Relative Humidity and Wet/Dry Transitions in Salt Spray Corrosion Tests
盐雾腐蚀测试中的相对湿度和干/湿转换

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Q-Lab Corporation

Discussion Topics

- Reproducibility and Deliquescence

实验可再现性和盐的潮解

- Theoretical effects of wet/dry transition times

干/湿转换时间的影响

- Case Studies
  - ASTM G85 Annex 5 (Prohesion)
  - SAE J2334: OEM Implementation

- How today's standards handle moisture transitions

现今腐蚀测试标准中湿度的转换

Corrosion Test Reproducibility
腐蚀测试的可再现性

Wet/dry cyclic tests…
干湿循环测试：

- Generally are more realistic than continuous salt spray
比持续盐雾测试更加真实

- Often have such poor reproducibility that many companies do not use them despite better realism
实验可再现性不佳导致很多公司采用，即使有更好的相关性

Salts in the Environment & TOW
环境中的盐和潮湿时间

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

盐的潮解 - 吸收空气的水分直到溶解并形成溶液

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

所有可溶性的盐在湿度小于100%下都可溶解

- This leads to increased **time of wetness** and increased **corrosion**

盐的潮解可以增加潮湿时间和提高腐蚀速率

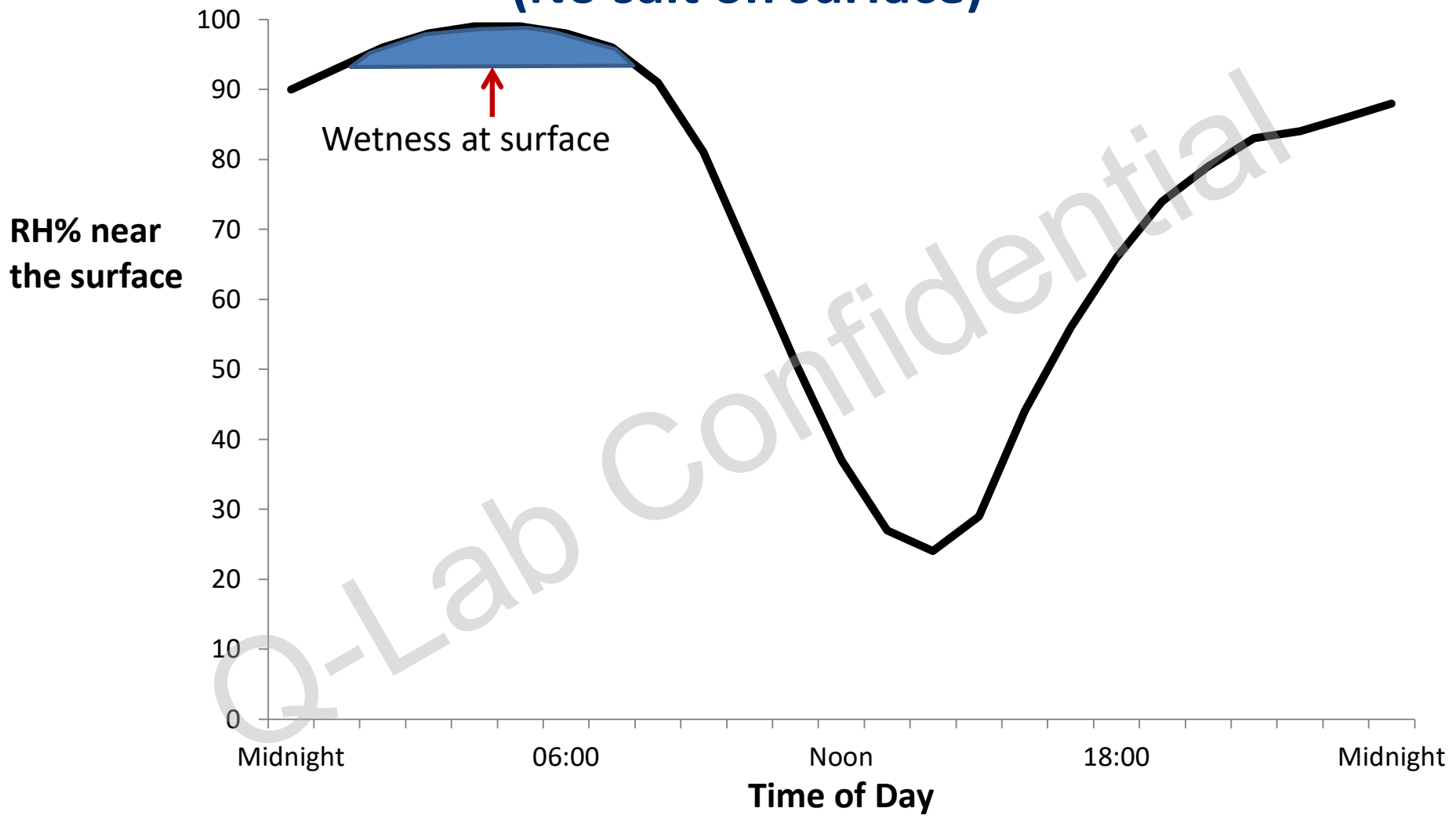
Deliquescence Relative Humidity
潮解湿度(DRH)

Salt	DRH
Potassium Chloride (KCl)	85%
Ammonium Sulfate $(NH_4)_2SO_4$	81%
Sodium Chloride (NaCl)	***76%***
Sodium Nitrate ($NaNO_3$)	74%
Magnesium Chloride ($MgCl_2$)	33%
Calcium Chloride ($CaCl_2$)	***31%***

if the environment is above this RH, a liquid salt solution will form

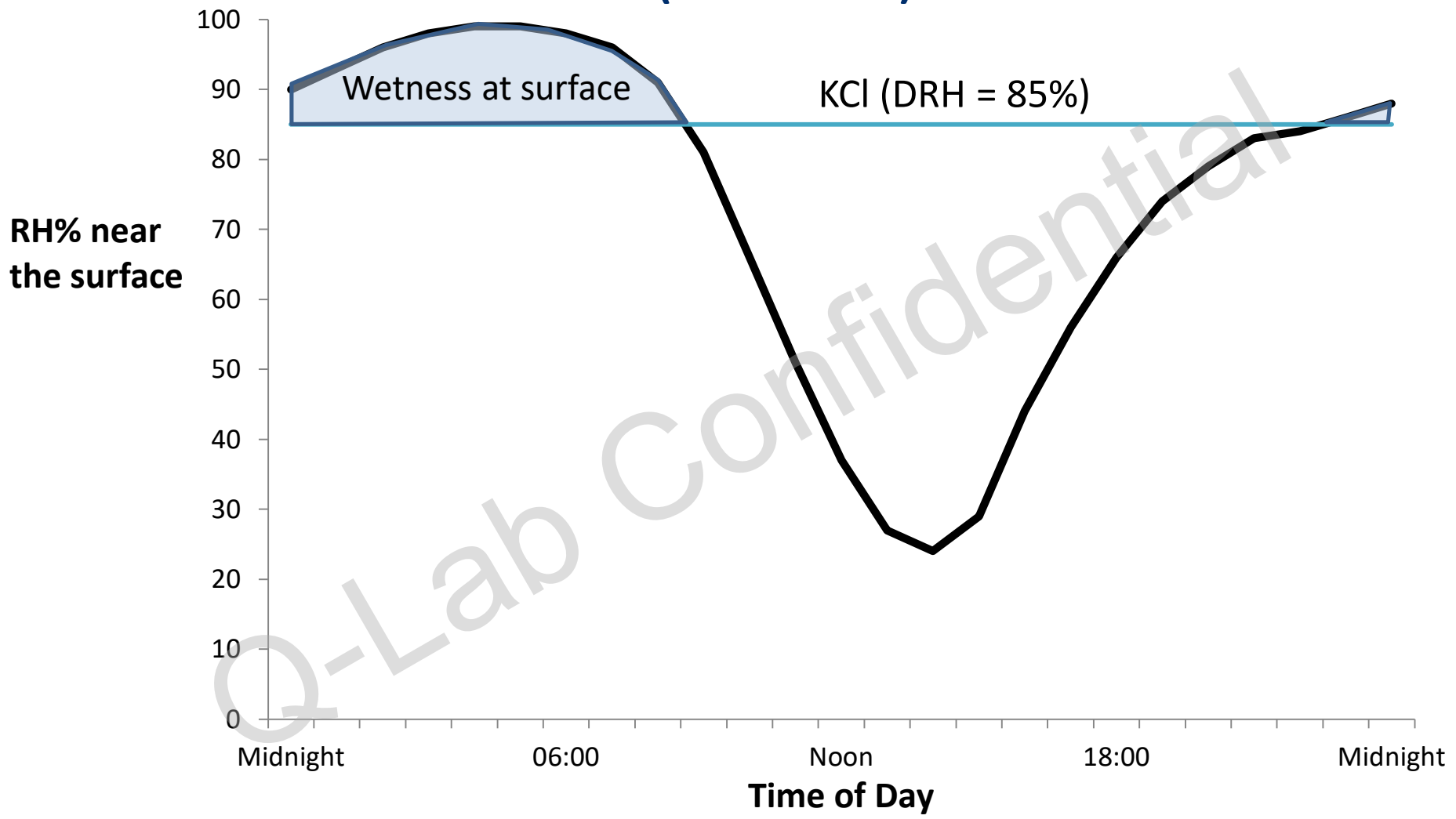
RH and Time of Wetness

(No salt on surface)



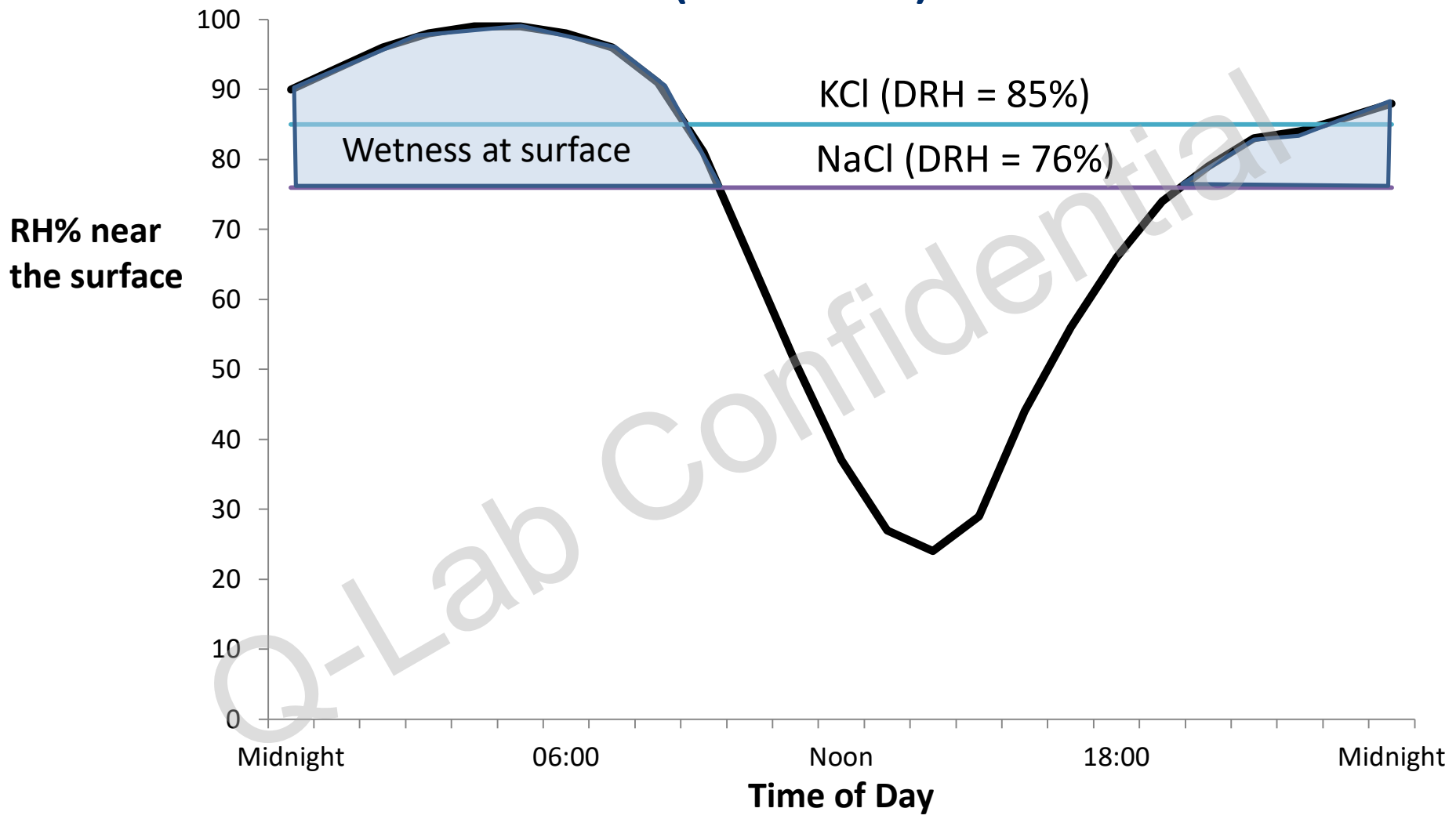
RH and Time of Wetness

KCl (DRH = 85%)



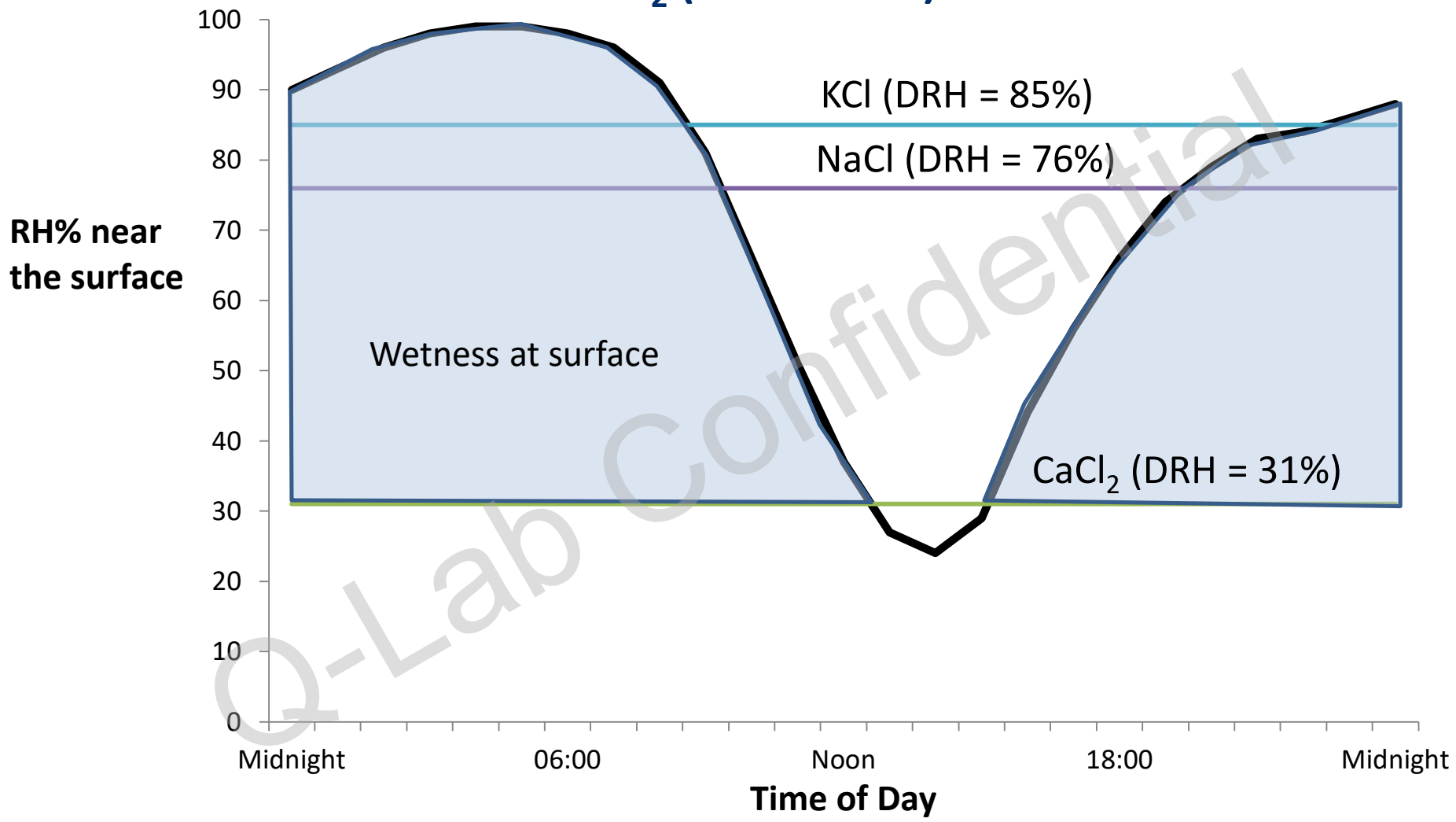
RH and Time of Wetness

NaCl (DRH = 76%)



RH and Time of Wetness

$CaCl_2$ (DRH = 31%)

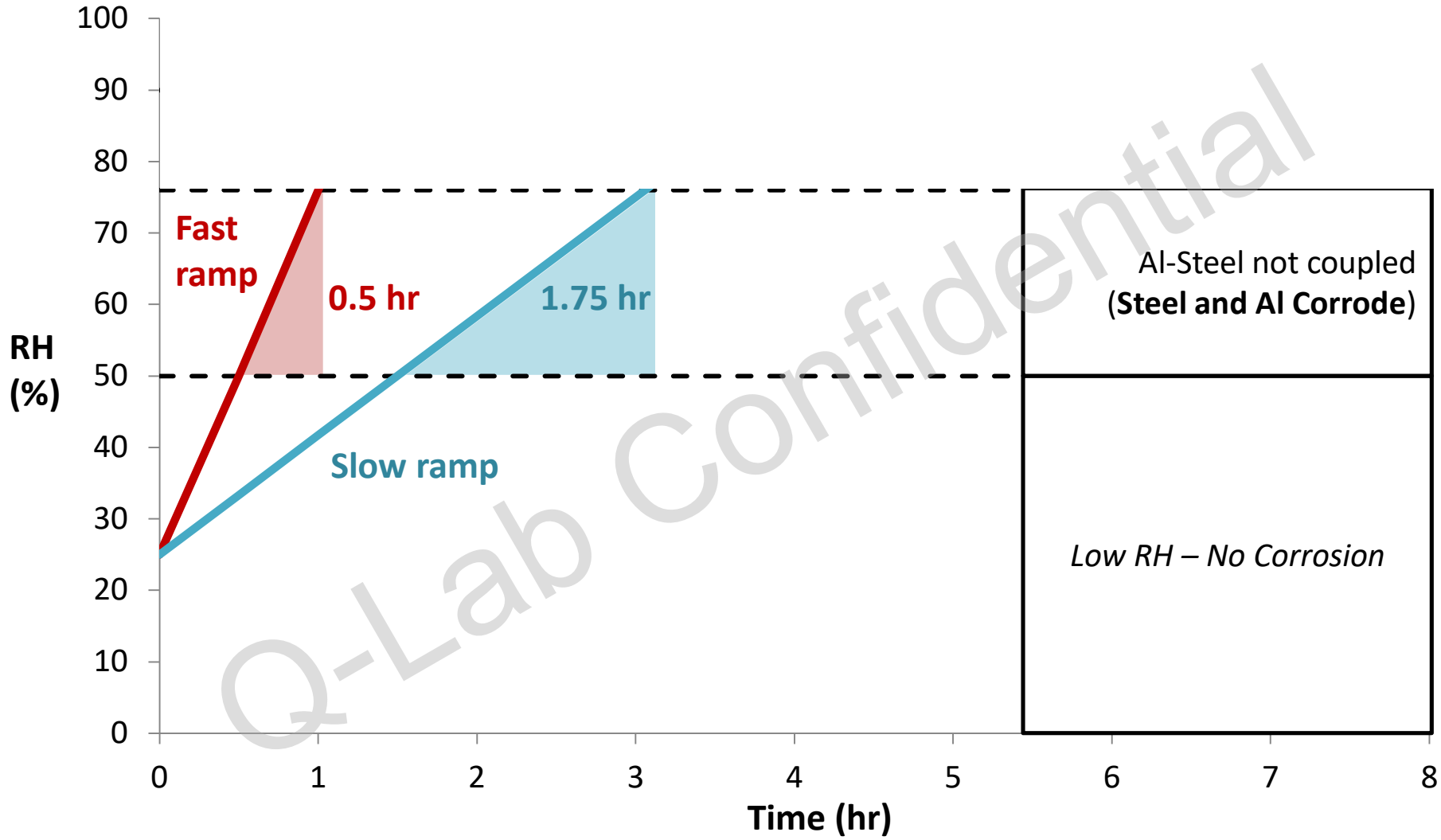


Relative Humidity and Corrosion
相对湿度和腐蚀的关系

Condition	RH Range	Result
Dry 干燥	**≤ 50%**	Very little corrosion from NaCl 几乎不发生腐蚀
Electrolytic cells around salt crystals; film formation as RH increases 盐开始潮解，但未形成连续的薄液层	**50-76%**	• Corrosion of **steel** (maximum corroded area ~70% RH) and **aluminum** 铁和铝都腐蚀 • AL-Steel galvanic couple broken 未形成电偶腐蚀
Uniform Electrolytic Film formation 均匀的电解液形成	**≥76%**	• Maximum cathode area for steel; deeper non-uniform corrosion 铁成为阴极区 • **Al corrosion** in galvanic couple with steel 电偶腐蚀形成，铝腐蚀

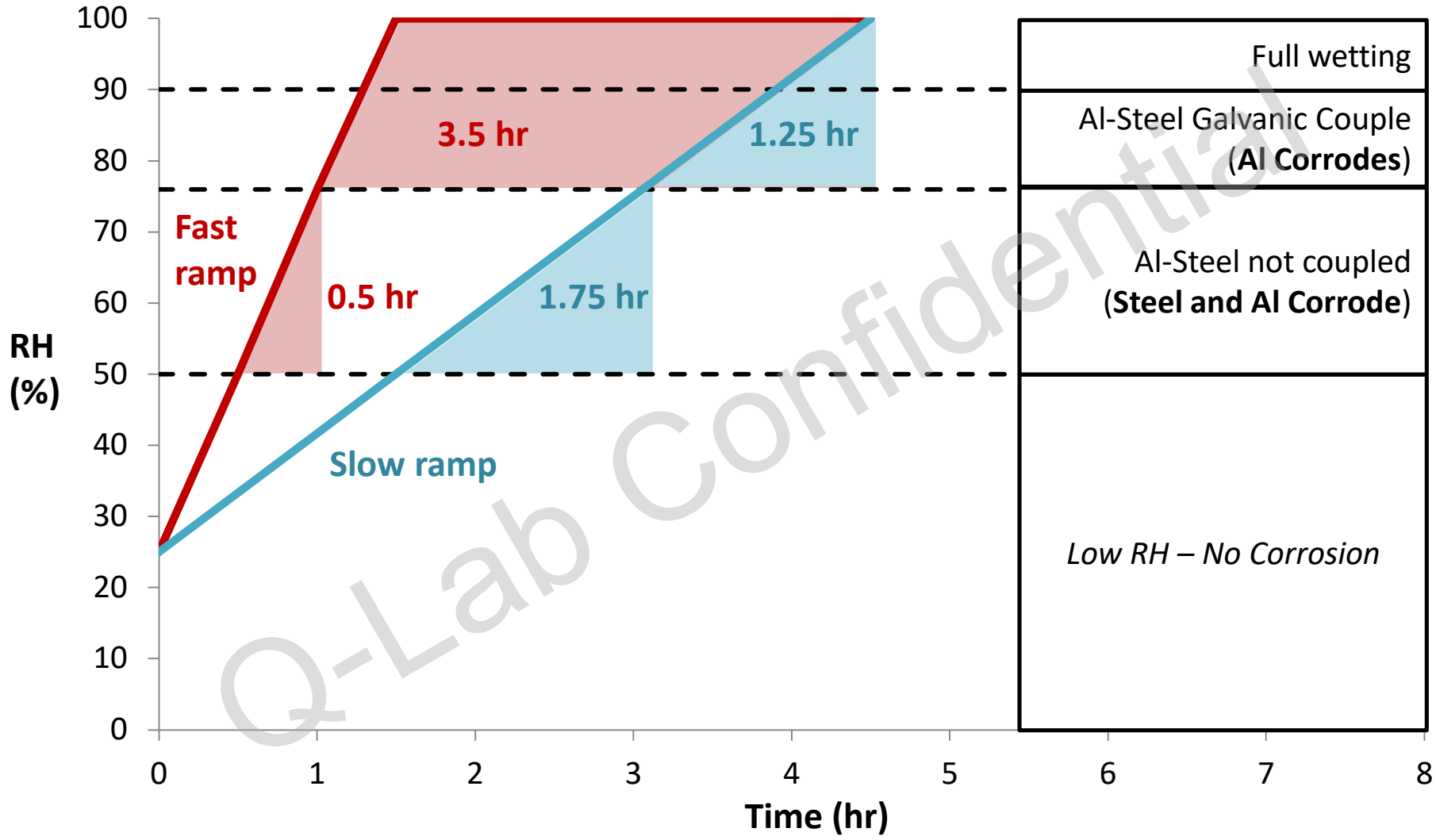
Galvanic corrosion during ramping

50% < RH < 76%



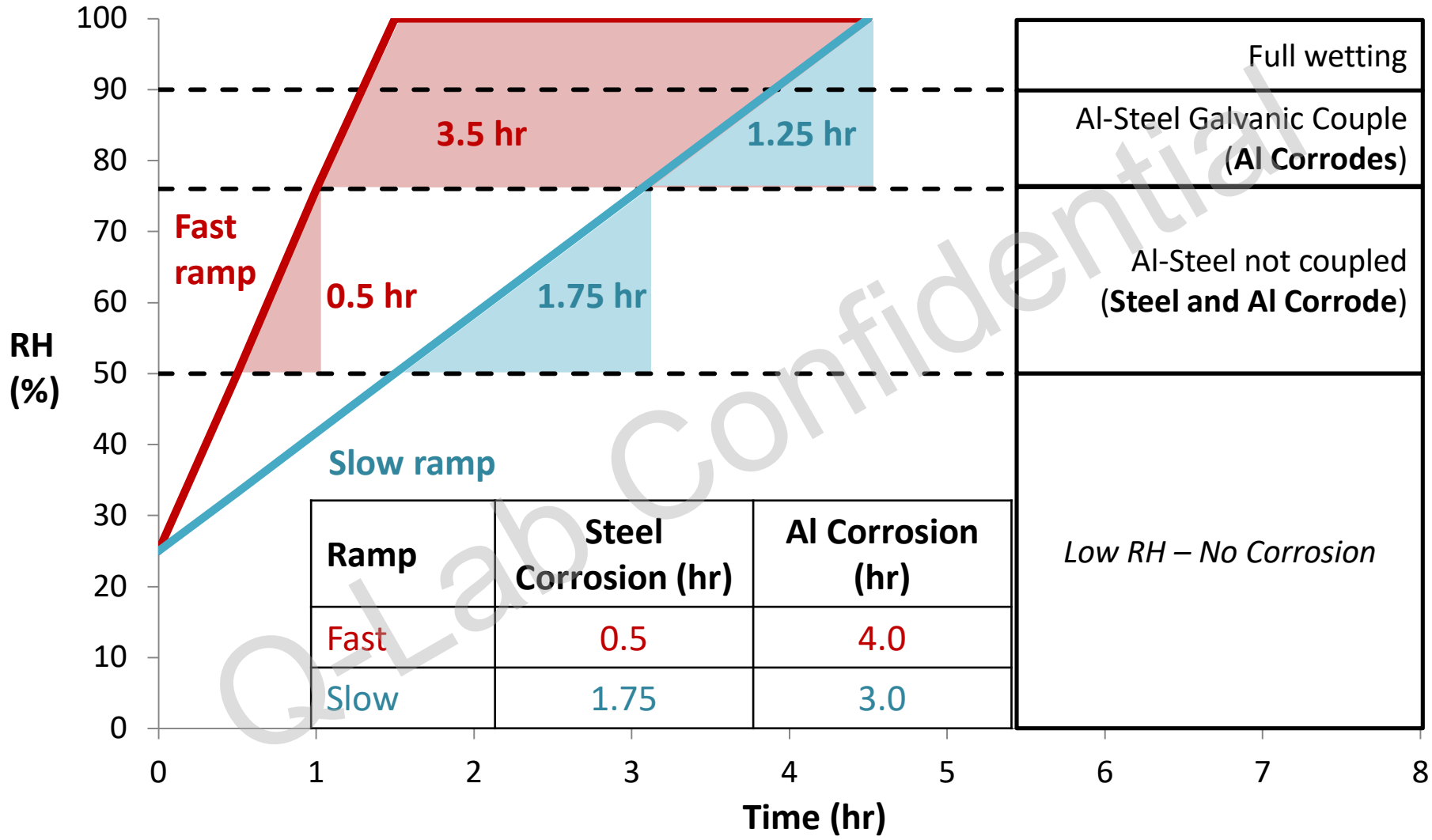
Galvanic corrosion during ramping

High RH > 76%



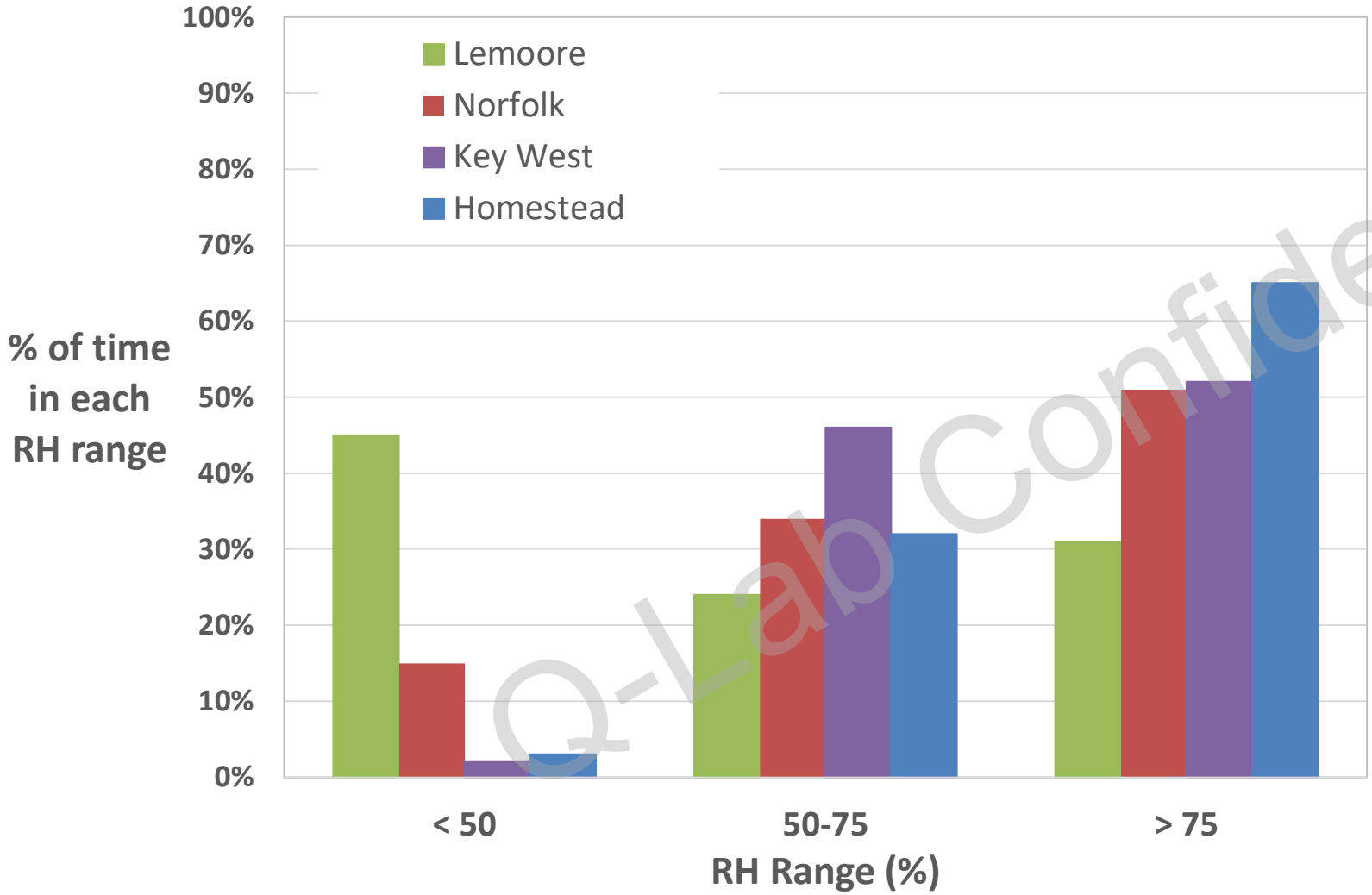
Galvanic corrosion during ramping

High RH > 76%



Ramp	Steel Corrosion (hr)	Al Corrosion (hr)
Fast	0.5	4.0
Slow	1.75	3.0

RH Conditions in the Natural Environment



ASTM G85 Annex 5 (Prohesion)

1 Hour fog at “ambient” temperature
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?

怎样才算干燥？

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

需要多久才能达到干燥？

Answers are in the non-mandatory appendix:
“within ¾ hour all visible moisture is dried off the specimens”
“在3/4小时内样品表面无可见的水”

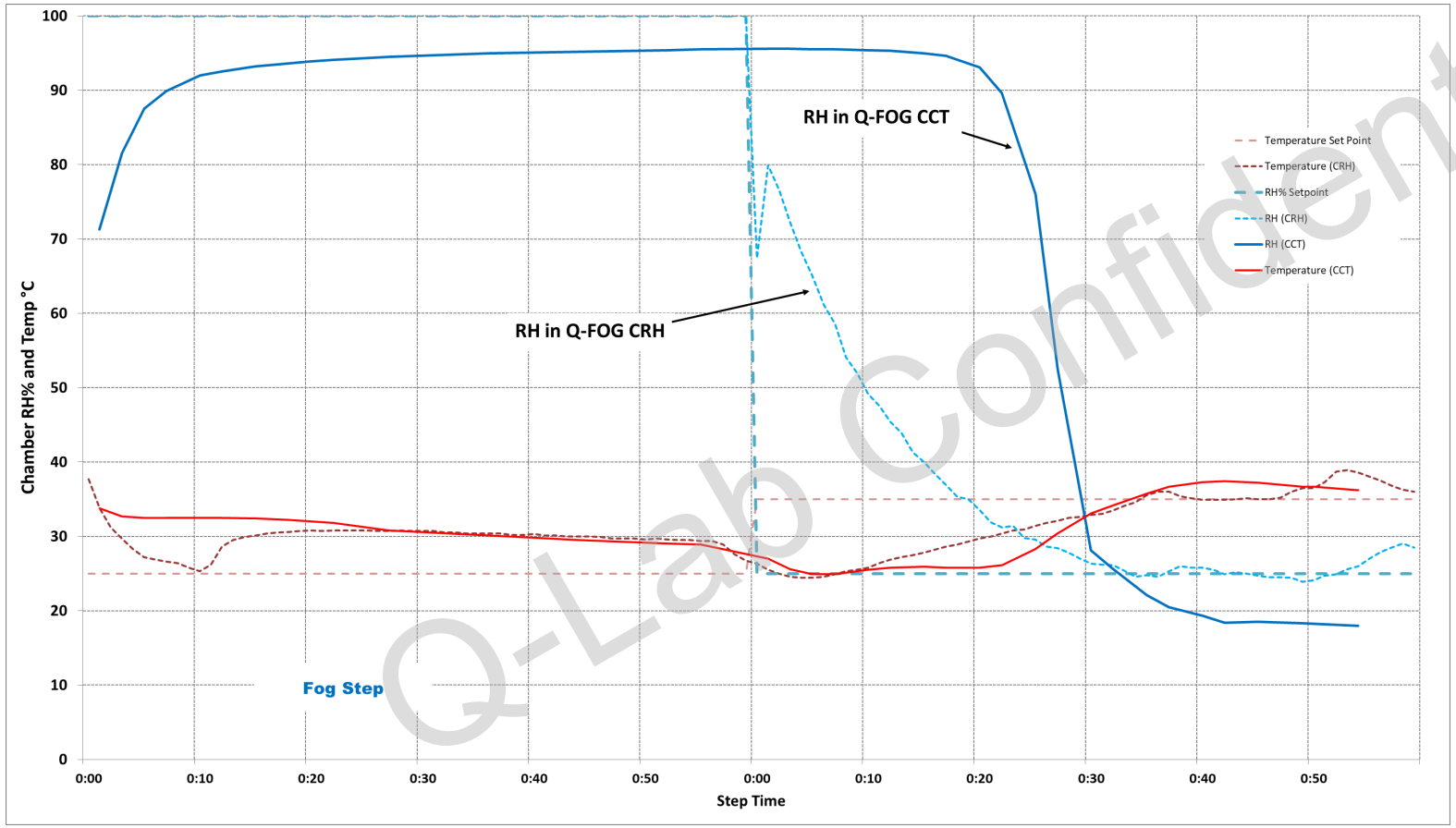
Problem Statement

My new chamber isn't as severe as my old one
我的新盐雾箱测试结果没有老箱子厉害

After 1000 hours of Prohesion, new chamber produced less severe results on a coatings test
1000小时的Prohesion测试，新设备的实验结果没有老设备严重

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:

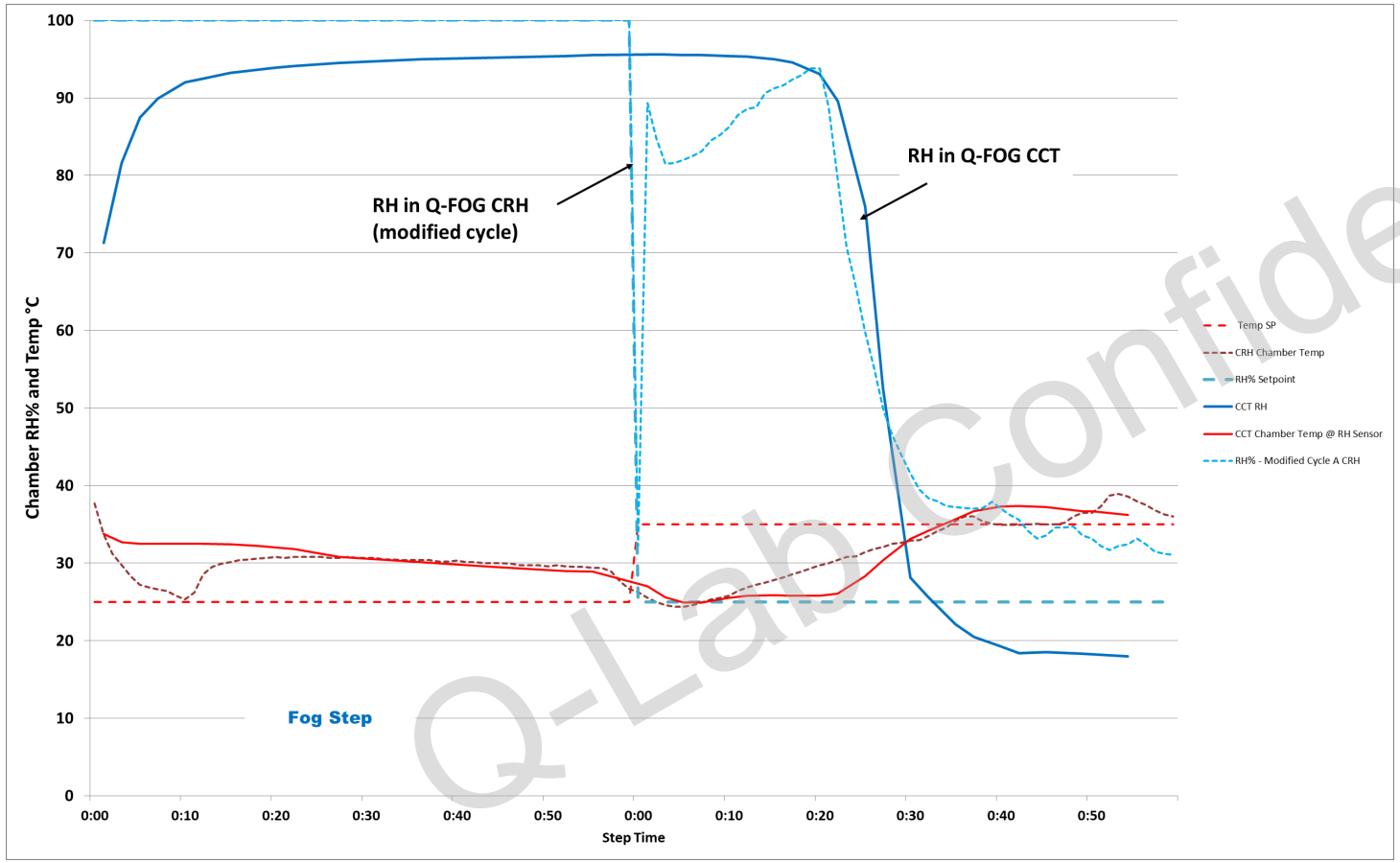
Step 1: Fog 24°C 1:00

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

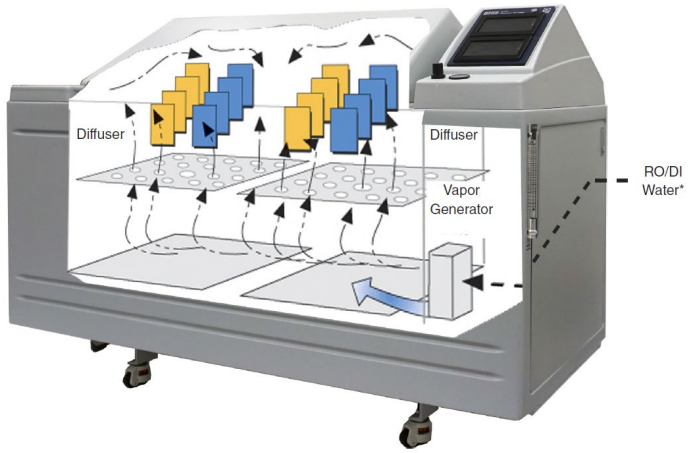
Step 4: Go to Step 1

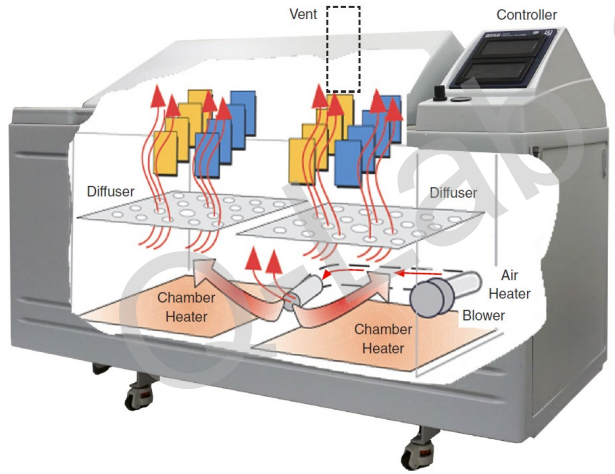
Q-FOG CCT

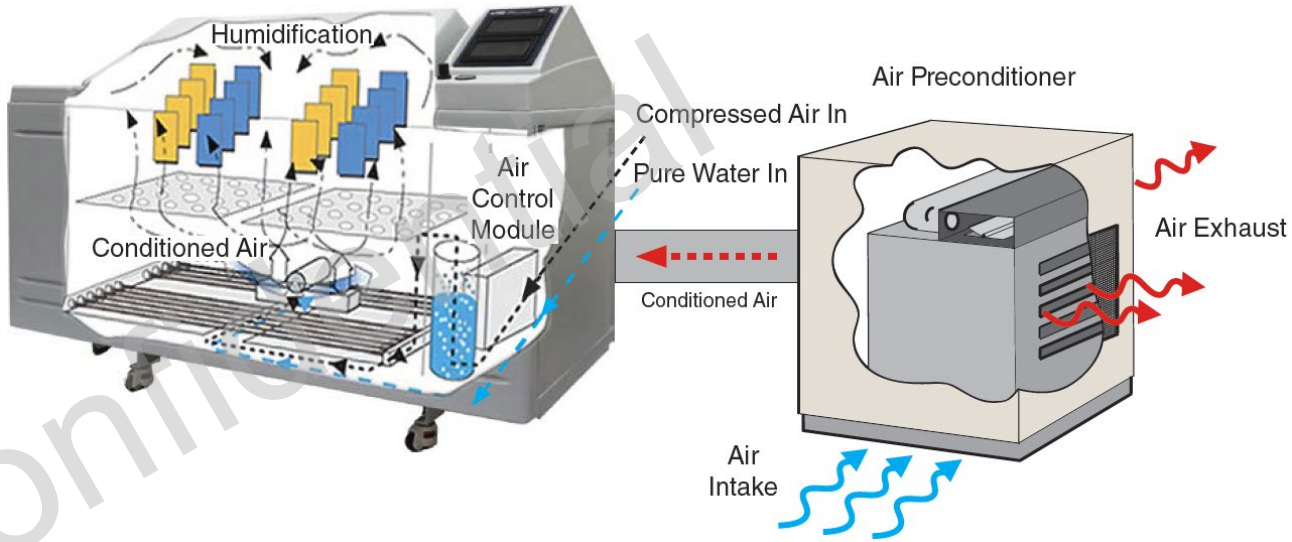
Q-FOG CRH (modified cycle)

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 CCT机型通过热蒸汽加湿，通过鼓热风干燥

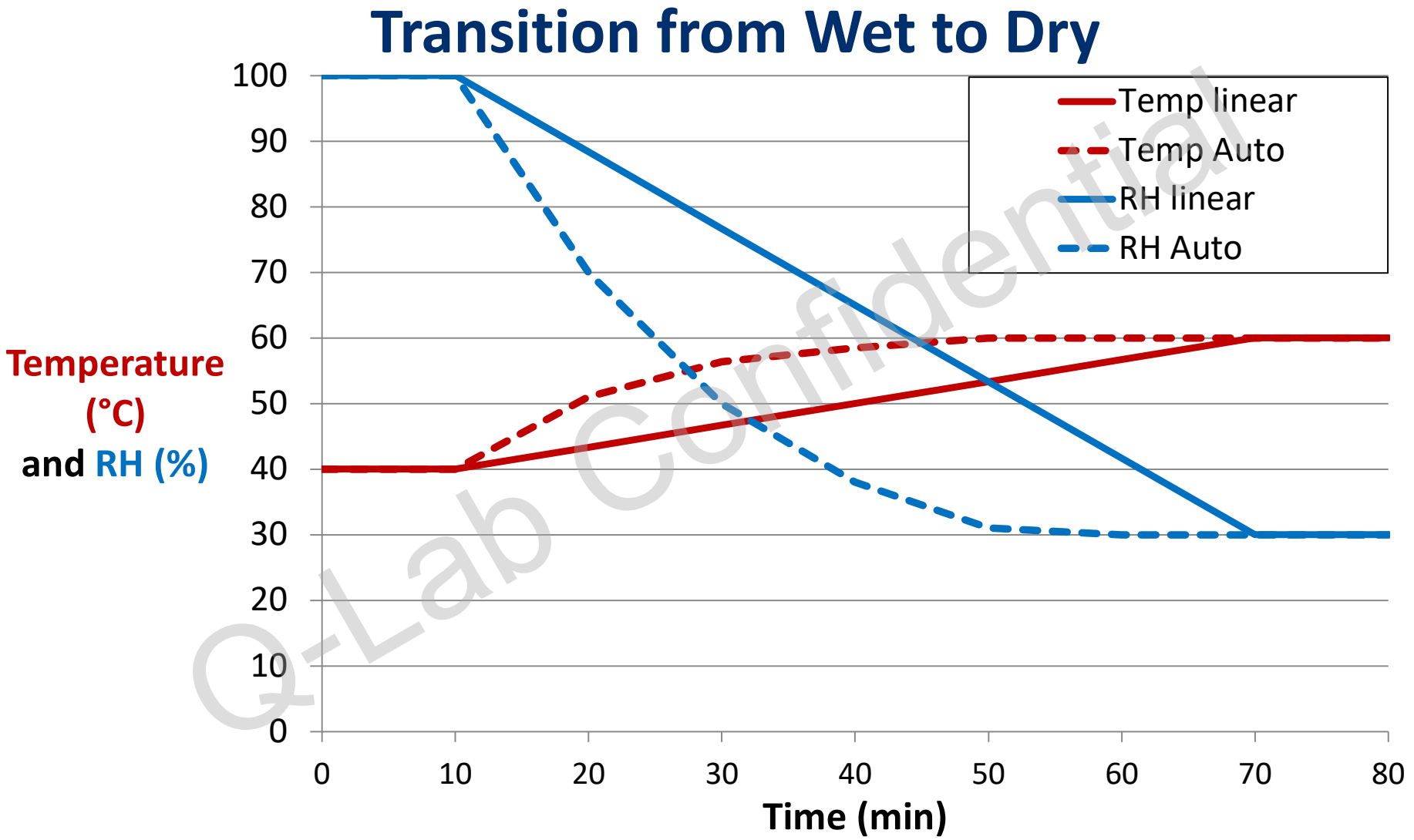






Q-FOG CRH has atomizing humidification nozzles, an air drier (chiller), and a recirculation system with damper to regulate moist and dry air streams
Q-FOG CRH有加湿雾化喷嘴，压缩机干燥，和内循环系统来调节空气的湿度

Q-FOG CRH Linear and Auto Ramping



SAE J2334

Test Solution

0.5% NaCl

0.1% $CaCl_2$

0.075% $NaHCO_3$

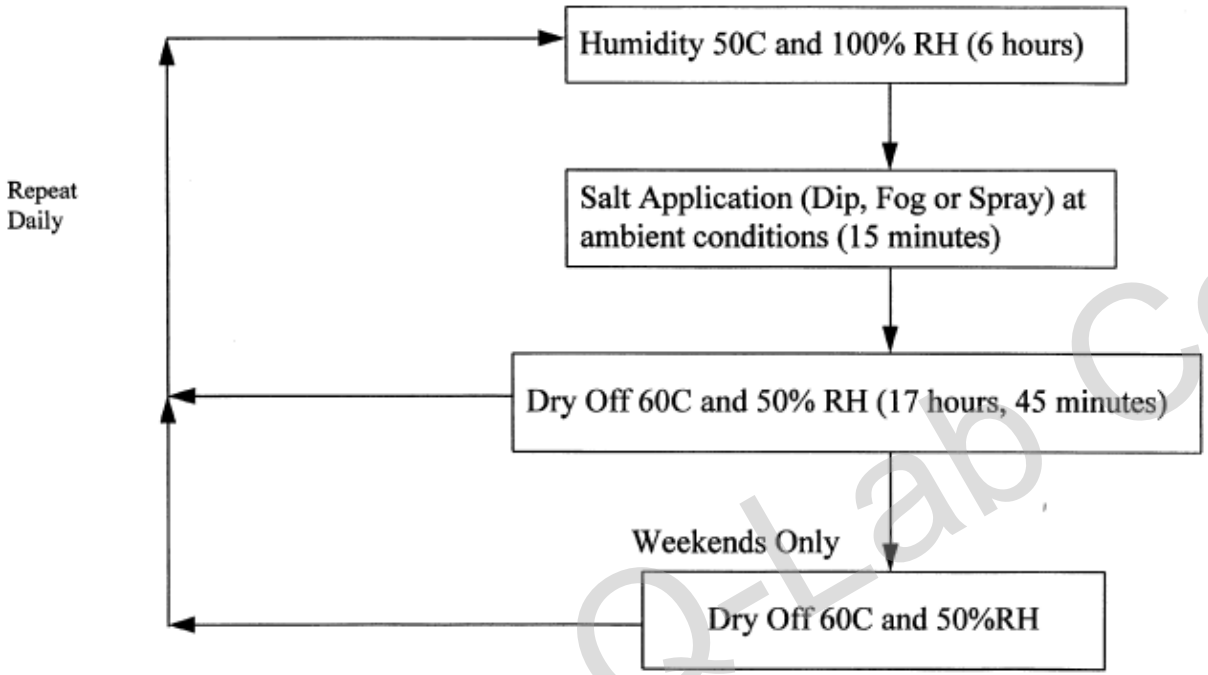
This is the same as GM 9540P and GMW 14872

Salt solution applied by

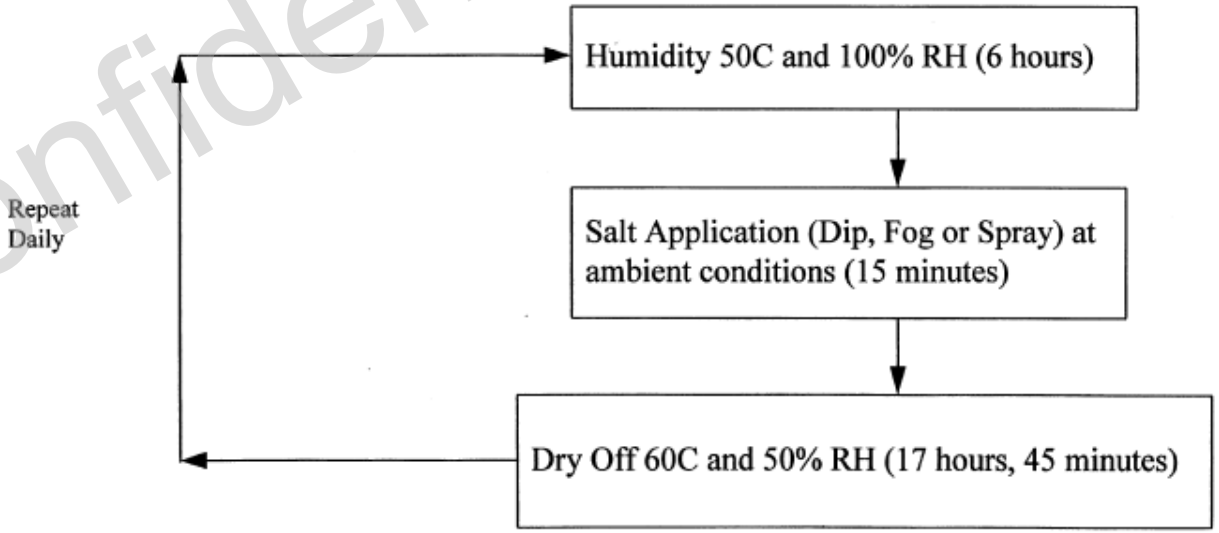
- *Immersion (used to develop method)*
- *Fog (may not deposit much salt on specimens)*
- *Shower (most common today)*

SAE J2334

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



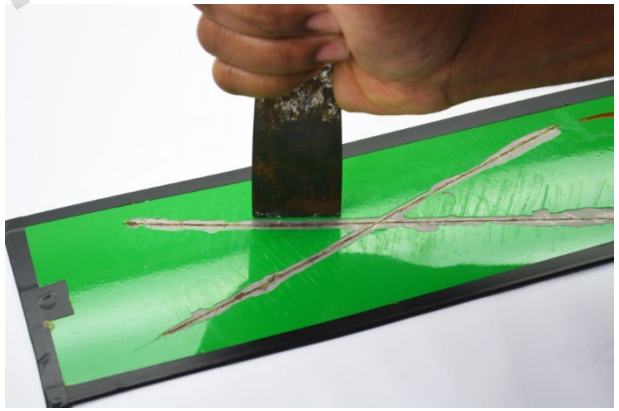
Cosmetic Corrosion LabTest Cycles
SAE J2334 - 7 Day/Week - Automatic Operation



OEM Implementation of J2334

Added mass loss requirement after 20 cycles: 1.3 – 3.0 g
20个循环后的质量损失：1.3-3.0 g

Topcoat specification:
Rust “Creepback Value Before Scraping”
Average: 4, maximum 6.5
腐蚀蔓延平均值：4，最大6.5



The Problem

- U.S. lab “passed” a formulation (average CVBS < 3)

美国实验室通过测试（平均腐蚀蔓延<3）

- European lab “failed” same formulation (average CVBS > 6)

欧洲实验室未通过测试（平均腐蚀蔓延>6）

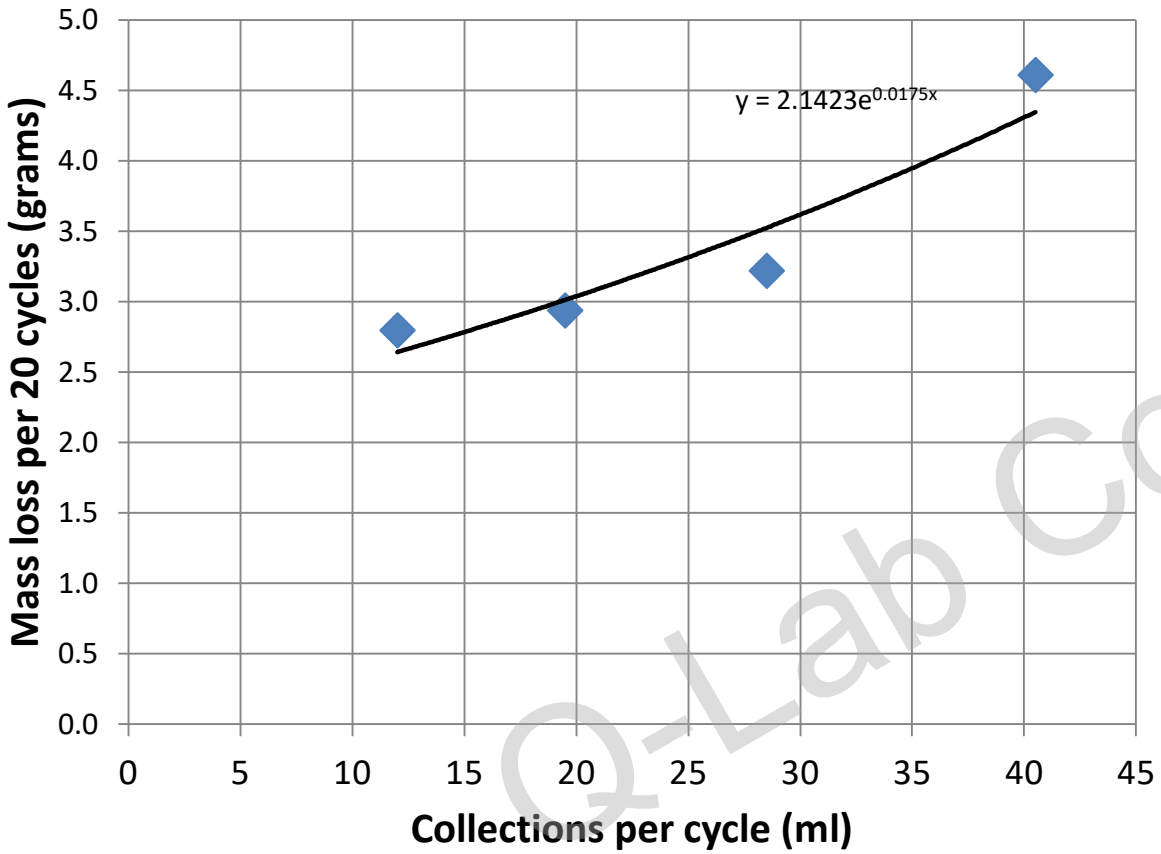
- Formulation was a proven durable system (used as a test control)

测试样品作为标准样，不应该出现如此大的偏差

- European lab coupon mass loss too high (~5 g after 20 cycles—3 g is max allowed)

欧洲实验室的标准片的质量损失太高（20个周期~5 g – 最大值不超过3g）

Experiment 1: Salt Shower Quantification



- Amount of collections correlated with mass loss (previously known from GMW 14872 testing)

沉降量和质量损失的关系（从GMW14872测试中获得的经验）

- Adjusted spray on/off time to reduce spray (10ml/cycle)

调整喷淋 on/off 脉冲

- Mass loss remained high!

质量损失依然很高！

What about chamber conditions?

- Wet to dry transitions were programmed differently in U.S. lab (other chamber) and European lab (Q-FOG CRH)

两地使用的盐雾箱潮湿-干燥的转换是不同的

  - 20 minute transition step added to U.S. chamber to speed up RH reduction (a common practice)

    在美国的箱子中有插入20分钟的转换步骤用于快速的湿度下降（常规操作）

Experiment 2: Rapid and Slow Dry Times
实验2：快速和缓慢的干燥时间

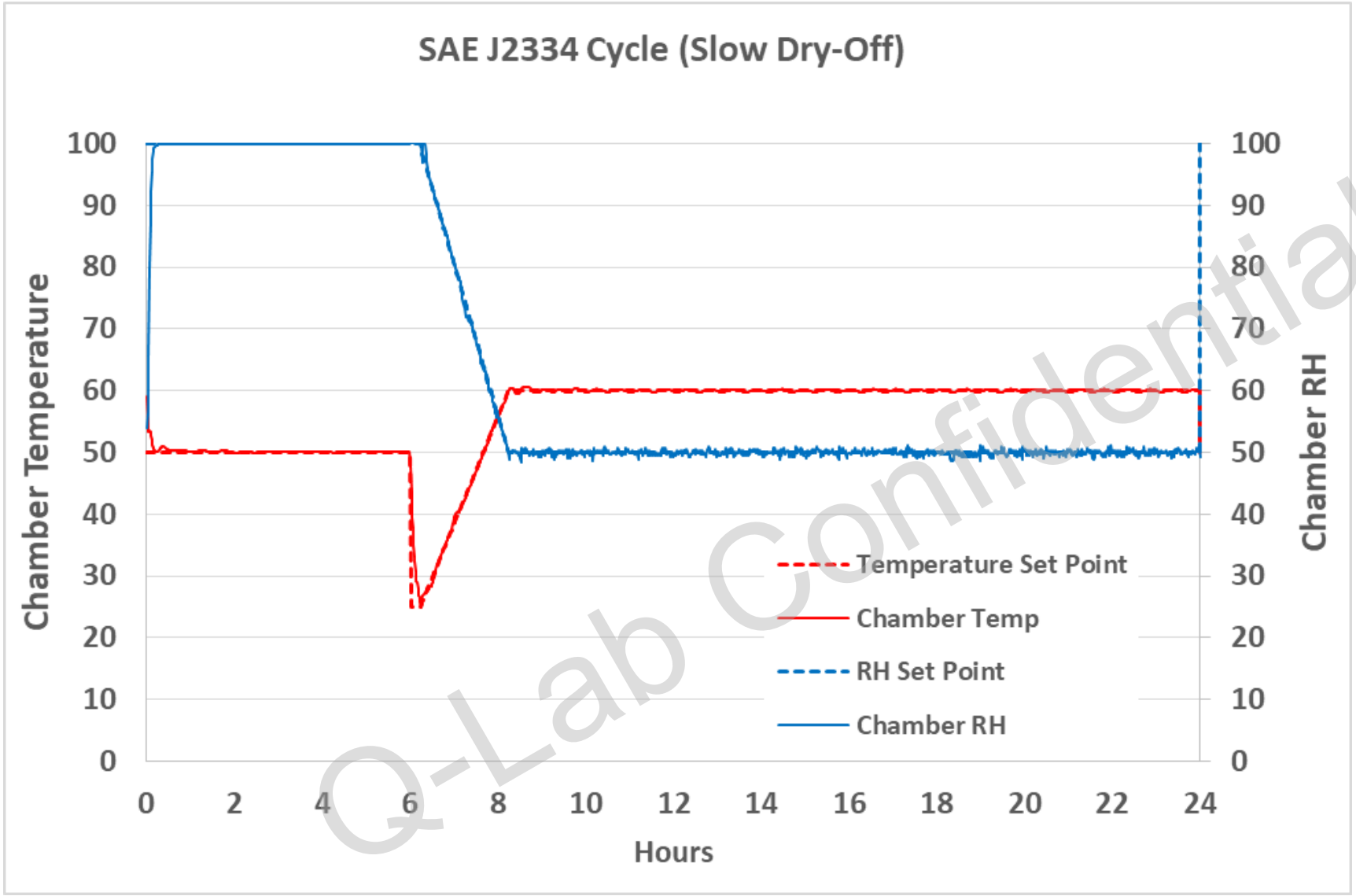
- Test original default SAE J2334 cycle in Q-FOG and another cycle designed to achieve faster dry-off time

Q-FOG在执行SAE J2334标准时候被分别设计成快速和缓慢的干燥

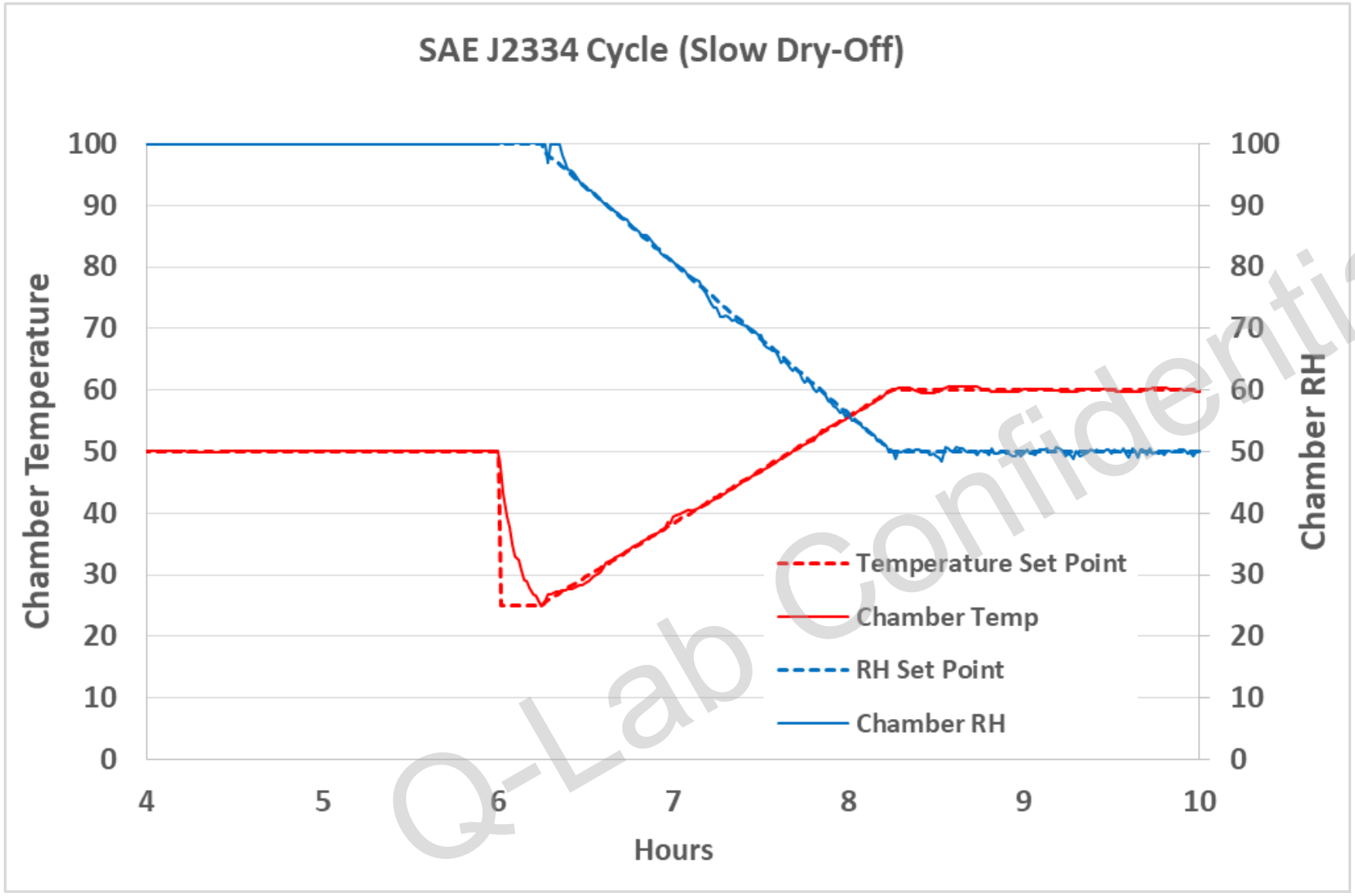
Slow Dry-off

Programming Cycle

Step	Function	Chamber Air Temp (°C)	RH (%)	Step Time (hh:mm)	Ramp
1	RH	50	100	6:00	Auto
2	SHOWER	25		0:15	
3	RH	60	50	17:45	Linear (2:00)
4	Final Step - Go To Step 1				



This version of the test was Q-Lab's default program for J2334 Linear transition after spray



Zoomed in view of the transition

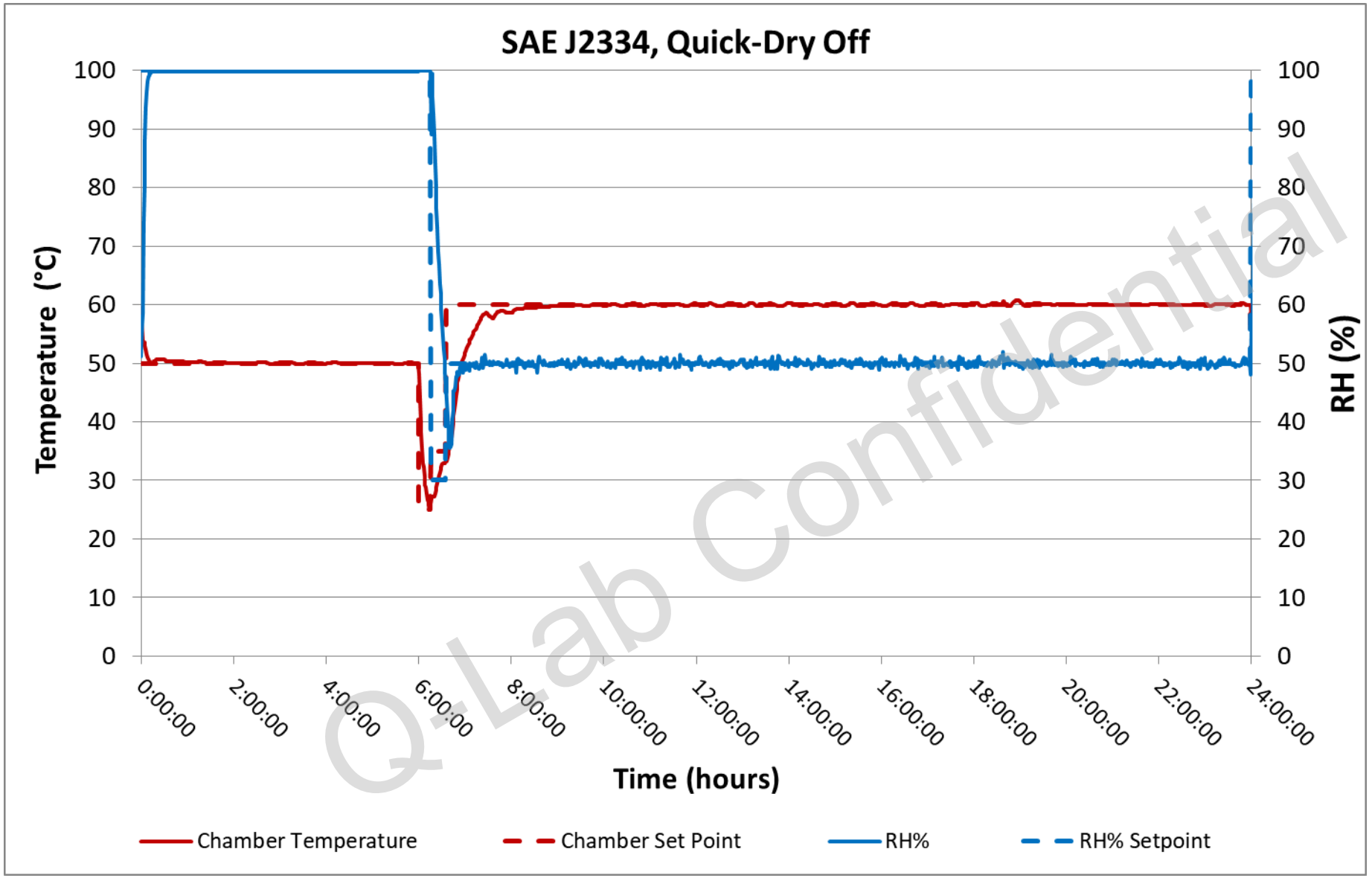
During the transition, the time above the Deliquescence RH of NaCl is about 1 hour

在过渡期间，NaCl潮解的时间是1个小时

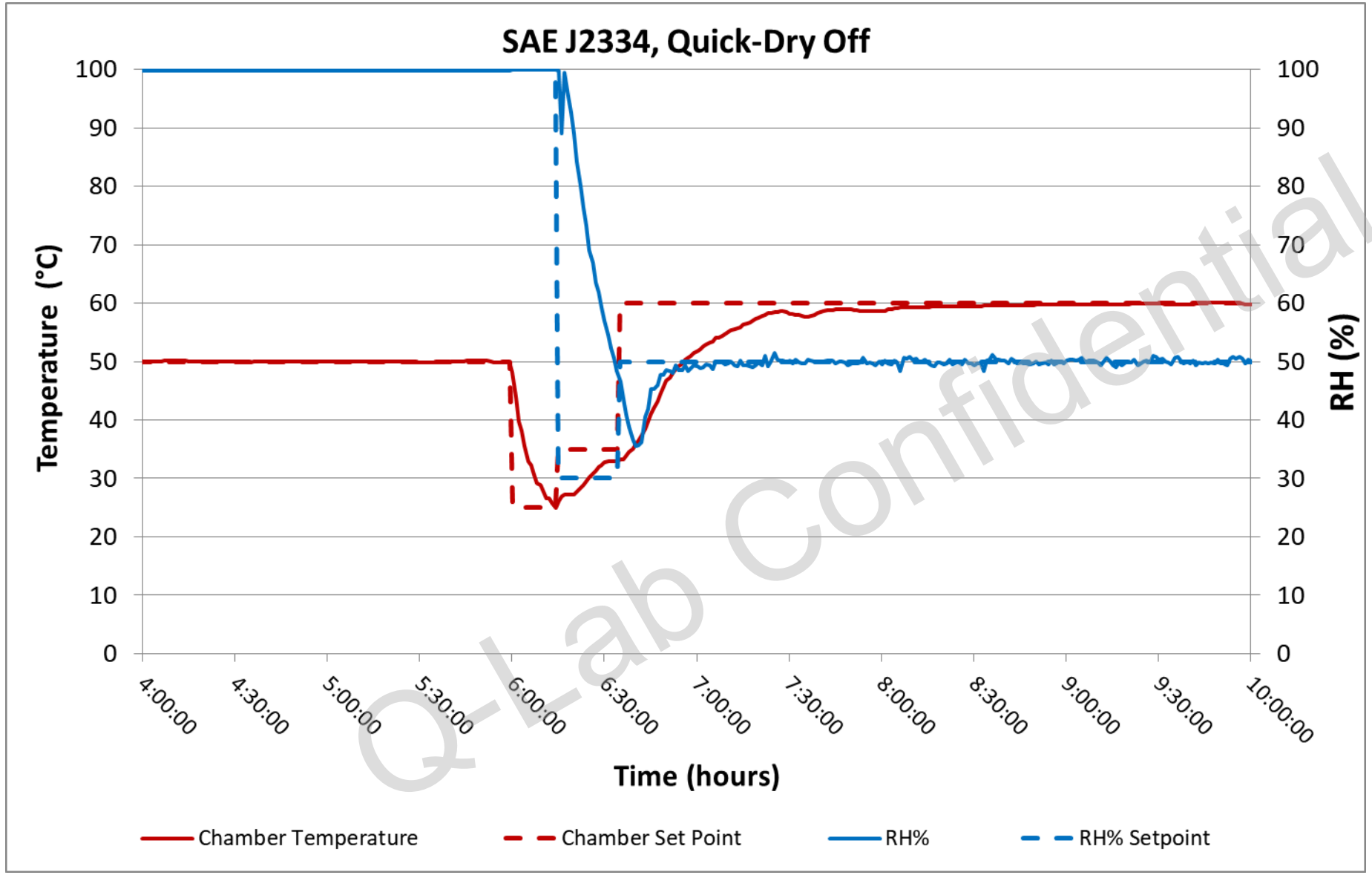
Rapid Dry-off

Programming Cycle

Step	Function	Chamber Air Temp (°C)	RH (%)	Step Time (hh:mm)	Ramp
1	RH	50	100	6:00	Auto
2	SHOWER	25		0:15	
3	RH	35	30	0:20	
3	RH	60	50	17:25	Auto
4	Final Step - Go To Step 1				



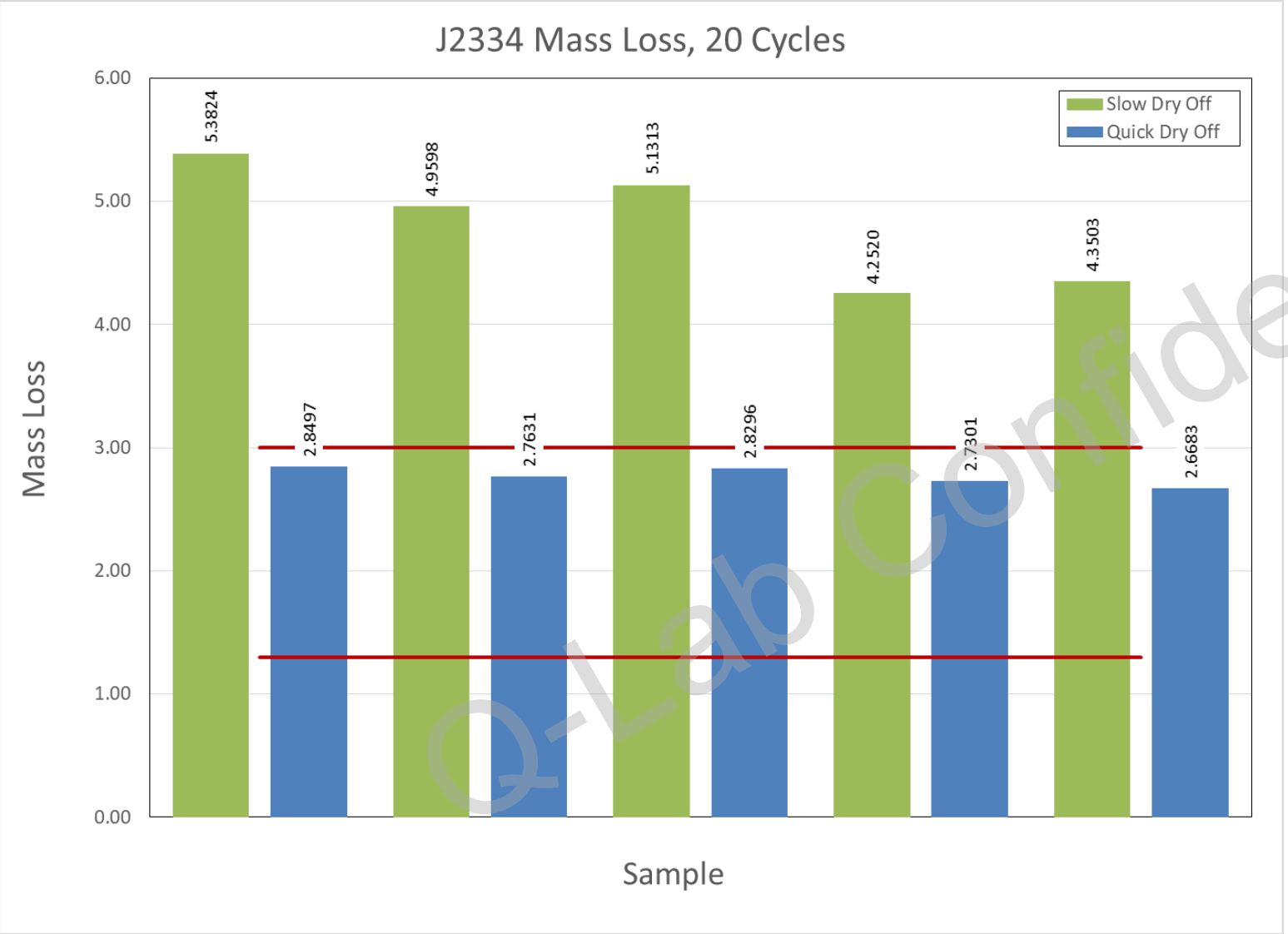
This version of the test cycle is programmed to be similar to customer's U.S. laboratory (in a different chamber)



Zoomed in view of the transition

During the transition the time above the Deliquescence RH of NaCl is about 10 minutes
在过渡时间，NaCl潮解的时间是10分钟

Corrosion Coupon Mass Loss



Green bars represent test under slow dry-off conditions

Blue bars represent test under rapid dry-off conditions

Red lines represent tolerance of OEM standard

Under the rapid dry test, the coated panels once again passed the test

Case Study Conclusions

- Reproducibility issues largely due to RH transitions

实验可再现性和相对湿度的变化关系很大

- The longer the test, the bigger the difference between chambers

测试时间越长，不同箱子之间的测试区别越大

- Amount of spray not a major contributor to reproducibility (but it contributes some)

喷淋量的大小不是主要的因素

Environmental Transitions in Today's Standards: Two Approaches

Rapid (<30 minutes wet to dry)

- Japanese Car Companies
- CCT I, II, IV, JASO M609
- Renault ECC1

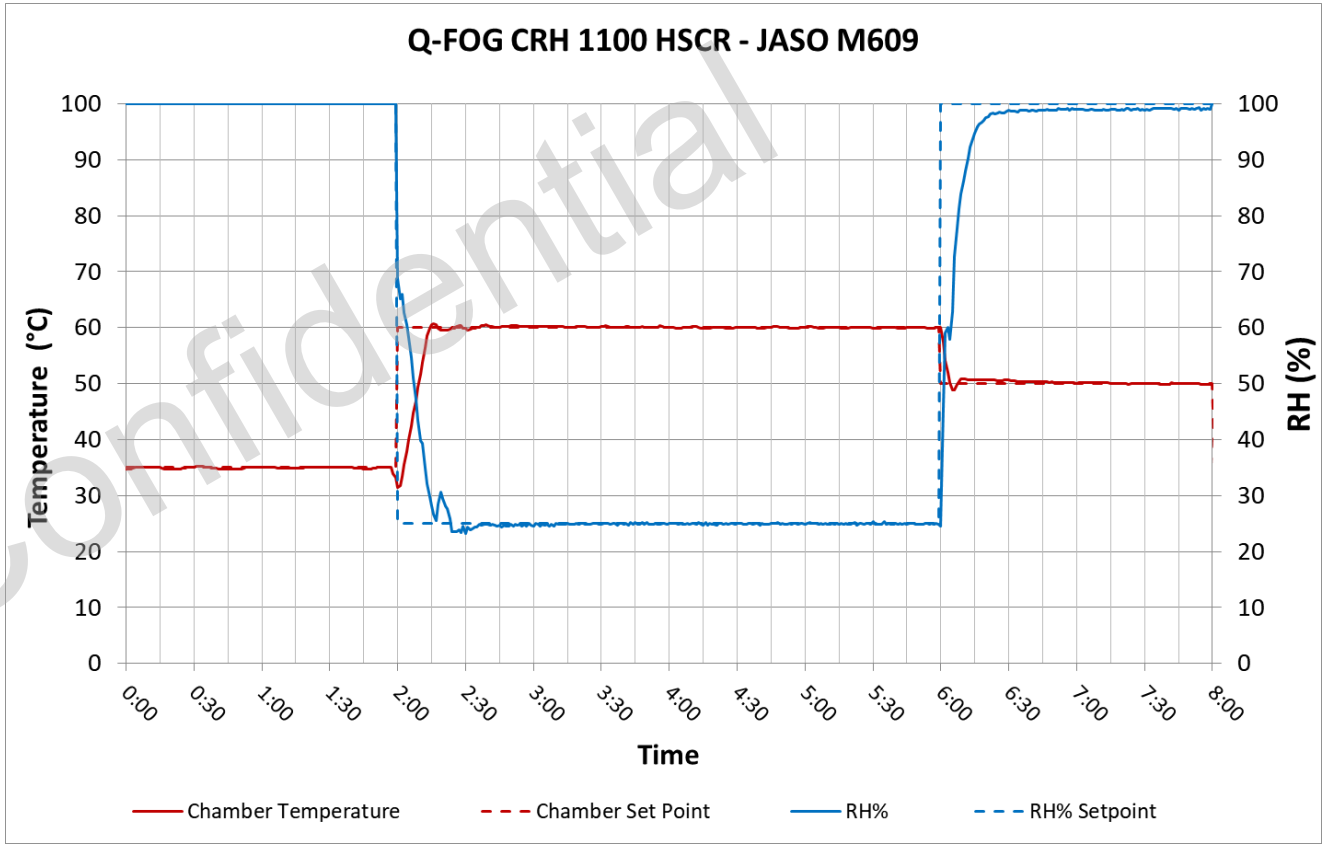
Controlled/Linear

- Volvo ACT1
- Volvo ACT2/Ford L-467
- GMW 14872
- Renault ECC1
- VDA 233-102

JASO M609 (ISO 14993, 11997-1)

- Chamber Volume – 1100 l
- Chamber Load – 240 x 4” x 6” Steel Panels
- Laboratory Room Temperature – 28-30 °C

Step	Function	Chamber Air Temp (°C)	RH (%)	Step Time (hh:mm)	Ramp
1	FOG	35		2:00	< 0:30
2	RH	60	25	4:00	< 0:30
3	RH	50	100	2:00	< 0:15
4	Final Step – Go To Step 1				



JASO M609

Transition times for JASO M609 in full Q-FOG CRH 1100 HSCR Chamber.

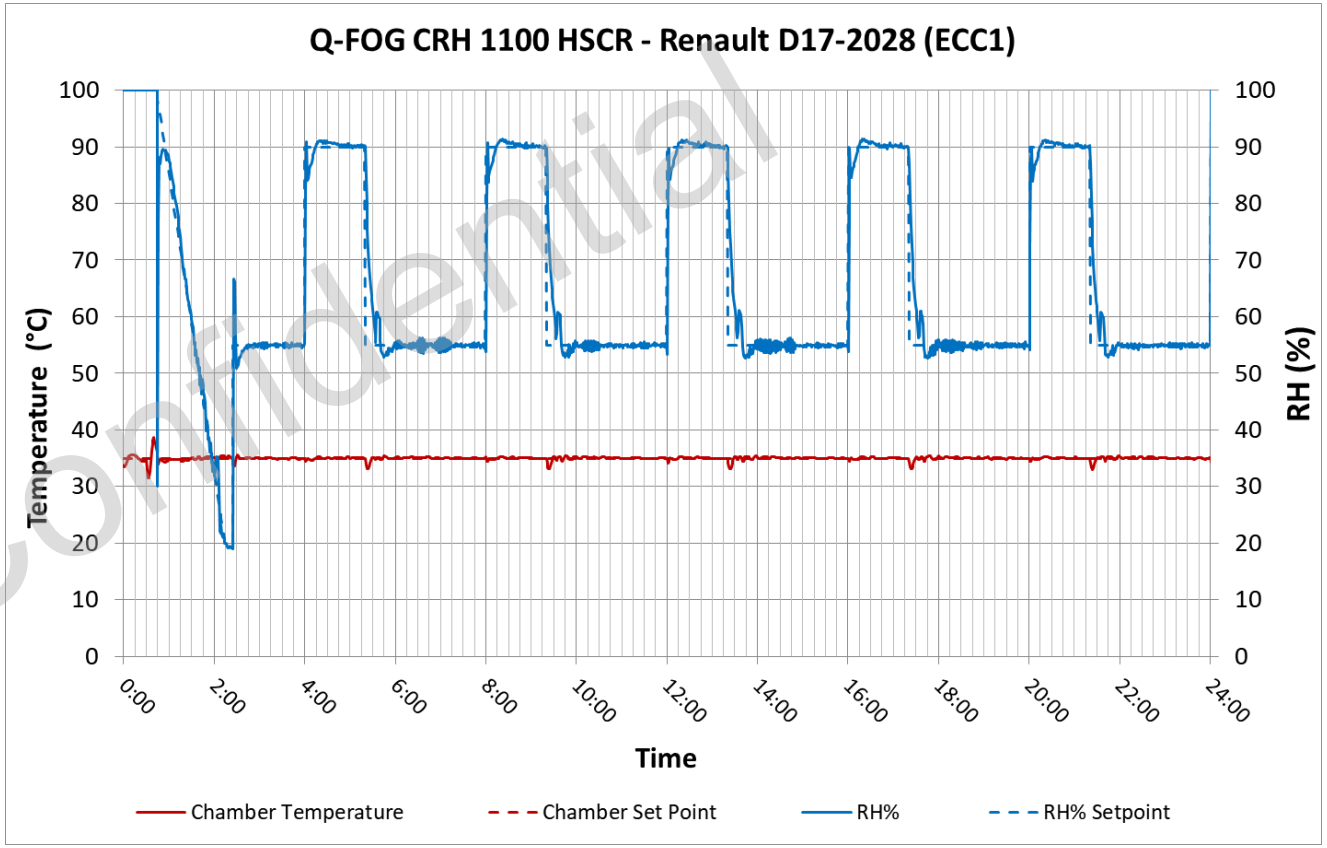
			Transition Requirement	Time for Temperature to reach requirement	Time for Relative Humidity to reach requirement
JASO M609	Fog to Dry	35 °C ➔ 60 ± 1 °C / 20 - 30% RH	< 0:30	0:13	0:14
	Dry to Wet	60 ± 1 °C / 20 - 30% RH ➔ 50 ± 1 °C / > 95% RH	< 0:15	0:04	0:15
	Wet to Fog	50 ± 1 °C / > 95% RH ➔ 35 °C	< 0:30	0:06	

Renault D17-2028 (ECC1)

- Chamber Volume – 1100 l
- Chamber Load – 240 x 4” x 6” Steel Panels
- Laboratory Room Temperature – 26-28 °C

Step	Function	Chamber Air Temp (°C)	RH (%)	Step Time (hh:mm)	Ramp
1	FOG	35		0:35	
2	RINSE	35		0:05	
3	FOG	35		0:05	
4	RH	35	20	1:40	Linear 1:30
5	RH	35	55	1:35	Auto
6	Subcycle*				
7	RH	35	90	1:20	Auto
8	RH	35	55	2:40	Auto
9	Final Step – Go To Step 1				

*Step 6: Subcycle Repeat Steps 7-8 5x

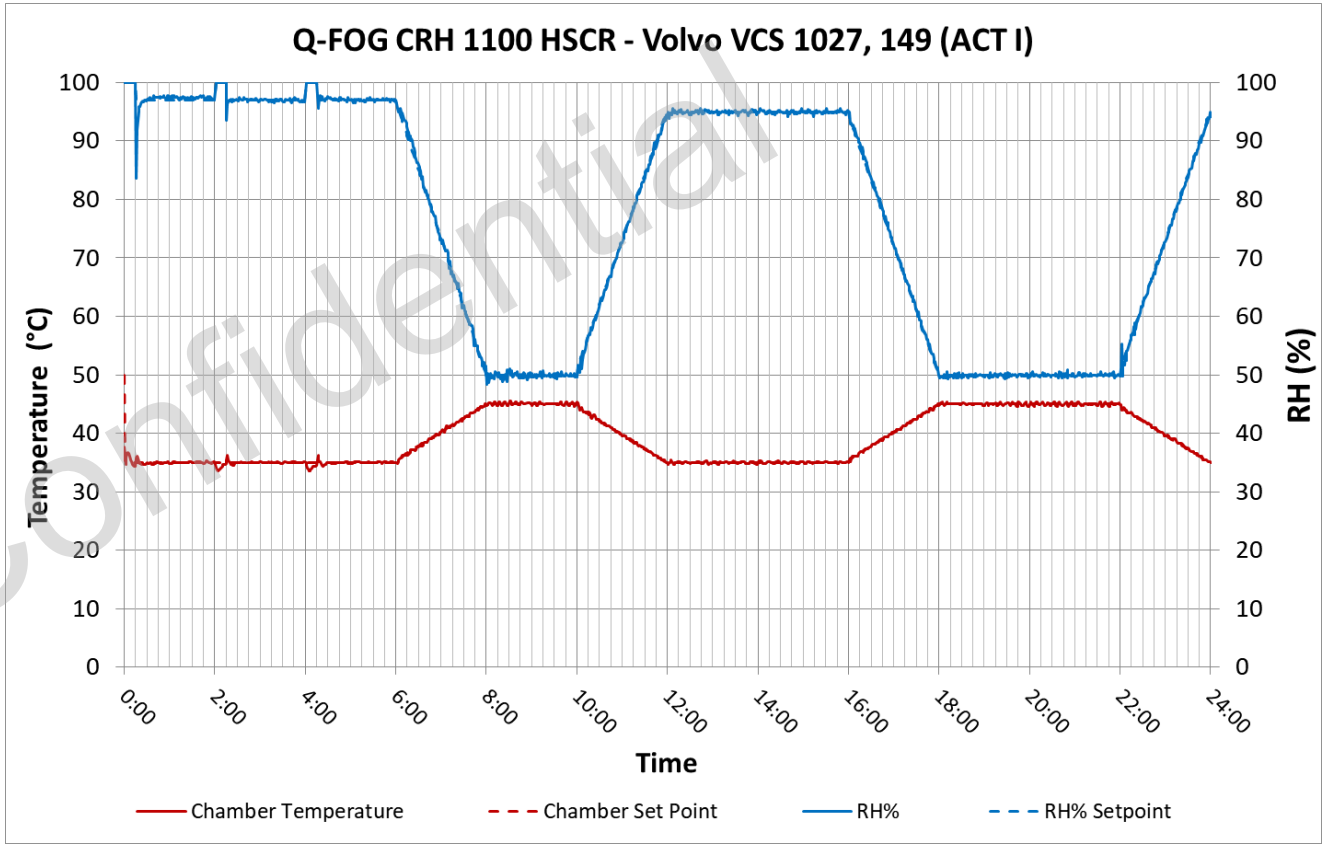


Volvo VCS 1027, 149 (ACT I)

- Chamber Volume – 1100 l
- Chamber Load – Empty
- Laboratory Room Temperature – 22-25 °C

Step	Function	Chamber Air Temp (°C)	RH (%)	Step Time (hh:mm)	Ramp
1	Subcyle*				
2	SHOWER	35		0:15	
3	RH	35	97	1:45	Auto
4	RH	45	50	4:00	Linear 2:00
5	RH	35	95	2:00	Linear 2:00
6	Subcyle**				
7	RH	35	95	4:00	
8	RH	45	50	6:00	Linear 2:00
9	RH	35	95	2:00	Linear 2:00
10	Final Step – Go To Step 1				

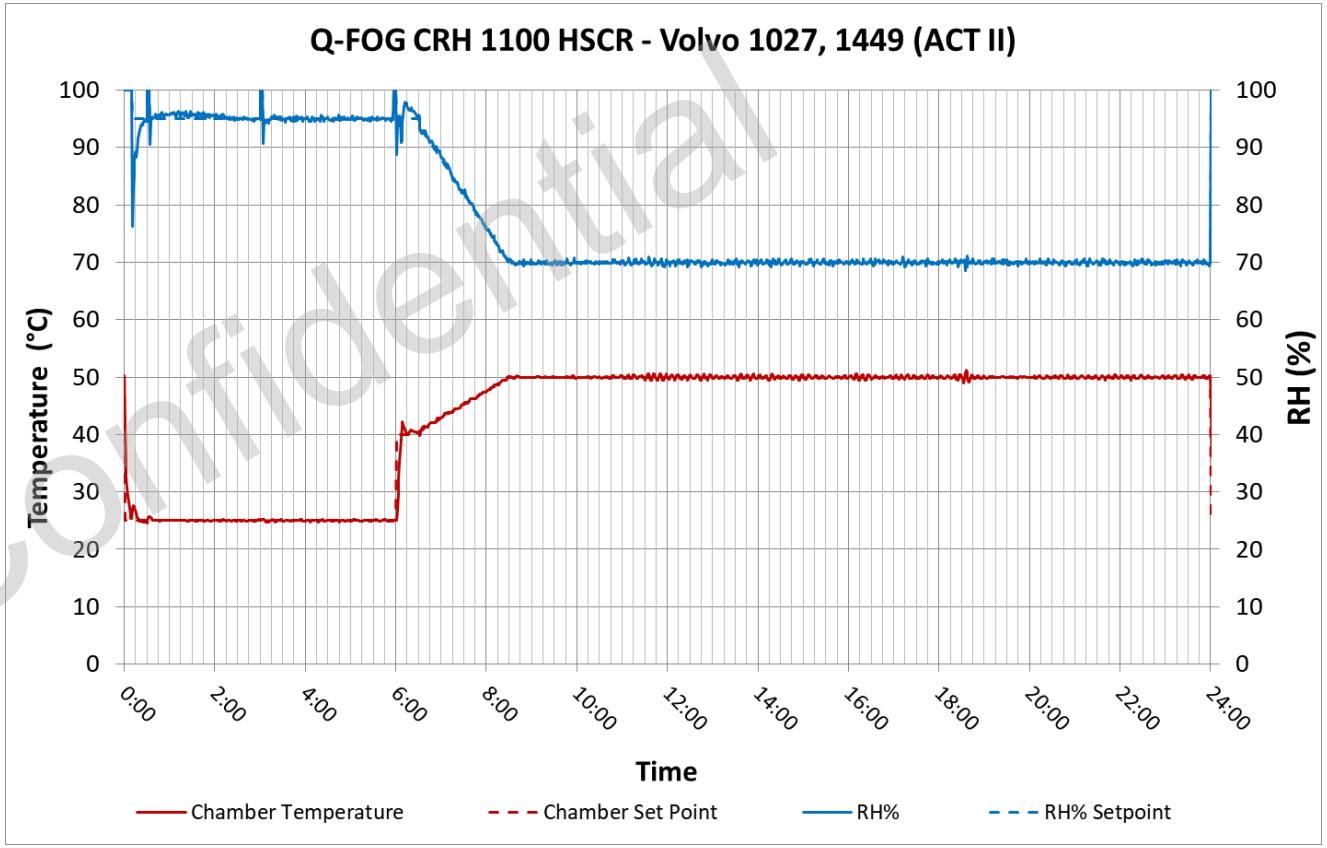
*Step 1: Subcycle Repeat Steps 2-3 3x
**Step 6: Subcycle Repeat Steps 7-9 7x



Volvo VCS 1027, 1449 (ACT-II)/Ford L-467

- Chamber Volume – 1100 l
- Chamber Load – Empty
- Laboratory Room Temperature – 22-25 °C

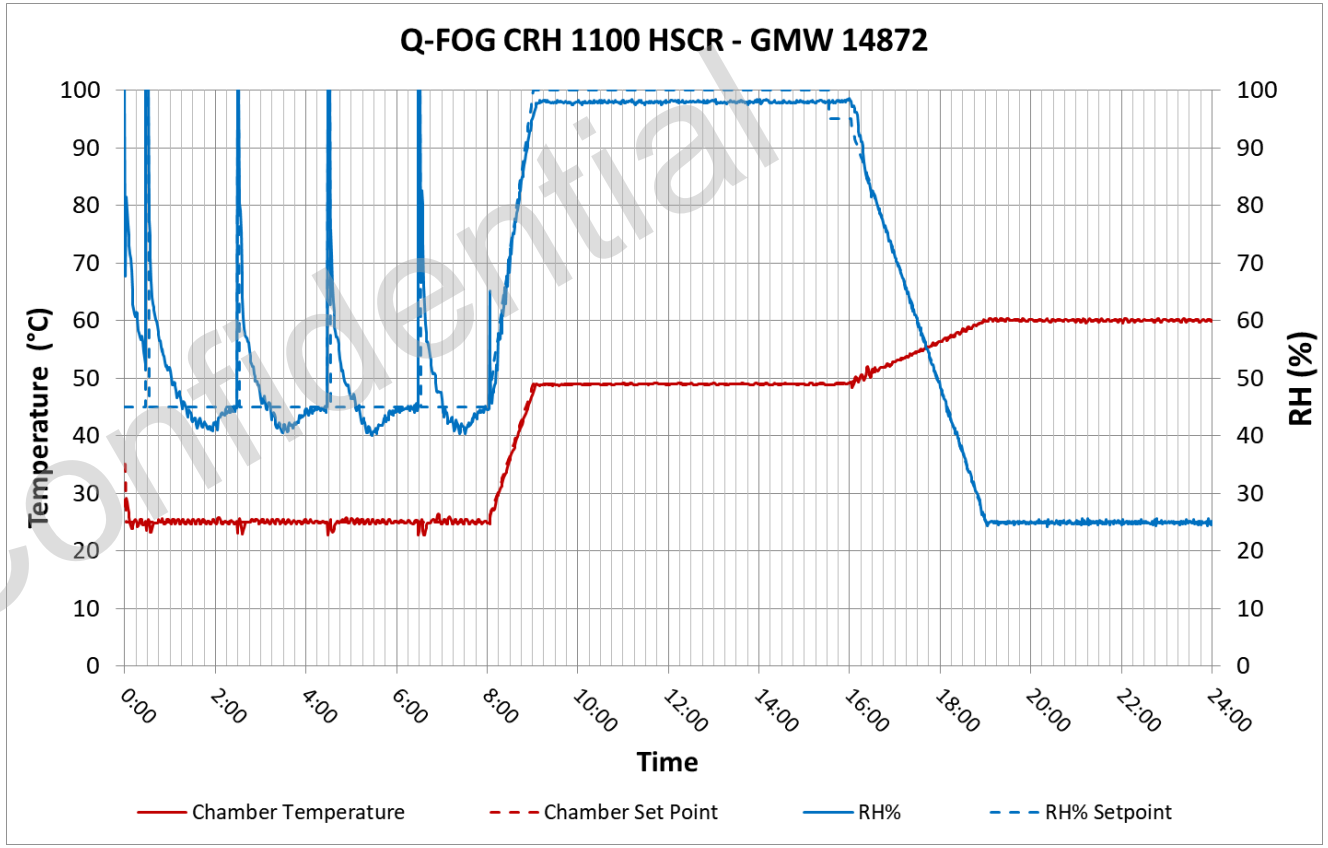
Step	Function	Chamber Air Temp (°C)	RH (%)	Step Time (hh:mm)	Ramp
1	Subcyle*				
2	SHOWER	25		0:10	
3	RH	25	95	0:20	Auto
4	SHOWER	25		0:03	
5	RH	25	95	2:27	Auto
6	SHOWER	25		0:03	
7	RH	25	95	2:54	Auto
8	SHOWER	25		0:03	
9	RH	40	95	0:30	< 0:30
10	RH	50	70	17:30	Linear 2:00
11	RH	50	70	48:00	Auto
12	Final Step – Go To Step 1				
*Step 1: Subcyle Repeat Steps 2-10 5x					



GMW 14872

- Chamber Volume – 1100 l
- Chamber Load – Empty
- Laboratory Room Temperature – 22-25°C

Step	Function	Chamber Air Temp (°C)	RH (%)	Step Time (hh:mm)	Ramp
1	Subcycle*				
2	RH	25	45	0:27	Auto
3	SHOWER	25		0:03	
4	RH	25	45	1:30	Auto
5	RH	49	100	7:30	Linear 1:00
6	RH	49	95	0:30	Auto
7	RH	60	25	8:00	Linear 3:00
8	Final Step – Go To Step 1				
*Step 1: Subcycle Repeat Steps 2-4 4x					



Question?

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