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Semprius' Approach to Flash Testing

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Semprius Design Advantages

World's Highest Efficiency

- 35.6% efficiency
- Near-term path to 42%

High Efficiency, Low-Cost Microcells

- 600 x 600 microns
- >41% triple junction cells
- Substrate reuse cuts cost in half

Lightweight
(7.3kg)

Thin
(68 mm)

Zero Cost Thermal Management

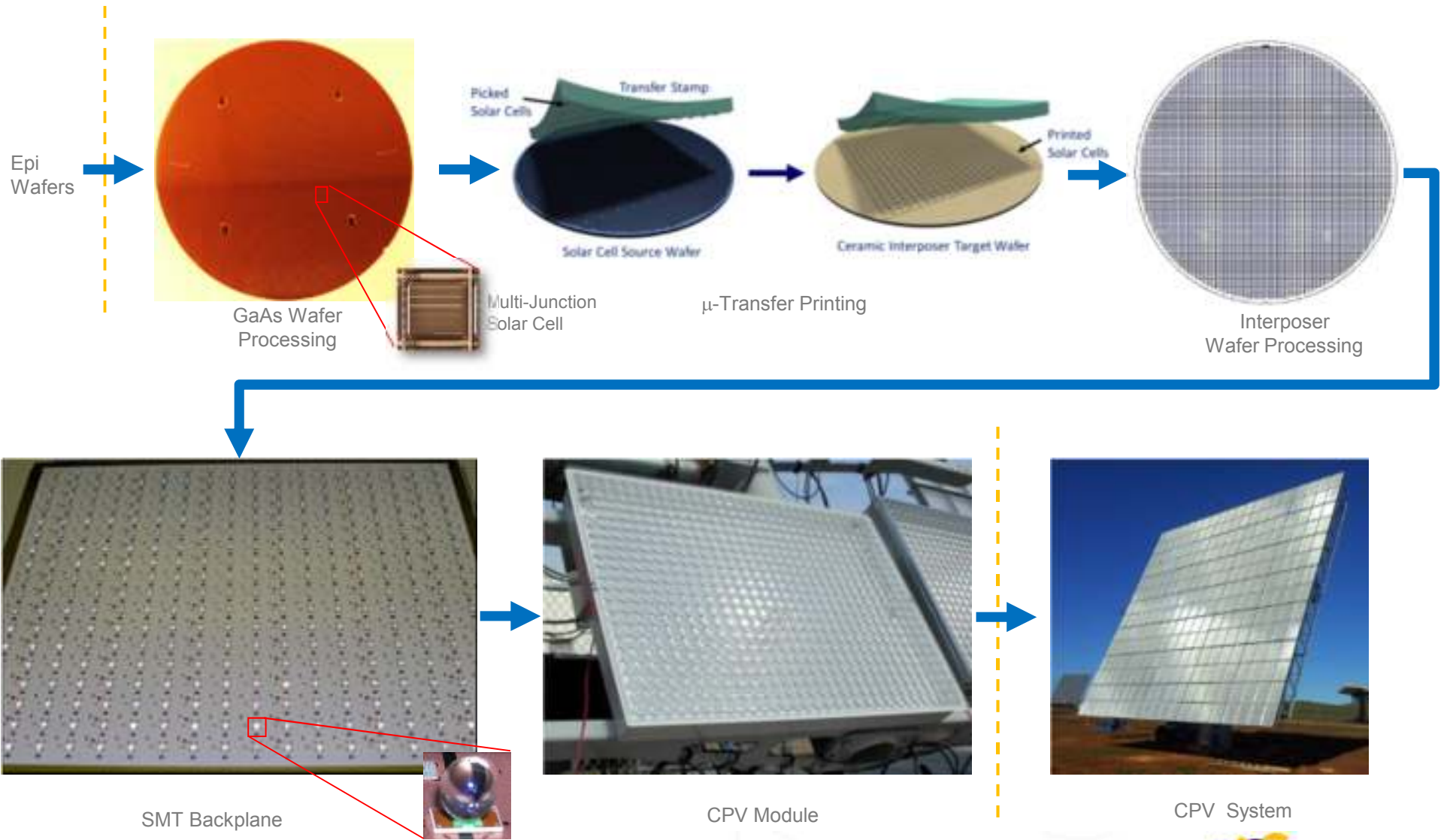
High-Performance, Low-Cost Optics

- 1,100 → 1600X concentration
- Wide angle of acceptance
- Uniform energy flux on cell

Standard Manufacturing Processes

High Efficiency – Low Cost – High Reliability

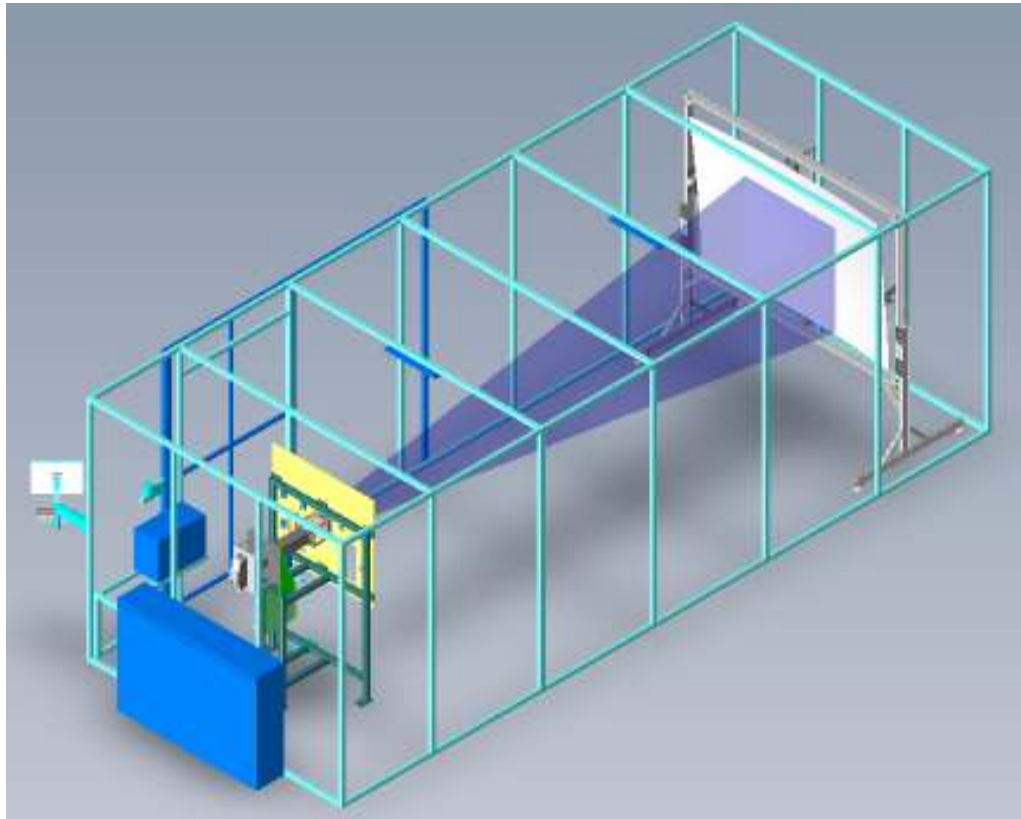
Overview of Semprius CPV Approach



100% Quality Control Testing

- Solar cells
 - Printed solar cell within 10um of nominal position
 - NIR inspection for voids in cell attach
 - Automated visual inspection for defects
- Solar cell on interposer
 - Dark & Light IV
 - Electroluminescence image inspection for defects
 - Thermal transient testing to evaluate die attach
- Backplane
 - Dark-IV testing (shunt & series resistance)
 - Reverse bias for by-pass diode check
- Module
 - Electroluminescence image inspection for defects
 - Leak test of seal integrity (pressure decay)
 - Hipot (3600V for 1sec) & wet hipot on sampling basis
 - **Flash test**

Semprius Flash Test System



- ABB rating (ASTM E927-05) for spectral match, spatial uniformity, and temporal stability
- Xenon flash bulb capable of nearly 1000 W/m² in test plane (Si detector)
- Collimation better than 0.4 degrees
- Custom spectral filter to match AM1.5D spectrum
- 3 isotype cells, silicon reference cell, and triple-junction mini-module

Flash



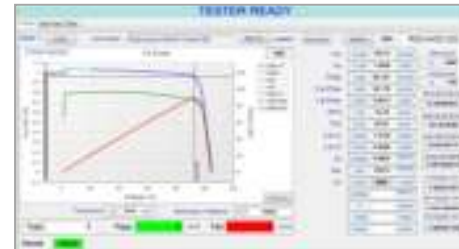
Reflect



Illuminate



Measure

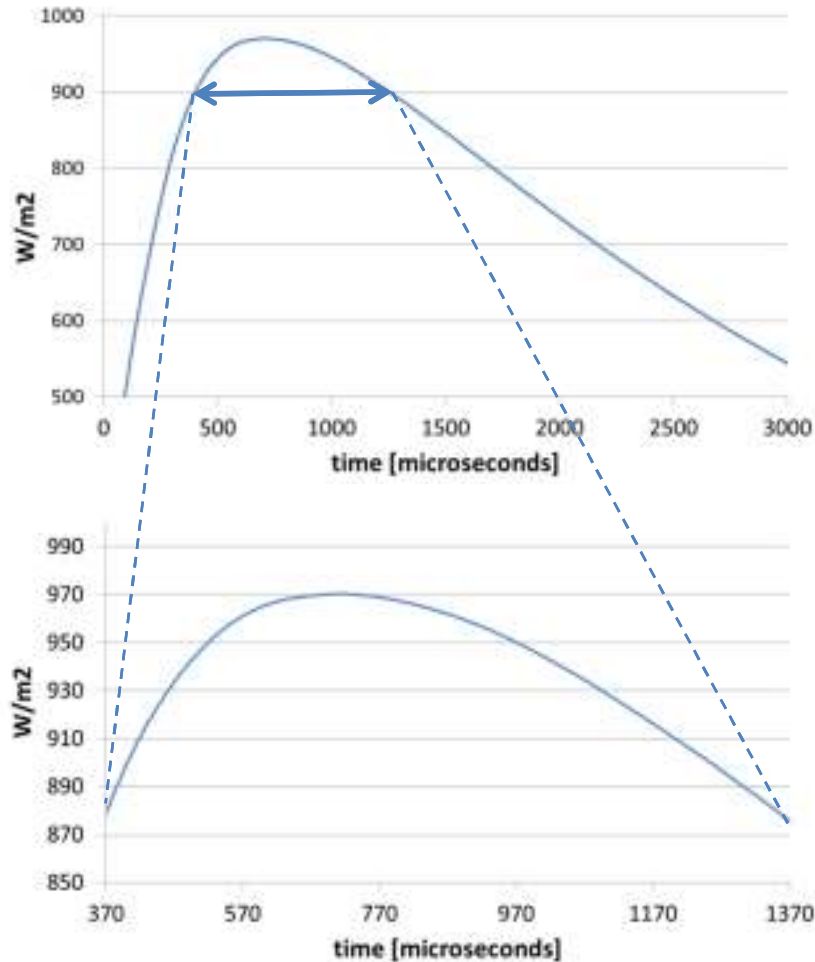


Label

SEMPRIUS Reference Test Module		Serial Number: 100-1000-000	
Part Number: SM-100-001-1001			
Rated Power (at 100%)	88.3 W	Open Circuit Voltage	166.6 V
Voltage at Rated Power	82.8 V	Short Circuit Current	1.04 A
Current at Rated Power	0.98 A	Fuse Rating	2 A
Maximum System Voltage	1200 V	Application Class	Class B
Note: at +/- 0.5% at 10°C at 1000W/m ² SM-100-001-1001 will temperature			
WARNING - Electrical Hazard! This solar module generates high voltages and current in sunlight. Read and observe all instructions before attempting installation or service. Do not disconnect under load!			

Temporal Stability

Flash Pulse Duration

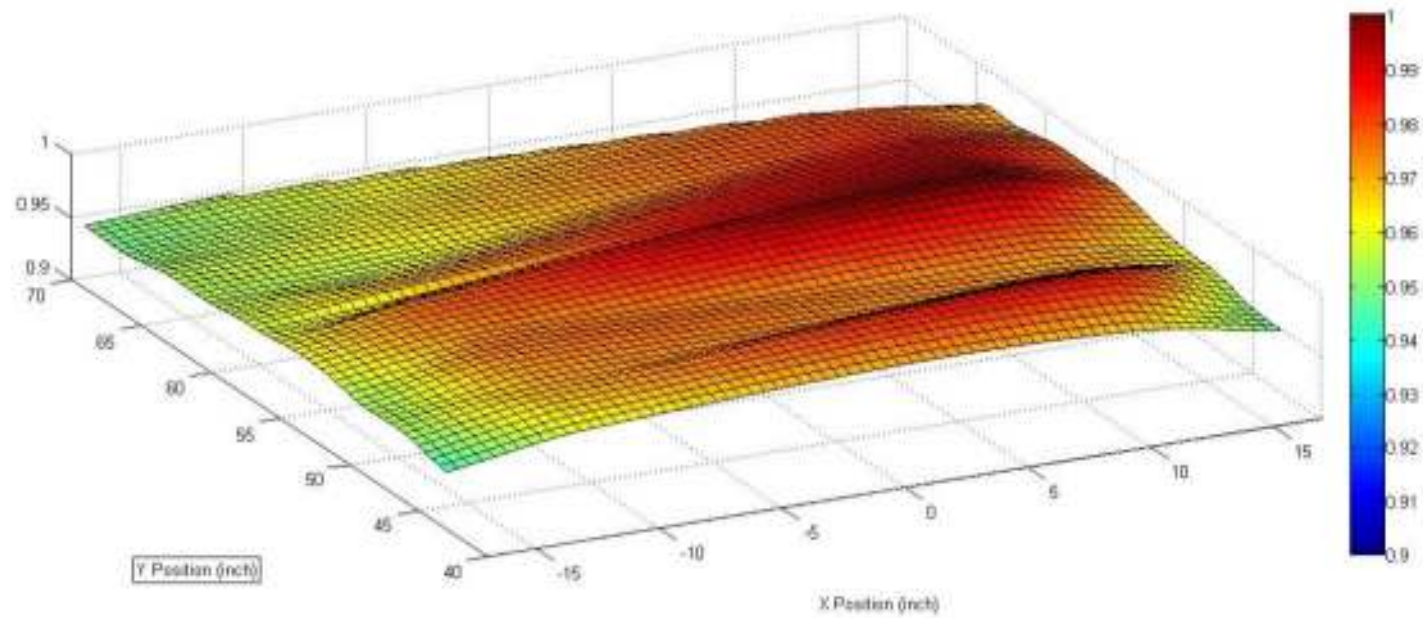


- Flash duration of several milliseconds
- 200-point LIV curve acquired in 1.0 msec
- Temporal stability of $< \pm 5\%$ (Class B)



Spatial Uniformity

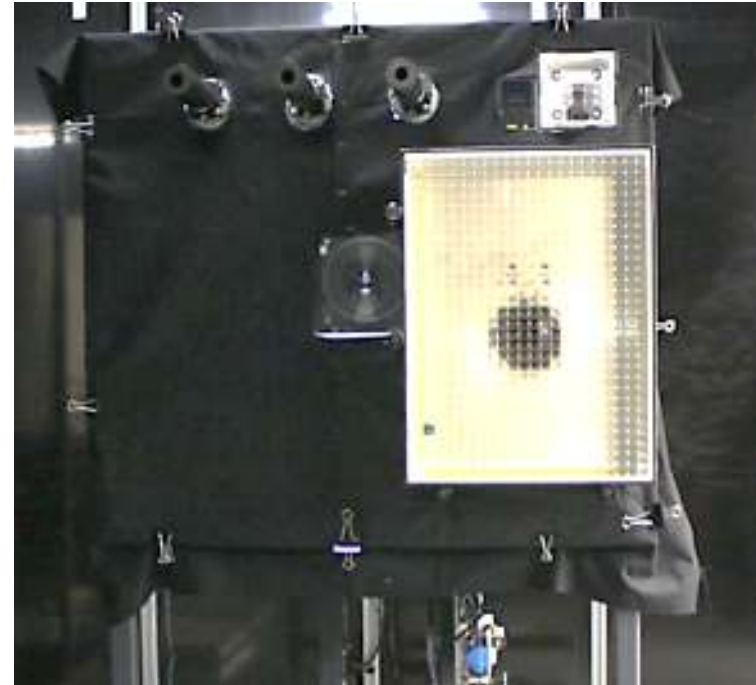
- 40 measurements with Si detector over 1m² area
- 2.8% non-uniformity, defined as $(\max - \min)/(\max + \min)/2$
- Class A uniformity defined as <2% non-uniformity (ASTM E927-05)



Spectral Match

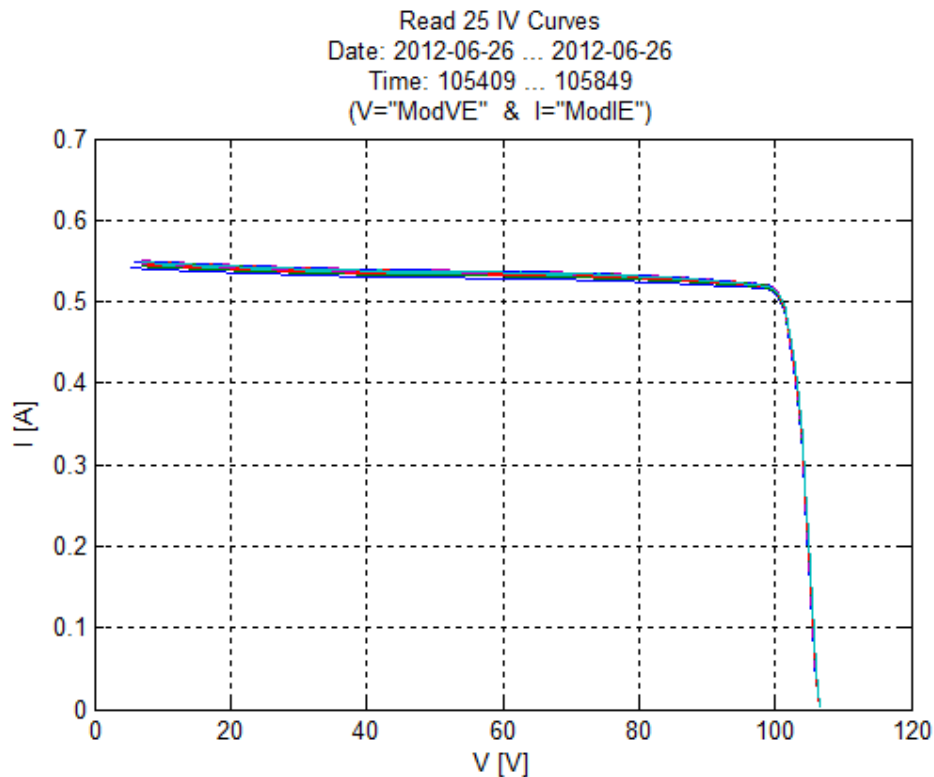
- Custom filter designed so spectral matching ratios (SMR) for triple-junction cell emulate AM1.5D spectrum
- 3 isotype cells (grown by epi supplier and calibrated at NREL) allow SMR measurements during flash
- Minimodule measured during flash to correct for spectral response by normalizing measured module current

{3 isotypes} mini-module



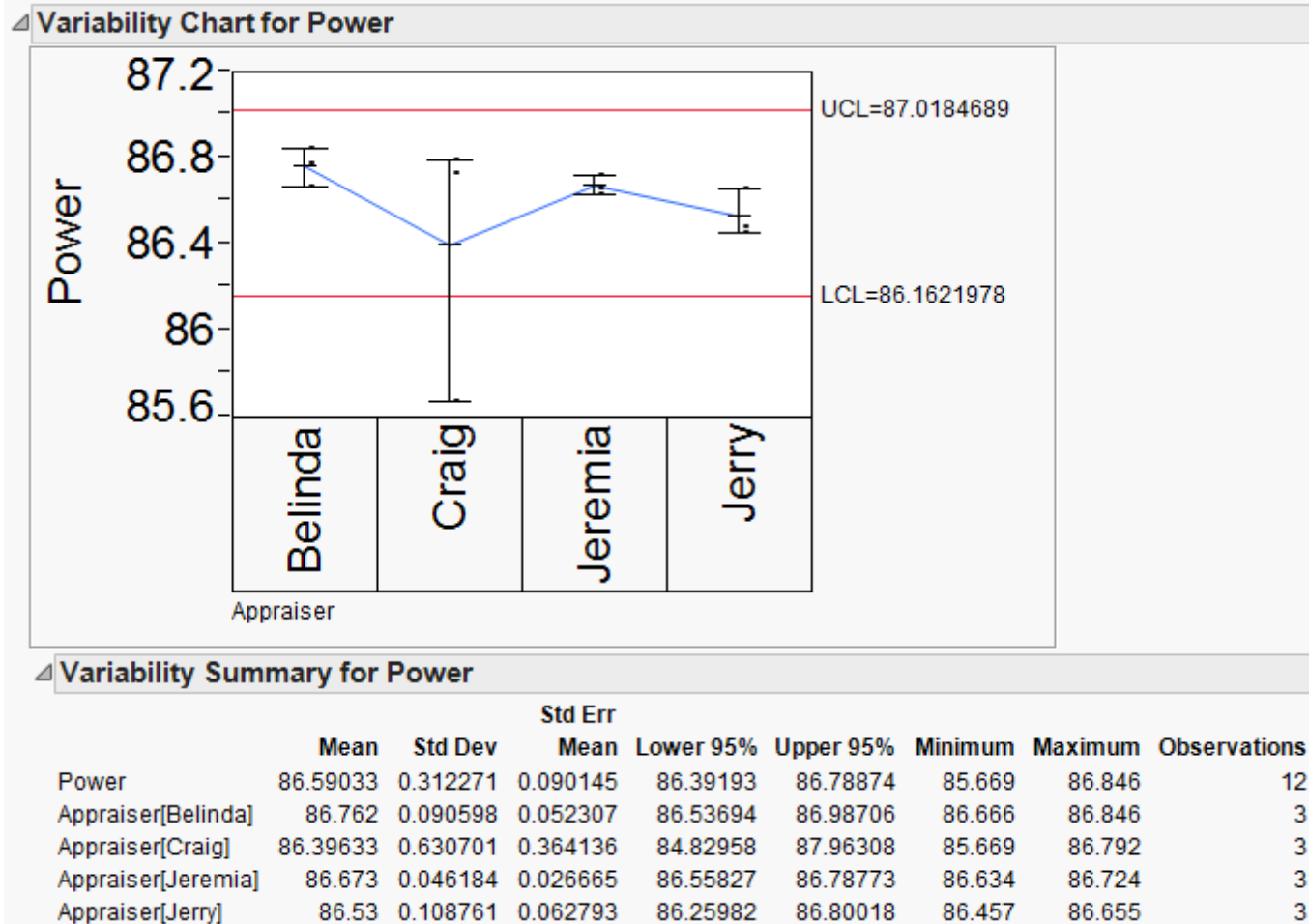
Flash Repeatability (without removing module)

- 10-sec interval between flashes
- Repeated 25X in a row
- Demonstrates recovery time of flash bulb system
- Demonstrates repeatability of data acquisition during 1ms window of flash



Metric	STDEV (%)
Voc	0.04%
Isc	0.39%
Vmp	0.05%
Imp	0.21%
Pmax	0.22%
Fill Factor	0.22%

Variability of Flash Power by Appraiser (with removing module)



Flash test repeatability better than $\pm 0.5W$ ($\sim 0.5\%$)

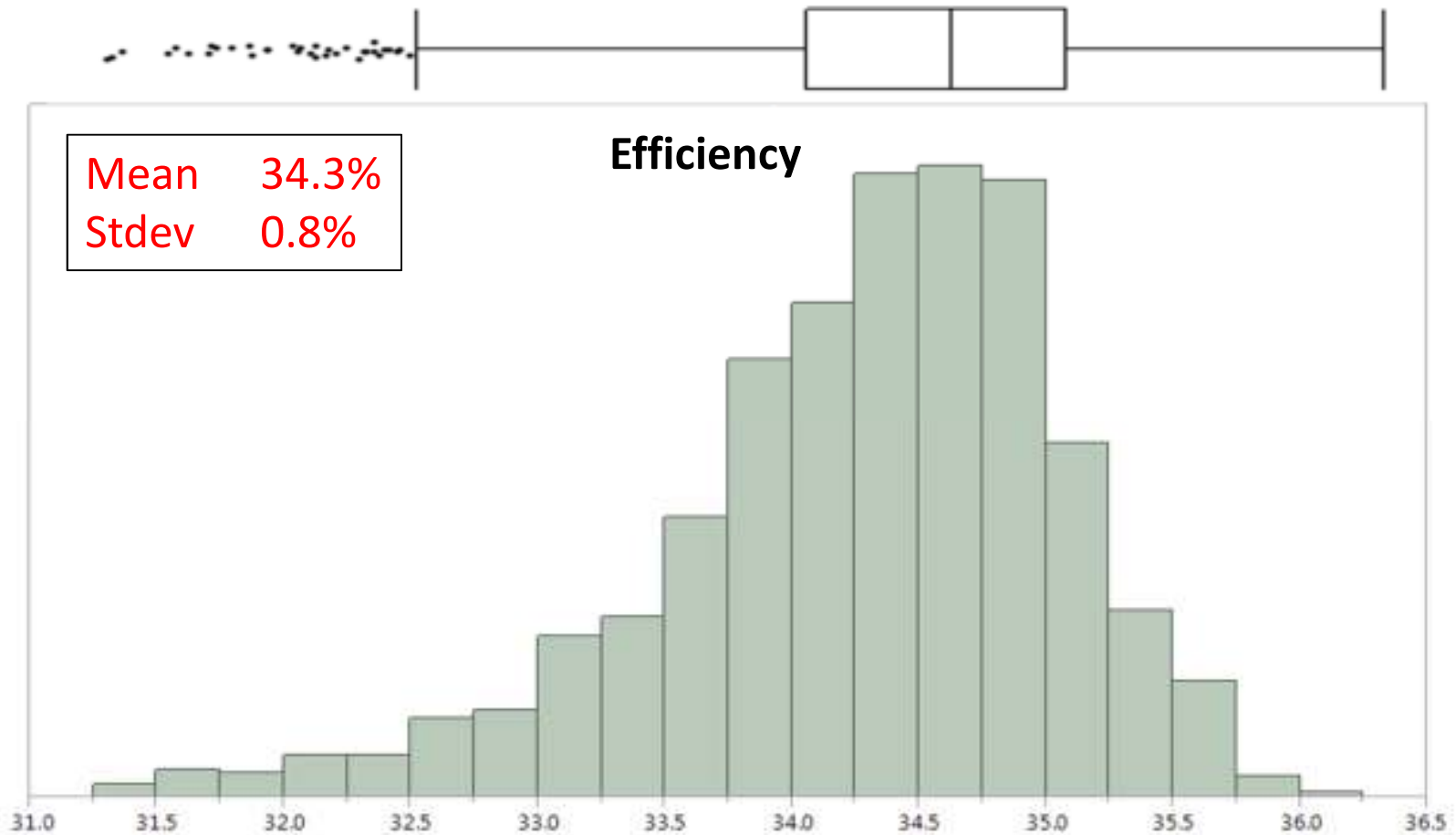
Reference Module Over Time (SPC of Tool)



Beside Pmax, also monitor flash intensity, Voc, Isc, SMR ratio on daily basis

Flash Test Results

- 1000 modules produced in Jan & Feb 2015

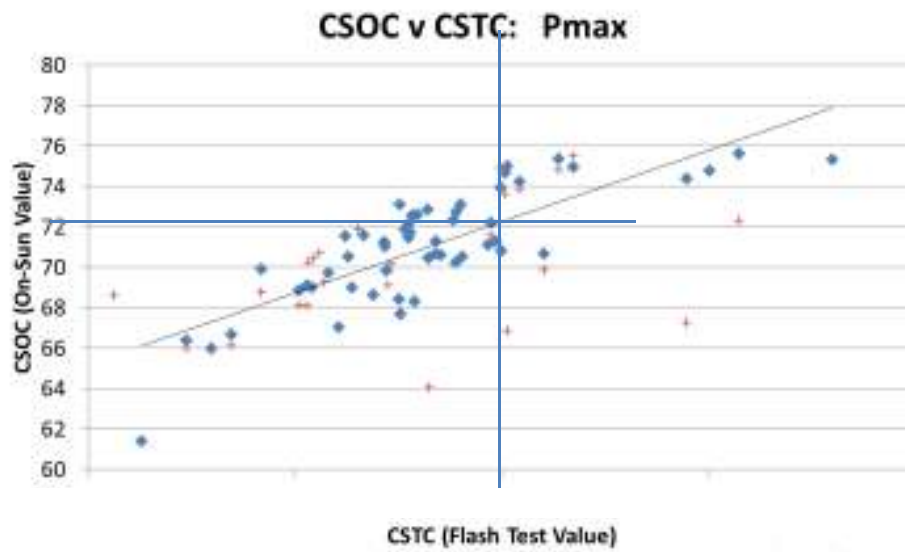


CSTC to CSOC correlation

- Concentrator standard test & standard operating conditions

Condition	Irradiance (W/m ²)	Temperature (C)	Spectrum	Wind Speed (m/s)
CSTC	1000	25C cell	AM1.5D	0
CSOC	900	20C ambient	AM1.5D	2.0

- Reference modules measured at Fraunhofer & UPM (Spain) to correlate on-sun performance to flash test results
- At Semprius, 75 modules flash tested then placed on-sun to compare performance



<5% uncertainty in CSTC to CSOC correlation at 2-sigma level

Additional Flash Test Projects

- Zero voltage ramp testing
 - Monitor module current vs isotype cell currents during entire flash duration (during which spectrum shifts) to determine which subcell limiting
 - Enables characterization of Air-Mass dependence of module response
- Module angle-of-acceptance testing
 - Tip-tilt stage allow full AOA map in 15 minutes
 - Further development will allow full AOA map in single shot
- Flash test performance vs temperature
 - Heating/cooling to simulate on-sun performance vs temperature
 - Check for impact of pitch variation, focal length, etc.
- Future considerations
 - Automation: horizontal module orientation to allow conveyORIZED flash testing
 - More powerful light source and larger mirror for larger modules
 - 4J & 5J solar cells
 - More sensitive to spectral matching to AM1.5D
 - Custom light source & filter required but can't sacrifice light intensity

Thank You!