New ITO Supplier Qualification Results

Roy Chancellor

ITO Qualification Results

- Background and Motivation
- Qualification test
  - Green Ys
  - Test procedure
- Analysis and Results
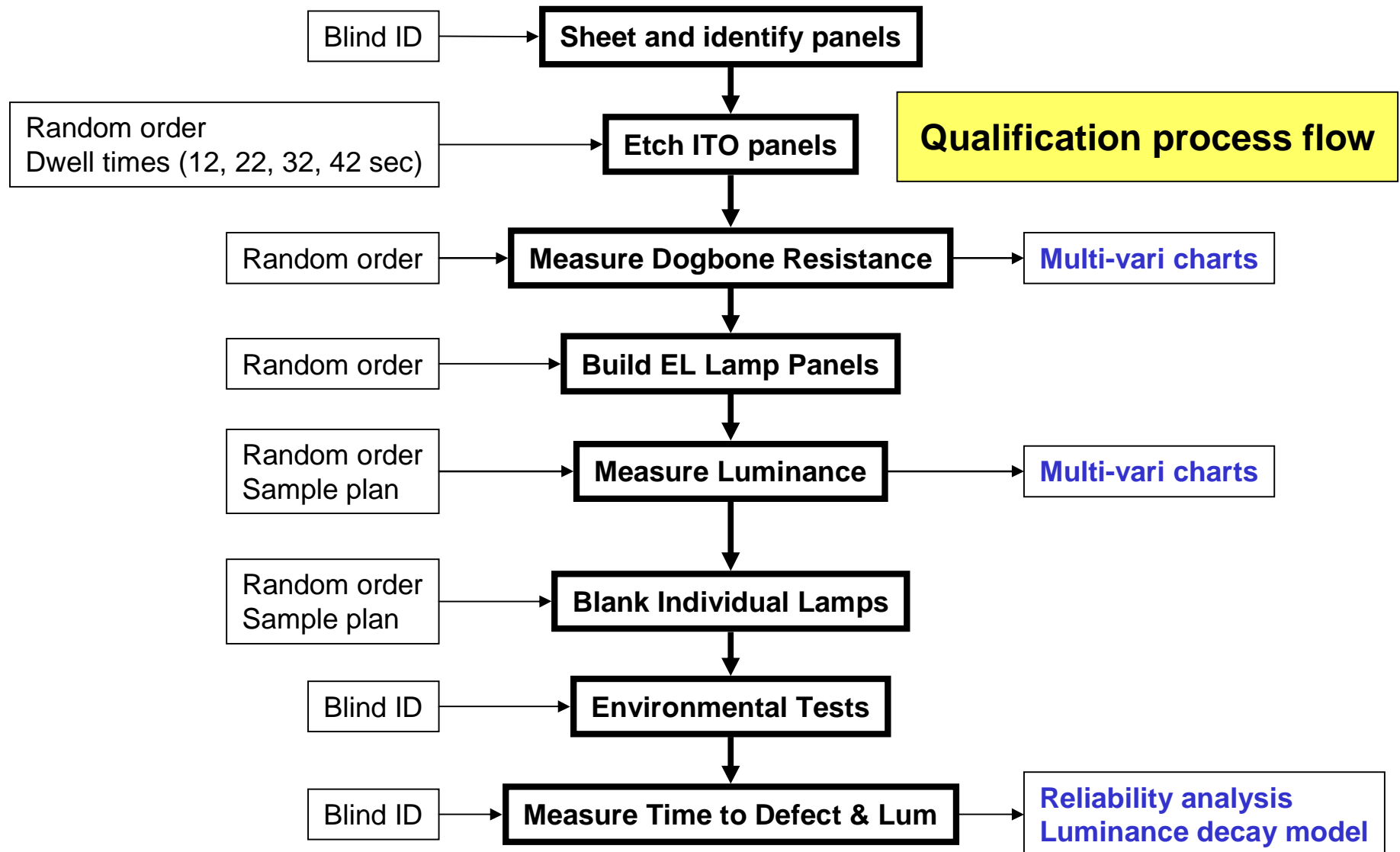- Conclusions and Recommendations

ITO Qualification Results

- ## Background and Motivation
  - Solidify ITO supply chain by qualifying a second source (equivalent to existing)
  - Previous attempts to qualify ### material were hampered by
    - Material problems (ITO formulation; oxygen level)
    - Test uncertainties
  - Objective
    - Perform a statistically designed reliability test that compares Supplier A to Supplier B (current standard)

ITO Qualification Results

- ## Qualification test

  - ## Green Ys (Green = color of money)

    - Sheet resistivity (Ω / square)

    - Dogbone resistance (kΩ)

    - Lamp luminance @ t=0 (fL)

    - Lamp luminance decay in high temp / high humidity environment

    - Time to formation of defects in HT/HH environment

  - ## Test procedure

    - Emphasis on **blindness** to ensure impartiality

    - **Randomization** to avoid time-related biases

ITO Qualification Results

Blind ID → **Sheet and identify panels**

Random order
Dwell times (12, 22, 32, 42 sec) → **Etch ITO panels**

Qualification process flow

Random order → **Measure Dogbone Resistance** → **Multi-vari charts**

Random order → **Build EL Lamp Panels**

Random order
Sample plan → **Measure Luminance** → **Multi-vari charts**

Random order
Sample plan → **Blank Individual Lamps**

Blind ID → **Environmental Tests**

Blind ID → **Measure Time to Defect & Lum** → **Reliability analysis
Luminance decay model**

ITO Qualification Results

- Test materials
  - Three lots of Standard chosen at random
  - Five lots of NEW
    - Two production lots from machine NV1
    - Three lots with different b* value from NV2
- Panels sampled from the beginning, middle, and end of the rolls

Blind ID	Supplier	Lot #	Common ID
300		NV1-1787-A3	NV1-A3
764		NV1-1787-A1	NV1-A1
113		NV2-344-A2	b* = 3.0
699		NV2-344-A3	b* = 0.0
469		NV2-344-A1	b* = 1.0
400		5310283-1D	283-1D
103		5310274-1L	274-1L
627		5310259-1G	259-1G

Panel ID	
1	
2	
3	
4	Beginning of Roll (First 12')
5	
6	
7	
8	

9	
10	
11	
12	Middle of Roll (Middle 12')
13	
14	
15	
16	

17	
18	
19	
20	End of Roll (Last 12')
21	
22	
23	
24	

ITO Qualification Results

- Analysis and Results
  - **Dogbone resistance**
  - Luminance at t=0
  - Time to defects (reliability)
  - Luminance decay
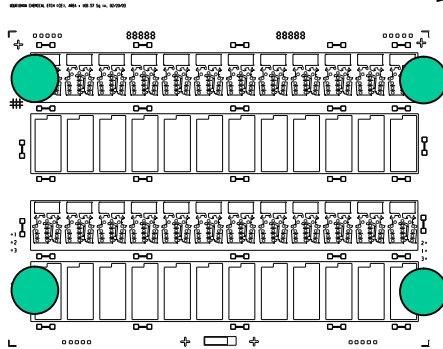
ITO Qualification Results

Green Y = Dogbone Resistance, kΩ (measure of Degree of Etch)

Variation Family	**Notes**

Orientation – Orientation Same Side

Not measured

Side – Side Same Row

Large contrast for NEW b* 1, 2, 3 material; small contrast on STD materials. Larger contrast for 32 sec than 22 sec dwell.

Row – Row Same Panel

Medium contrast for 22 sec dwell; larger for 32 sec. Medium contrast for b* 1, 2, 3 material; small contrast for STD material
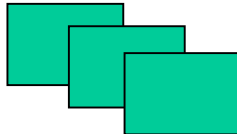
Panel – Panel Same Web Location

Small contrast (large for b* 3 @ 32 sec)

Web Loc – Web Loc Same ITO Type

Small contrast overall; medium contrast for b* 3 @ 32 sec. No leverage (non-random pattern)

NEW   STD

ITO Type – ITO type Same Dwell Time

Small contrast for STD and NEW NV1 rolls; large contrast for b* rolls (by design); variation is much larger for b* 1, 2, 3 rolls

12 s   22 s   32 s   42 s

Dwell Time – Dwell Time

High contrast. Variation increases significantly with dwell for NEW b* 1, 2, 3 rolls; **22 sec is best dwell for both materials**

ITO Qualification Results

IDUR184XA CHEMICAL ETCH (CE), AREA = 108.57 Sq in, 02/20/03

**Left** **Data collection plan for dogbone resistance** **Right**

Row 1

ITO Qualification Run Plan

ITO ID	Panel ID	Dwell Time, sec	Web Loc	Panel Rep	Row	Dogbone, kohm		Run Order	Unique	Group
						Left	Right			
699	22	32	3 (E)	2	1			48	15378	4
699	22	32	3 (E)	2	4			48	15378	4
103	13	32	2 (M)	1	1			47	1339	4
103	13	32	2 (M)	1	4			47	1339	4
469	13	32	2 (M)	1	1			46	6097	4
469	13	32	2 (M)	1	4			46	6097	4
103	14	32	2 (M)	2	1			45	1442	4
103	14	32	2 (M)	2	4			45	1442	4
400	6	32	1 (B)	2	1			45	2400	4

Row 4

5/29/2003

9

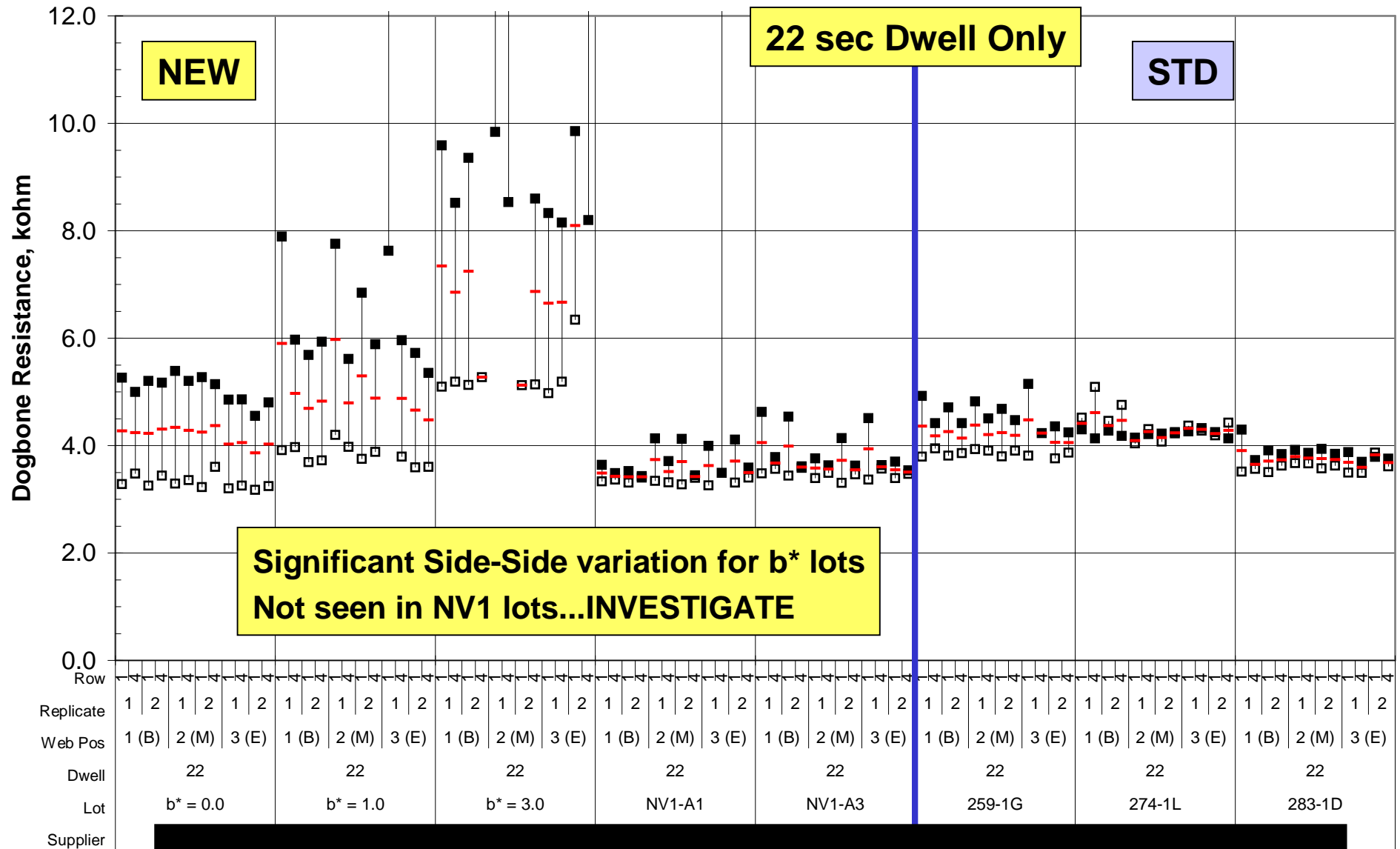# ITO Qualification Results
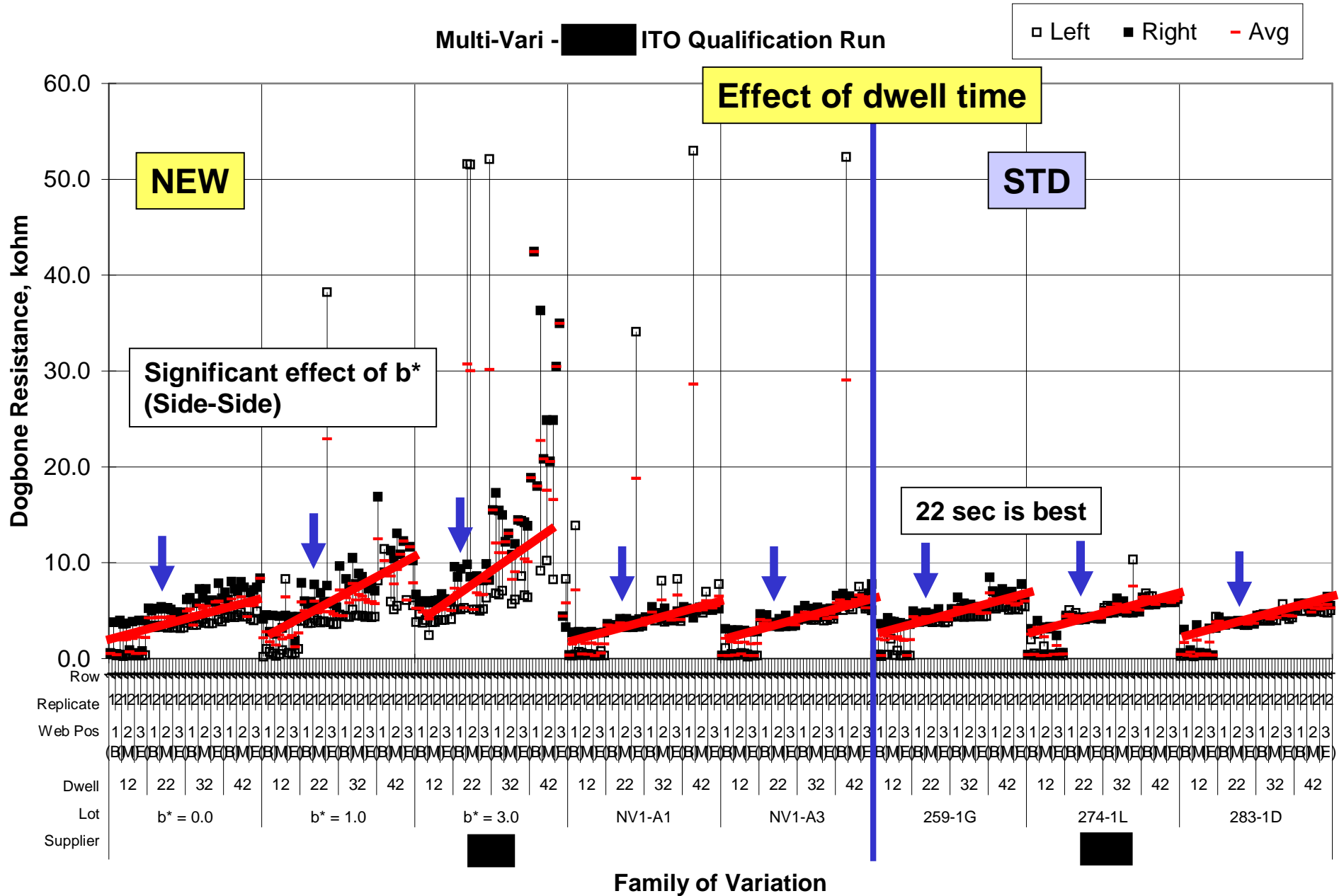
ITO Qualification Results

- ## Dogbone resistance
  - ### Dwell time of 22 seconds is the "best"
    - ITO is fully etched
    - No evidence of over-etched edges
    - Achieved easily in production
  - ### b* lots had more side-side variation
    - Made on NV2 -> is this significant?
      - 52" roll cut into two 24" rolls
  - ### Resistance of NV1 rolls is consistent and equivalent to the three STD rolls
- ## Look at panels etched at 22 seconds for more detail...

ITO Qualification Results

ITO Qualification Results

- Analysis and Results
  - Dogbone resistance
  - **Luminance at t=0**
  - Time to defects (reliability)
  - Luminance decay

ITO Qualification Results

Green Y = Luminance @ t = 0, fL

Variation Family	**Notes**

Orientation – Orientation Same Side — **Not measured**

Side – Side Same Row — **Medium contrast** (not ITO related).

Row – Row Same Panel — **Low contrast.**

Panel – Panel Same Web Location — **Not measured**
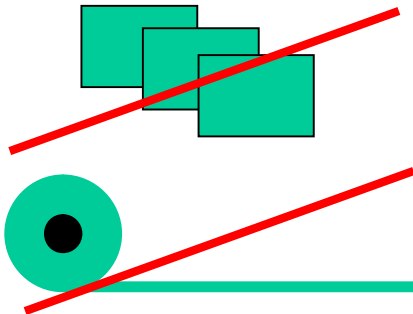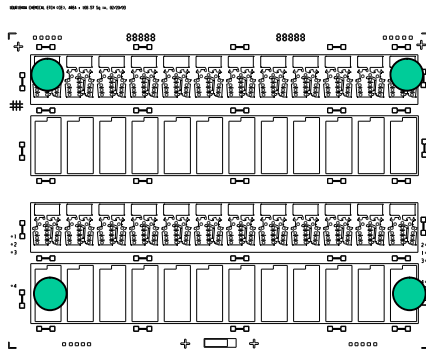
Web Loc – Web Loc Same ITO Type — **Not measured**

ITO Type – ITO type Same Dwell Time — **Low contrast.**

Dwell Time – Dwell Time — **Low contrast.**
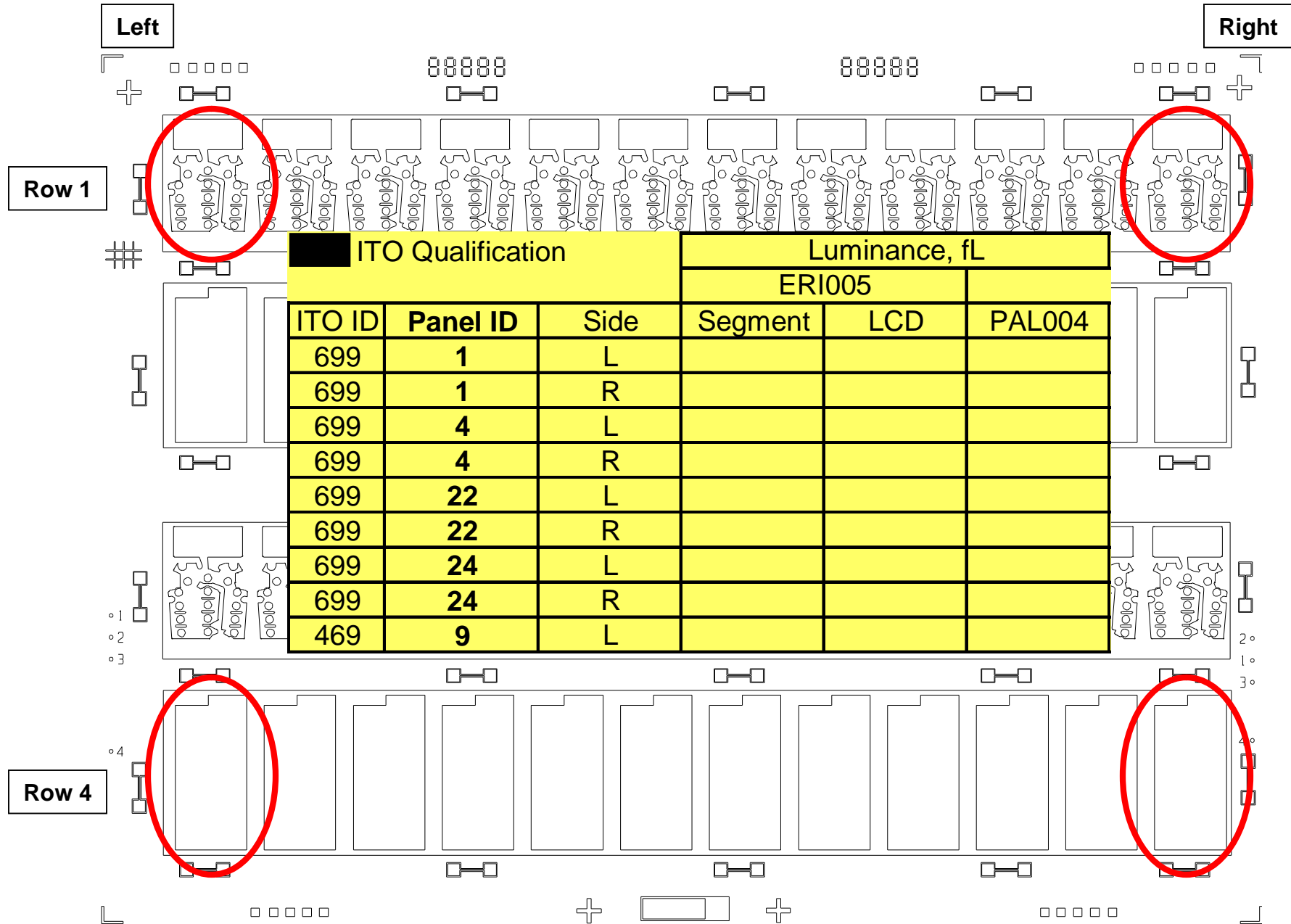
NEW   STD

12 s   22 s   32 s   42 s
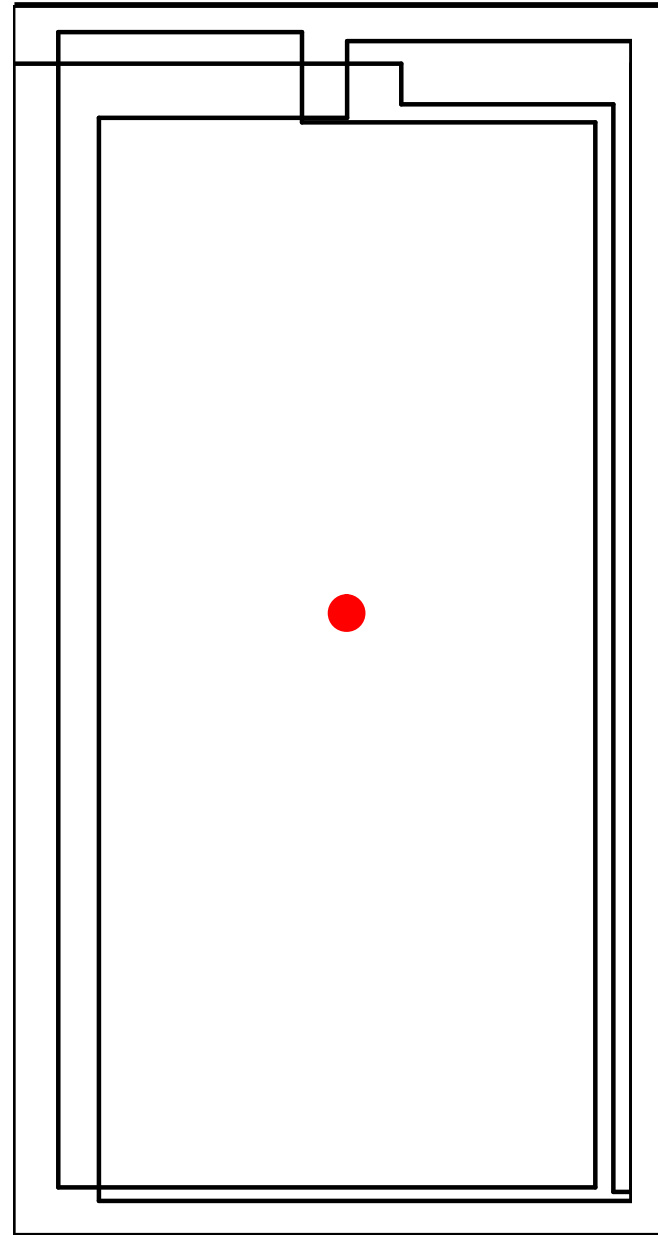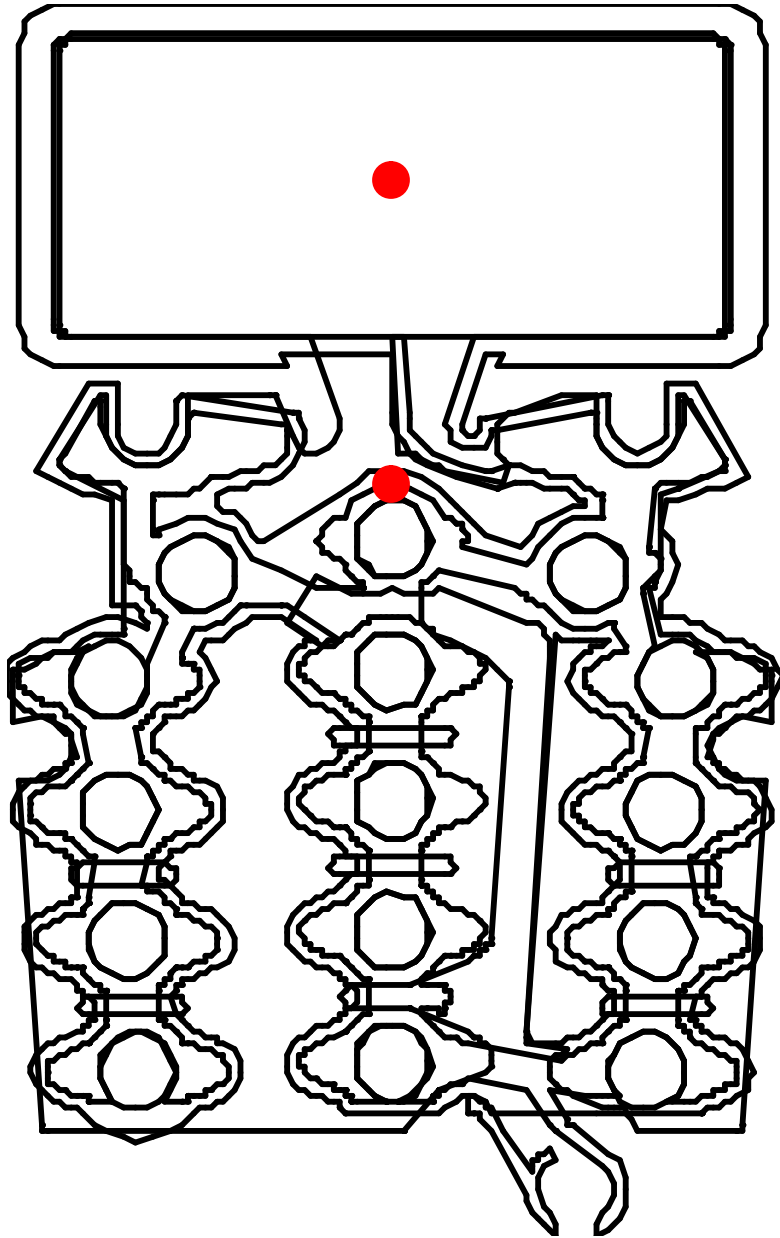
ITO Qualification Plan: Luminance Measurement Plan

IDURI84XA CHEMICAL ETCH (CE), AREA = 108.57 Sq in, 02/20/03

Left **Right**

Row 1

Row 4

ITO Qualification			Luminance, fL		
ITO ID	Panel ID	Side	ERI005		PAL004
			Segment	LCD	
699	1	L			
699	1	R			
699	4	L			
699	4	R			
699	22	L			
699	22	R			
699	24	L			
699	24	R			
469	9	L			

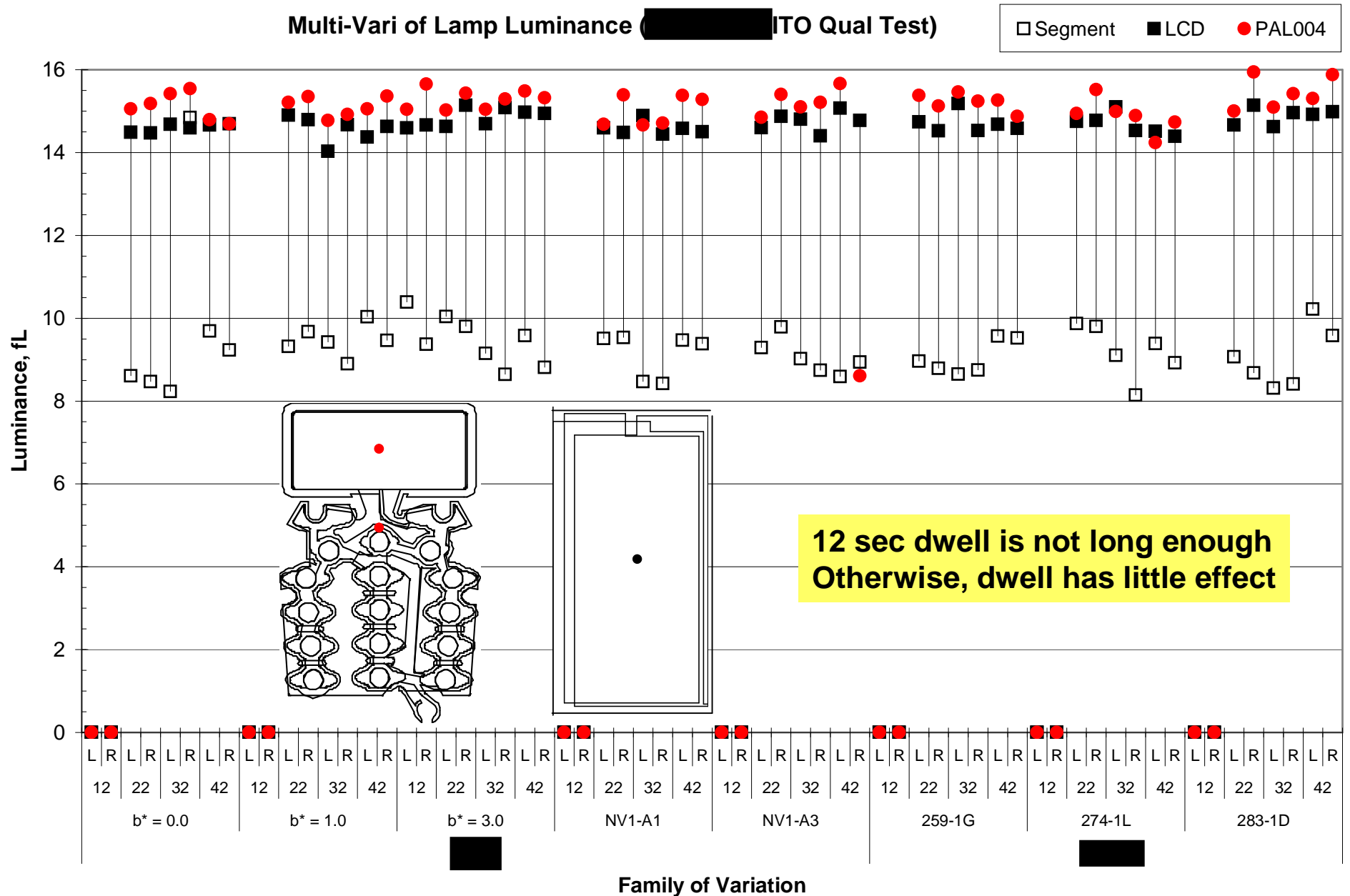5/29/2003

15

ITO Qualification Plan: Luminance Measurement Plan

ITO Qualification Results

Multi-Vari of Lamp Luminance (███████ ITO Qual Test)

12 sec dwell is not long enough
Otherwise, dwell has little effect

ITO Qualification Results

Multi-Vari of Lamp Luminance (███████ ITO Qual Test)

■—LCD

No significant patterns of variation

ITO type does not affect luminance

Luminance, fL

| 12 | 22 | 32 | 42 | 12 | 22 | 32 | 42 | 12 | 22 | 32 | 42 | 12 | 22 | 32 | 42 | 12 | 22 | 32 | 42 | 12 | 22 | 32 | 42 | 12 | 22 | 32 | 42 | 12 | 22 | 32 | 42 |

| b* = 0.0 | b* = 1.0 | b* = 3.0 | NV1-A1 | NV1-A3 | 259-1G | 274-1L | 283-1D |

Family of Variation

ITO Qualification Results

Multi-Vari of Lamp Luminance (██████████ ITO Qual Test)

No significant patterns of variation
ITO type does not affect luminance
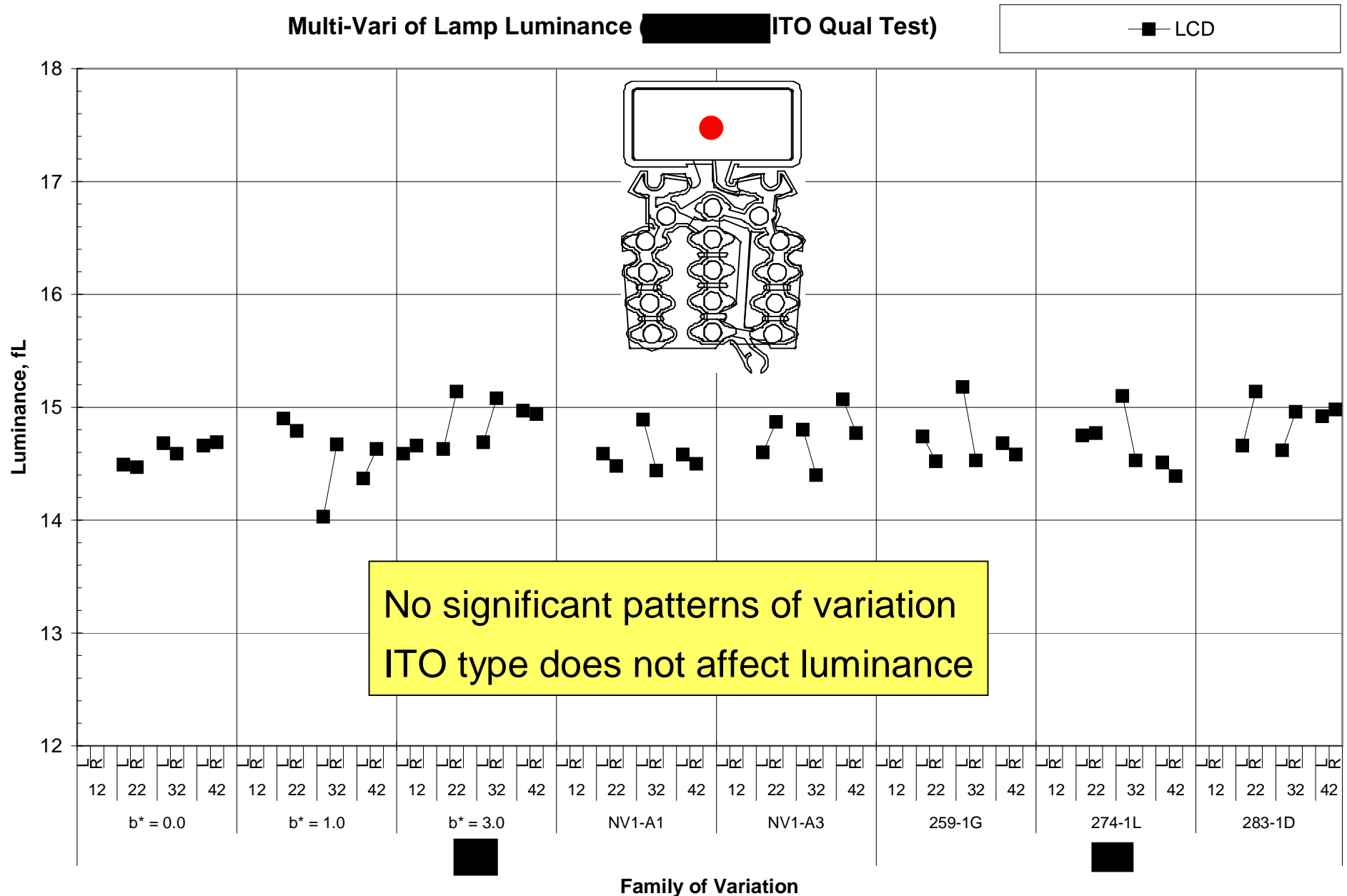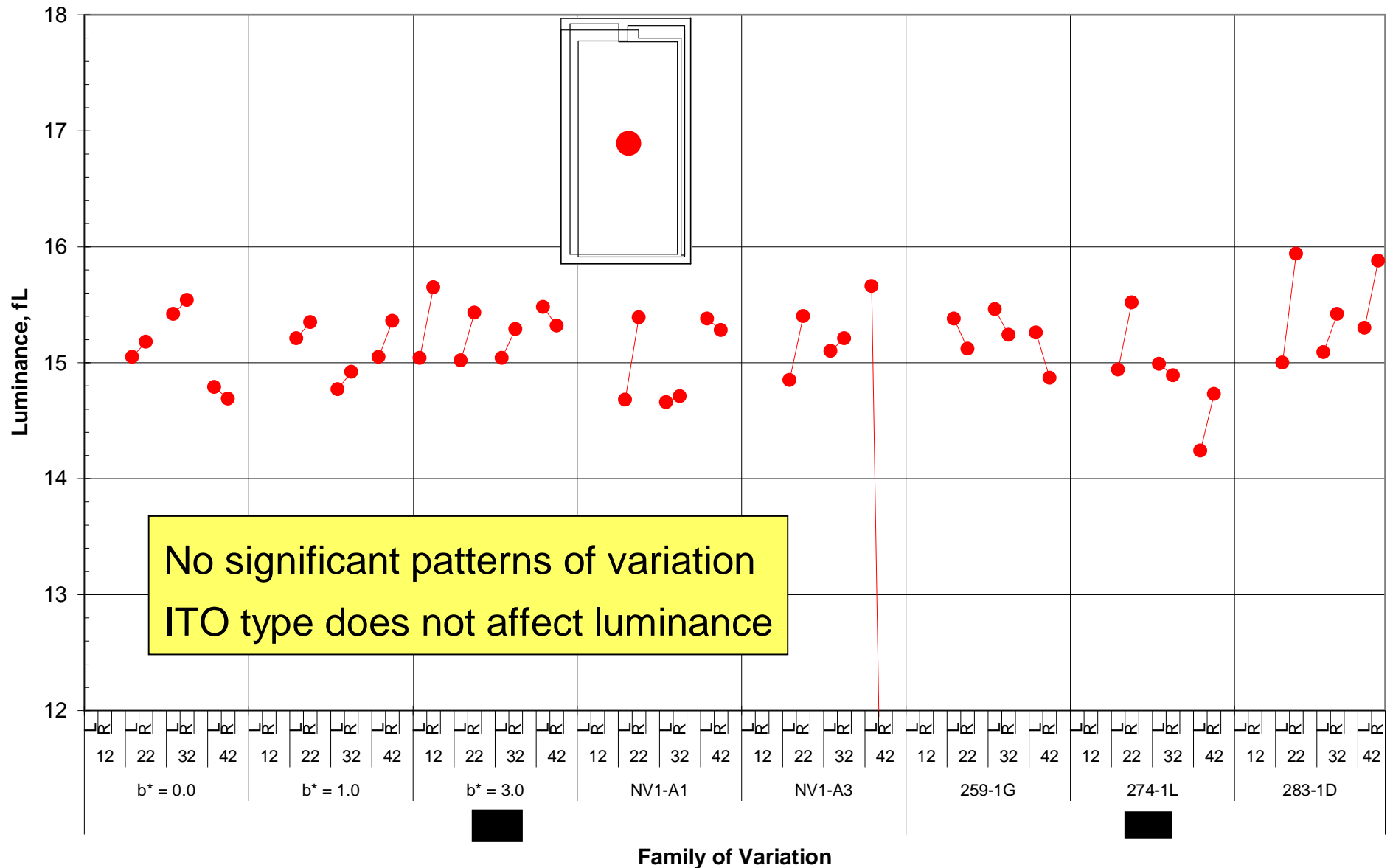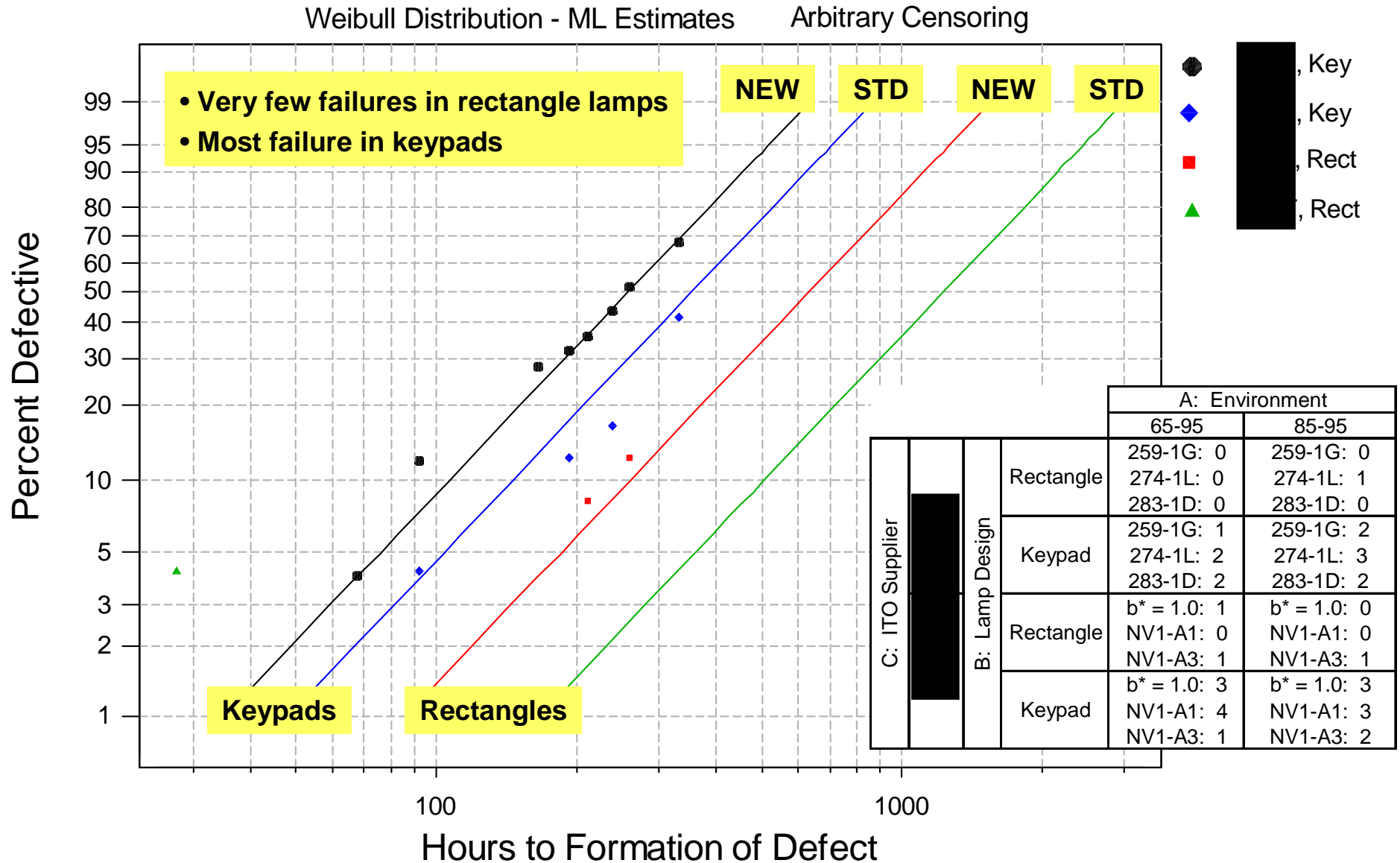
ITO Qualification Results

- Analysis and Results
  - Dogbone resistance
  - Luminance at t=0
  - **Time to defects (reliability)**
  - Luminance decay

ITO Qualification Results

- Sampling plan
  - Select lamps with 22 sec dwell only
  - NEW: b* 1.0, NV1-A1, NV1-A3 (b* 0 and b* 3 were **NOT** tested)
  - STD: all three lots
  - Random panel selection (web position and panel replicate)
  - Four lamps per panel (one per quadrant)
- Test conditions
  - 65 C / 95% RH
  - 85 C / 95% RH
  - 100% duty cycle, 80 V, 200 Hz
- Measurements
  - Luminance (decay)
  - Cosmetic defects (black spots)
    - Pictures with digital camera
    - Time it first occurred
- Measurement frequency
  - Luminance: per standard protocol
  - Cosmetics: once per 24 hour period
- Total test time
  - 65-95: 380 hours
  - 85-95: 330 hours

ITO Qualification Results
Probability Plot for Time to Defective

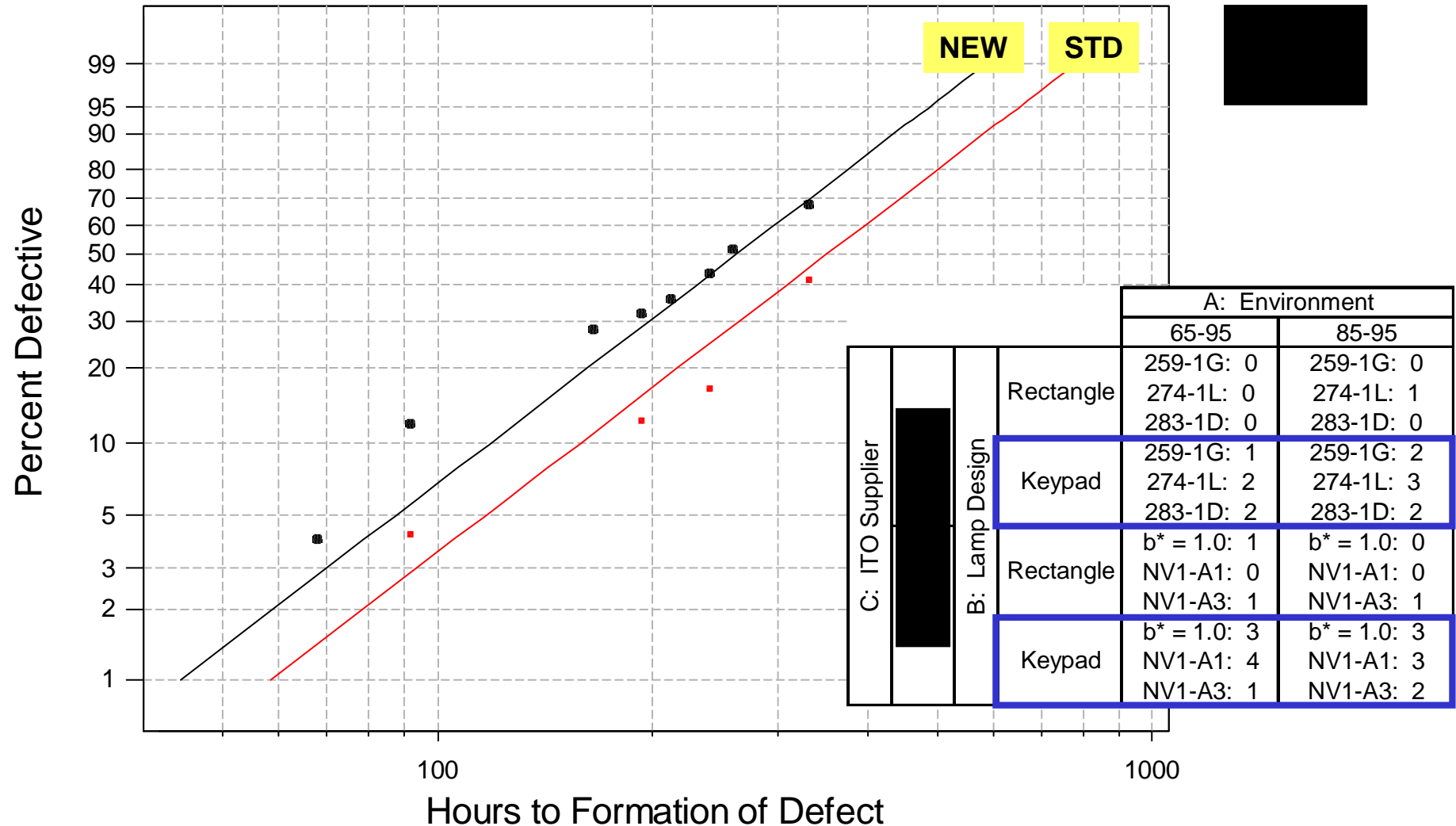Weibull Distribution - ML Estimates   Arbitrary Censoring

ITO Qualification Results
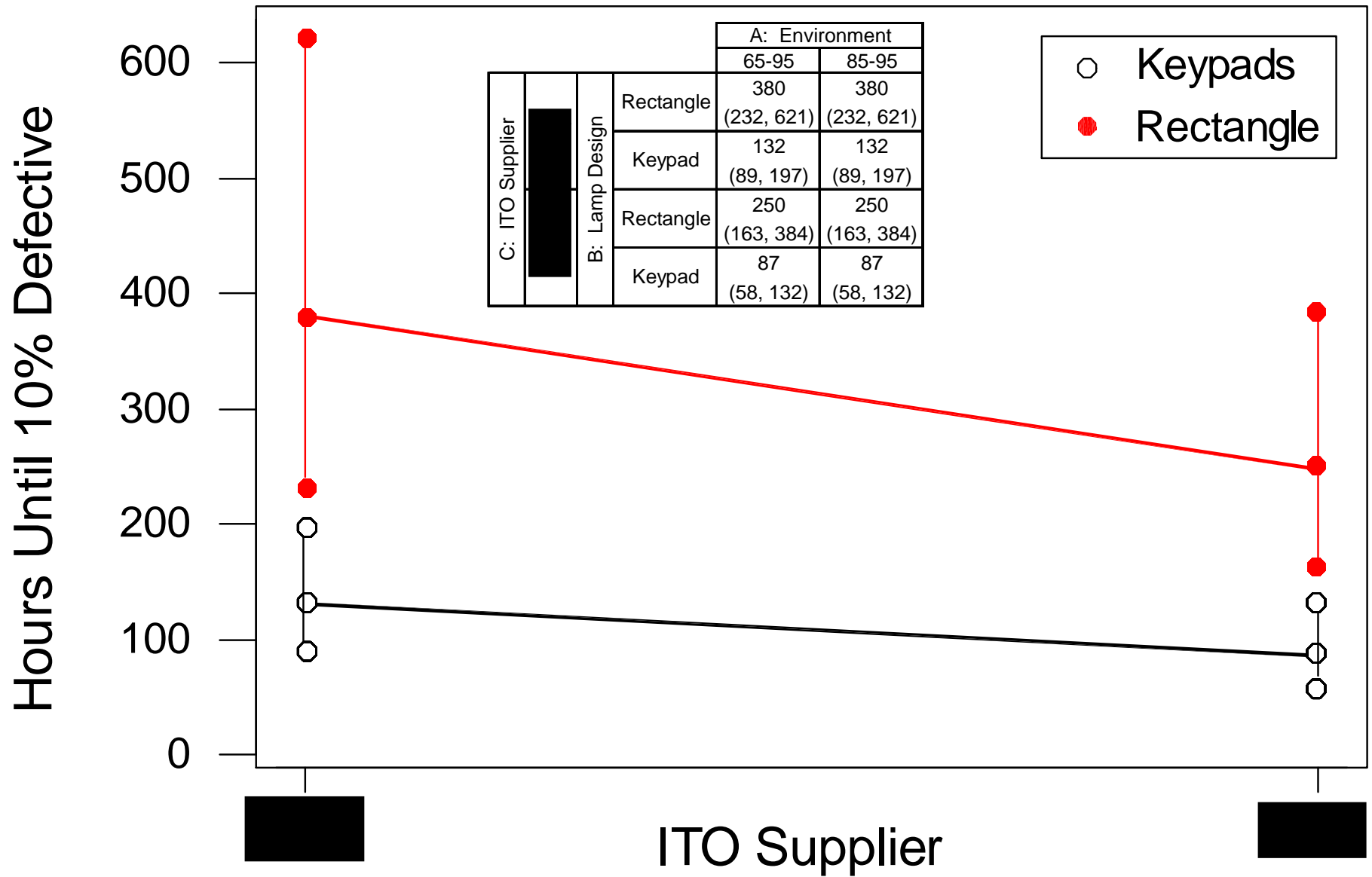
Probability Plot for Time to Defective

Weibull Distribution - ML Estimates   Arbitrary Censoring

*** Keypads ***

ITO Qualification Results

			A: Environment	
			65-95	85-95
		Rectangle	380 (232, 621)	380 (232, 621)
		Keypad	132 (89, 197)	132 (89, 197)
		Rectangle	250 (163, 384)	250 (163, 384)
		Keypad	87 (58, 132)	87 (58, 132)

C: ITO Supplier

B: Lamp Design

- ○ Keypads
- ● Rectangle

Hours Until 10% Defective

ITO Supplier

ITO Qualification Results

Survival Rate at 100 Hours

ITO Supplier

				A: Environment	
				65-95	85-95
C: ITO Supplier		B: Lamp Design	Rectangle	99.8% (0.985, 0.999)	99.8% (0.985, 0.999)
			Keypad	94.6% (0.865, 0.982)	94.6% (0.865, 0.982)
			Rectangle	99.0% (0.960, 0.998)	99.0% (0.960, 0.998)
			Keypad	87.0% 0.748, 0.943)	87.0% 0.748, 0.943)

○ Keypad
● Rectangle

ITO Qualification Results

				A: Environment	
				65-95	85-95
C: ITO Supplier		B: Lamp Design	Rectangle	96.5% (0.893, 0.991)	96.5% (0.893, 0.991)
			Keypad	72.4% (0.572, 0.843)	72.4% (0.572, 0.843)
			Rectangle	90.8% (0.798, 0.966)	90.8% (0.798, 0.966)
			Keypad	54.5% (0.392, 0.692)	54.5% (0.392, 0.692)

Survival Rate at 240 hours

ITO Supplier

○ Keypads
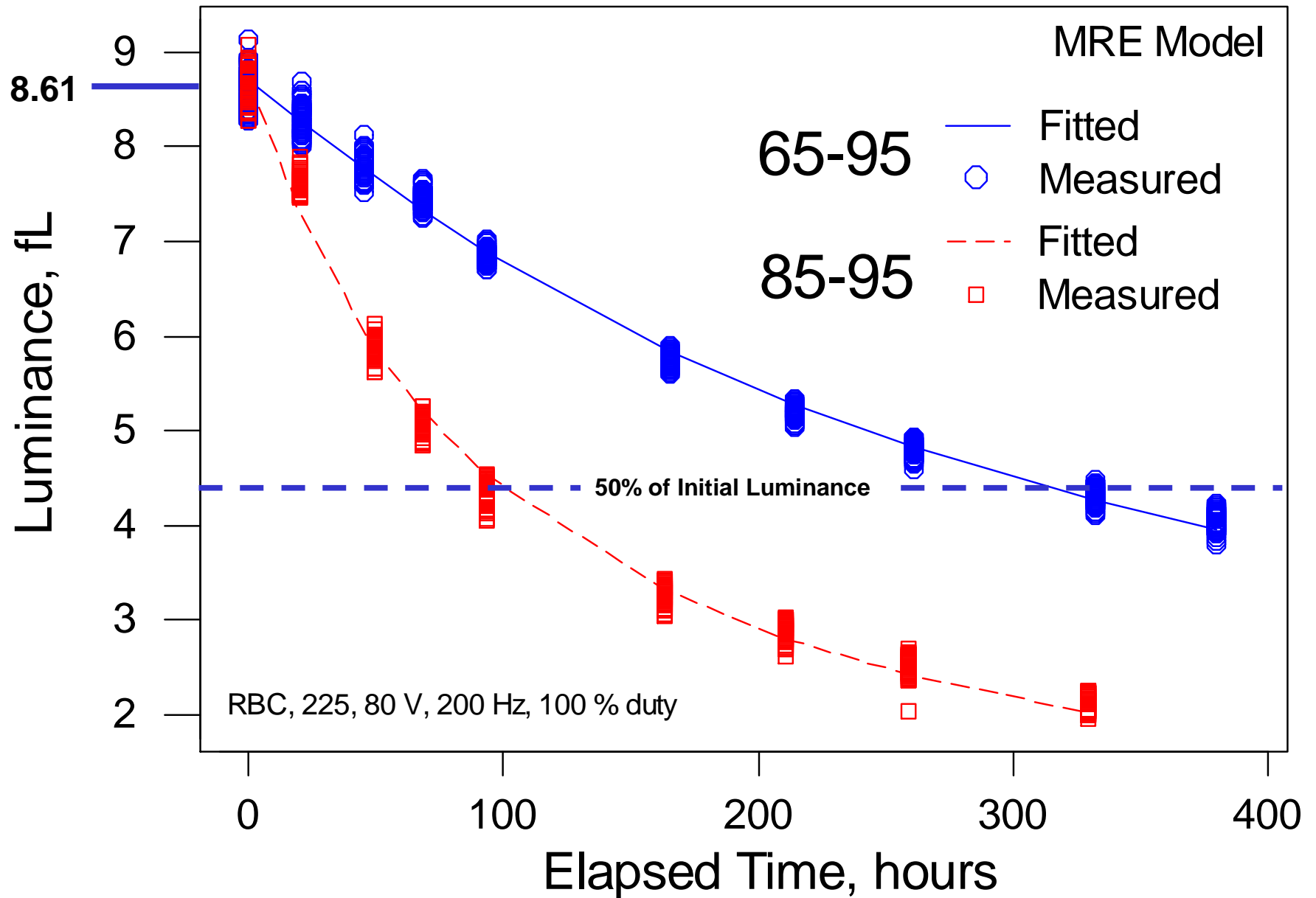● Rectangle

Examples of Defects
(Unlit Keypad Segments)
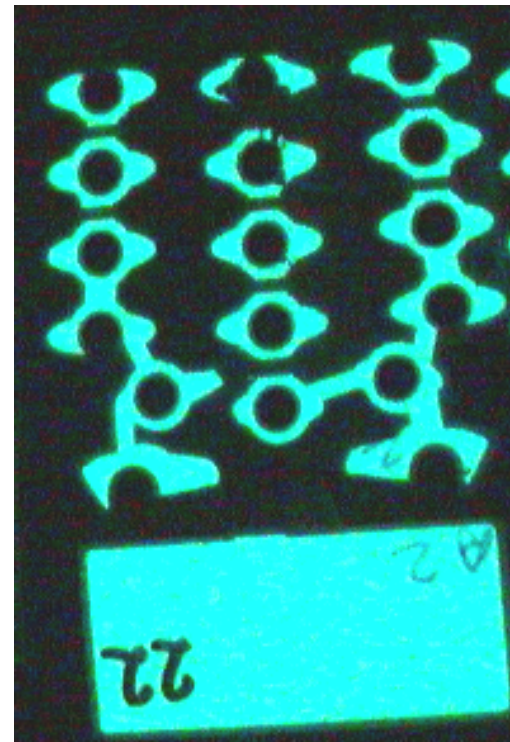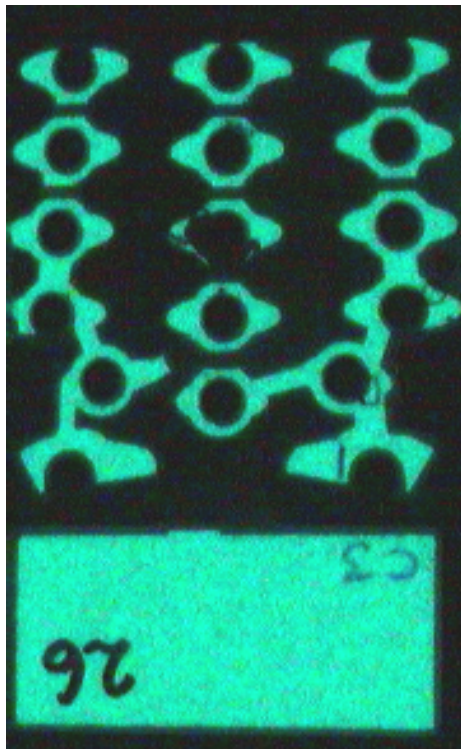
ITO Qualification Results

- Analysis and Results
  - Dogbone resistance
  - Luminance at t=0
  - Time to defects (reliability)
  - **Luminance decay**

ITO Qualification Results

ITO Qualification Results

$$Lum = \frac{L_0}{(1 + \beta \cdot t^{\gamma})}$$

$$Lum = \frac{(L_0 + \lambda_E E + \lambda_D D + \lambda_S S)}{\left[1 + (\beta_0 + \beta_E E + \beta_D D + \beta_S S) \cdot t^{\gamma_0 + \gamma_E E + \gamma_D D + \gamma_S S}\right]}$$

Coefficient Estimates								
Coeff	Est	Diff	Coeff	Est	Diff	Coeff	Est	Diff
λ_0	8.707		β_0	0.00198		γ_0	1.079	
λ_Env	0.0869	1.00%	β_Env	0.0073	**370.8%**	γ_Env	-0.066	**-6.1%**
λ_Des	-0.0816	-0.94%	β_Des	-0.0000295	-1.49%	γ_Des	0.001729	0.16%
λ_Sup	0.0093	0.11%	β_Sup	0.0000545	2.75%	γ_Sup	-0.00482	-0.45%

- **Only the environment affects luminance decay**
- **Design and supplier effects are not significant**

ITO Qualification Results

- Background and Motivation
- Qualification test
  - Green Ys
  - Test procedure
- Analysis and Results
- **Conclusions and Recommendations**

ITO Qualification Results

- **Etchability**
  - Variation in sheet resistivity in three b* lots
    - NV1 lots are quite consistent
    - NV2 lots had more side-side variation in dogbone resistance
  - Resistance of b* 3.0 lot is too high
    - Does not have a significant impact on luminance; not tested in environments
  - b* between 0 and 1 is good (maybe -0.5 to 2.0 is acceptable range)
- **Luminance**
  - No significant difference between suppliers (all lots tested)
- **Defects in environments**
  - Significant practical difference in time to defects due to **lamp design**
    - Keypad design performed worse than rectangle design
  - Statistical difference due to **supplier**
    - ITO has lower time to formation of defects
    - **Practical difference is difficult to determine** (e.g. how does environmental performance translate to field performance?)
    - How would b* 0 perform?
- **Recommendations**
  - Conditional approval of NEW material
    - Non-automotive applications until additional testing is performed
  - Specification for b* needs to be finalized and control plan implemented