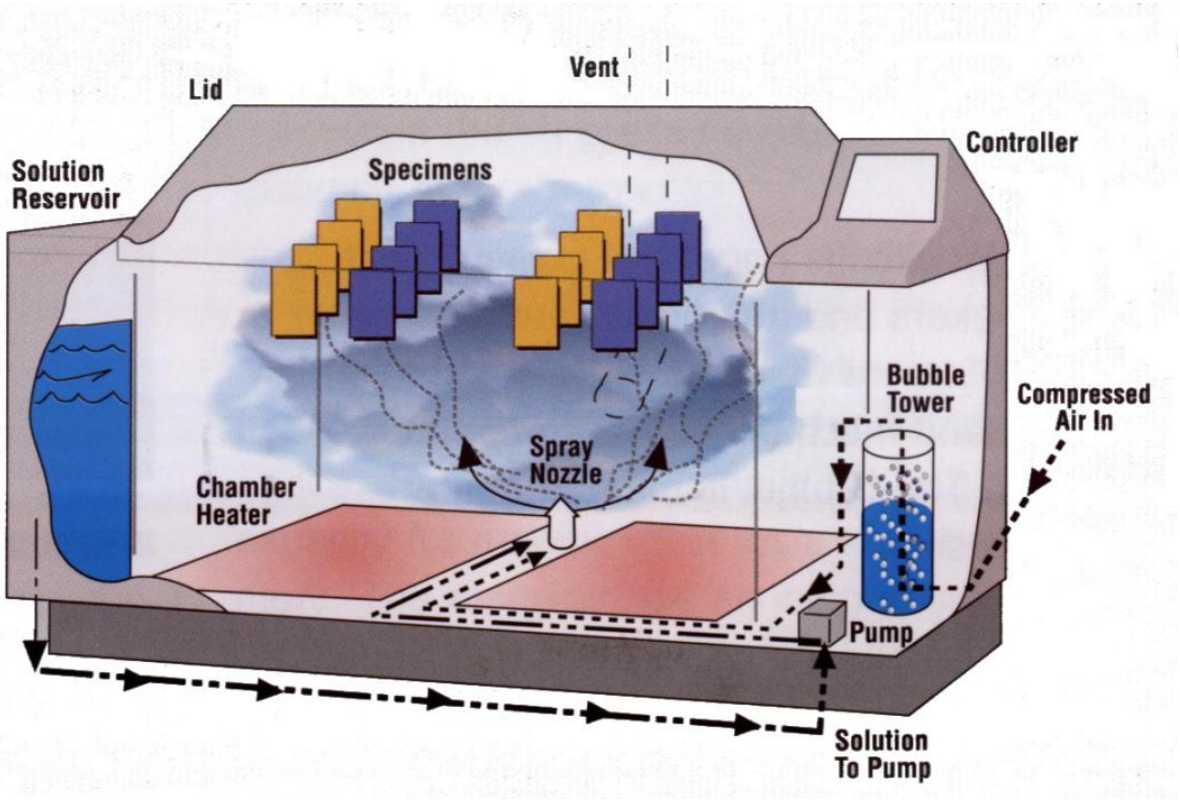
- Introduction of new weathering protocols allows for more rapid and accurate accelerated weathering results. These can be **correlated** with outdoor test data to give powerful information.

Corrosion Testing

Types of Accelerated Tests

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification
Correlative	Rank-ordered data	• Open-ended • Medium	Natural exposure (Benchmark site)
Predictive	Service life Acceleration factor	• Open-ended • Long	Natural exposure (Service environment)

Step 1: Continuous Salt Spray
Salt Fog



Continuous Salt Spray
ASTM B117

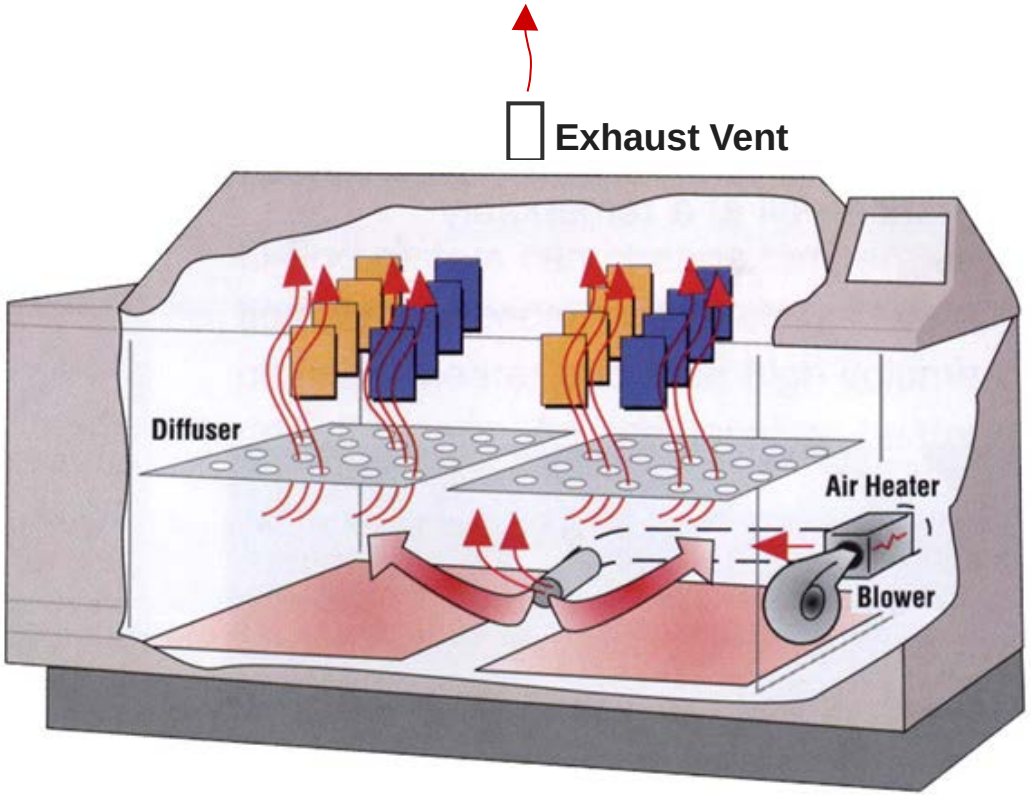
- 5% NaCl salt fog at 35 °C
- Neutral pH
- Fine mist (atomized with compressed air) sprayed indirectly onto specimens
- ISO 9227 contains the same test
- When correctly followed, test has reasonable repeatability and reproducibility

100 years later, ASTM B117 is still the most widely-used corrosion standard today, primarily for quality control and metallic/conversion coatings

Limitations of Salt Spray

- Not a good simulation of most service environments – not realistic!
- Typically produces different corrosion products than natural exposure
- Poor rank order correlation with outdoor corrosion

Step 2: Wet/Dry Cyclic Tests
Salt Fog → **Dry-Off**



Wet/Dry Cyclic Tests: Moving Forward
Prohesion (***Pro***tection is Ad***hesion***)

- Alternating spray and dry-off
- Development began in England, 1960's
- Dilute NaCl, $(NH_4)_2SO_4$
- American Architectural Manufacturers Association recently replaced ASTM B117 with this test in AAMA 2605, "Superior" coatings on aluminum

Test Results from Early Corrosion Standards

Laboratory Test Method	Correlation w/Severe Marine Environment
Conventional Salt Spray (ASTM B117)	**-0.11**
Cyclic Test (Prohesion)	**-0.07**

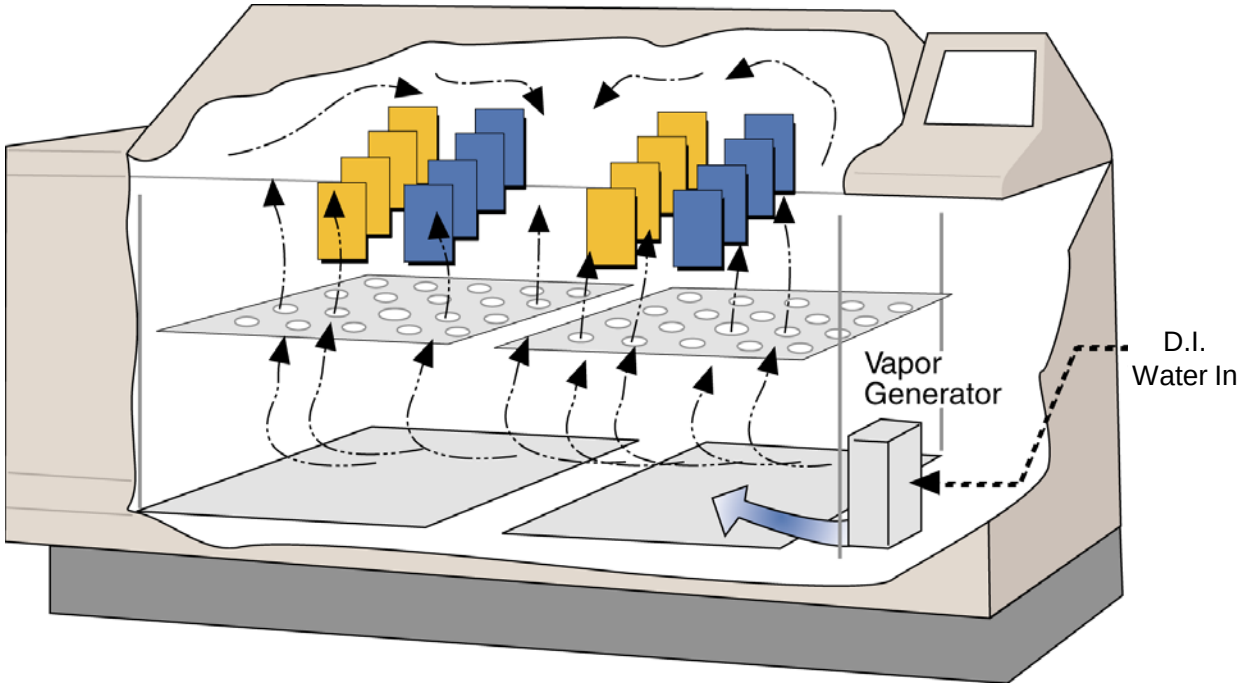
Spearman Rank
1.0 = Perfect rank order
0 = Random
-1.0 = Inverse rank order

Useful pass/fail tests…
Worse than flipping a coin for correlation to service environment!

Wet/Dry Cyclic Tests
Limitations

- Poor repeatability and reproducibility
- Poor correlation in some cases
  - Automotive
  - Industrial maintenance coatings on steel
- Attempts to improve correlation & repeatability include…
  - Wet bottom (water retained at chamber bottom)
  - Changing temperature of bubble tower
  - *Both are crude* *"workarounds" for poor RH control technology*

Step 3: Cyclic Automotive Tests
Salt Fog → Dry-Off → **Wetting (Humid)**



Wetting specimens after dry-off reinitializes corrosion

First-Generation Cyclic Automotive Tests
Salt Fog → Dry-Off → **Wetting (Humid)**

Example: GM 9540P

- NaCl and $CaCl_2$ to simulate road salts
- Solution applied by direct Spray, not Fog
- Salt spray applied intermittently in “ambient” conditions
- Use of corrosion coupons to minimize test variability
- SAE & American Iron & Steel Institute rated this method best predictor of outdoor performance in 1991

Relative Humidity & Corrosion

- **Corrosion accelerates once it starts**
  - Formation of complex oxides
  - Wet time increases as new oxides form
- **Corrosion is dependent on relative humidity**
  - As RH increases, surface wetness increases
  - Corrosions of metals in galvanic couples (Al/steel) strongly affected by differences in RH.

Relative Humidity and Corrosion

Condition	RH Range	Result
Dry	**≤ 50%**	Very little corrosion from NaCl
Electrolytic cells around salt crystals; film formation as RH increases	**50-76%**	• Corrosion of **steel** (maximum corroded area ~70% RH) and **aluminum** • AL-Steel galvanic couple broken
Uniform Electrolytic Film formation	**≥76%**	• Maximum cathode area for steel; deeper non-uniform corrosion • **Al corrosion** in galvanic couple with steel

First generation cyclic automotive methods
What was missing?

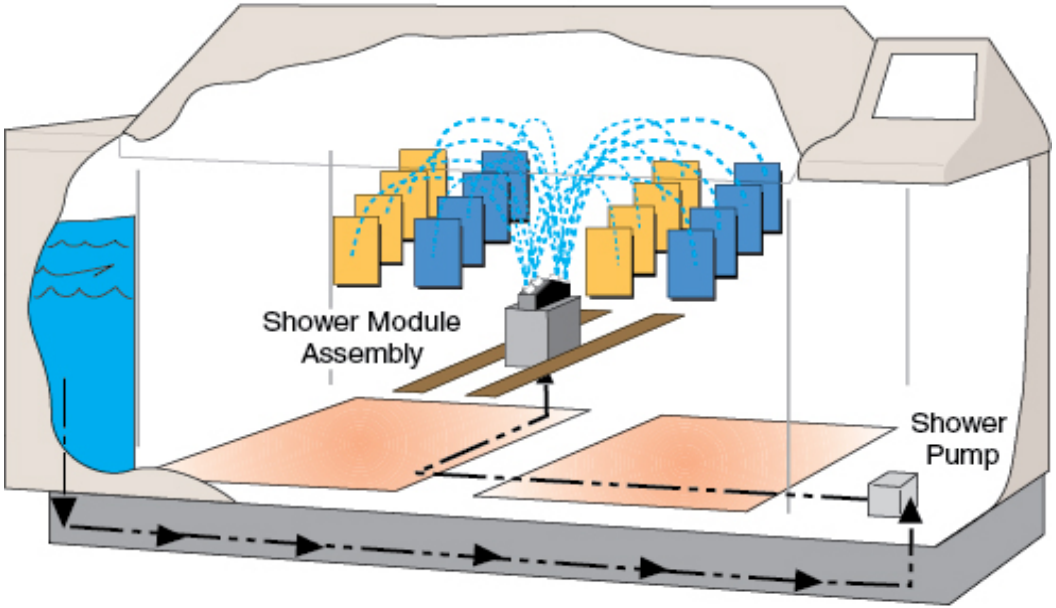
Lack of comprehensive RH control

- Conditions limited to full wetting, dry, uncontrolled room/ambient
- No control of RH transition times
- Variable specimen dry-off rates
- No RH just below or above DRH

Slow application of salt solution (fog)

- Little time for dry-off and re-wetting of specimens

Modern Corrosion Tests
Salt fog/shower → Dry-off →Controlled RH



- Salt “Fog” sometimes replaced by shower
- Controlled Relative Humidity during “ambient” phase
- Controlled Transition Times

Modern Automotive Corrosion Tests

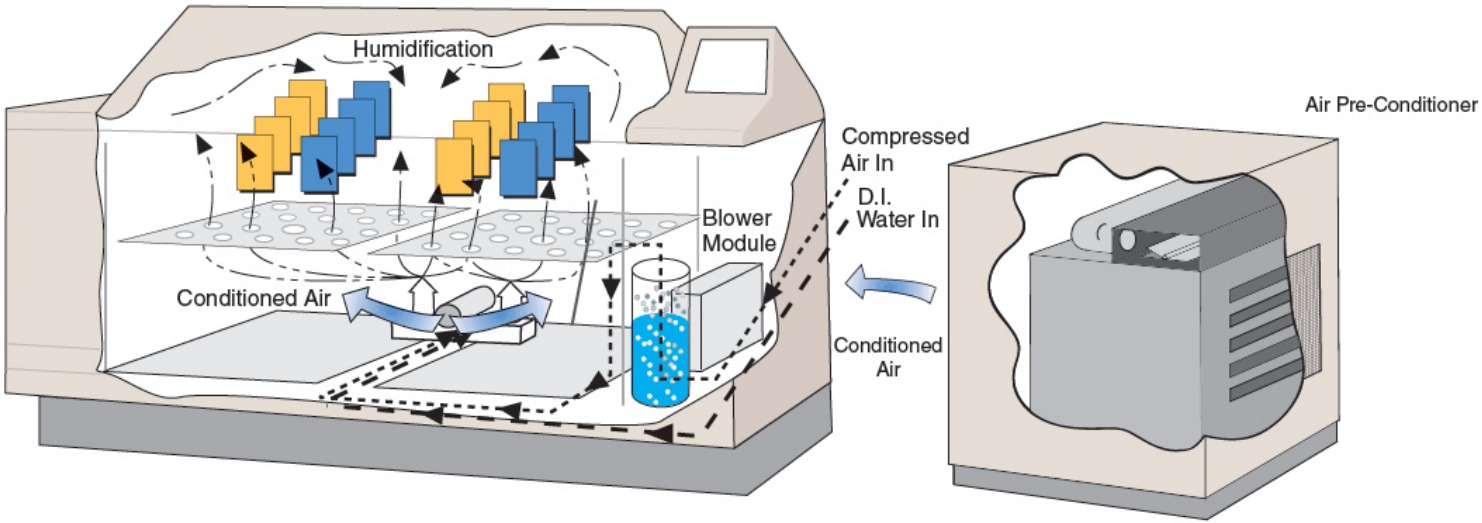
Fog

- Toyota TSH1555G
- VDA 621-415
- Renault D17 2028

Shower

- GMW 14872
- Volvo VCS-1027, 14 & 149
- Volvo VCS 423-0014
- ISO 16701
- Ford CETP 00.00-L-467

Air Pre-Conditioner enables precise RH control



Why the Air Pre-Conditioner is *Necessary* for Modern Corrosion Tests

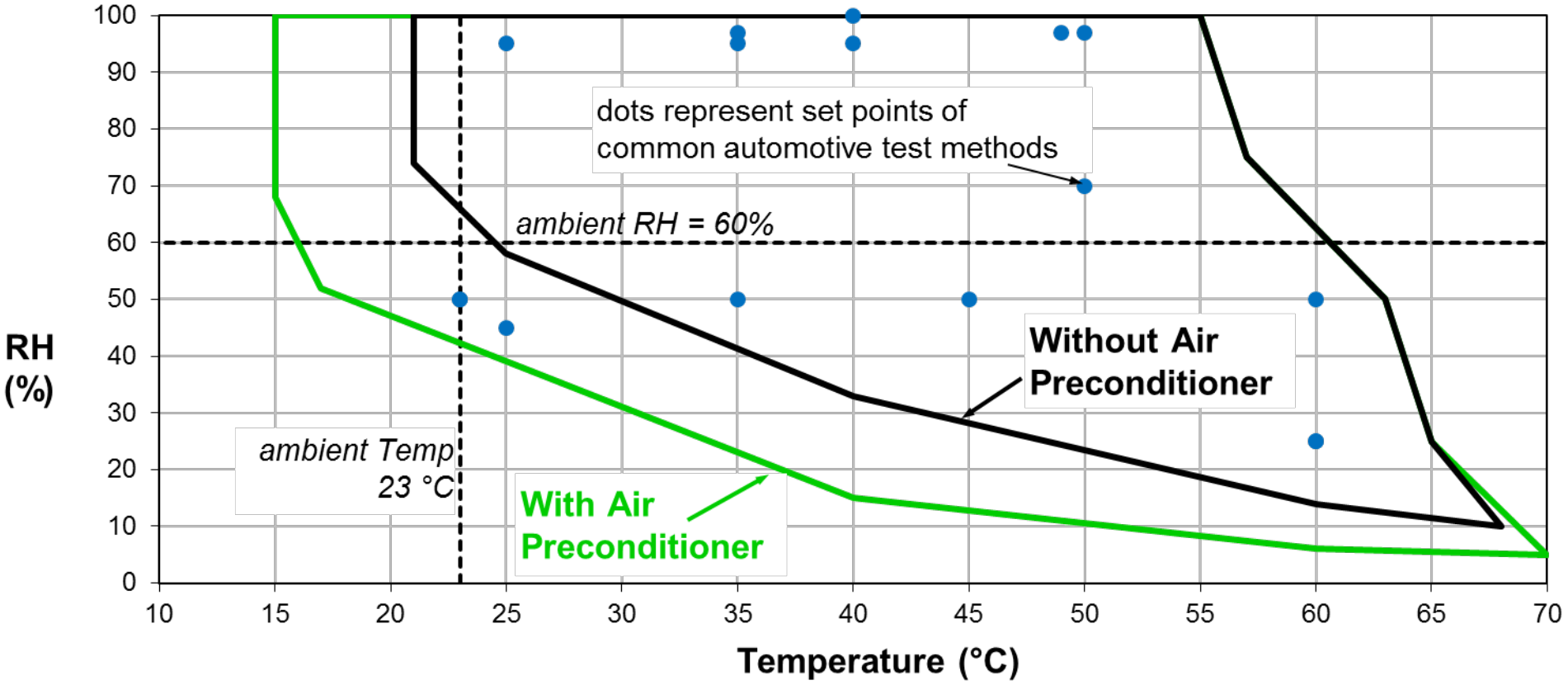
1. **Accurate control of “ambient” conditions**

   Either the laboratory has to be perfectly controlled, or the chamber must have dehumidification

2. **Accurate Ramping of Temperature & Humidity**

   System starts with dry cool air and adds precise amounts of heat and humidity to achieve controlled conditions

Corrosion Test Operational Range



Conclusions
Corrosion Testing

- Salt spray tests are good pass/fail screening tests
- Wet/Dry tests are good comparative tests for some systems but not repeatable
- First-generation cyclic automotive tests moved testing towards correlation, but were not repeatable
- Modern autmotive corrosion tests are more realistic and offer better repeatability and reproducibility

Conclusions
Modern Accelerated Testing

- Accelerated testing of both Weathering and Corrosion can be performed at different lvels of complexity yielding different sets of information (pass/fail, qualification, correlation)
- Early weathering and corrosion tests did not accurately reproduce service environments and are typically effective only as pass/fail tests
- Improved scientific research led to weathering and corrosion standards that offered some correlative power but lacked ablity to reproduce certain failures and be conducted repeatably
- Modern weathering and corrosion standards use precise environmental control to deliver realistic, reproducible testing

Questions?