Combined Weathering & Corrosion Testing
综合老化和腐蚀试验

Sunny Sun 孙杏蕾
Q-Lab China

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Topics

- Accelerated tests for product qualification
- 加速测试，用于产品鉴定
- History of combined weathering & corrosion testing
- 综合老化与腐蚀试验的背景
- Overview of current methods
- 现行试验方法概述
- Recent Studies 近期研究
- Reproducibility challenges 再现性挑战

Matrix of Accelerated Tests 加速测试类型

Accelerated Test Type 加速测试类型	Result 结果表示	Test Time 试验时间	Results compared to 试验结果用于比较	Research? 研究? Development? 开发? Certification? 认证?
Quality Control 质量控制	Pass / fail 通过 / 失效	• Defined 确定的 • Short 较短时间	Material specification 材料规范	Certification 认证 & Research 研究
Qualification / validation 鉴定 / 验证	Pass / fail 通过 / 失效	• Defined 确定的 • Medium-long 中长时间	Reference material or specification 参照材料或规范	Certification 认证 & Development 开发
Correlative 相关性	Rank-ordered data 排序数据	• Open-ended 不确定 • Medium 中等时间	Natural exposure (Benchmark site) 自然曝晒 （基准曝晒地点）	Development 开发
Predictive 预测	Service life Acceleration factor 使用寿命 加速因子	• Open-ended 不确定 • Long 较长时间	Natural exposure (Service environment) 自然曝晒 （使用环境）	Development 开发 & Warranty Contracts 保修合同

What happens when your customer's qualification test gives incorrect data?

当您的客户的鉴定测试给出不正确的数据，会发生什么？

They still want their warranty!

他们还是要保修！

Protective Coatings 防护涂层
Industrial Maintenance Coatings 工业保养涂料
Marine Coatings 船舶涂料

- Primary job is to protect steel structures, industrial hardware, or other infrastructure in corrosive environments
- 主要是在腐蚀环境中保护钢结构，工业硬件或其它基础设施
- Sunlight exposure is often a factor
- 阳光照射通常是一个因素
- Re-coating can be very expensive
- 重新涂层可能非常昂贵

Infrastructure Protection 基础设施防护

- Bridges 桥梁
- Metal buildings 金属建筑物
- Petrochemical plants 石化工厂

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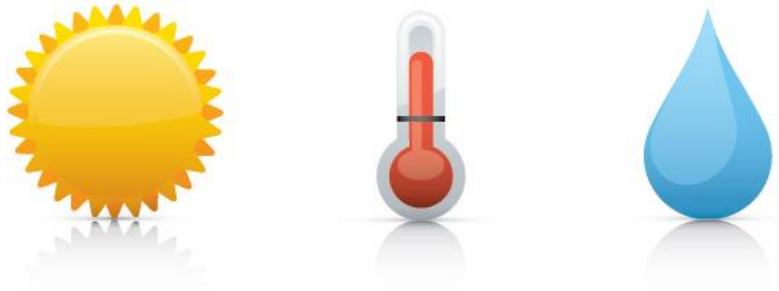
Weathering and Corrosion 老化和腐蚀



Weathering 老化

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.

由于暴露于**太阳光**中的辐射以及**热**（包括温度循环）和**水**（主要是湿度、露水和雨水）而引起的材料性质的变化

(Atmospheric) Corrosion 腐蚀

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.

在大气环境中，由于金属表面的**电化学反应**而引起的材料及其重要性能的退化和破坏。当表面被雨水、雾和冷凝形成的**湿气弄湿**时，就会发生这种情况

Combined Corrosion/Weathering
综合腐蚀/老化

- Developed in the 1980s by Sherwin Williams
- 20世纪80年代由Sherwin Williams公司开发

Combined Corrosion/Weathering

As a coating degrades from UV exposure, its ability to protect against corrosion is reduced

当涂层受到紫外线照射发生退化时，它的耐腐蚀性能也下降

Combined Weathering/Corrosion Cycle

7 Days

UVA-340	*4:00*	*0.89 W/m²/nm*	*60°C*
Condensation	*4:00*		*50°C*

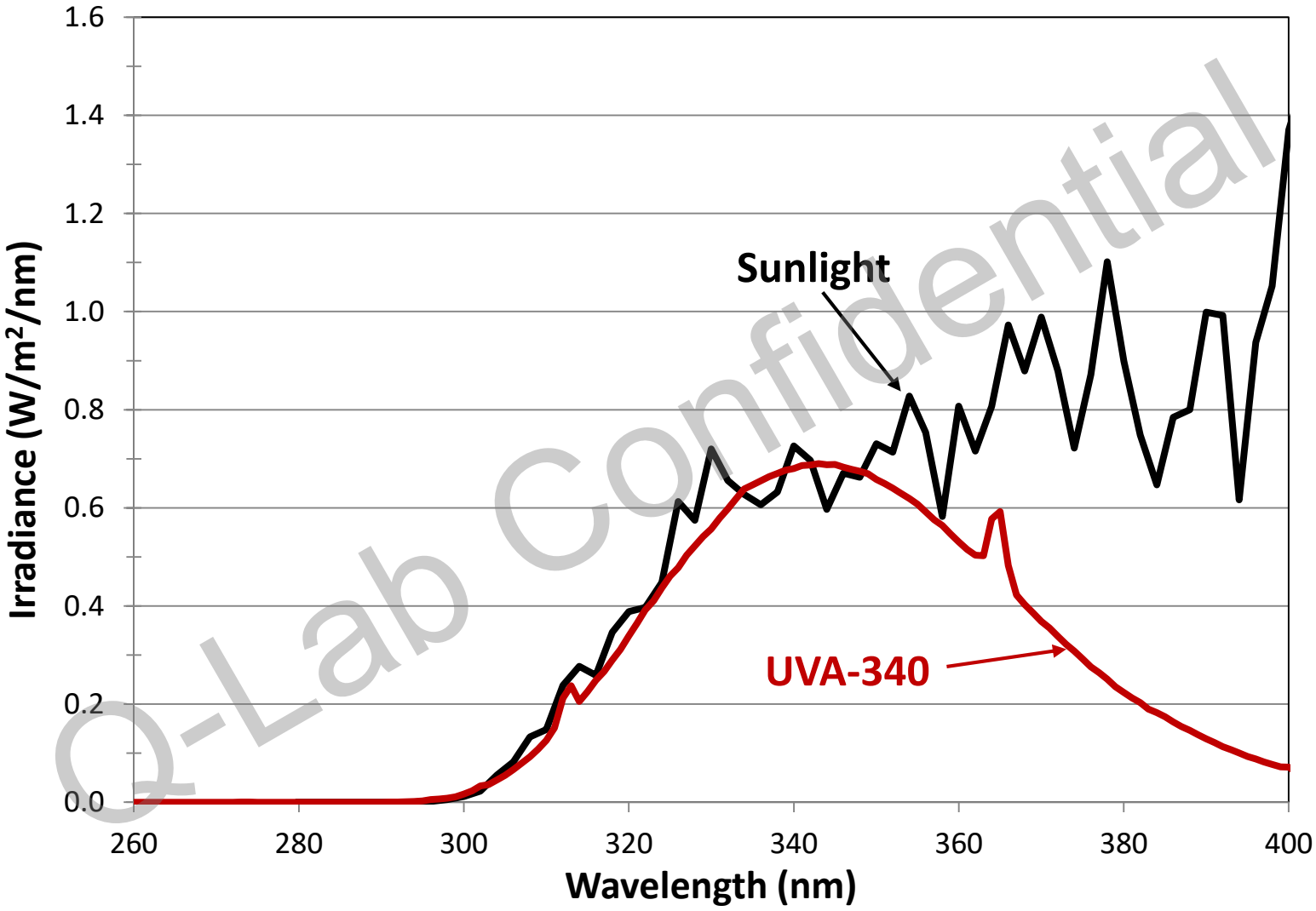
7 Days, ASTM G85 A5

Fog (dilute solution)	*1:00*	*24°C*
Dry-off	*1:00*	*35°C*

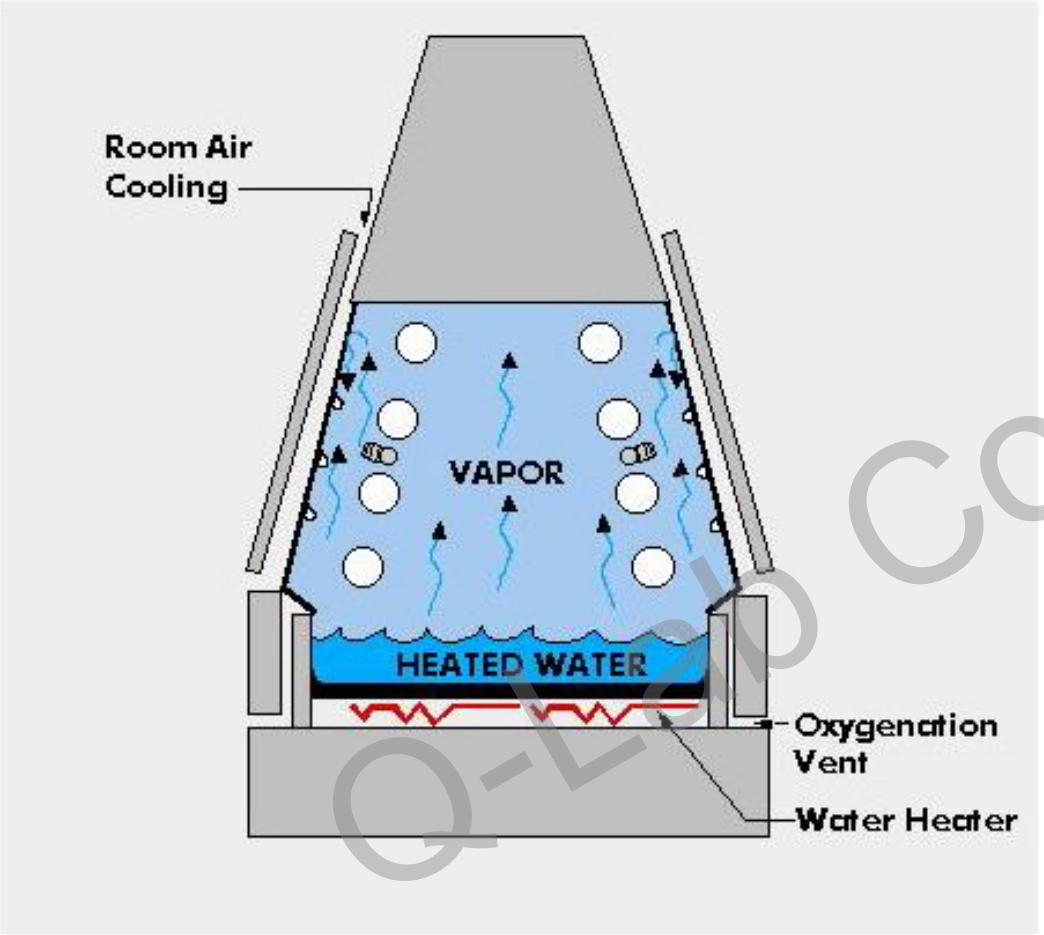
Fluorescent UV Weathering Tester
荧光紫外老化试验机

QUV shown with new dual-touchscreen controller
新的双触摸屏控制器 QUV

UVA-340 Lamps

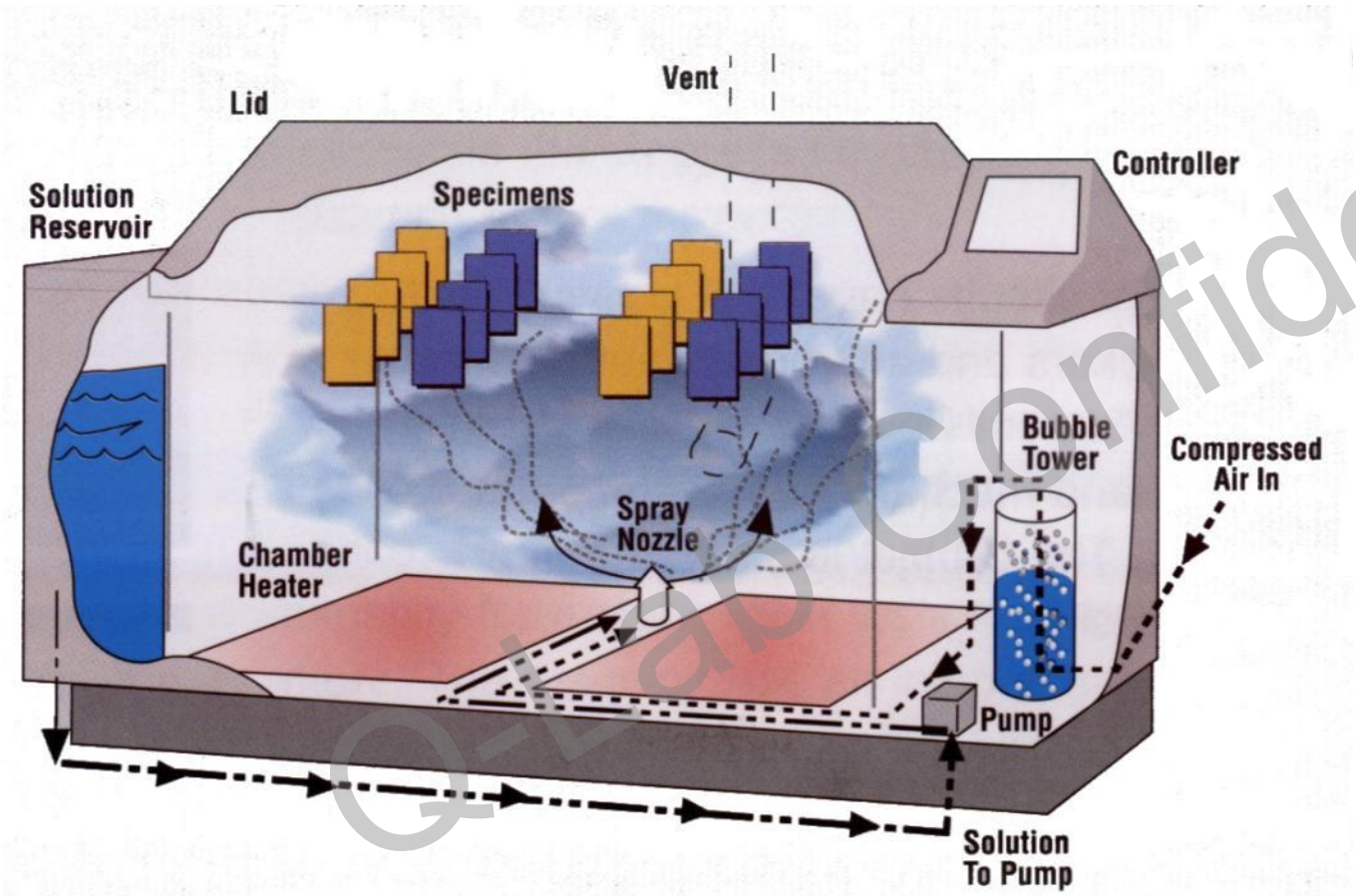


Condensation 冷凝



Hot condensation is very effective at simulating moisture absorption in a wet environment such as Florida.
热冷凝在模拟潮湿环境（如佛罗里达）中的水分吸收时非常有效

Continuous Salt Spray 连续盐雾
Salt Fog Environment 盐雾环境



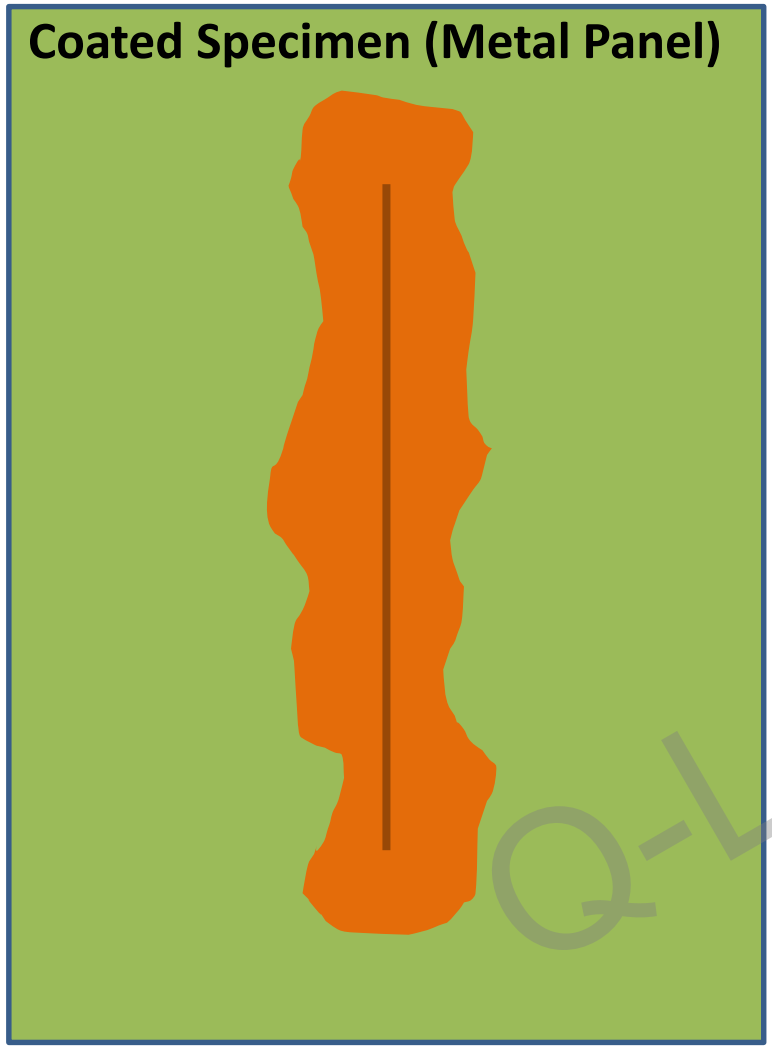
A solution of NaCl or other salts is pumped to an atomizing spray nozzle along with moisturized compressed air, creating a very fine mist that appears similar to fog.

氯化钠或其它盐溶液与湿润的压缩空气一起被泵送到雾化喷嘴，形成一种非常细的水汽，看起来像雾

Corrosion Specimen Evaluations
腐蚀试样评估

- ***Corrosion creep along a scribe***
- *沿划痕的腐蚀*
- Blistering
- 起泡
- Degree of rusting (ASTM D610)
- 锈蚀程度 (ASTM D610)

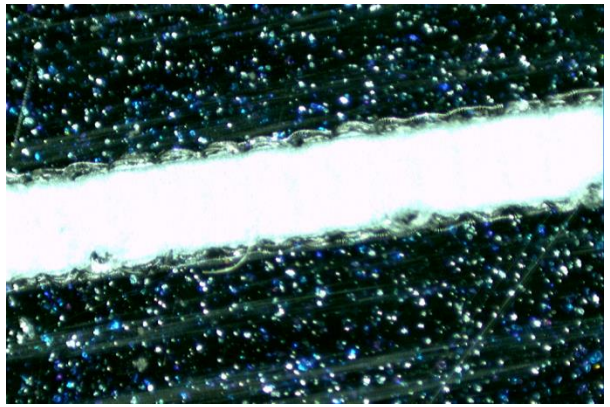
Corrosion Along a Scribe



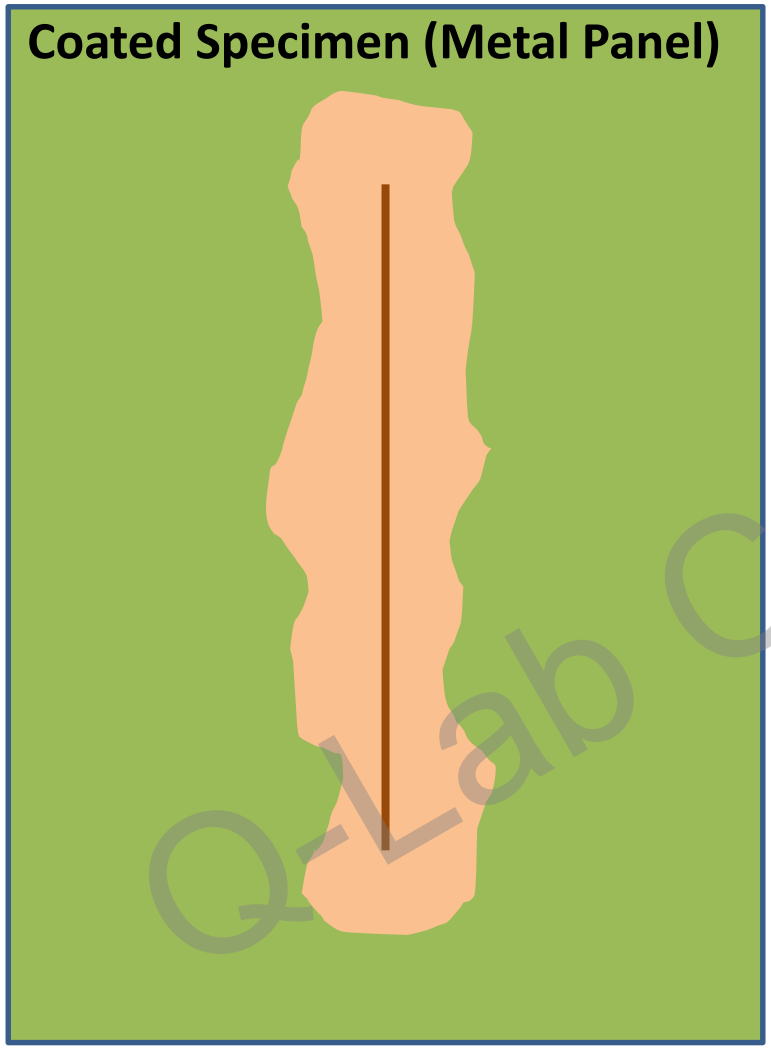
Scribing Tool

Scribe (cut) through the coating to the metal substrate

Expose the panel and allow corrosion to “creep” from the scribe



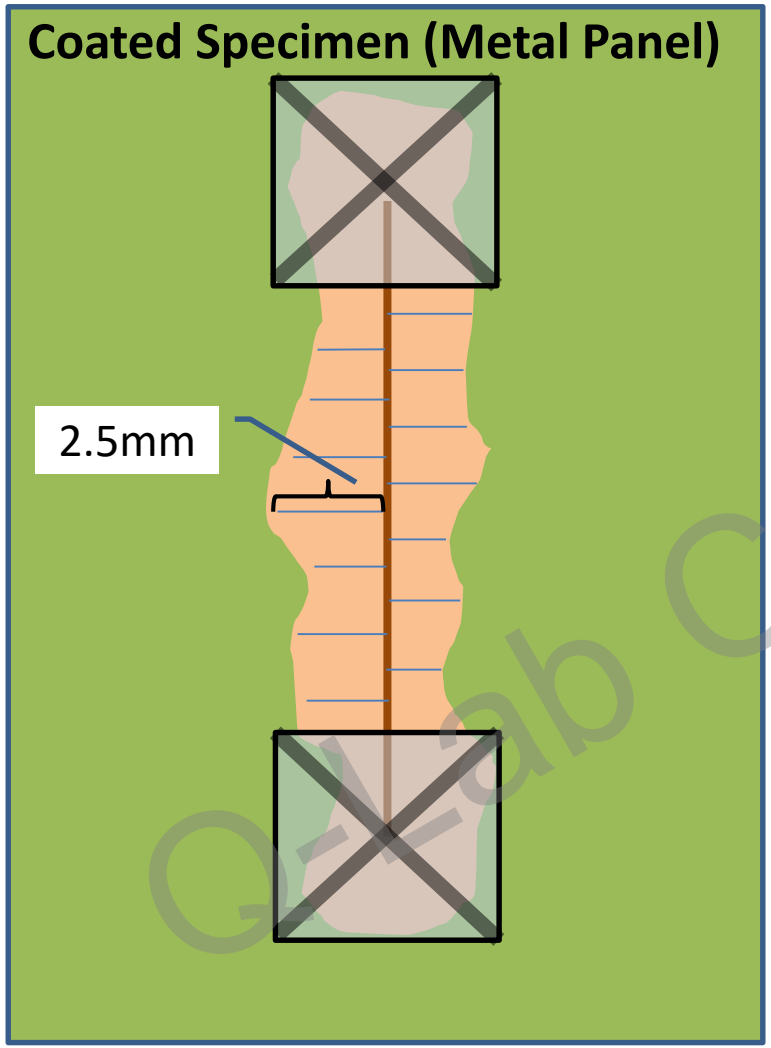
Corrosion Along a Scribe



Remove rust “scab” with dull blade

Now the panel is ready for evaluation

Corrosion Along a Scribe



Ignore corrosion areas near ends of scribe (approximately 6-12 mm)

Create grid lines (minimum of 6) from scribe perpendicular to edge of corroded areas—transparency can be placed over panel for this purpose

Measure distance between scribe and edge of corrosion

Paint removed due to loss of adhesion is a separate measurement

Corrosion Specimen Evaluations

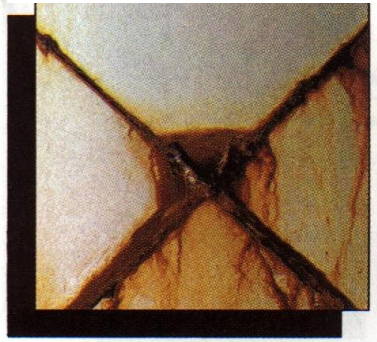
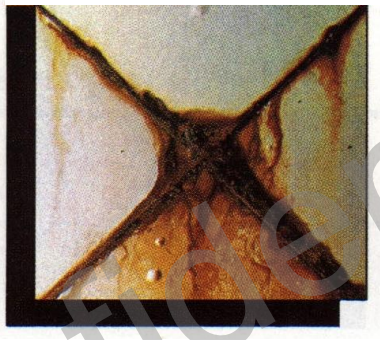
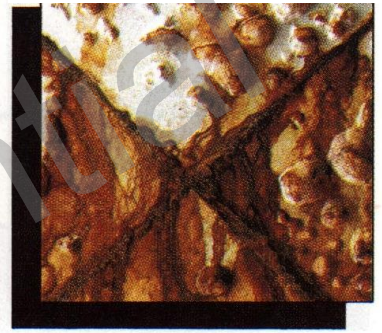
Corrosion creep

Vs

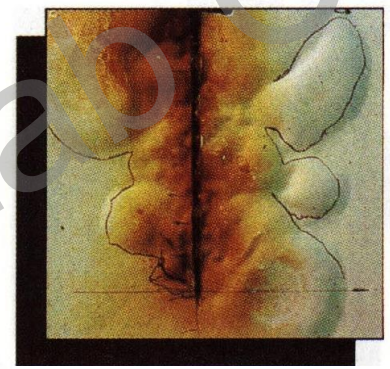
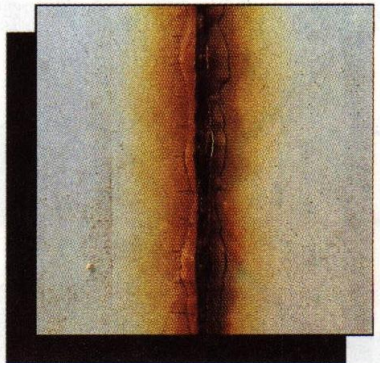
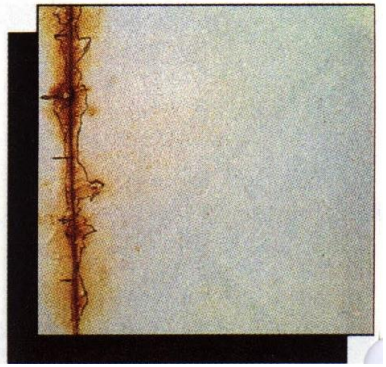
Loss of adhesion (cathodic delamination)

In this study, delamination data from laboratory tests correlated best to outdoor data

Salt Spray vs Outdoors 盐雾 vs 户外

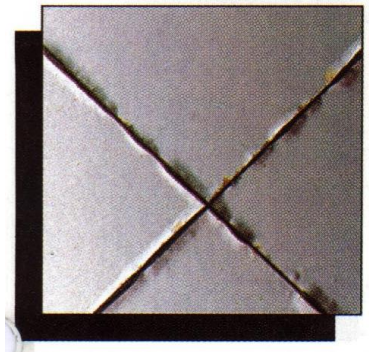
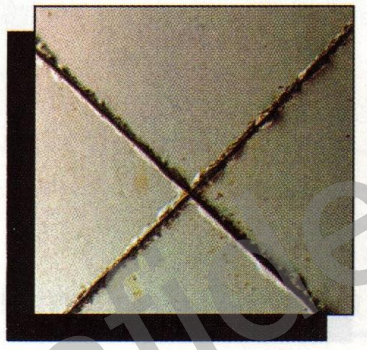
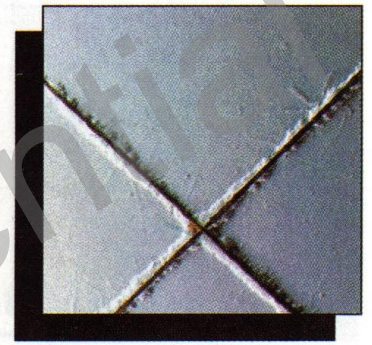
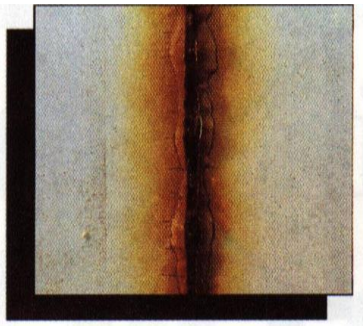
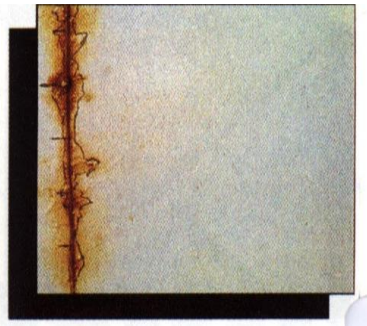
	Epoxy 环氧树脂	Alkyd 醇酸树脂	Latex 乳胶
Salt Spray			

Salt Spray for 2000 hours (1000 for latex)

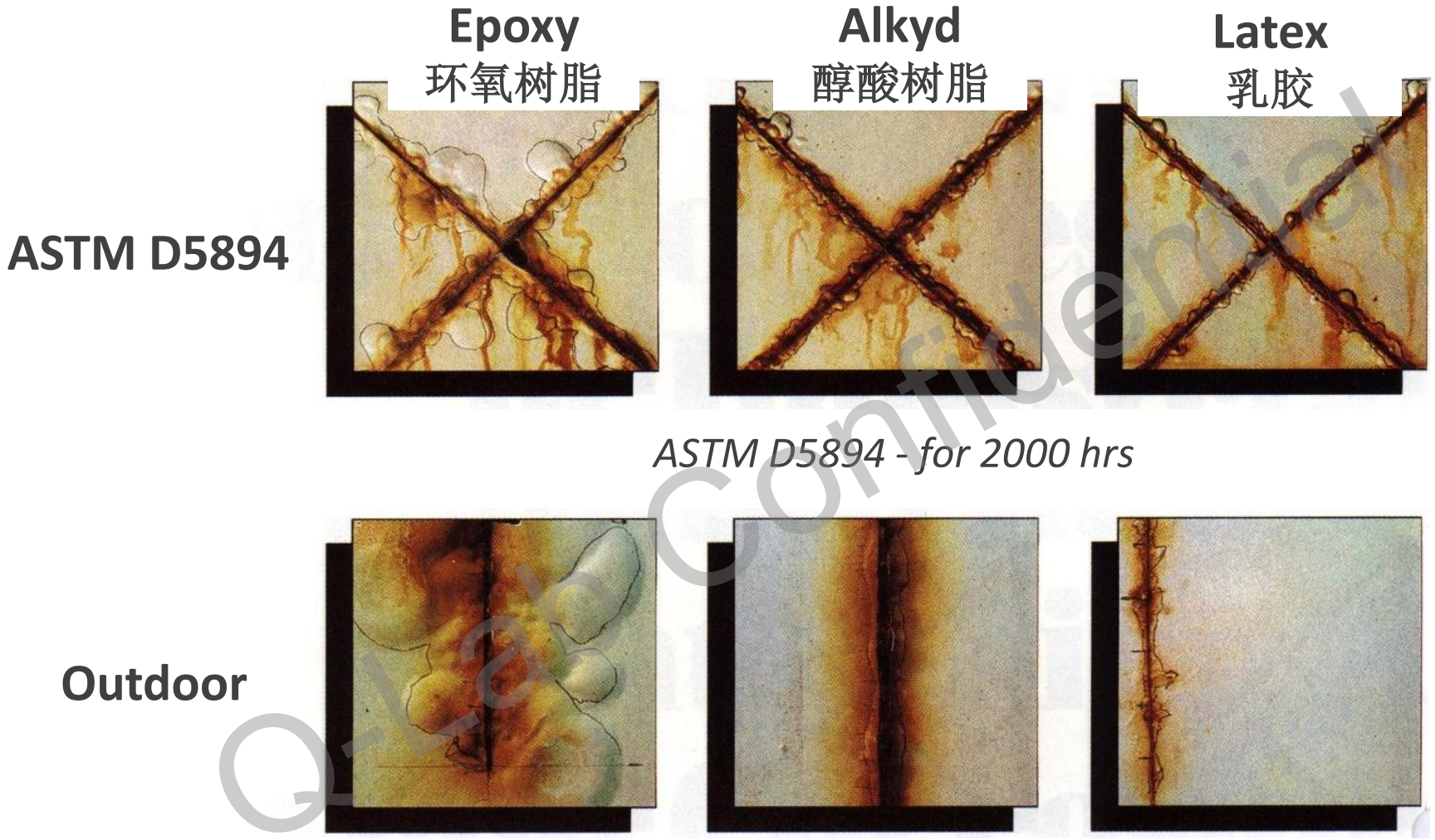
Outdoor			

27 months outdoor marine environment

Cyclic Wet/Dry vs Outdoors 循环湿/干 vs 户外

	Epoxy 环氧树脂	Alkyd 醇酸树脂	Latex 乳胶
Prohesion (ASTM G85 A5)			
	Salt Spray for 2000 hours (1000 for latex)		
Outdoor			
	27 months outdoor marine environment		

Combined Corrosion/Weathering vs Outdoors



Corrosion/Weathering Validation
腐蚀/老化验证

- **Society for Protective Coatings (SSPC)**
- **防护涂料协会**

- Cleveland Society for Coatings Technology (CSCT)
- 克利夫兰涂料技术协会

- American Association of State Highway and Transportation Officials (AASHTO)
- 美国国家公路和运输工作者协会

SSPC

- Society for Protective Coatings
- 15 different systems
- Outdoor vs. accelerated
  - 31 months
- Accelerated tests
  - Salt spray 5%
  - Prohesion
  - 2 types of cyclic immersion tests
  - Combined corrosion/ weathering test

SSPC Test Results

Laboratory Test Method	Correlation w/Severe Marine Environment
Conventional Salt Spray	-0.11
Prohesion	0.07
Cyclic Immersion Procedures	0.48
Cyclic Immersion with UV Procedure	0.61
Combined Corrosion/ Weathering Cycle	0.71

Results stated are Spearman rank coefficient 1.0 = perfect correlation, 0 = random, -1 = perfect rank reversal

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ASTM D5894

7 Days

UVA-340	*4:00*	*0.89 W/m²/nm*	*60°C*
Condensation	*4:00*		*50°C*

7 Days, ASTM G85 A5

Fog (dilute solution)	*1:00*	*24°C*
Dry-off	*1:00*	*35°C*

ASTM D5894 Variations

- NACE TM0304, TM0404 (National Association of Corrosion Engineer)
  - Replaces dilute NaCl/$(NH_4)_2SO_4$ solution with ASTM D1141 synthetic seawater
  - 用ASTM D1141中的合成海水代替NaCl/$(NH_4)_2SO_4$溶液
- Freeze cycling added to US Federal Highway Administration test
- 美国联邦公路管理局测试中增加了冷冻循环

Synthetic Sea Water (ASTM D1141)

Compound 化合物	Concentration (g/L) 浓度
NaCl (sodium chloride)	24.53
$MgCl_2$ (magnesium chloride)	5.20
Na_2SO_4 (sodium sulfate)	4.09
$CaCl_2$ (calcium chloride)	1.16
KCl (potassium chloride)	0.695
$NaHCO_3$ (sodium bicarbonate)	0.201
KBr (potassium bromide)	0.101
All Others	<0.10

pH of synthetic seawater is 8.2

ISO 12944-6:2018

“Corrosion of steel structures by protective coating systems”

防护涂料体系对钢结构的腐蚀防护

- Corrosivity categories described in ISO 12944-2 (based on ISO 9223)
- 腐蚀类别见ISO 12944-2
- Durability classes described in ISO 12944-1
- 耐候等级见ISO 12944-1
- ISO 12944-9 covers “off-shore” structures CX corrosivity classification (replaces ISO 20340)
- ISO 12944-9涵盖了“海上” 结构 CX腐蚀分类

ISO 12944-6

Annex B Cyclic Ageing Test 循环老化测试

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
UV/condensation — ISO 16474-3			Neutral salt spray — ISO 9227			Low-temp. exposure at (−20 ± 2) °C

Repeat for 72 hours:
4 hours UVA-340, 0.83 W/m²/nm at 340 nm, 60°C
4 hours dark condensation, 50°C

72 hours of continuous salt fog at 35°C

Rinse panels and put in a freezer for 24 hours

Which Weathering/Corrosion Test is the Best?
哪种老化/腐蚀试验最好？

- Actually, all generally exhibit good correlation to field studies
- 实际上，所有测试都与户外研究表现出良好的相关性

- Test severities are similar at equal duration
- 在相同试验时间内，测试的严重性是相似的

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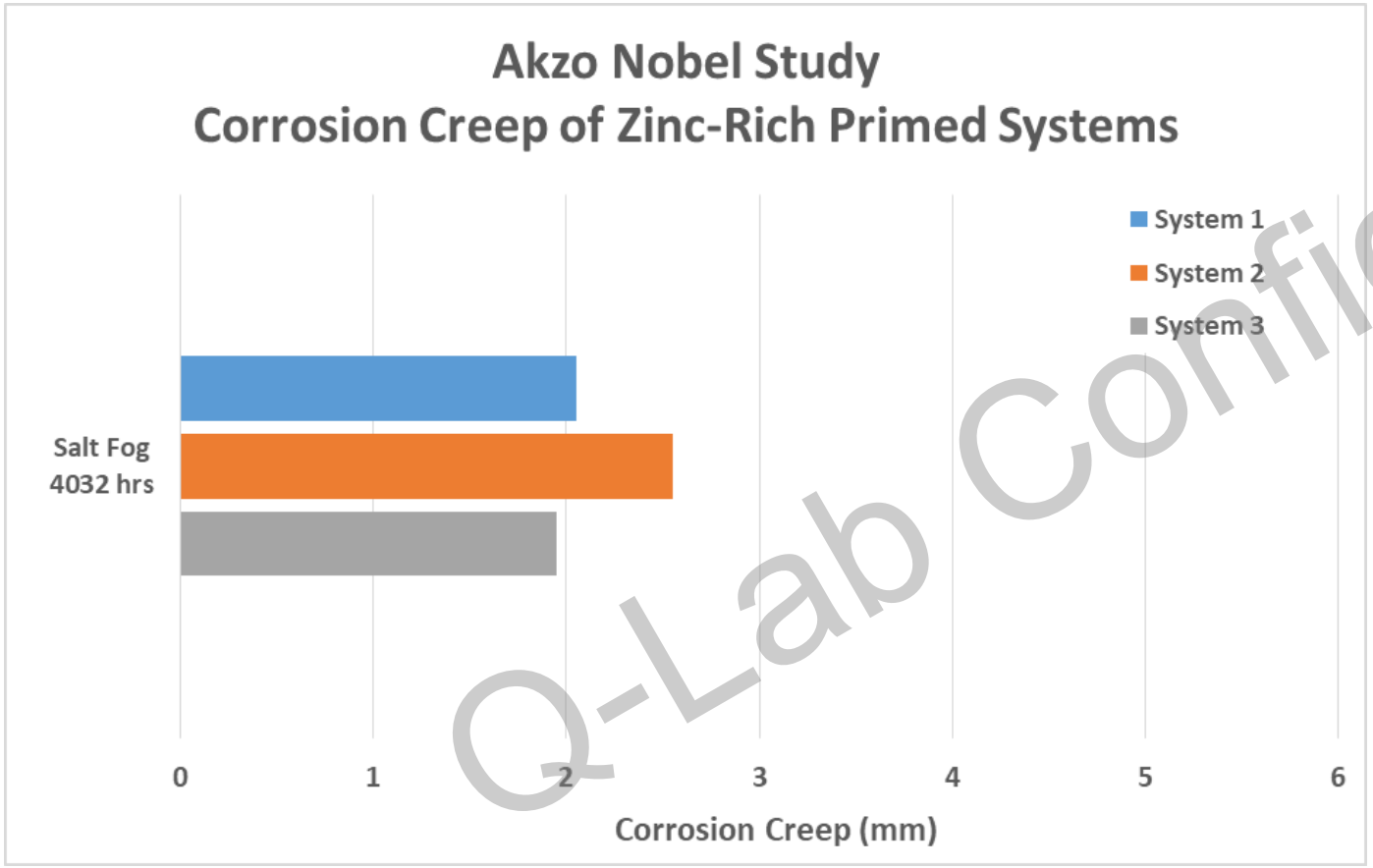
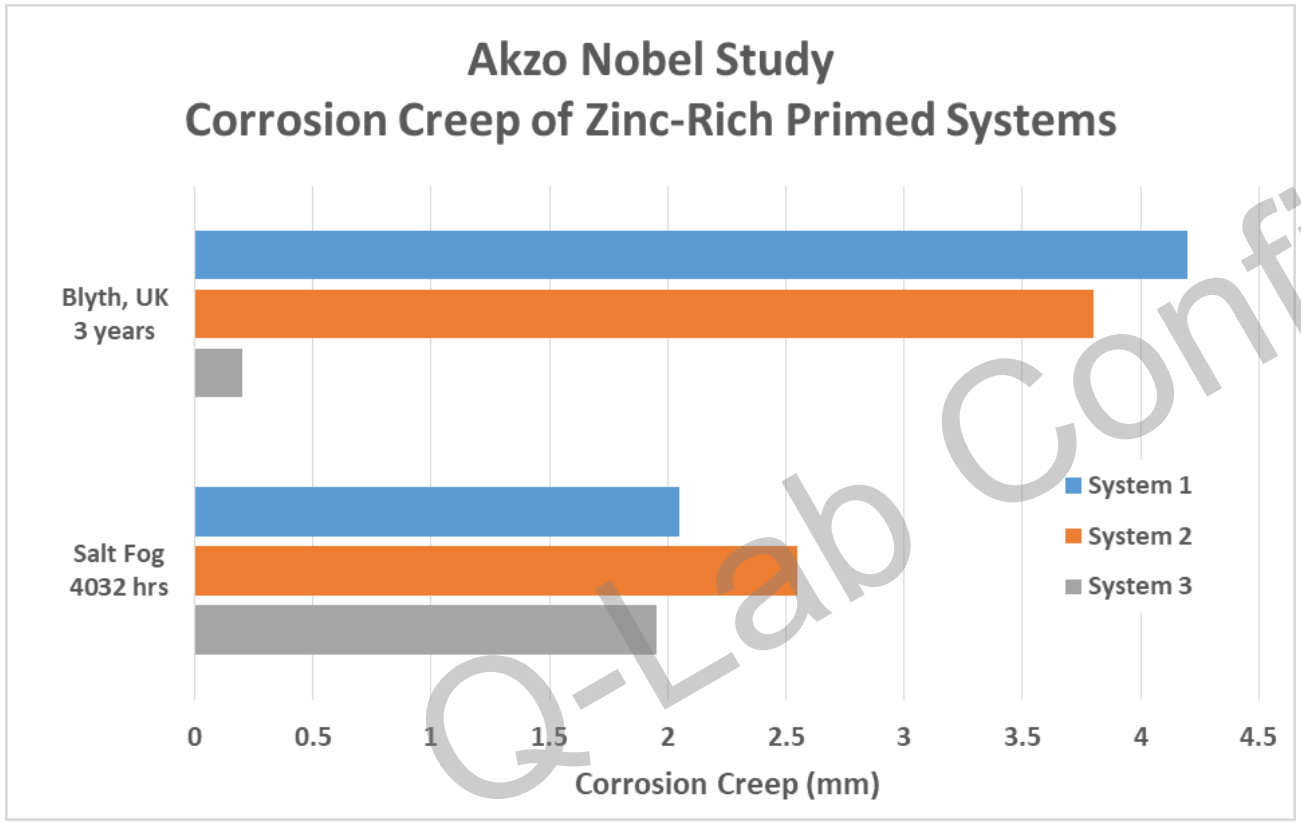
Correlation Study (Akzo Nobel) 相关性研究

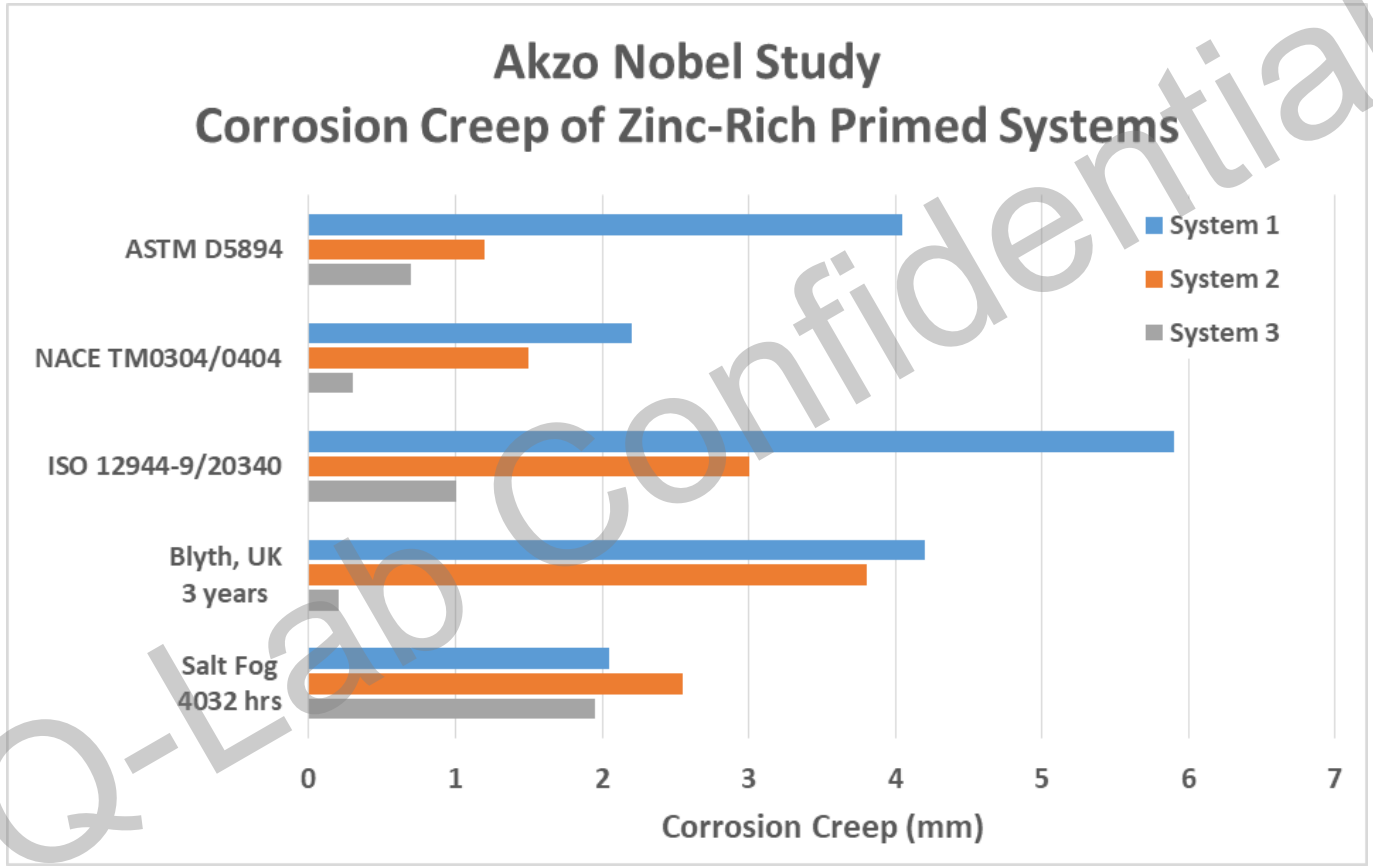


Three systems perform similarly to continuous salt fog

Salt Fog versus Outdoor Coastal Exposure
盐雾 vs 户外海岸暴露



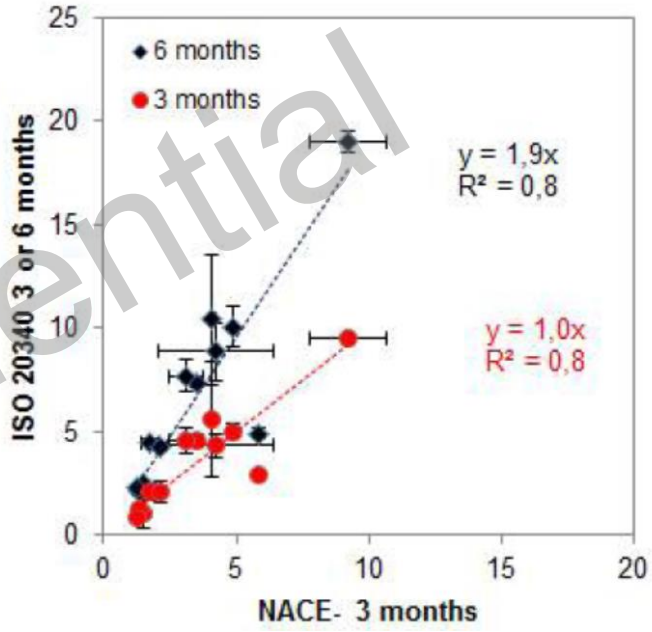
Combined Weathering/Corrosion Cycles
综合老化/腐蚀试验



ISO 20340/12944-9 vs NACE TM0304

	Acceptable		Excluded	
ISO 20340 6 months	Zn primer	Other	Zn primer	Other
	≤3 mm	≤8 mm	>3 mm	>8 mm
Scribe 2,0mm	S1 S2	S6 S9 S12	S3 S4 S5	S7 S8 S10 S11
NACE rust creepage 3 months	Zn primer	Other	Zn primer	Other
	<1,5 mm	<3,5 mm	>1,5 mm	>3,5 mm
Scribe 2,0 mm	S1 S2	S6 S12	S3 S4 S5	S7 S8 S9 S10 S11

12 Coating systems on grit blasted steel panels
Pass/fail agreement on 11 of the 12 systems



ISO 20340/12944-9 and NACE methods have equal severity on a time scale

Nathalie LeBozec and Cecile Hall, French Corrosion Institute; Denis Melot, Total
NACE Corrosion 2014 Paper 3762

Reproducibility Concerns 再现性问题

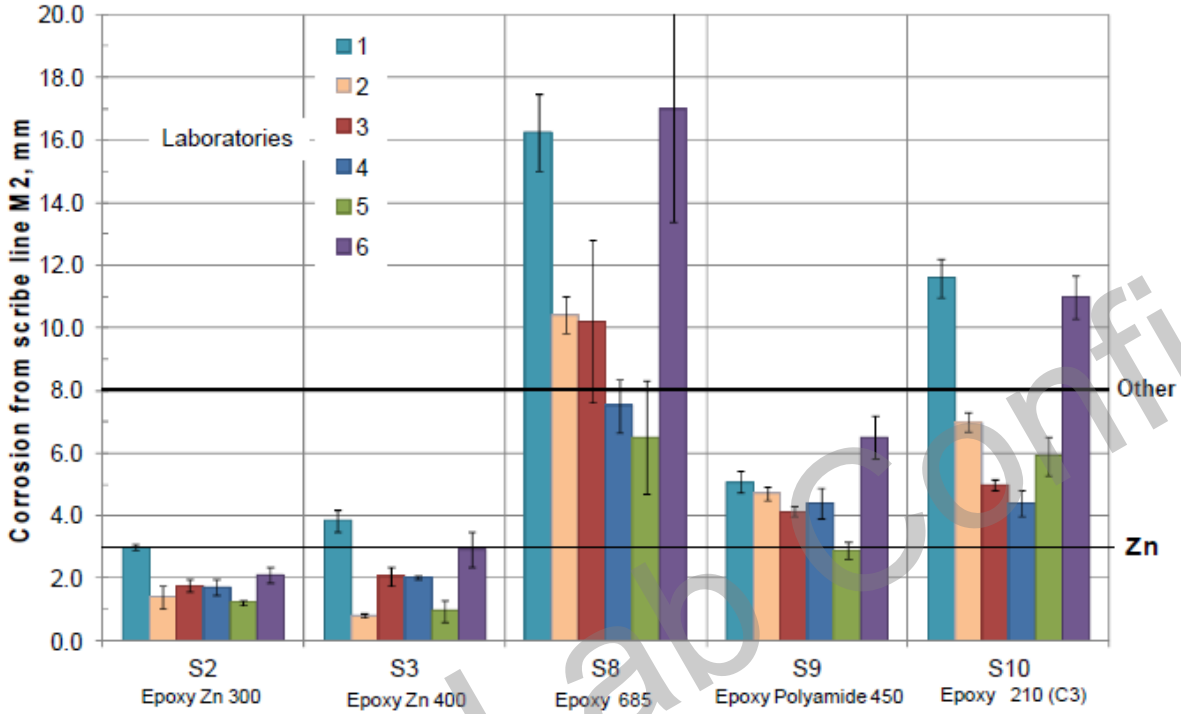


Figure 2 : Corrosion extent from the scribe line after ISO 20340 Annex A test. Requirements for Zn Primer (<3mm) and non-Zn primer (<8mm) are highlighted.

- *For 2 of 5 coating systems, all six labs agreed on pass/fail result*
- *2 of 5 systems had multiple contradictory pass/fail results*

Nathalie LeBozec, French Corrosion Institute; Laurence Bougon, CEREMA; John Carter, EXOVA; Tanja Scholz, Fraunhofer IFAM; Ole Oystien Knudsen, SINTEF; Adeline Flogard, SP Technical Research Institute of Sweden

NACE Corrosion 2016 Paper 6991

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Reproducibility Case Study – Prohesion
再现性案例研究 - Prohesion

- ASTM G85 Annex 5 (Prohesion)
- Part of ASTM D5894, modified in NACE standards

ASTM G85 Annex 5 (Prohesion)

1 Hour fog at “ambient” temperature (room should be 24°C)
1 hour dry-off 35°C

Solution: 0.05% NaCl
0.35% $(NH_4)_2SO_4$
pH: 5.0 - 5.4

ASTM G85 Annex 5 (Prohesion)

- How dry is dry?
- How long does it take to achieve a “dry” condition?

Answers are in the non-mandatory appendix: “within ¾ hour all visible moisture is dried off the specimens”

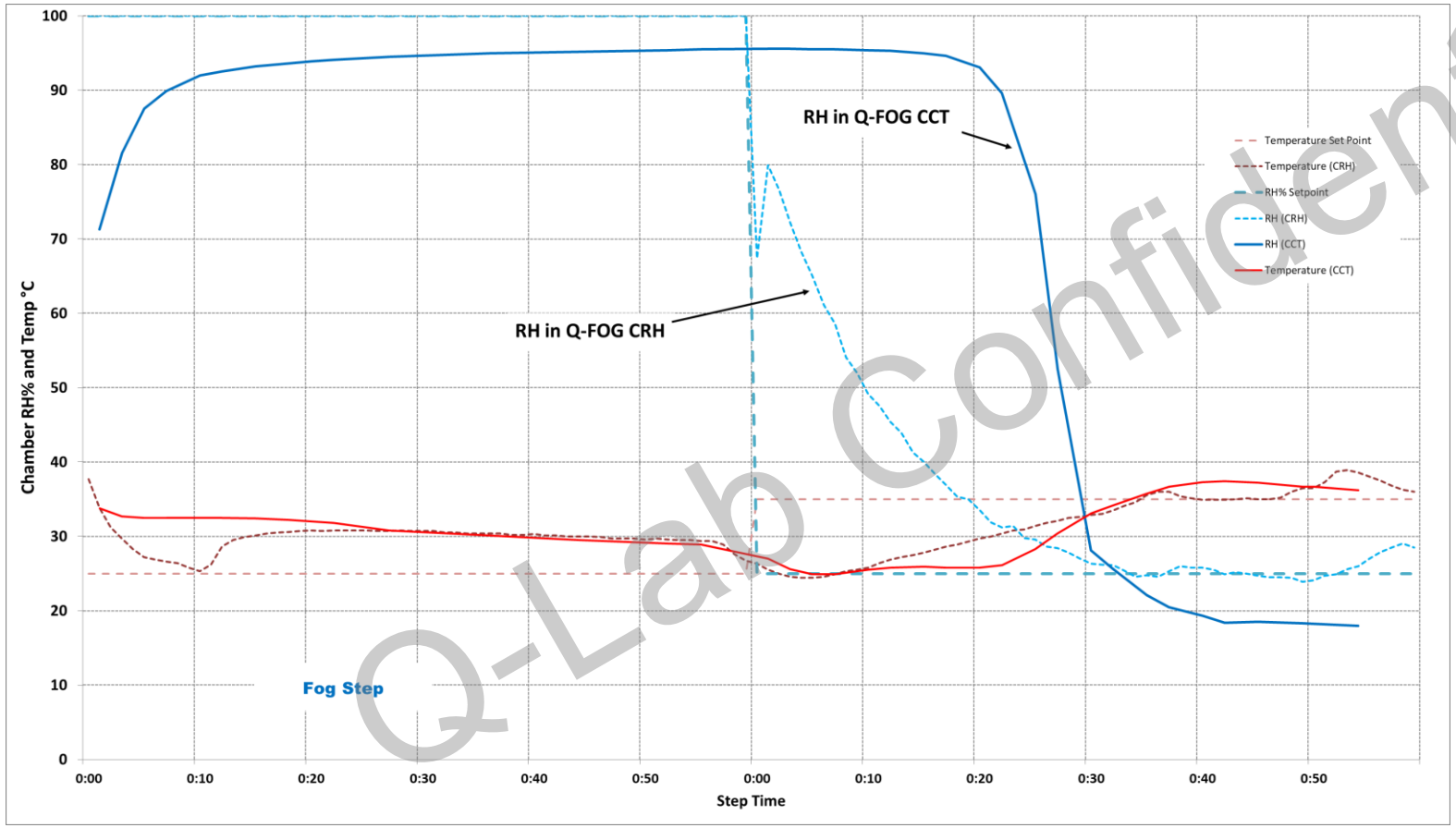
Problem Statement

My new chamber isn't as severe as my old one

After 1000 hours of Prohesion, new chamber produced less severe results on a coatings test

Q-FOG CCT *Q-FOG CRH*

Prohesion RH Profile in Two Chambers



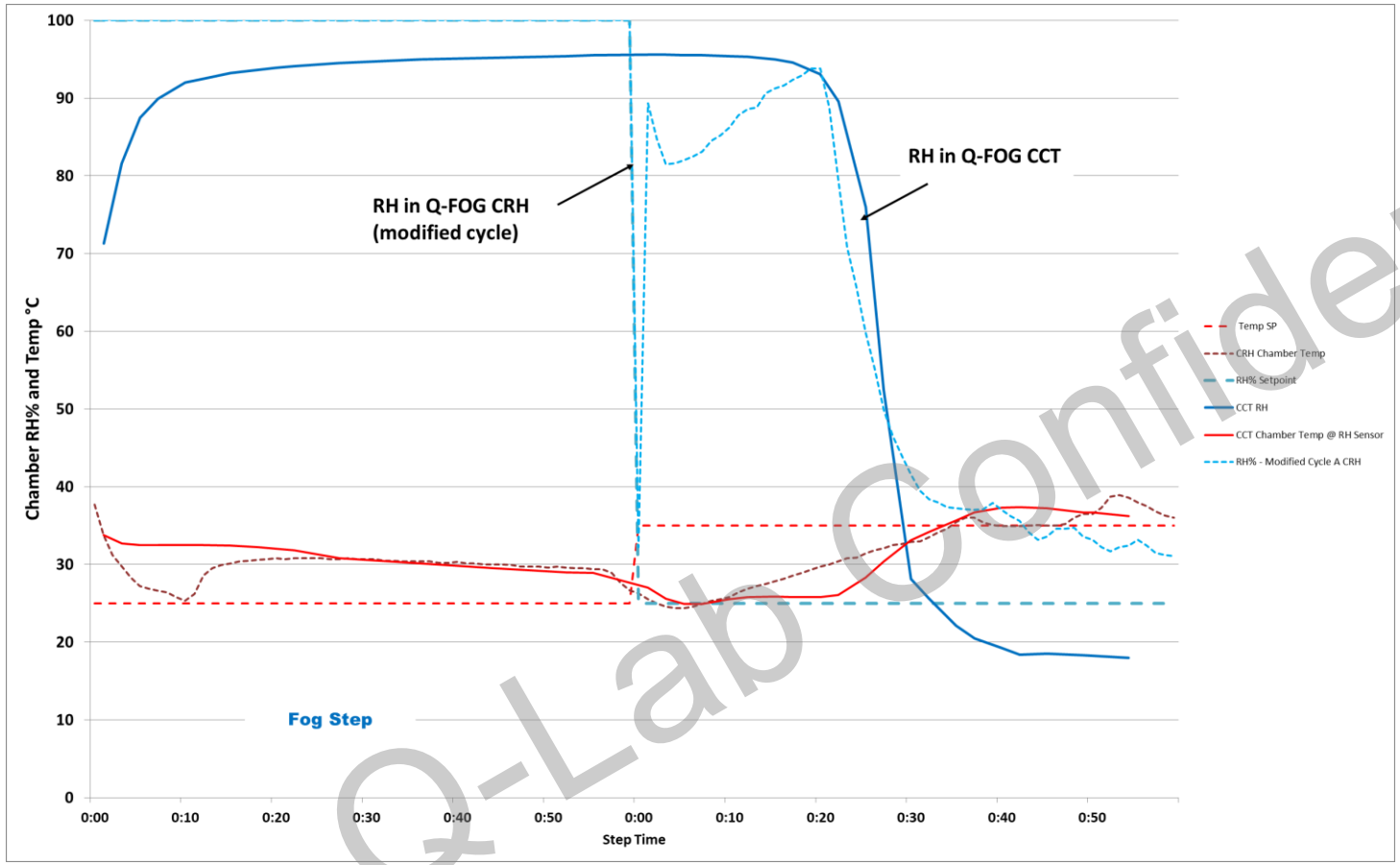
Q-FOG CCT Cycle:

Step 1: Fog 24°C 1:00
Step 2: Dry 35°C 1:00
Step 3: Go to Step 1

Q-FOG CRH Cycle:

Step 1: Fog 24°C 1:00
Step 2: RH 35°C, 25% RH 1:00
Auto transition
Step 3: Go to Step 1

Modified CRH Prohesion Cycle



Modified Prohesion Cycle:

Step 1: FOG 24°C 1:00

Step 2: RH 35°C, 95%RH 0:30

Auto transition

Step 3: RH 35°C, 25% RH 0:30

Auto transition

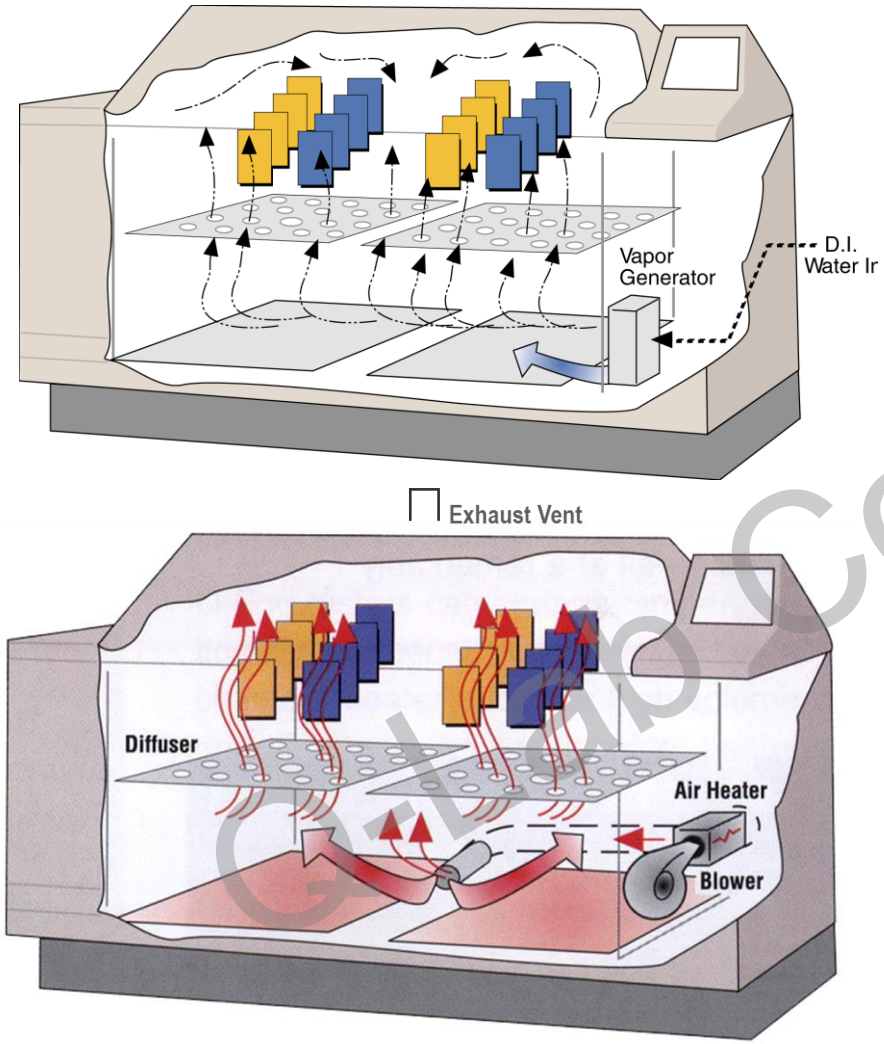
Step 4: Go to Step 1

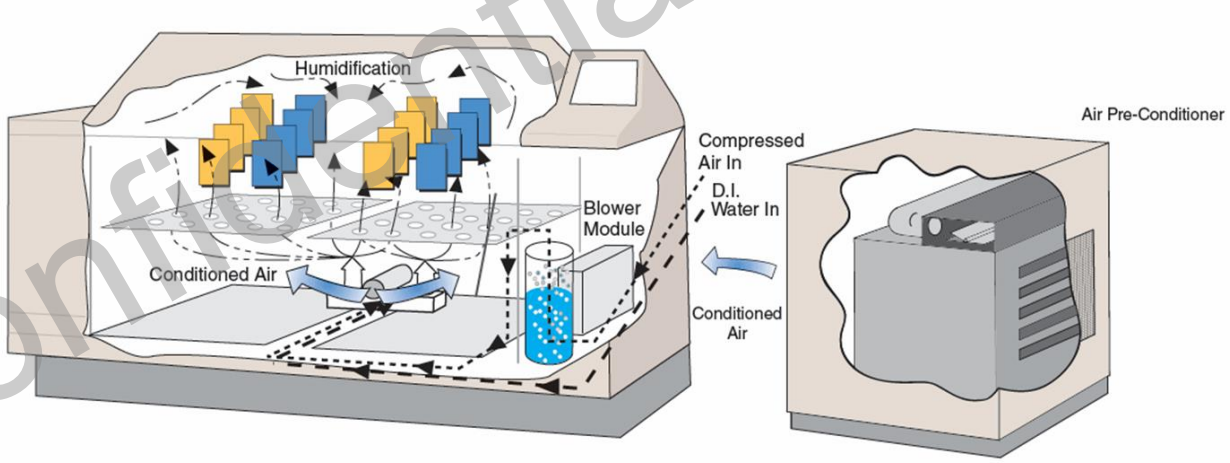
Q-FOG CCT

Q-FOG CRH (modified cycle)

Q-FOG CCT vs CRH

Q-FOG CCT has simple humidity generation without air flow and dry-off by blown heated air through chamber

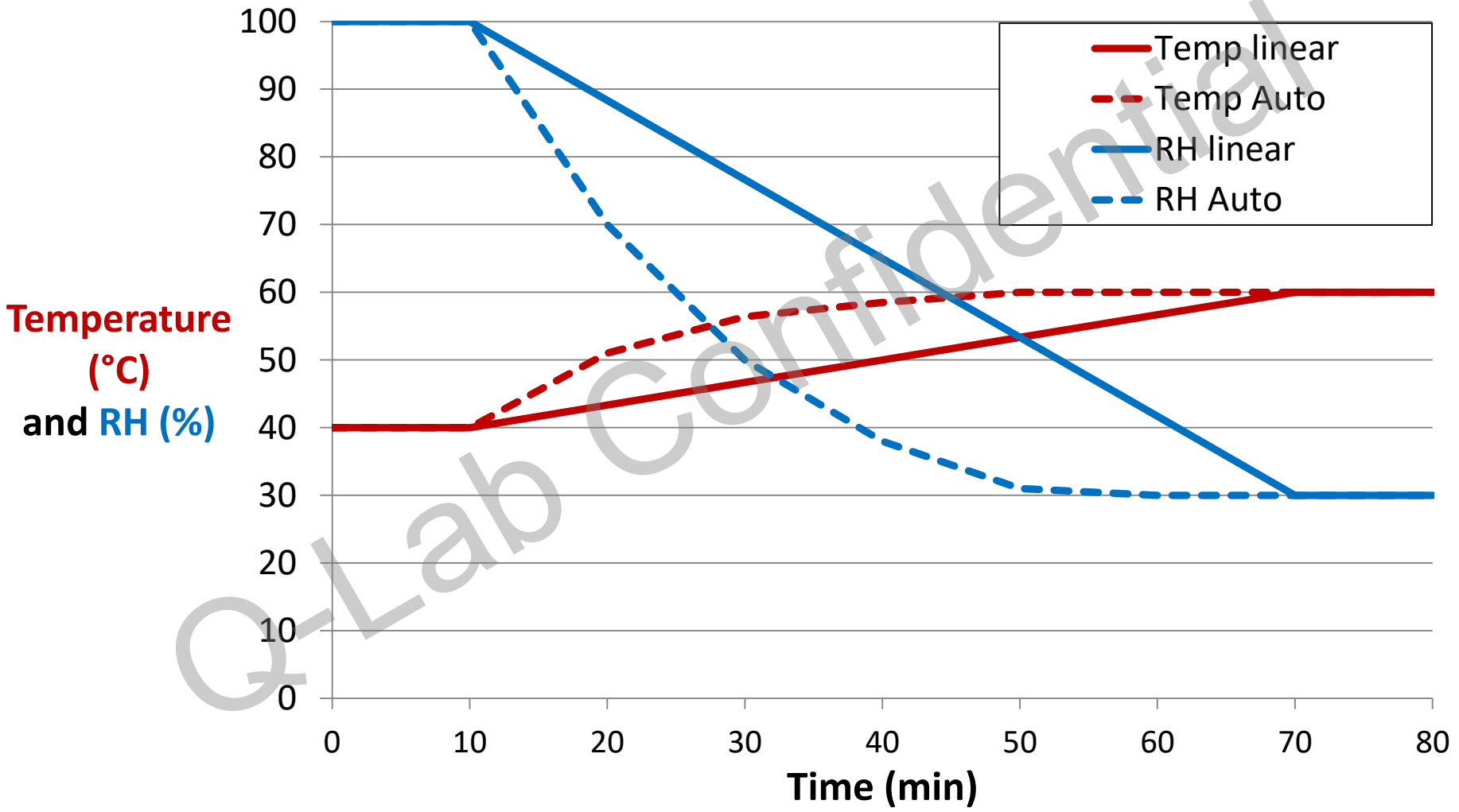




Q-FOG CRH has atomizing humidification nozzles, an air drier (chiller), and a recirculation system with damper to regulate moist and dry air streams

Q-FOG CRH Linear and Auto Ramping

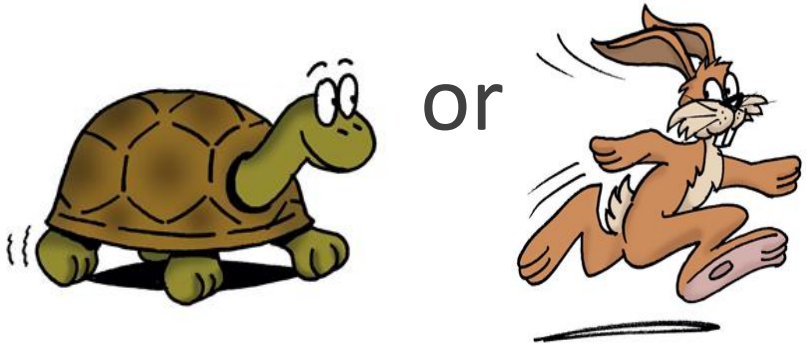
Transition from Wet to Dry



Improving Test Reproducibility
提高试验再现性

- Specify chamber RH and transition times of corrosion cycles
- 指定腐蚀循环的箱内相对湿度和过渡时间
- Develop specimen handling instructions that reduce variability (lab conditions during handling, maximum time outside the chamber, whether rinsing should be performed)
- 制定减少变数的试样处理规范 (实验室条件，从试验箱取出的最长时间，是否进行冲洗)

Which technician runs the test?



or

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