Modern Corrosion Testing
现代腐蚀测试

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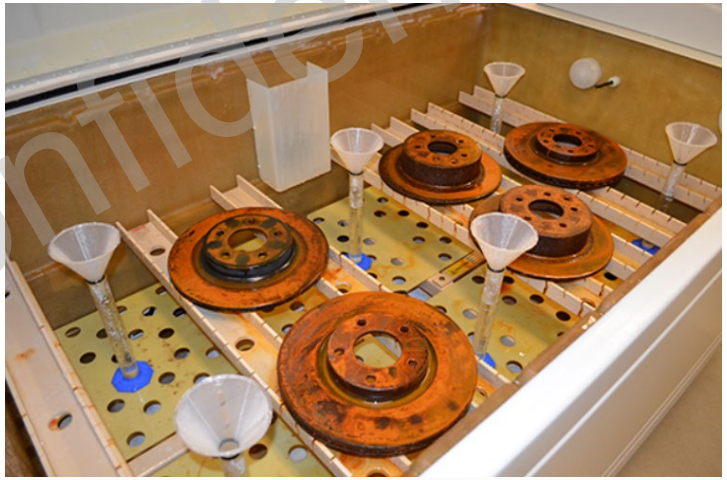

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Topics

- Types of Accelerated tests

加速测试的类型

- Continuous Salt Spray (Neutral & Acidified)

持续盐雾（中性和酸性）

- Wet/Dry Cyclic Tests

潮湿/干燥循环测试

- First-Generation Cyclic Automotive Tests

第一代汽车循环测试

- Modern Corrosion Test Methods

现代腐蚀测试方法

- Verifying Corrosion Test Performance

验证腐蚀测试表现

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Types of Accelerated Tests
加速测试类型

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control 质量控制	Pass / fail **通过/失效**	• Defined **确定的** • Short **短**时间	Material specification **材料**规格
Qualification / validation 验证	Pass / fail **通过/失效**	• Defined **确定的** • Short **短**时间	Reference material or specification **参比材料**
Correlative **相关性**	Rank-ordered data **排序相关**	• Open-ended **不确定** • Medium **中等**时间	Natural exposure (Benchmark site) **自然曝晒**（户外基准点）
Predictive **寿命**预测	Service life Acceleration factor **加速因子**	• Open-ended **不确定** • Long 长时间	Natural exposure (Service environment) **自然曝晒**（实际环境）

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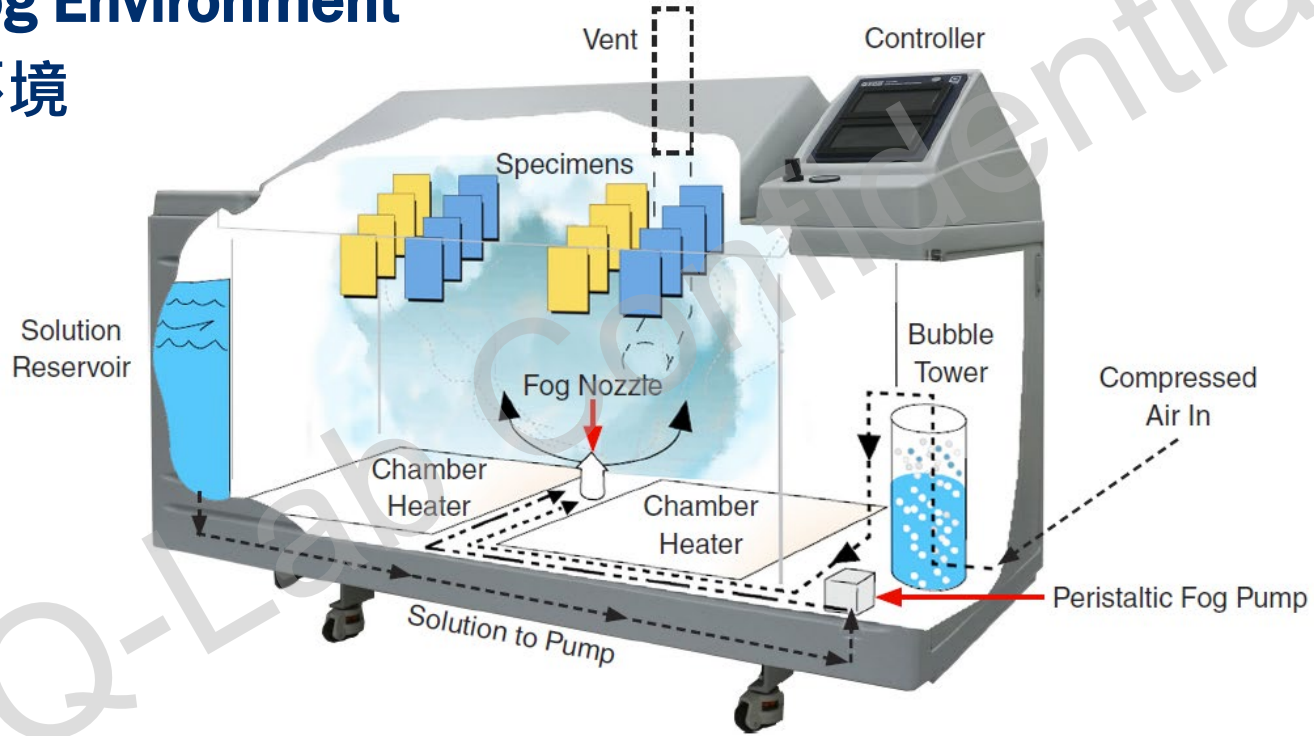
Continuous Salt Spray 持续盐雾测试

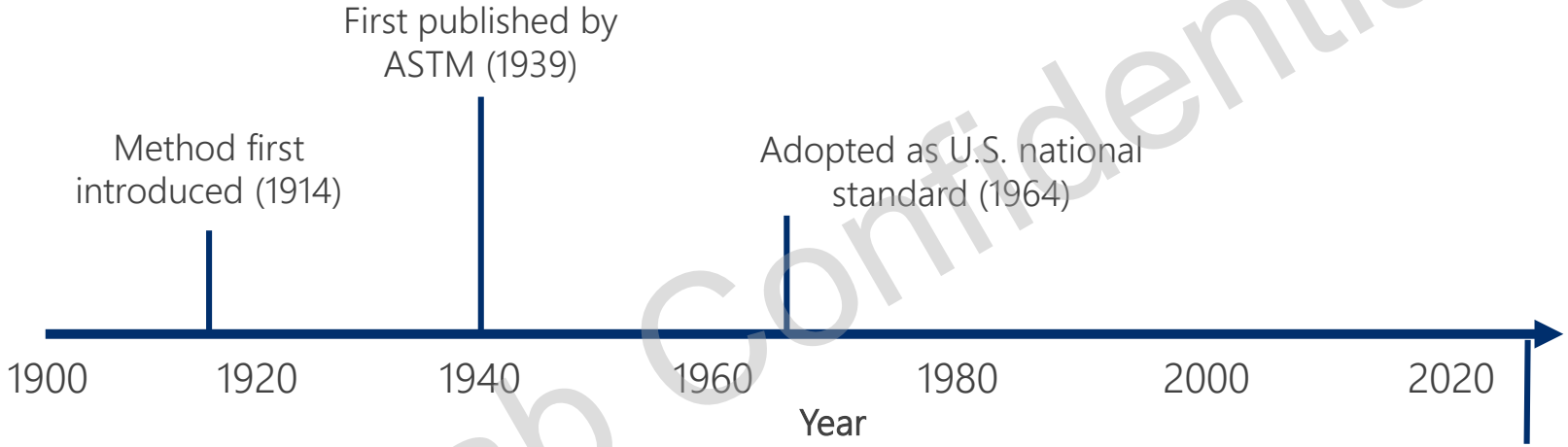
Salt Fog Environment

盐雾环境



Continuous Salt Spray 持续盐雾测试

ASTM B117



ASTM B117 is the most widely-used corrosion standard today, primarily for quality control and metallic/conversion coatings
ASTM B117 **是世界上使用最广泛的**盐雾标**准，主要用于**QC**和**转化膜涂层

Continuous Salt Spray 持续盐雾测试

ASTM B117

- 5% NaCl salt fog at 35°C

5%氯化钠盐雾，35 °C

- Neutral pH

中性PH

- Fine mist (atomized with compressed air) sprayed indirectly onto specimens

压缩空气打成细雾，非直接喷洒在样品上

- ISO 9227 contains the same test

ISO 9227有一样的测试

- When correctly followed, test has reasonable repeatability and reproducibility

测试程序正常，测试结果有好的可重复性和可再现性

Limitations of Salt Spray
盐雾测试的局限性

- Not a good simulation of most service environments

不能模拟大多数环境

- Typically produces different corrosion products than natural exposure

通常会产生不同于自然环境下的腐蚀产物

- Poor rank order correlation with outdoor corrosion

与室外腐蚀相关性差

- Q: What type of accelerated tests are these?

Q：这是什么类型的加速测试？

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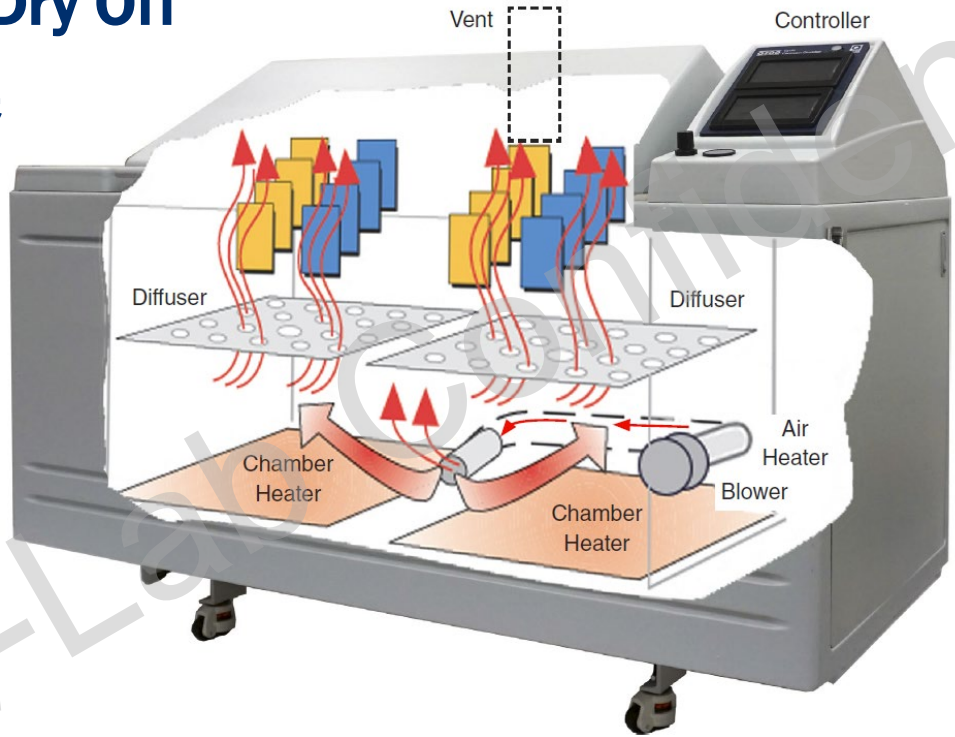
Wet/Dry Cyclic Tests 湿/干 循环测试

Salt Fog -> Dry Off

盐雾-> 干燥



Heater Configurations
加热器结构

- *Rapid Ramp Heaters required to meet some fast temperature transition times*

快速升温加热器可以满足一些对温度转换时间很快的标准

Wet/Dry Cyclic Tests 湿/干循环测试

Prohesion (Protection is Adhesion)

- Alternating spray and dry-off

交替盐雾和干燥

- Development began in England, 1960's

1960年代开发于英国

- Dilute NaCl, $(NH_4)_2SO_4$

稀氯化钠，硫酸铵溶液

- American Architectural Manufacturers Association recently replaced ASTM B117 with this test in AAMA 2605, "Superior" coatings on aluminum

美国建筑制造商协会将AAMA 2605中的ASTM B117替换为Prohesion实验

Combined Corrosion/Weathering
交替腐蚀老化测试

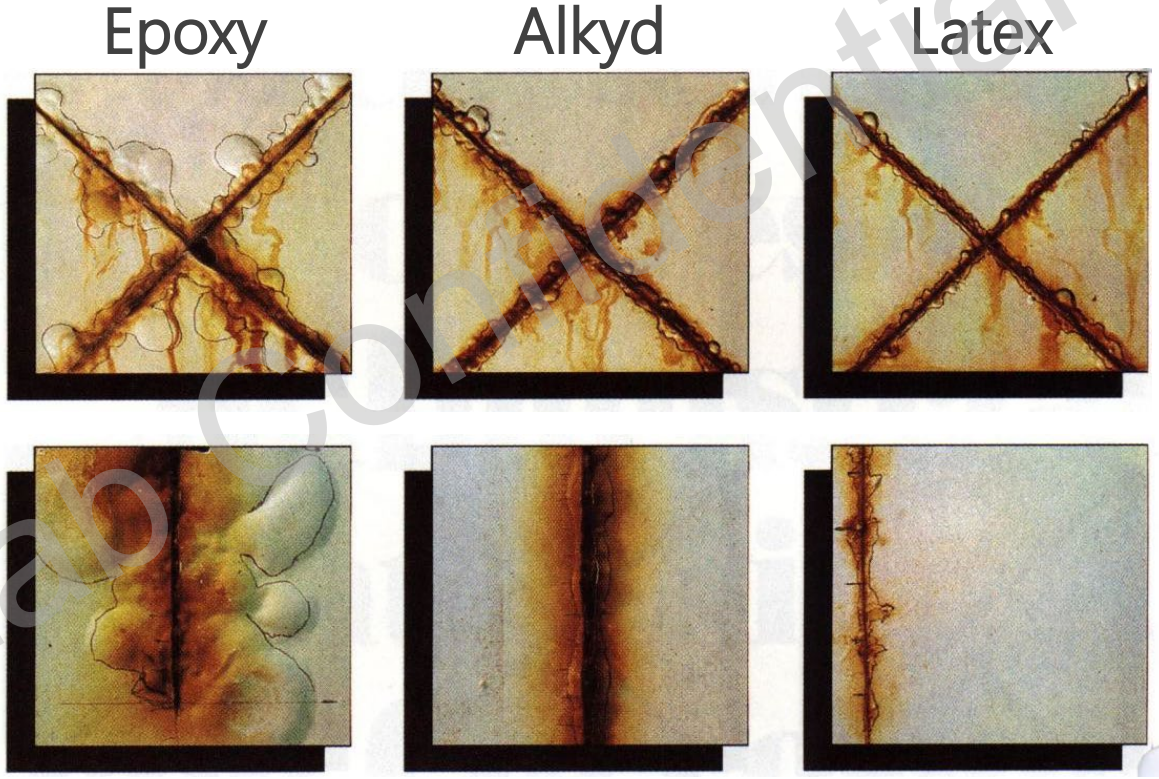
- As a coating degrades from UV exposure, its ability to protect against corrosion is reduced

当涂层因紫外线暴露而退化时，其防腐能力也降低

- Sherwin Williams developed a UV + Corrosion combined cycle in the 1980's to test this

Sherwin Williams在20世纪80年代开发了紫外+腐蚀循环来测试这一问题

Combined Corrosion/Weathering vs Outdoors
紫外/盐雾交替循环测试 vs 户外



Wet/Dry Cyclic Test Case Study

SSPC (Society for Protective Coatings)

- 15 different systems included

15种不同的涂层体系

- Outdoor testing (31 months)

户外测试31个月

- Accelerated tests (2000 hours)

实验室测试2000小时

  - Salt spray 5% 盐雾5%氯化钠
  - Prohesion 湿/干循环测试
  - 2 types of cyclic immersion 两种周期浸润
  - Combined corrosion/ weathering 腐蚀紫外交替

SSPC Test Results

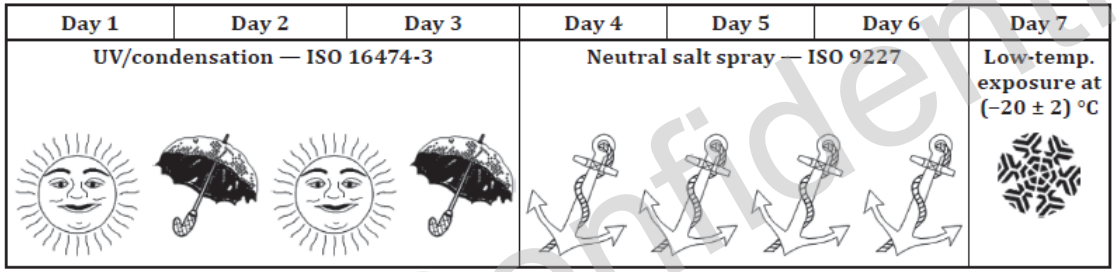
Laboratory Test Method	Correlation w/Severe Marine Environment
Conventional Salt Spray	-0.11
Prohesion	0.07
Cyclic Immersion Procedures	0.48
Cyclic Immersion with UV Procedure	0.61
Combined Corrosion/ Weathering	0.71

Good correlation from combined test!

循环测试有好的相关性

Combined Corrosion and Weathering

ISO 12944-6 (and -9)



- 4 hours UVA-340, 0.83 W/m^2/nm at 340 nm, 60 °C
- 4 hours dark condensation, 50 °C
- 72 hour cycle

- Continuous salt fog at 35°C
- Rinse panels and put in a freezer for 24 hours
- 72 hour cycle

Wet/Dry Cyclic Test Limitations
潮湿/干燥 循环测试的局限性

- Poor repeatability and reproducibility

不好的实验可重复性和可再现性

- Poor correlation in some cases 在有些测试中不好的相关性
  - Automotive 汽车
  - Industrial maintenance coatings on steel 钢件表面的工业防护涂料
- Attempts to improve correlation & repeatability include…

改善相关性和重复性的尝试包括。。

  - Wet bottom (water retained at chamber bottom)

    湿底（在箱体底部留有水）
  - Changing temperature of bubble tower

    改变鼓泡塔温度
  - Both are crude “workarounds” for poor RH control technology

    在较差的相对湿度控制技术下，变通的方法

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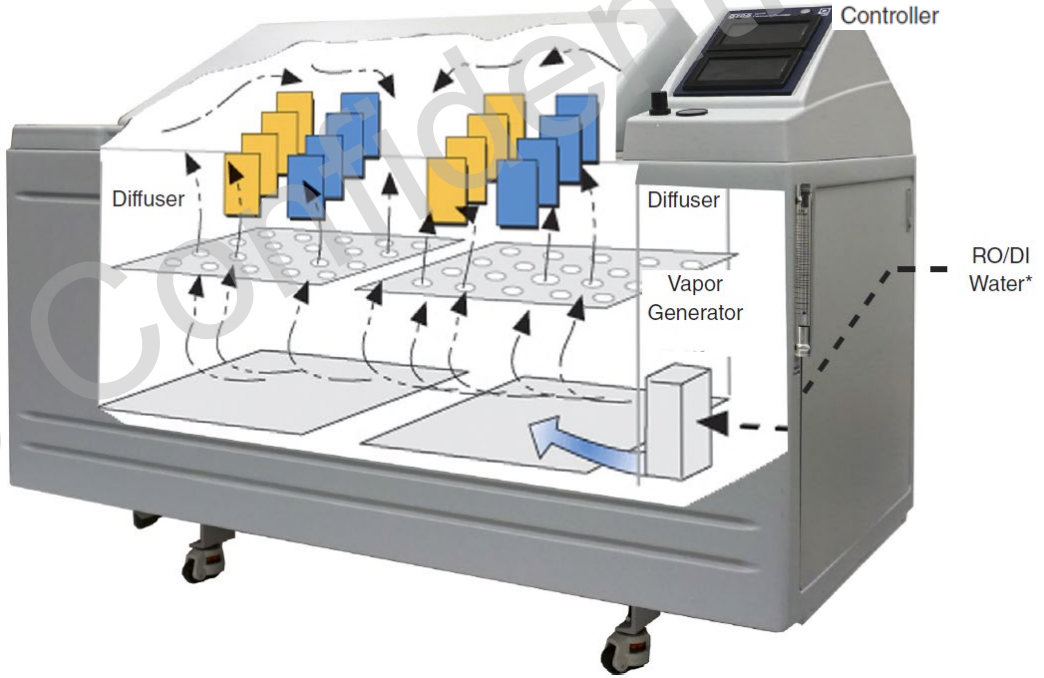
First-Generation Cyclic Automotive Tests

Salt Fog → Dry-Off → Wetting (Humid)

盐雾->干燥->潮湿

Wetting specimens after dry-off reinitializes corrosion
干燥后润湿试样重新开始腐蚀



First-Gen Cyclic Automotive Tests

Salt Fog → Dry-Off → Wetting (Humid)

Example: GM 9540P

- NaCl and $CaCl_2$ to simulate road salts

氯化钠和氯化钙模拟道路融雪剂

- Solution applied by direct Spray, not Fog

直接的盐水喷淋，不是喷雾

- Salt spray applied intermittently in “ambient” conditions

在环境温湿度条件下间歇施加盐溶液

- Use of **corrosion coupons** to minimize test variability

使用**参比样板**最小化测试可变性

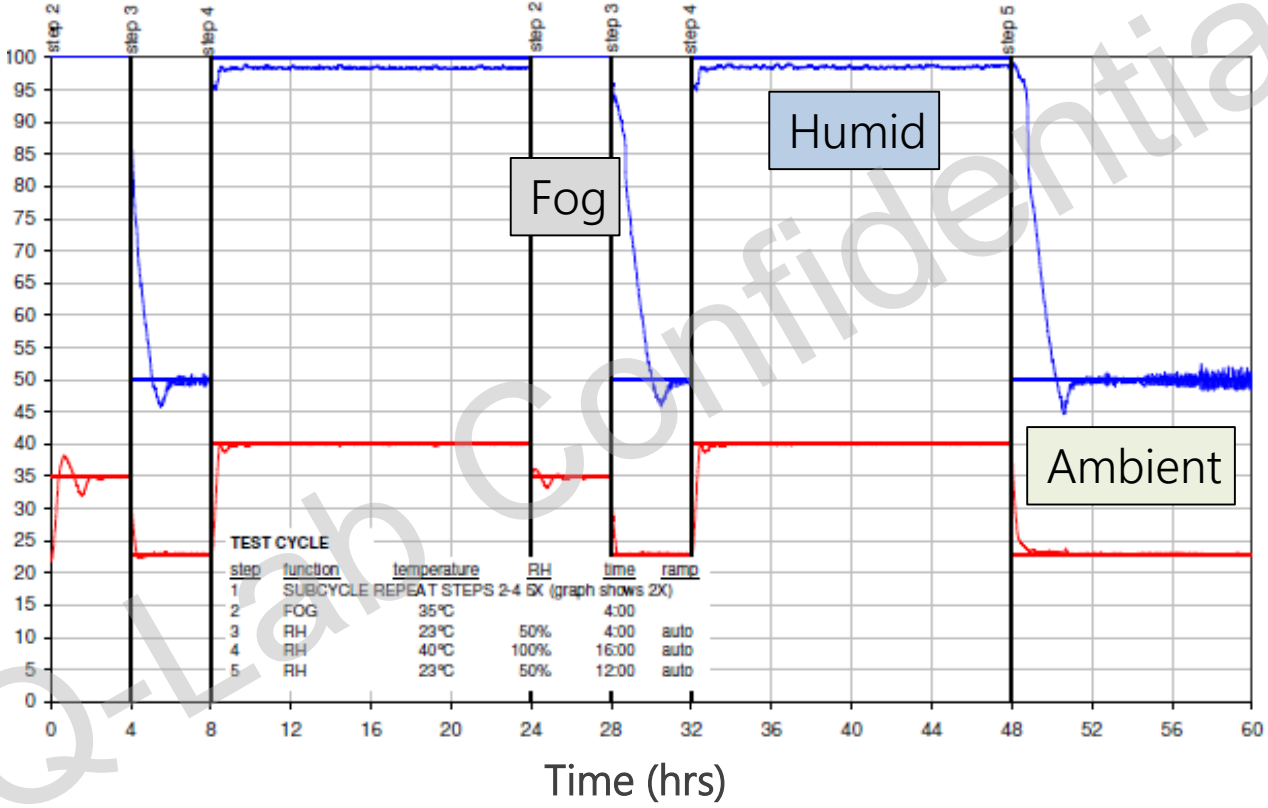
- SAE & American Iron & Steel Institute rated this method best predictor of outdoor performance in 1991

1991年，SAE和美国钢铁协会将该方法评为最能预测户外性能的腐蚀测试方法

First-Gen Cyclic Corrosion test

RH (%)

Temp (°C)



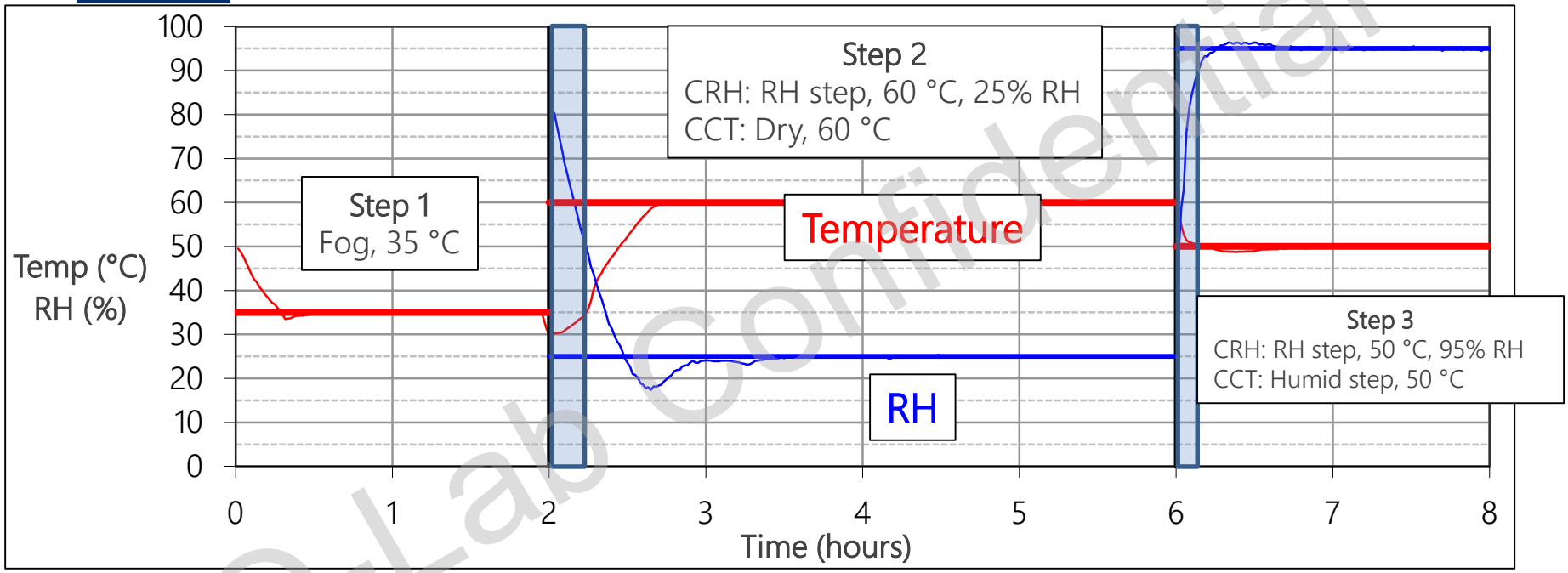
Relative Humidity and Corrosion

Controlling Step Transition Times 控制实验步骤转换时间

- "Linear" transition 线性转换
  - Specify Time in test cycle to change test conditions
    在指定时间内完成条件转换
  - Tester adjusts temperature & RH for linear transition from beginning to end of ramp time
    设备从第一步到下一步温度和湿度线性转换

- "Less Than" transition 小于某个时间段转换
  - Specify Time in test cycle to change test conditions
    在指定时间内完成条件转换
  - Tester attempts to achieve conditions within specified time – effectively as fast as possible
    在指定时间内尽可能快地实现转换
  - Fast "less than" transition times (e.g. JASO M609) designed to minimize test variability…
    快速转换（e.g. JASO M609）最小化测试的可变性

Fast Transition Times: JASO M609



Fast Transition Times Designed to Improve Reproducibility

快速转换时间为了提高测试可再现性

Very limited time in critical RH zone of 50-90%!

Limitations of First Generation CCT

Poor Repeatability and Reproducibility!

不好的实验可重复性和可再现性

- Different corrosion chambers give different results

不一样的腐蚀试验箱给出不一样的测试结果

- Huge variations in corrosion rates between different metals from test to test

若存在电偶腐蚀，不同盐雾箱之间会存在巨大差异

Case Study: SAE J2334

- Transition times are not specified in this standard

没有在标准中对转换时间做规定

- Coupon use is encouraged but no mass loss limits are included

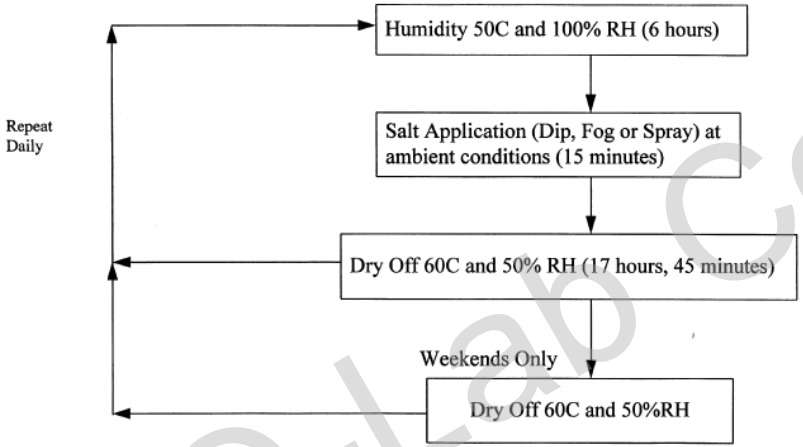
推荐使用参比样板但没有具体的质量损失的要求

- Some companies have implemented SAE J2334 with their own mass loss limits

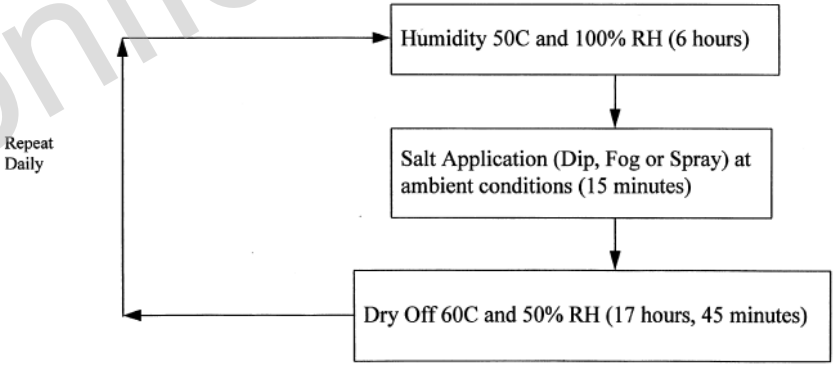
一些公司用SAE J2334，并制定了自己的质量损失限值

SAE J2334 Test Cycle

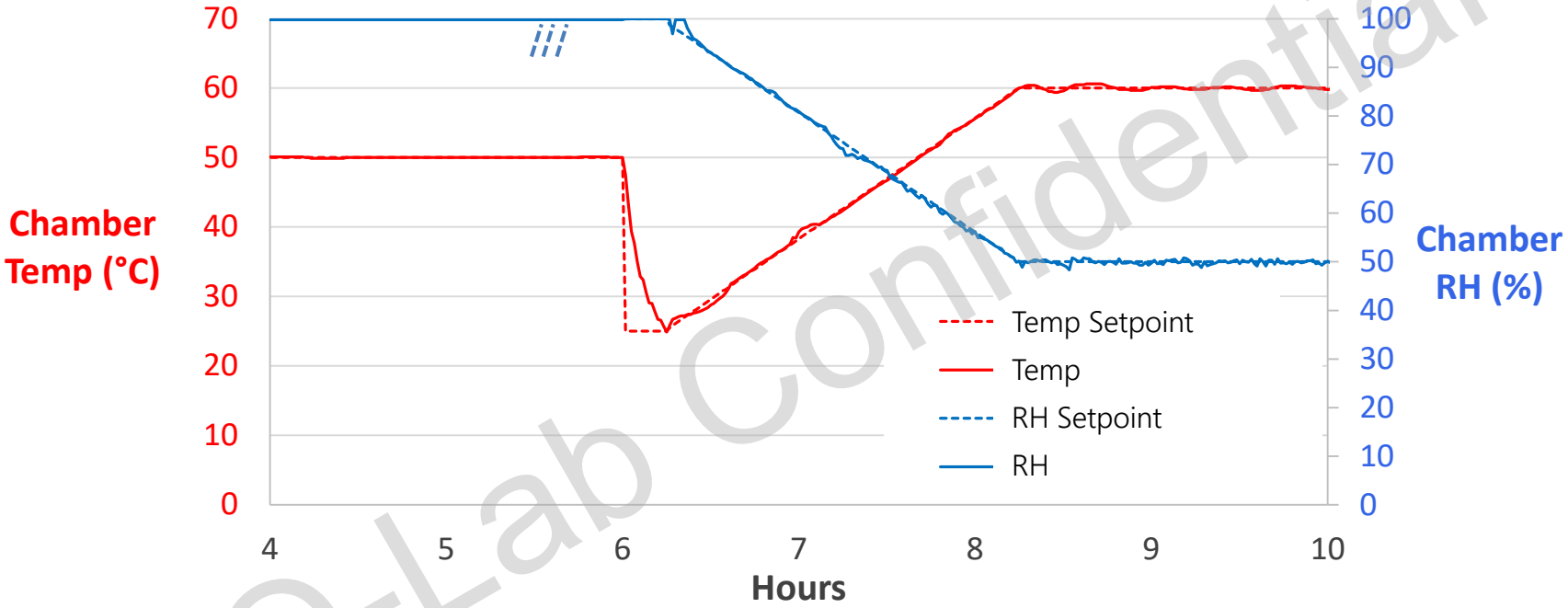
Cosmetic Corrosion LabTest Cycles
SAE J2334 - 5 Day/Week - Manual Operation



Cosmetic Corrosion LabTest Cycles
SAE J2334 - 7 Day/Week - Automatic Operation



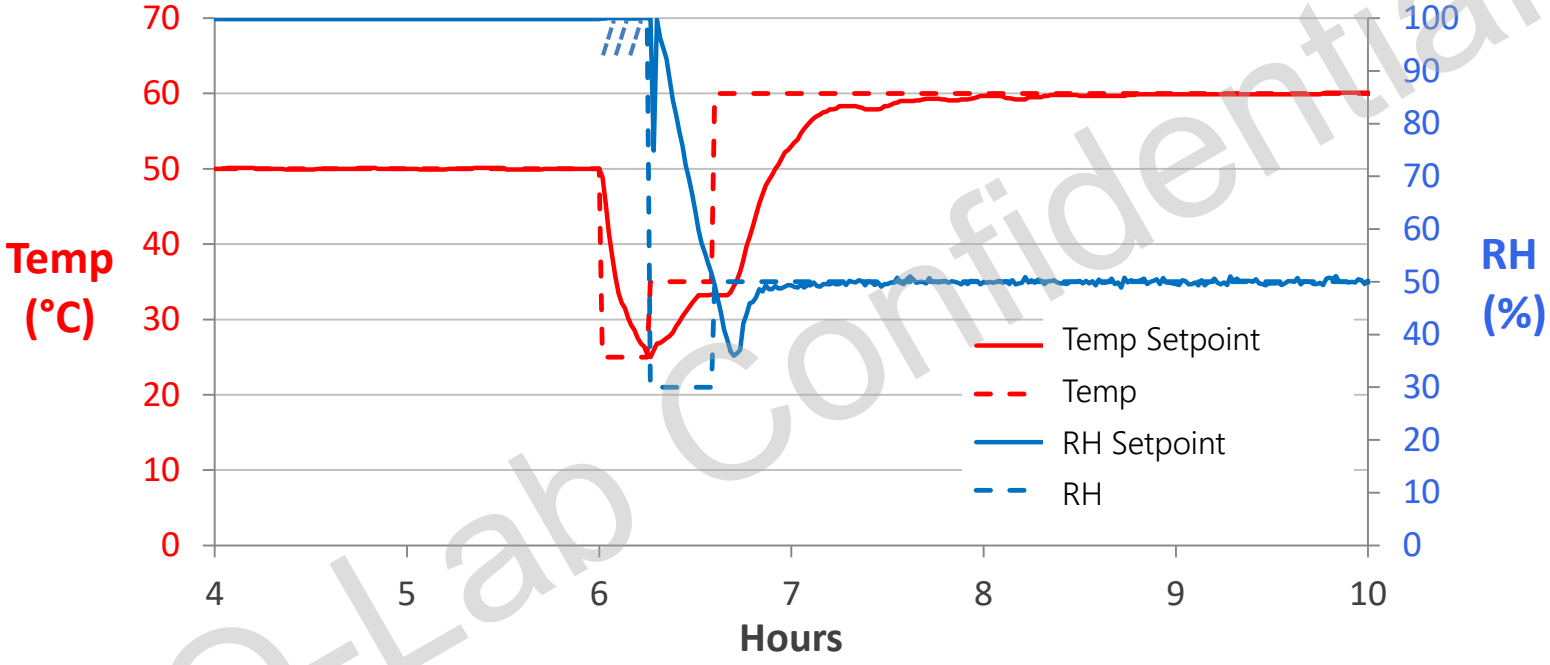
SAE J2334: Slow Dry-Off 缓慢干燥



*Time above the Deliquescence RH of NaCl is about **1 hour***

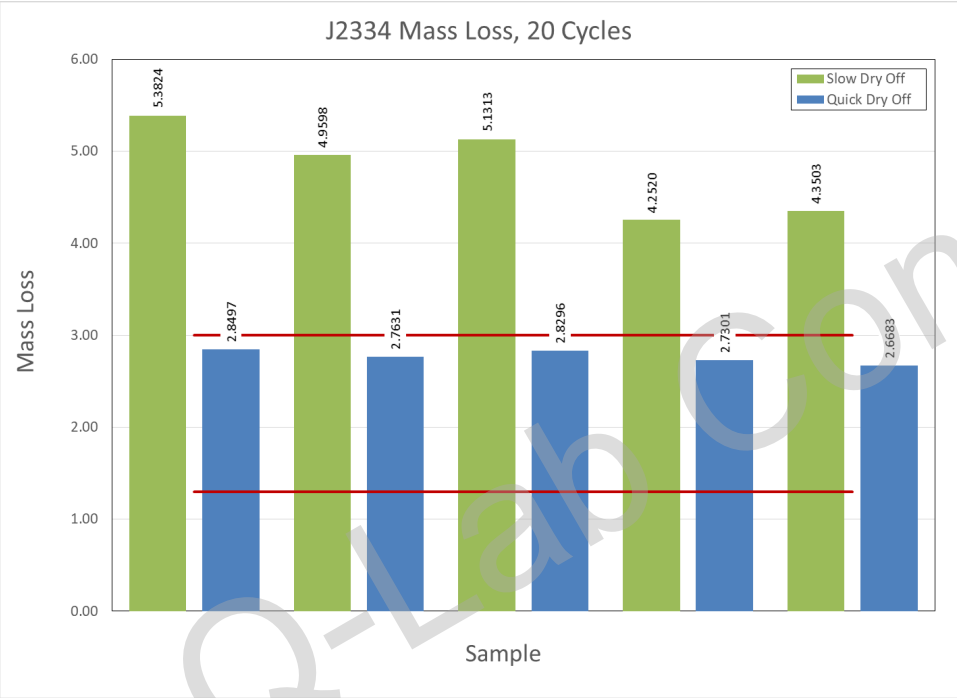
氯化钠潮解的时间大约1小时

SAE J2334: Fast Dry-Off 快速干燥



*Time above the Deliquescence RH of NaCl is about **10 minutes***
氯化钠潮解的时间大约10分钟

SAE J2334 Results



- Green bars represent test under slow dry-off conditions: panels fail

绿色代表缓慢干燥：涂层失效

- Blue bars represent test under quick dry-off conditions: panels pass

蓝色代表快速干燥：涂层通过

- Red lines represent tolerance of OEM standard

两条红色的线是厂家的要求

First generation cyclic automotive methods

What was missing?

- Lack of comprehensive RH control 缺少相对湿度控制
  - Conditions limited to full wetting, dry, uncontrolled room/ambient
  条件受限于潮湿，干燥和不可控的实验室环境
  - No control of RH transition times – used “workarounds” like fast transition times
  湿度转换不可控 – 使用变通的做法如快速转换
  - Variable specimen dry-off rates
  不一样的样品干燥速率
  - No RH values in critical transition zones (DRH)
  在关键阶段（DRH）没有湿度控制
- Slow application of salt solution (fog) 盐溶液的缓慢施加（盐雾）
  - Little time for dry-off and re-wetting of specimens
  试样干燥和再润湿时间短

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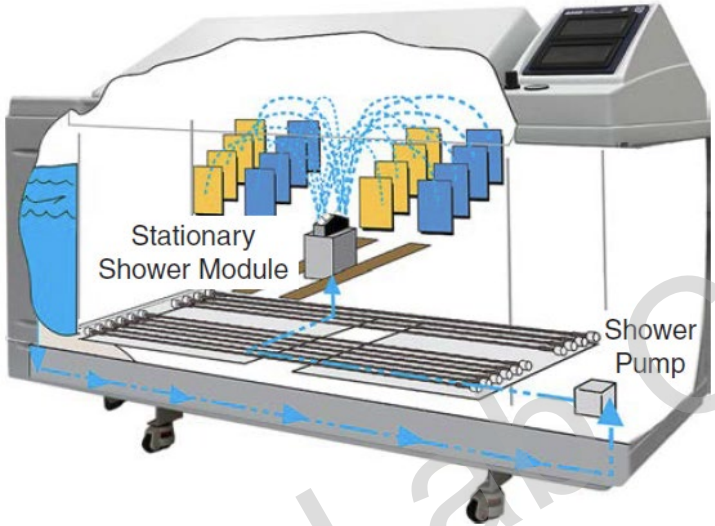
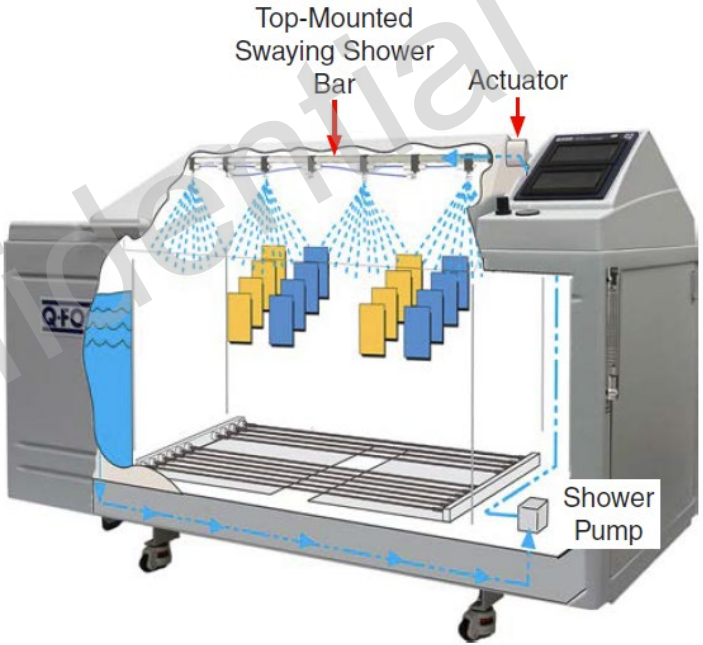
Modern Corrosion Tests

Shower Function 喷淋功能



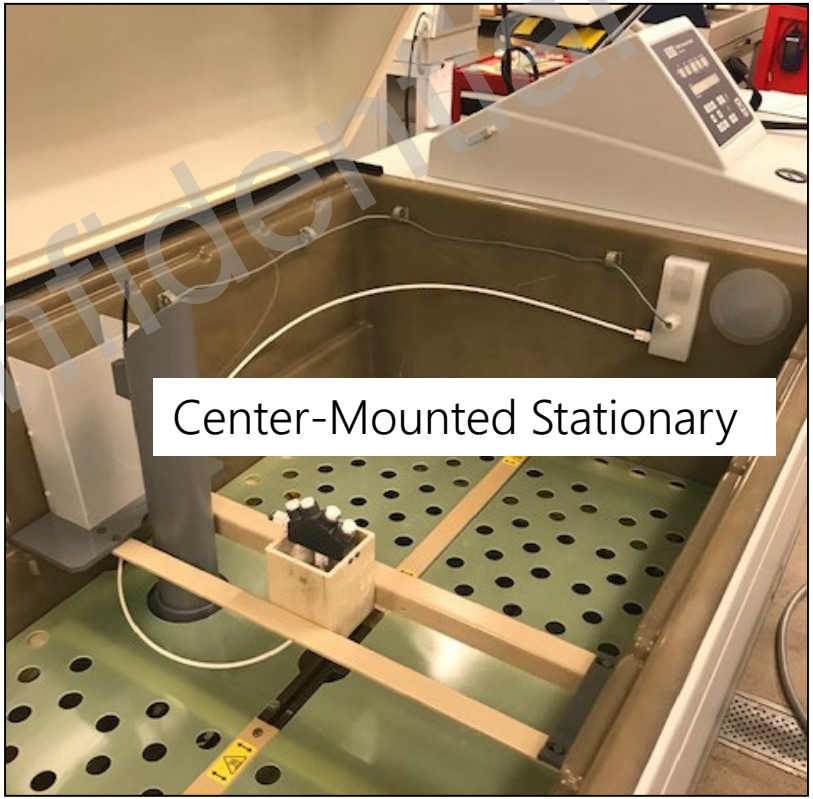
Stationary Shower Module (SSM)



Top-Mounted Swaying Shower Bar (TSSB)

Faster application of salt solution than Fog
喷盐水比喷雾更快使样品充分潮湿

Shower Configurations



Modern Automotive Corrosion Tests

Fog 盐雾

- Toyota TSH1555G
- VDA 233-102
- Renault D17 2028 (ECC1)

Shower 喷淋

- GMW 14872
- Volvo ACT 1
- ISO 16701
- Volvo ACT 2/ Ford L-467

No one "right way" to run a test but shower/spray has gained popularity

Relative Humidity & Corrosion
相对湿度和腐蚀

- Corrosion accelerates once it starts 腐蚀一旦开始就会加速
  - Formation of complex oxides
    复杂氧化物的形成
  - Wet time increases as new oxides form
    随着新氧化物的形成，湿润时间增加
- Salts deliquesce at different RH values
  盐在不同湿度下的潮解
- Formation of liquid solutions affects corrosion by creating a galvanic couple
  电解液的形成影响腐蚀通过产生电偶腐蚀

Automotive Tests & Road Salt
汽车测试和道路融雪剂

- Salts *deliquesce* - they absorb moisture from the atmosphere until they dissolve and form a solution.

盐的潮解 – 吸收大气的水分直到溶解形成溶液

- All soluble salts will liquefy for RH values <100%

所有可溶性的盐在100%湿度以下都会潮解

- This leads to increased time of wetness and increased corrosion

这会导致潮湿时间延长和腐蚀加剧

Deliquescence Relative Humidity (DRH)
潮解湿度

Salt	DRH
Potassium Chloride (KCl)	85%
Sodium Chloride (NaCl)	*76%*
Calcium Chloride ($CaCl_2$)	*31%*

If the environment is above this RH, a liquid salt solution will form
如果环境湿度高于该相对湿度，则会形成液态盐溶液

Galvanic Corrosion 电偶腐蚀

Active (Anode)

Noble (Cathode)

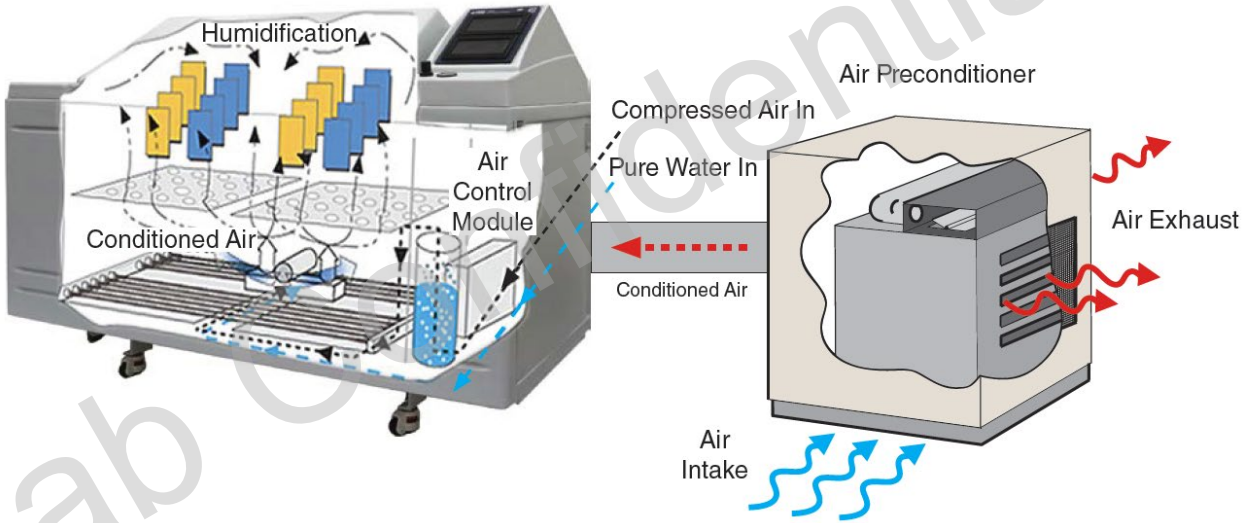
Magnesium
Zinc
Aluminum
Cast Iron/low carbon steel
Steel (low alloy)
Brass
Copper
Nickel
Stainless Steel (passive)
Silver
Gold
Platinum

- Affects products made from metals
  - Steel
  - Aluminum
  - Magnesium alloys
- Organic & Inorganic Protective Coatings

Galvanic Corrosion

Modern Corrosion Tests

Air Preconditioner



- Accurate control of “ambient” conditions

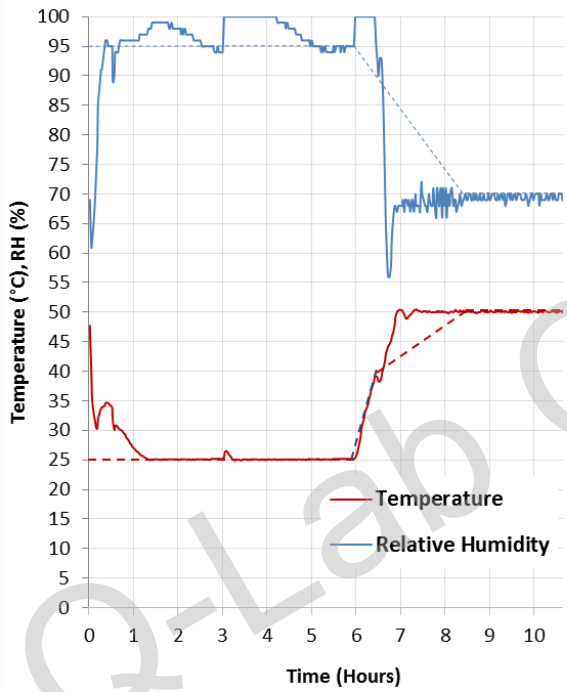
环境温湿度的精准控制

- Accurate Ramping of Temperature & Humidity

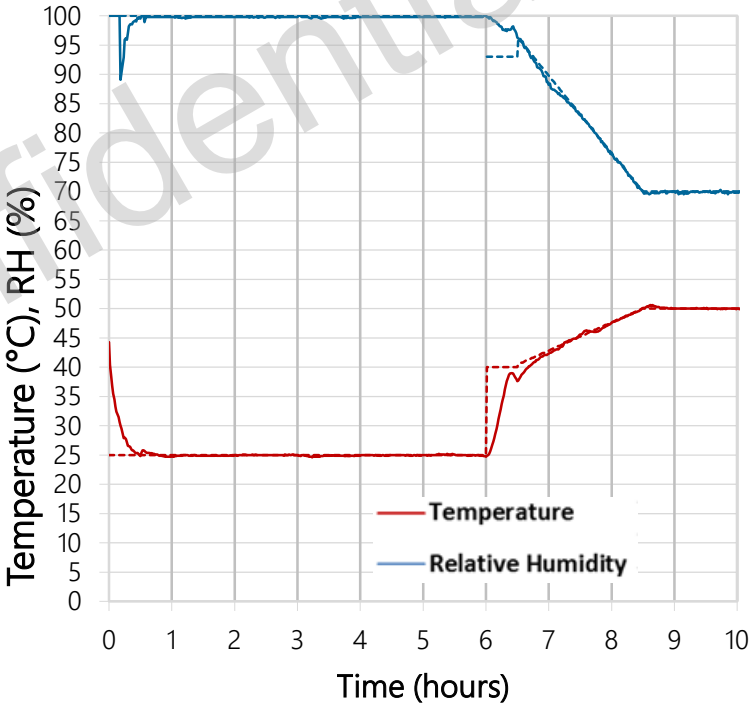
温度和湿度精准的转换控制

Performance Improvement with Preconditioner

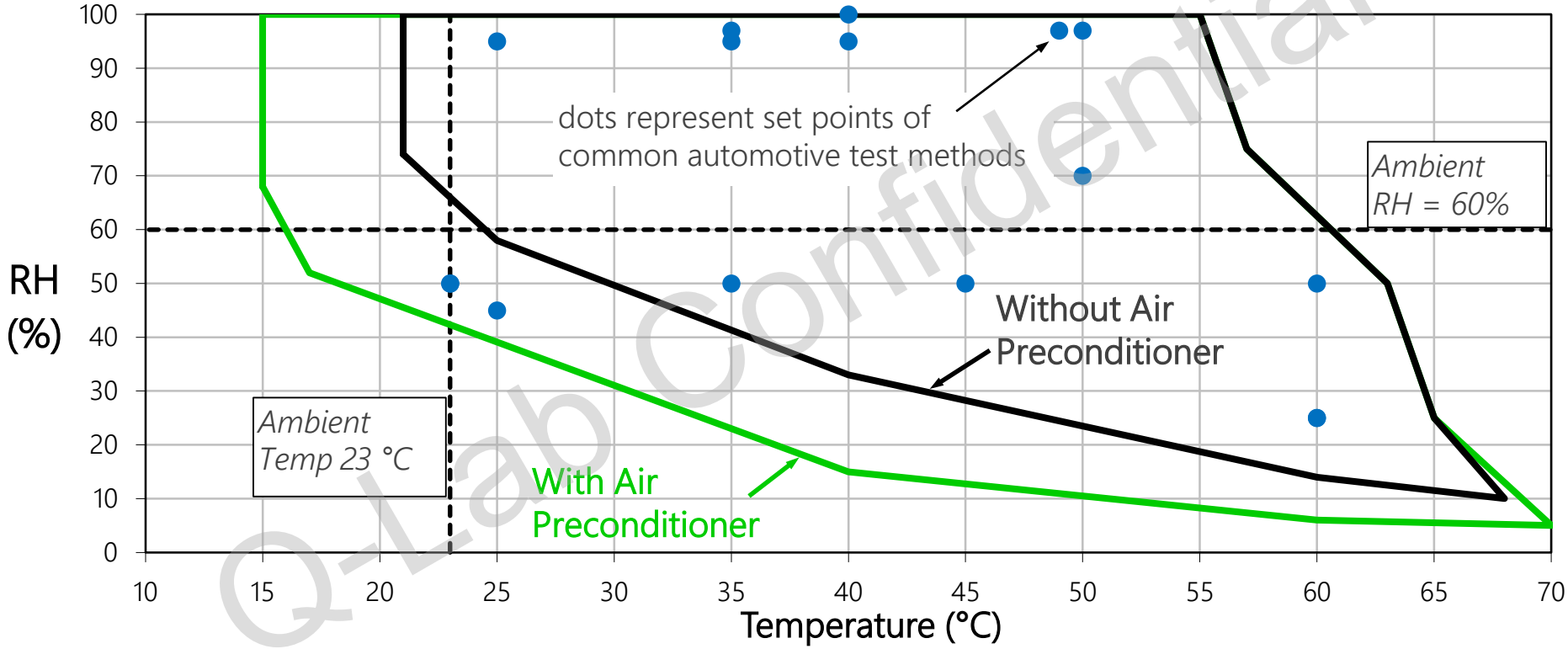
No Air Preconditioner



With Air Preconditioner

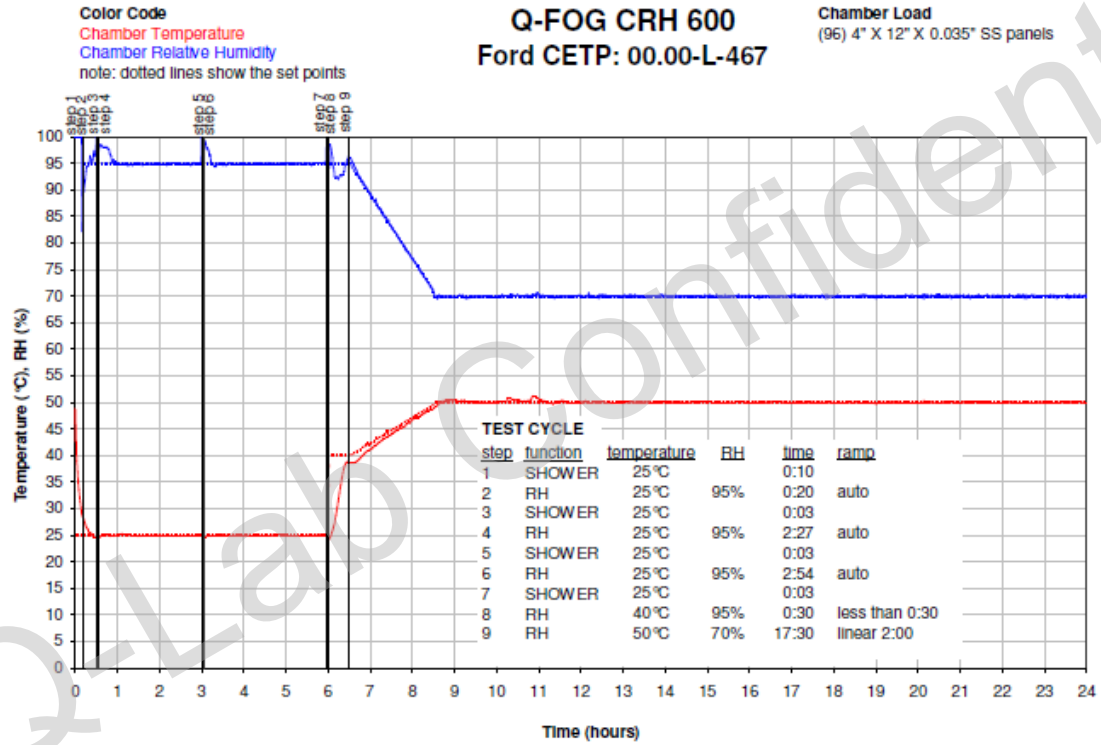


Q-FOG Operational Range: Well-Controlled Lab

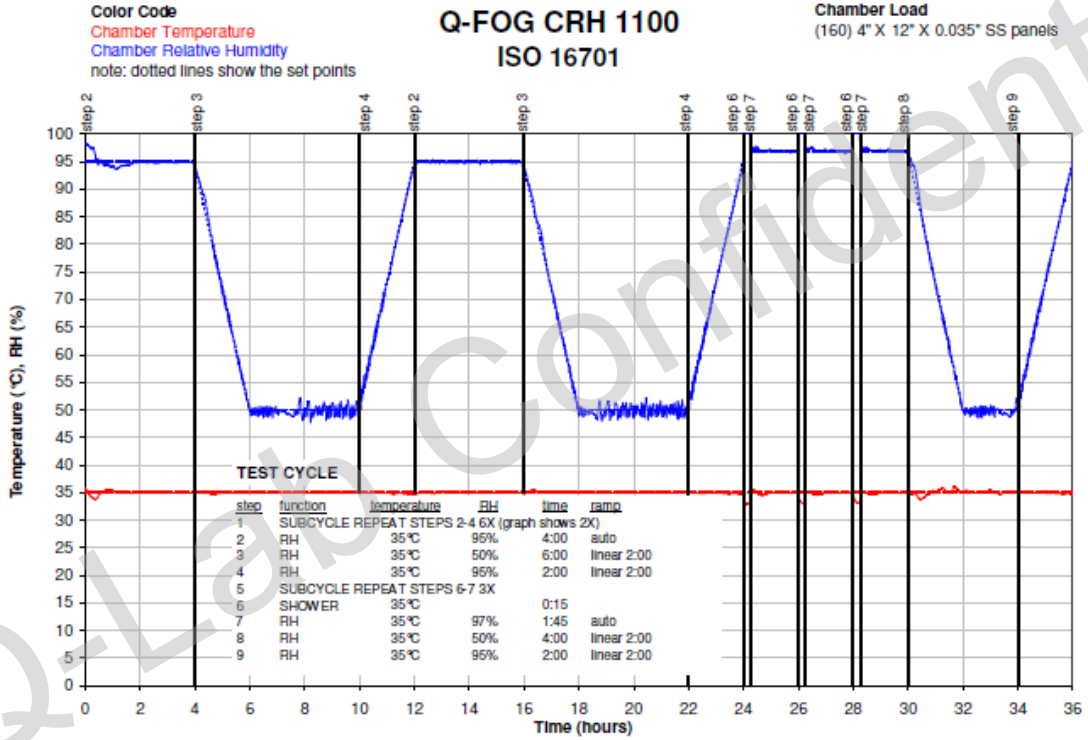


Modern Corrosion Test Examples

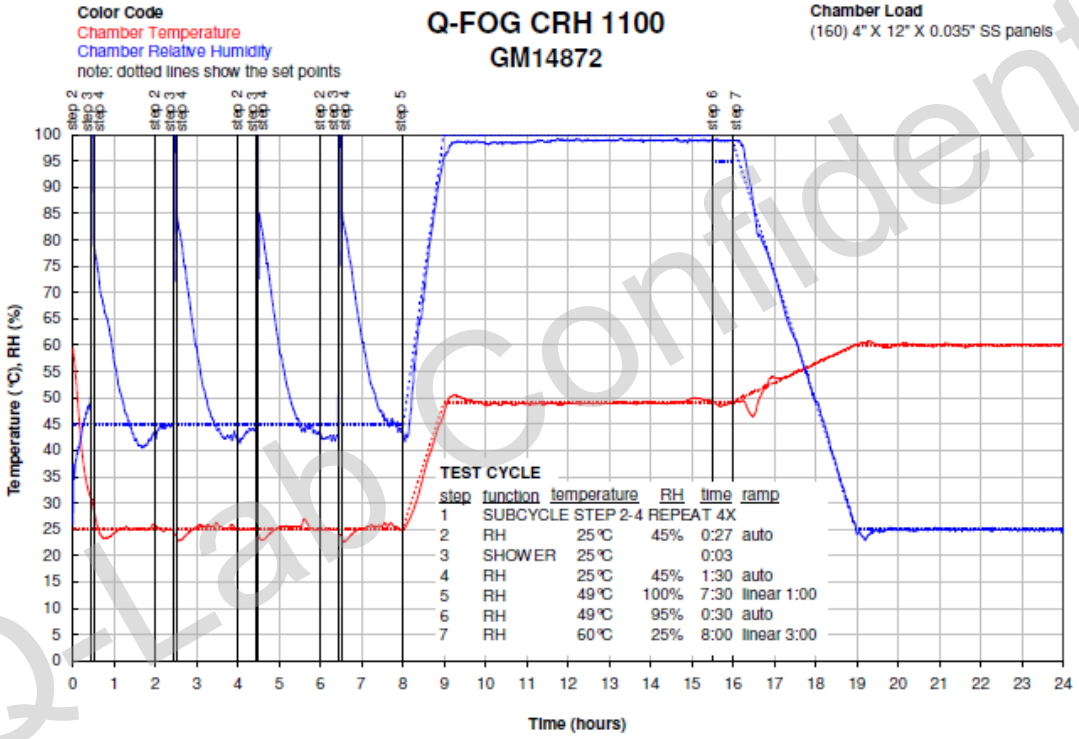
Ford CETP:00.00-L-467



ISO 16701



GMW 14872



Topics

- Types of Accelerated tests

加速测试的类型

- Continuous Salt Spray (Neutral & Acidified)

持续盐雾（中性和酸性）

- Wet/Dry Cyclic Tests

潮湿/干燥循环测试

- First-Generation Cyclic Automotive Tests

第一代汽车循环测试

- Modern Corrosion Test Methods

现代腐蚀测试方法

- Verifying Corrosion Test Performance

验证腐蚀测试表现

Corrosion (Mass-Loss) Coupons 腐蚀参比样板

- Standardized metal specimens

标准的金属样板

- Mass loss due to corrosion is measured during a test

在实验阶段评估质量损失

- Used by GM, VDA, ISO 16701 standards, and many others

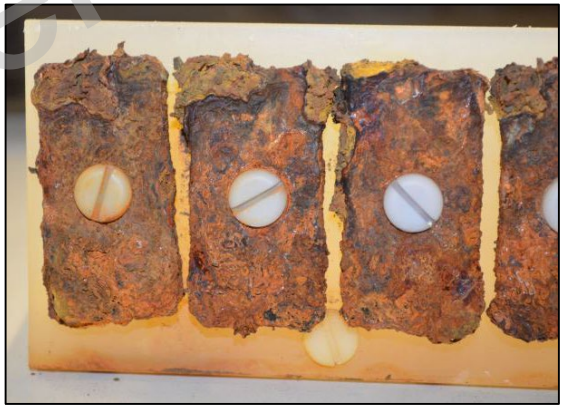
很多测试标准都在使用，如GM, VDA, ISO 16701

- GMW 14872 requires a specific rate of mass loss throughout a test

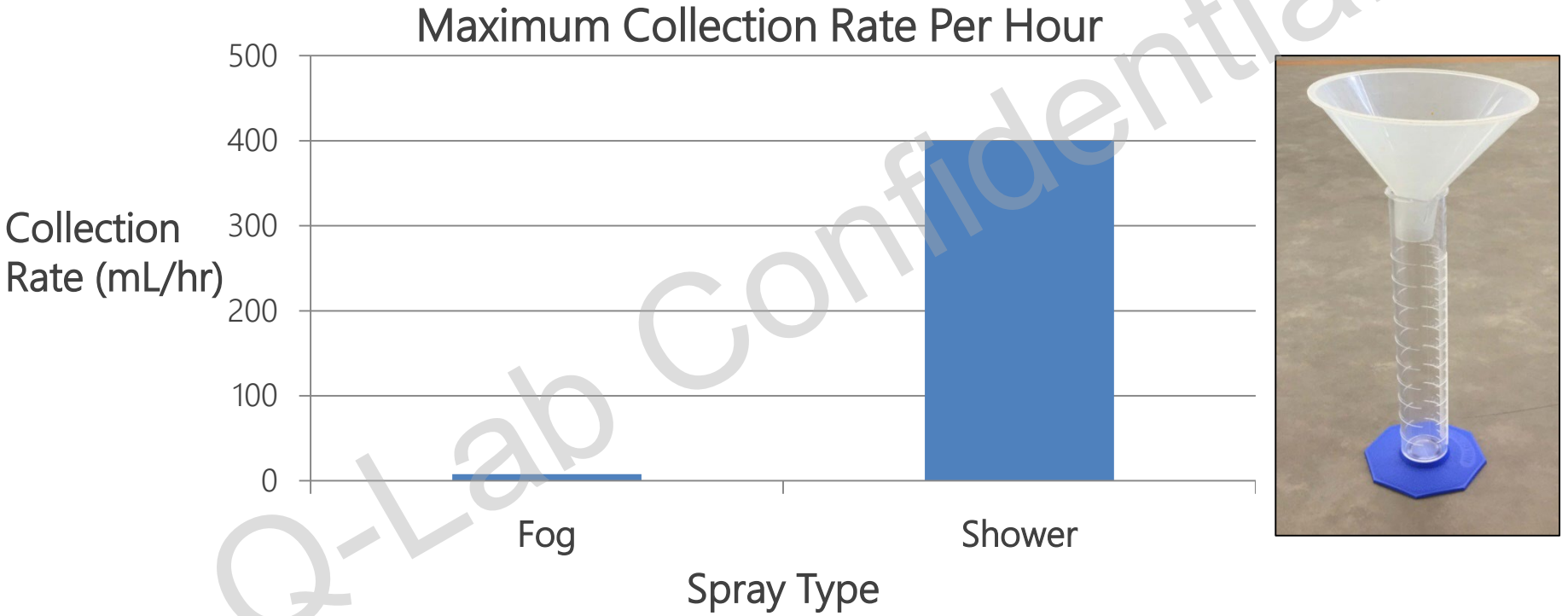
GMW 14872要求整个测试过程中的特定质量损失率

- Ensures corrosion chamber is maintaining proper conditions and operator is running the test correctly

确保腐蚀箱正常使用，操作员正确运行测试



Pluviometry 沉降量



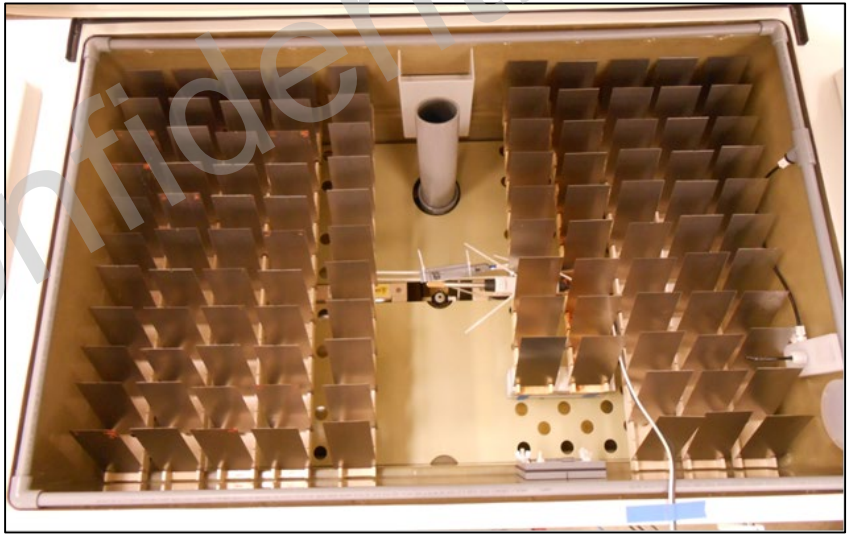
Independent Verification 独立验证

- Accurate and Precise Temperature/RH Sensor placed in center of chamber to independently verify Q-FOG CRH controller reading

精确的温湿度传**感器放置在**试验**箱中心，以独立**验证Q-FOG CRH**控制器**读**数**

- Chamber is full of steel panels

满**箱状**态



Verify Test in a Full Chamber
在满箱状态下验证测试

- To confirm a chamber is able to satisfy test requirements, validation should be conducted in a full chamber

为了确认盐雾箱能够满足试验要求，应在满载情况下进行验证

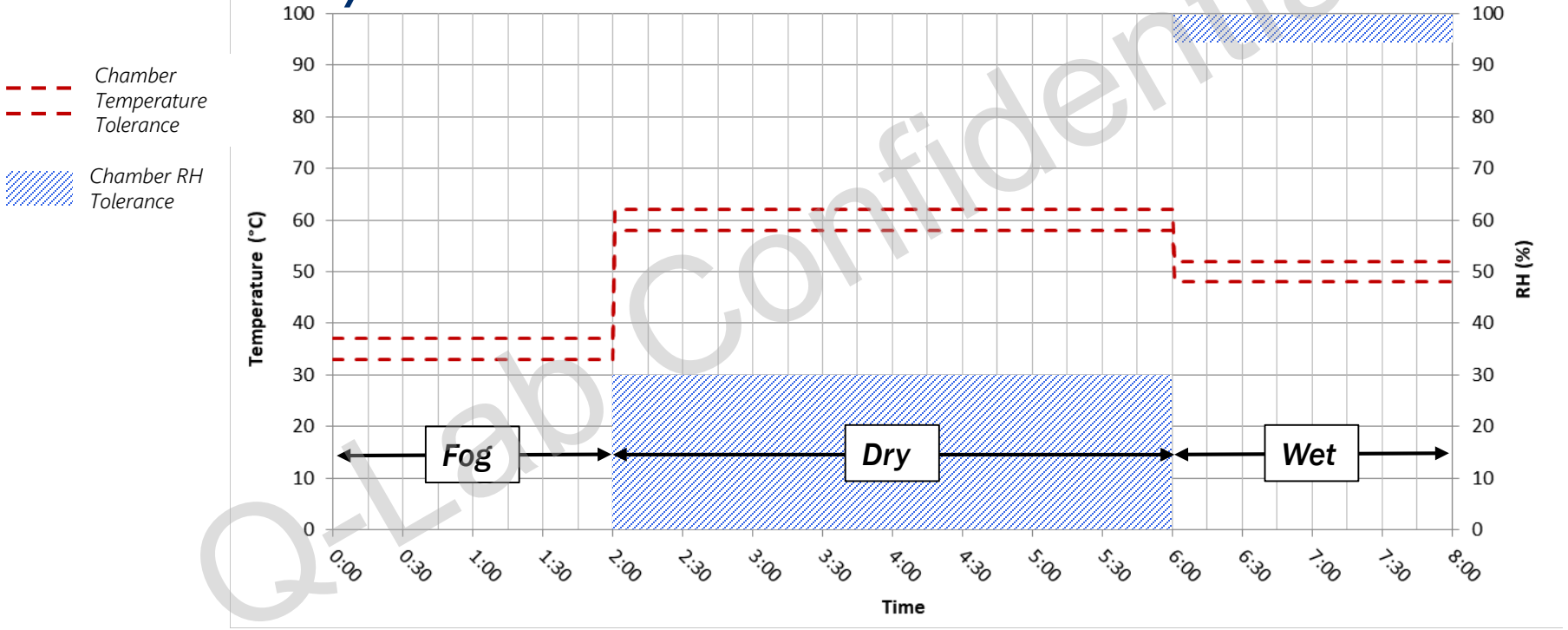
- Additional thermal mass of a fully-loaded chamber with metal panels will delay reaching temp setpoints

满载金属板的盐雾箱将延迟温度到达设定值

Verify that the test conditions can be reached with a chamber filled with specimens

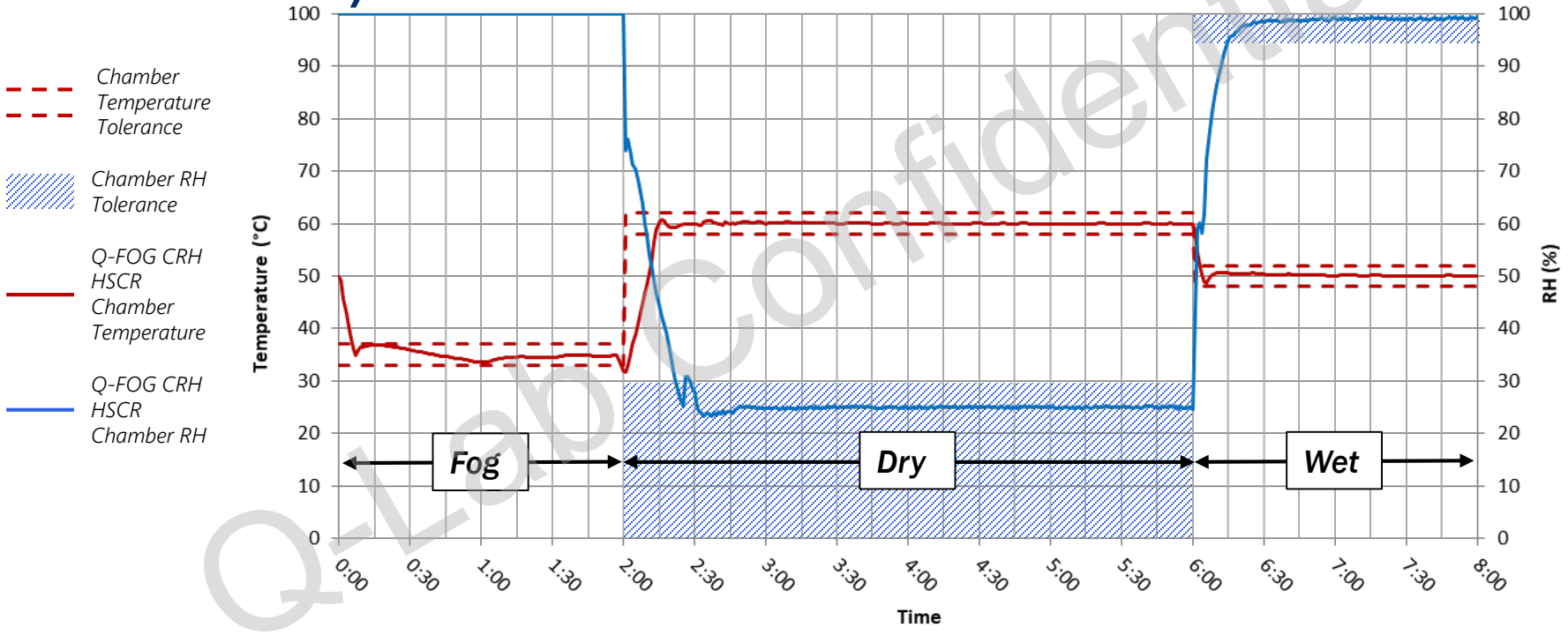
Q-FOG CRH HSCR Chamber Data

JASO M609 / ISO 14993



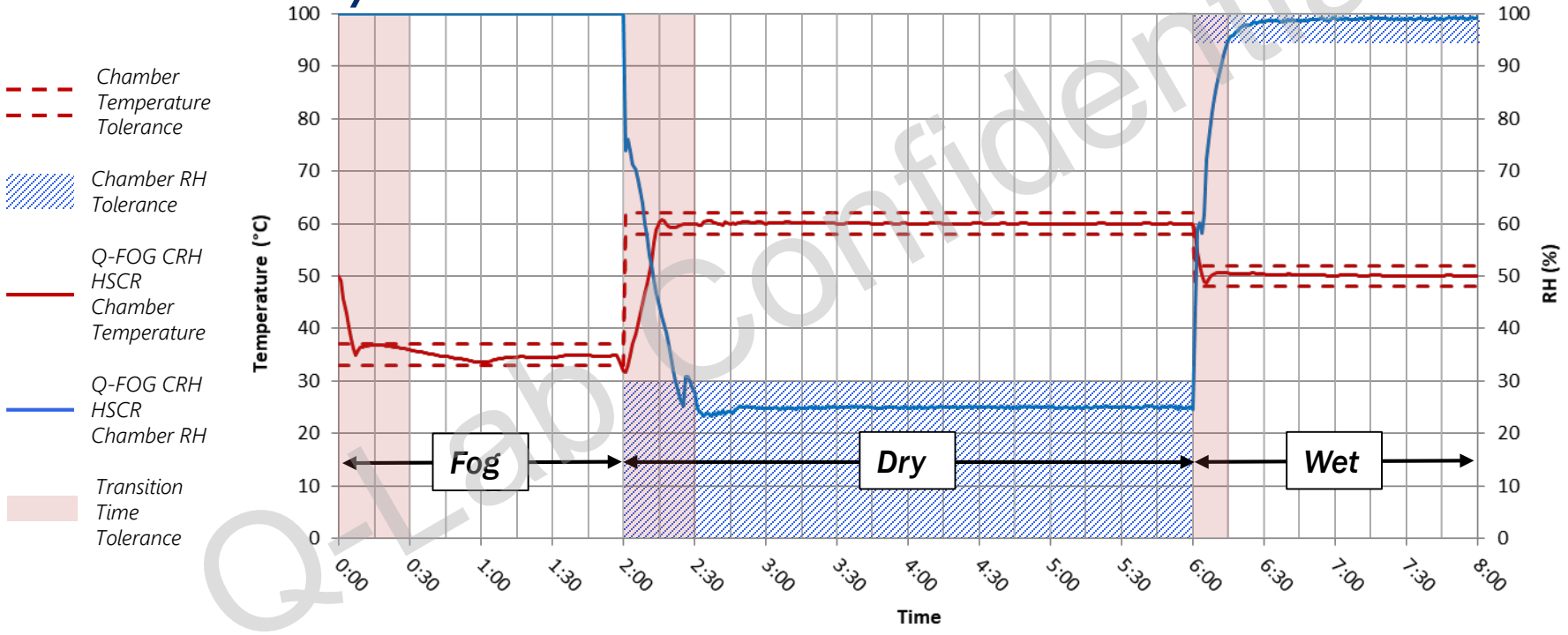
Q-FOG CRH HSCR Chamber Data

JASO M609 / ISO 14993



Q-FOG CRH HSCR Chamber Data

JASO M609 / ISO 14993



Conclusions

- Salt spray tests are good pass/fail screening tests

持续盐雾测试是好的pass/fail筛选测试

- Wet/Dry tests are good comparative tests for some systems but not repeatable

湿/干循环测试对有些材料是好的对比测试，但可重复性不高

- Combined weathering / corrosion cycles can provide good outdoor correlation for some materials

紫外/盐雾交替循环测试可以提供好的户外相关性

- First-generation cyclic automotive tests are comparative tests but not repeatable

第一代汽车循环测试是对比测试但可重复性不高

- Modern automotive corrosion tests are more realistic and offer better repeatability and reproducibility

现代汽车腐蚀测试更真实，提供更好的实验可重复性和可再现性

Questions?

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Q-LAB中国微信公众号及视频号:
耐候腐蚀测试技术

- ✓ 技术研讨会、网络研讨会信息
- ✓ 老化及腐蚀技术文章、最新测试标准解读等
- ✓ 参与视频直播- 设备维保操作培训
- ✓ 相关技术问题，也可通过平台留言，我们会在24小时内和您联系

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