

**The**

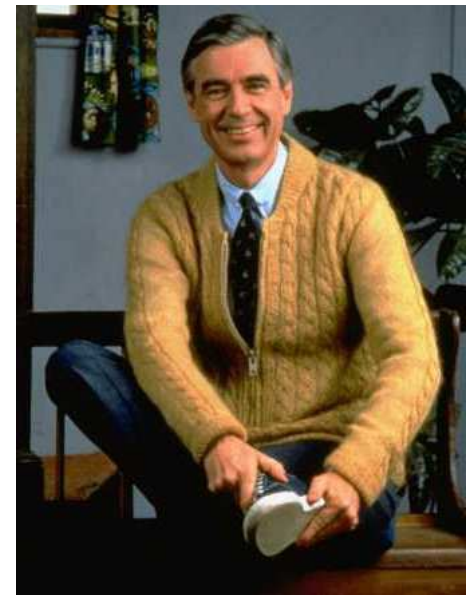


**Of UV Measurement &  
Process Control**



Instrument Markets  
Jim Raymont  
Sterling, VA

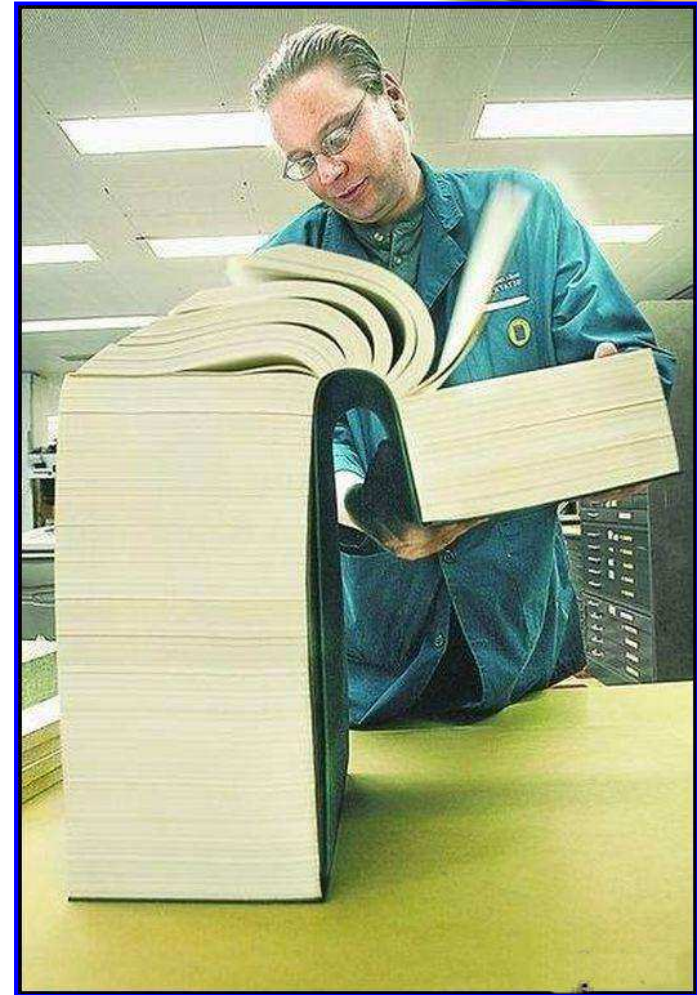
# The “Real” ABC Experts Were Not Available



# The ~~CBAV's~~ of UV Measurement & ABC's Process Control

## Webinar Agenda

- Review 'key' UV measurement & process control concepts
  - All inclusive? No
  - Good start? Yes-these are a few on my favorite terms
  - Reviewed by "letter" with some poetic license
- Resources
  - Copy of this presentation available
  - RadTech UV Measurement Glossary ([www.radtech.org](http://www.radtech.org))





# ABC's of UV Measurement & Process Control

- Wide variety of commercial instruments available for different sources and applications
- What are your needs?
  - Define a process?
  - Maintain process?
  - R&D?
  - Data Retention?
- Where will you measure?
  - Production environment or lab environment
- Who will use it?
  - Ease of use and features needed
- What is source type, size, expected dynamic range, spectral output?
- What values do you need?
  - Absolute: Joules, Watts, Irradiance Profile, Spectral Profile
  - Relative: Change over time, continuous monitoring



Let the fun begin.....



## Absolute Readings

- Units:  $\text{mJ}/\text{cm}^2$  and  $\text{mW}/\text{cm}^2$
- Want a “number”
  - Match a specification
  - Troubleshoot
  - Optimize a process
  - Compare multiple lines
  - Communicate data

	J/CM2	W/CM2
UVA	2.908	2.259
UVB	0.696	0.506
UVC	0.075	0.057
UVV	1.275	0.969
		RUN

## Arc Lamps



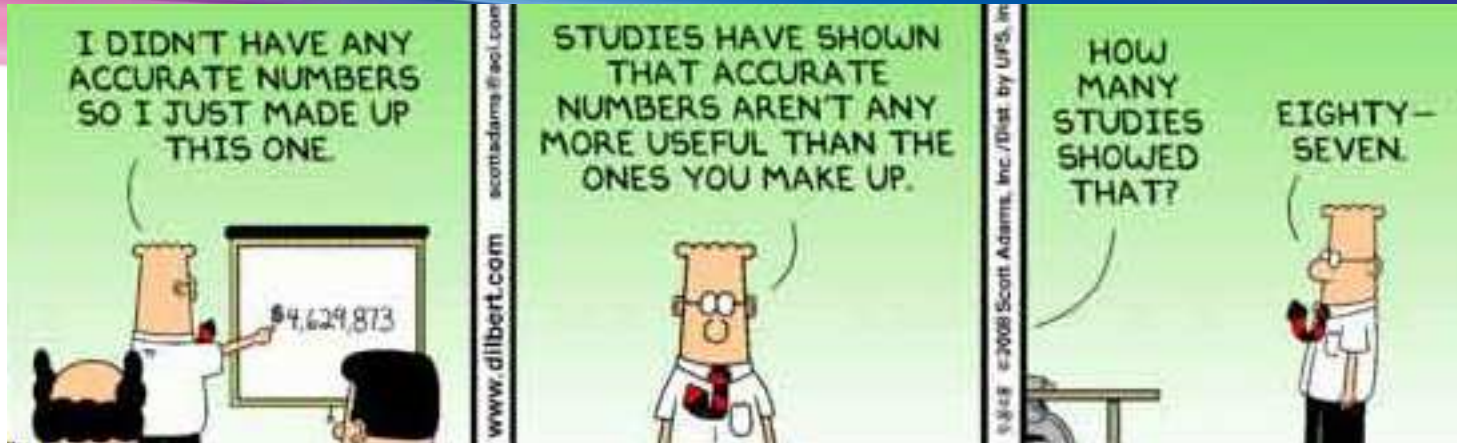
## Additive Lamps

- Spectral output matched to formulation
- AKA: Doped, Halide or Special Fill
- Alphabet Soup
  - Mercury (H)
  - Mercury-Iron (D)
  - Mercury-Gallium (V)



## Application

- Ability to measure?
- Strategy?



## Accuracy

- The degree of closeness to that quantity's actual (true) value
- Precision: The ability of a measurement to be consistently reproduced.



*accurate  
and precise*



*precise, but  
not accurate*



*not accurate  
not precise*

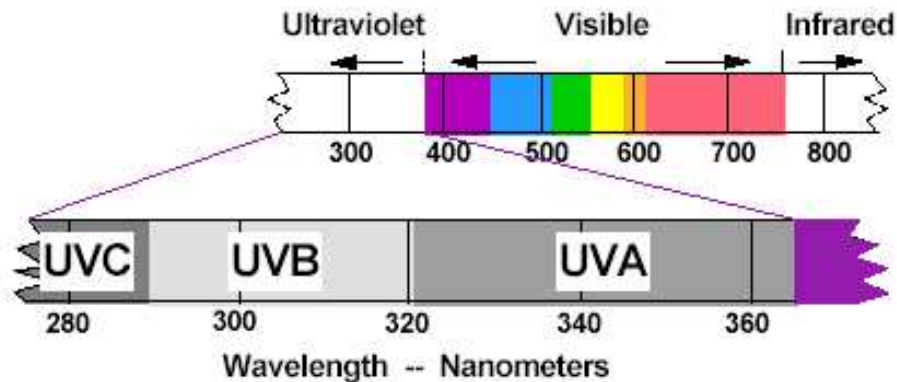
- Users expect the same accuracy as other instruments
- Current UV radiometer technology +/- 7-10%
- Improve under controlled conditions to  $\pm 2-3\%$





## Bands (UV Spectrum)

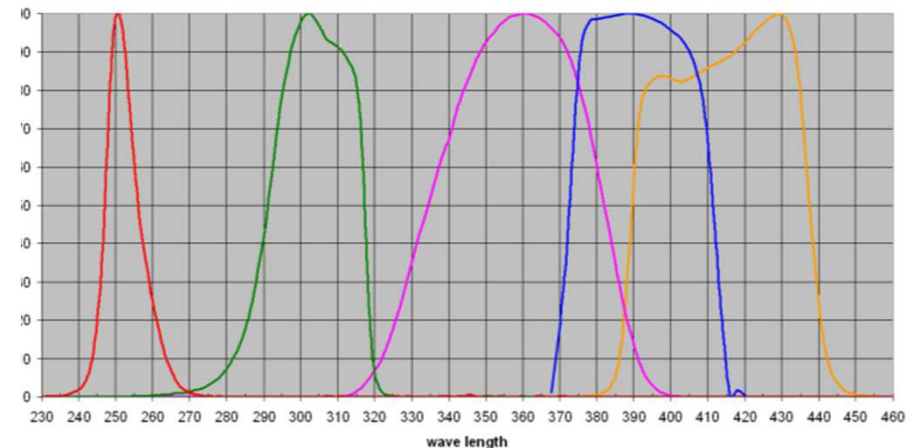
### ULTRAVIOLET SPECTRUM



- **UVA:** 320-390nm “Black light”, UV Inks, adhesion
- **UVB:** 280-320nm “Toughness”, skin response
- **UVC:** 200-280nm, germicidal (254 nm), surface cure, tack, chemical or scratch resistance
- **UVV:** 395-445nm, opaque/white, thick coats, adhesion, depth of cure

## Bands/Band Pass Filters (Instrument Response)

UVA, UVA2, UVB, UVC, UVV Transmission scan



- Match instrument to needs for your application
- Narrow vs. broad band instruments
- Advantages of looking at both short (UVC) and long (UVA, UVV)
- UVA2 Band for 395 nm LEDs



## Calibration & Service

- Instruments used in harsh production & manufacturing environments
- Compensate for changes
  - Electronics & Optics checked
  - Physical damage: Dropped, over temperature, external optics coated or damaged, unit went for a swim in coating )
- Frequency of calibration?

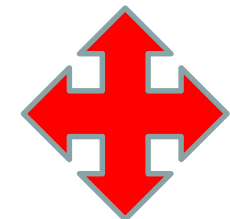


## Cosine Response

- Ability of instrument to measure UV at low incidence angles
- Replicate how coatings behave
- TBD-New sources (LEDs) behave the same or differently?

## Communication

- If you are not talking you may not be not curing
  - Formulator (Ink, Coating, Adhesive)
  - Application Equipment
  - UV Source Supplier
  - Substrate Supplier
  - UV Measurement Supplier







## Caution! I've Got Numbers

*But I get readings with my radiometer.....*

**Radiometer readings need to be qualified  
and understood!**

**RTM  
Read  
The  
Manual**

**Warning!**

**The use of a radiometer also  
requires the use of your brain**





## Dynamic Range (Instrument)

- Match Instrument to Source & Application
  - 10's of mW to 20,000+ mW/cm<sup>2</sup>
- Weigh a Baby on Truck Scale? But I Get Readings?
  - Barely trip instrument 'on' or using it in the suggested operating range
  - Low side of range-variation
  - Very, very, very stable readings: Did I max out unit?

## Dose (See Energy Density)

## Data Organization

- Do not rely only on formulator "radiometer"
  - Clipboard?
  - Electronic?
  - Procedures?

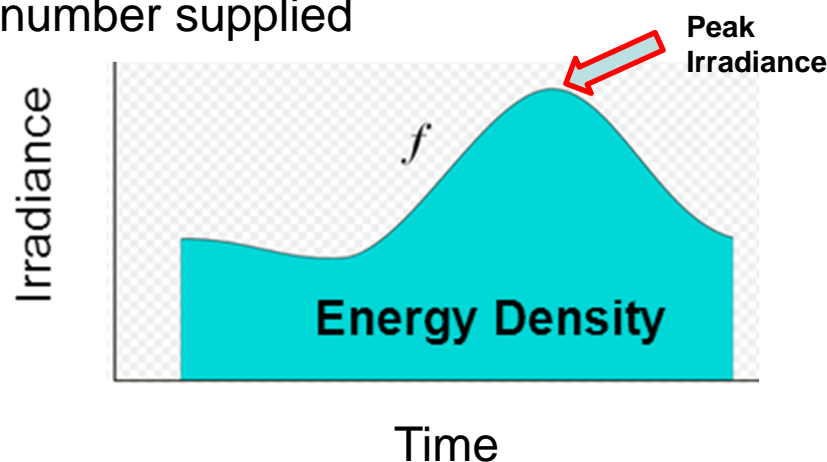


Where were those UV readings?



## (Radiant) Energy Density

- Expressed in Joules ( $\text{J}/\text{cm}^2$ ) or milliJoules ( $\text{mJ}/\text{cm}^2$ ) per square centimeter
- Incorporates time as part of the measurement
- One watt for One second = One Joule
- Area under the irradiance curve
- Often the only UV exposure guide number supplied



## Expectations (User)

- Treat and handle as an instrument
- Maintain, calibrate & service as required
- Use as designed within specs
- Avoid user induced errors
- PICNIC Errors: Problem In Chair, Not In Calibration

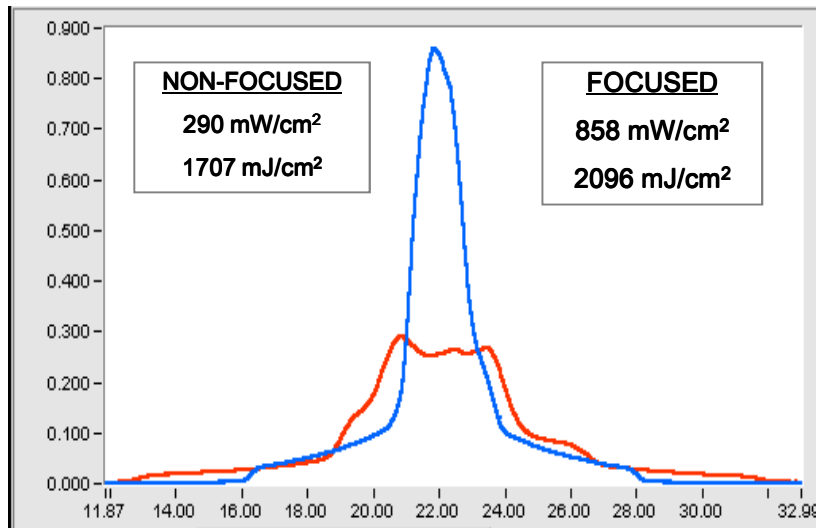
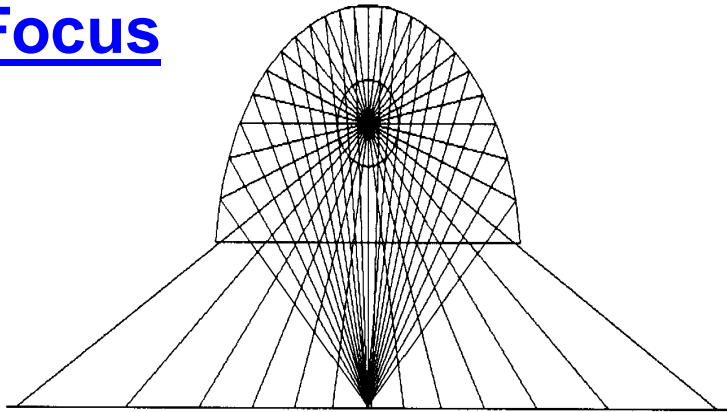
## Equipment Suppliers

- Use as a resource



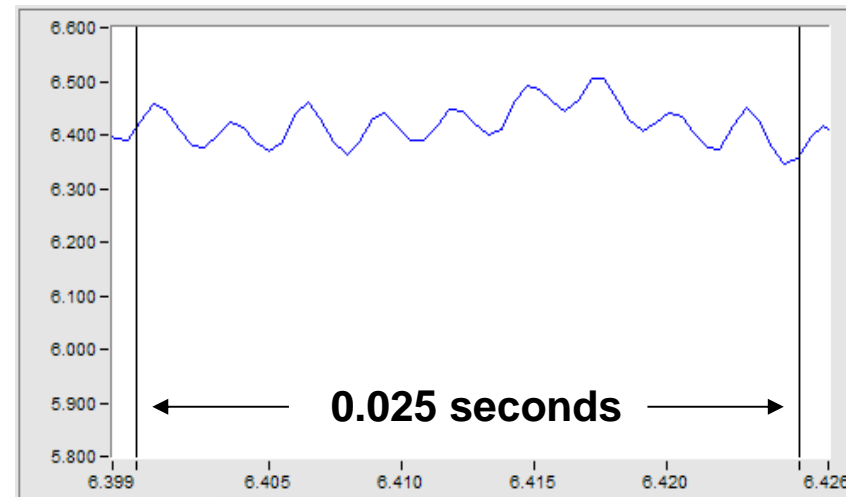


## Focus



## Frequency: Power Supply

- Traditional 50/60 Hz power supplies vs. higher frequency power supplies
- Impact on chemistry?



High frequency power supply

## Formulation/Formulator

- Match Formulation to Application
- Use Formulator as a Resource and not just a complaint department



## Goals

Goals are deceptive-the unaimed arrow never misses

Charles Knief (Kimo's Rules)

## Guess

Anything that you can measure, you have a better chance of controlling.  
Things that you do not measure become the cause of mysterious problems

Larry Goldberg-Beta Industries





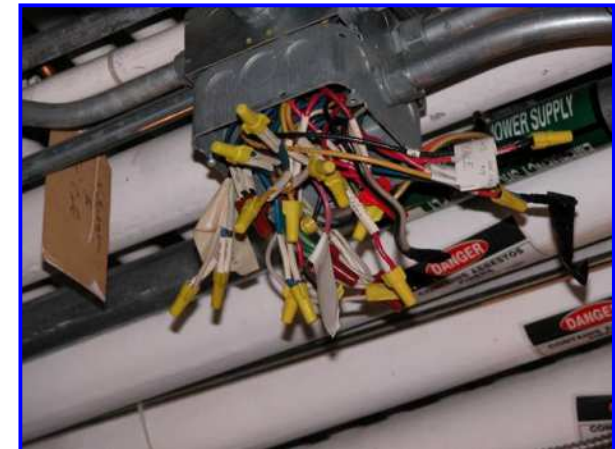
## Health & Safety

- [www.radtech.org](http://www.radtech.org)
- Chemical Safety
- PPE
- Housekeeping
- Reporting Requirements
- Hygiene
- Equipment Safety

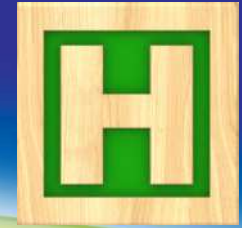


## How Often Do I Measure?

- Application?
- Value of Product?
- Type of Product?
- Process Window?

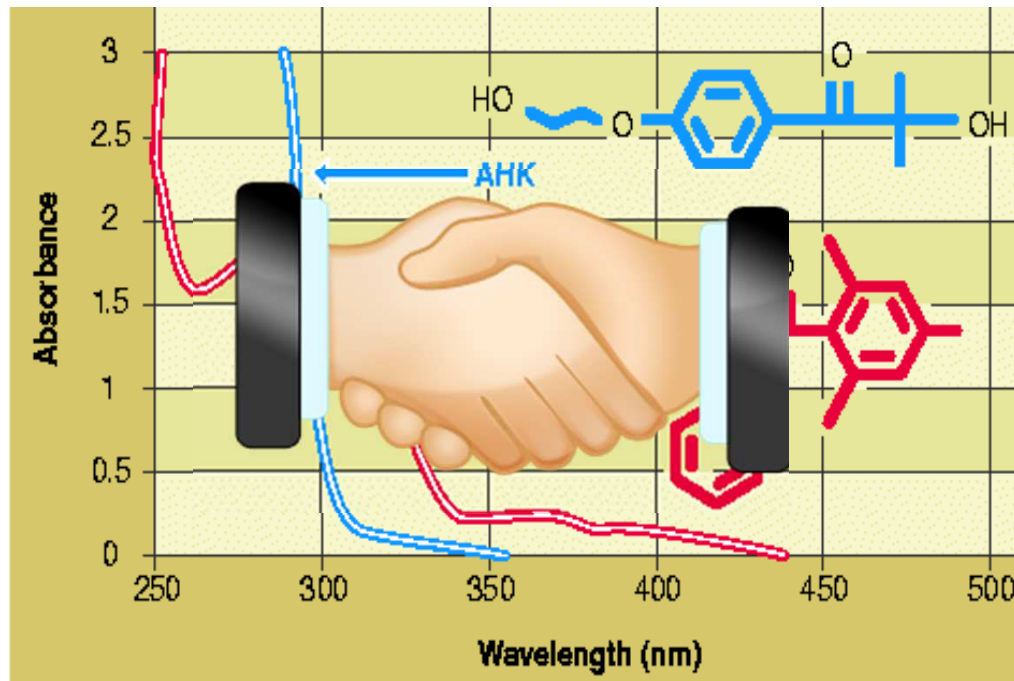






## Handshake

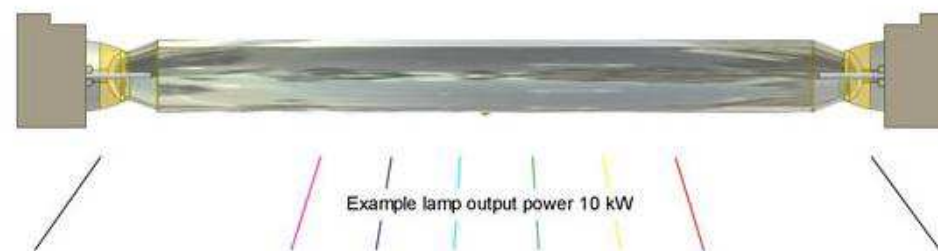
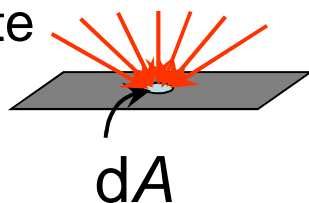
- The UV source and formulation need to do a “handshake”
- Modify formulation designed for broadband UV sources to work on a narrow band UV source such as UV LED
- Verify you get the desired properties and performance under a new source





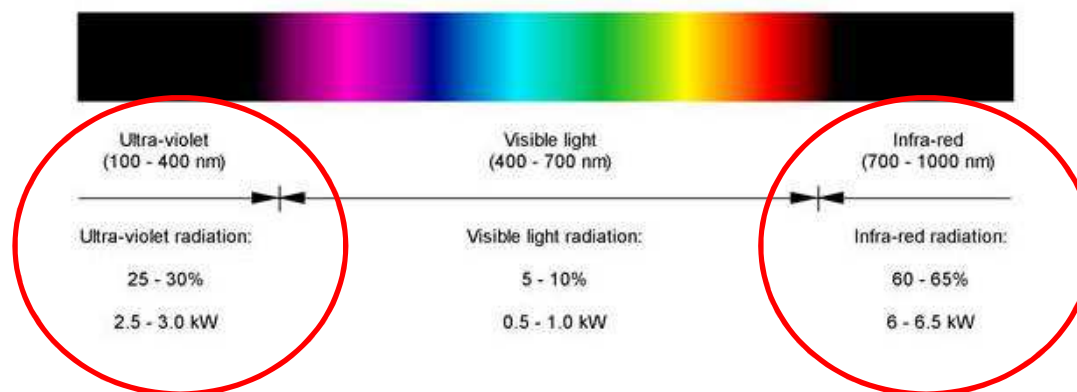
## Irradiance (Intensity)

- Expressed in watts or milliWatts per square centimeter ( $\text{W}/\text{cm}^2$  or  $\text{mW}/\text{cm}^2$ )
- Total **radiant power** of (all) wavelengths passing from **all incident** directions onto an infinitesimally small area ( $\text{cm}^2$ )
- Readings decrease with the square of the distance **(True for LEDs?)**
- Depth of cure, penetration through pigments and opaque colors, adhesion to the substrate



## Infrared

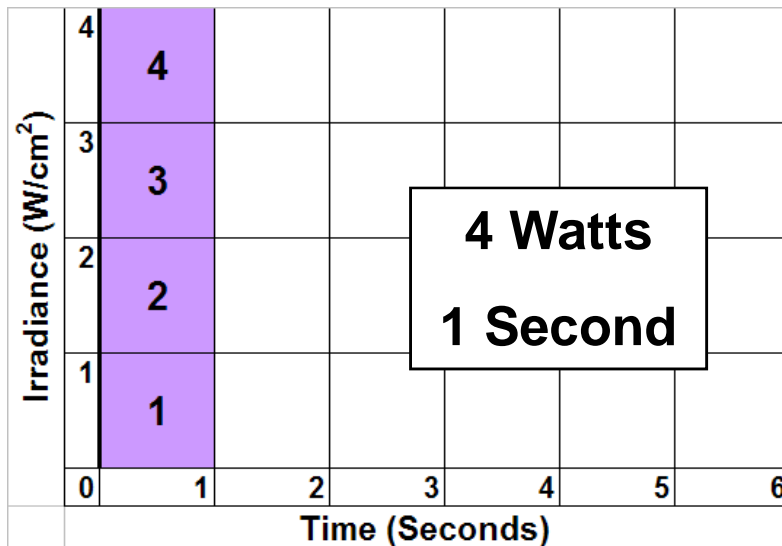
- What role does it play in your application?
  - Cure?
  - Substrate?
  - Cooling of UV Source?



# Coating Specification: 4 Joules/cm<sup>2</sup>

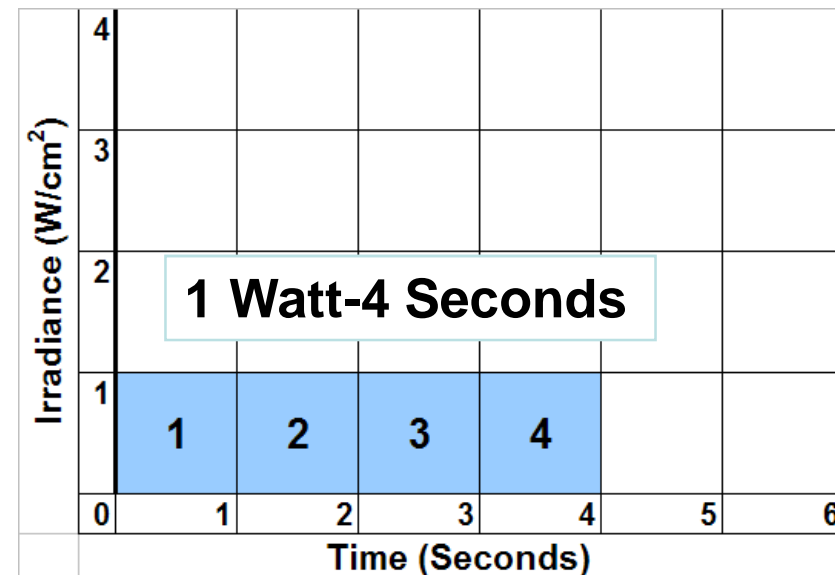
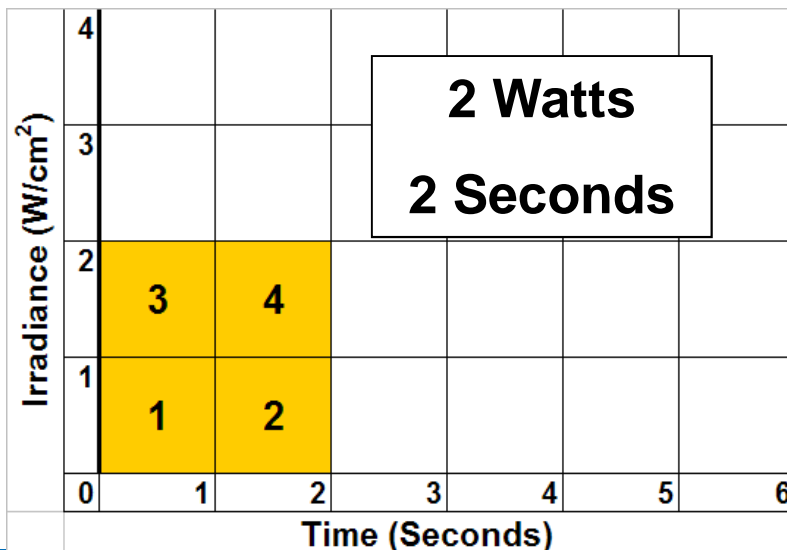


1 Joule = 1 Watt for 1 Second



## 4 Joule Exposures

- 4 Watts-1 Second
- 1 Watt-4 Seconds
- 2 Watts- 2 Seconds



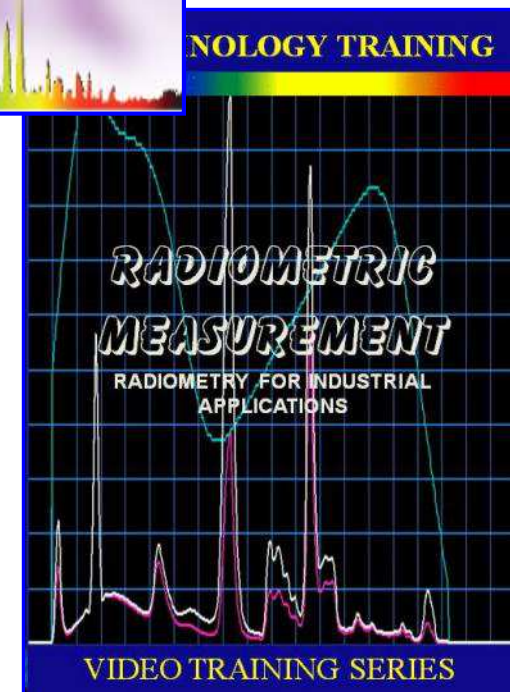
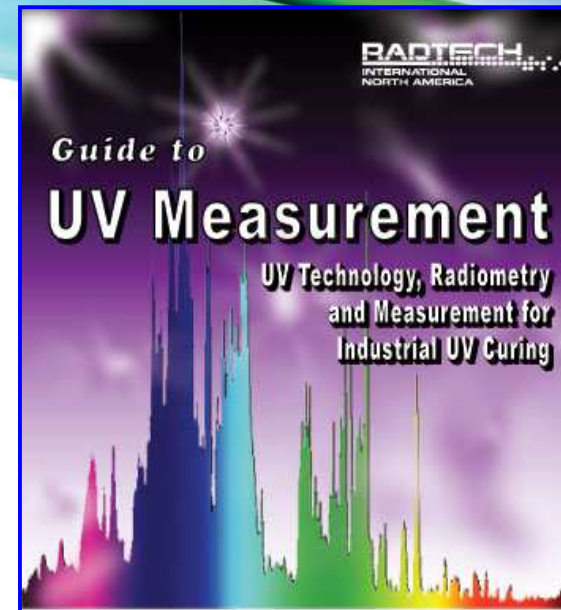
Equal Joules = Equal Cure?

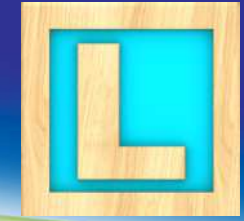




# Knowledge

- Web Sites
  - SGIA
  - RadTech Web site
  - Supplier/Vendor websites
- Articles
- Seminars/Webinars
- Conference & Trade Shows
- Trade Organizations (SGIA, RadTech, Industry)
- Suppliers/Vendors
- Training Materials (CD/DVD)





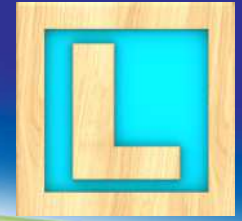
## Lamps



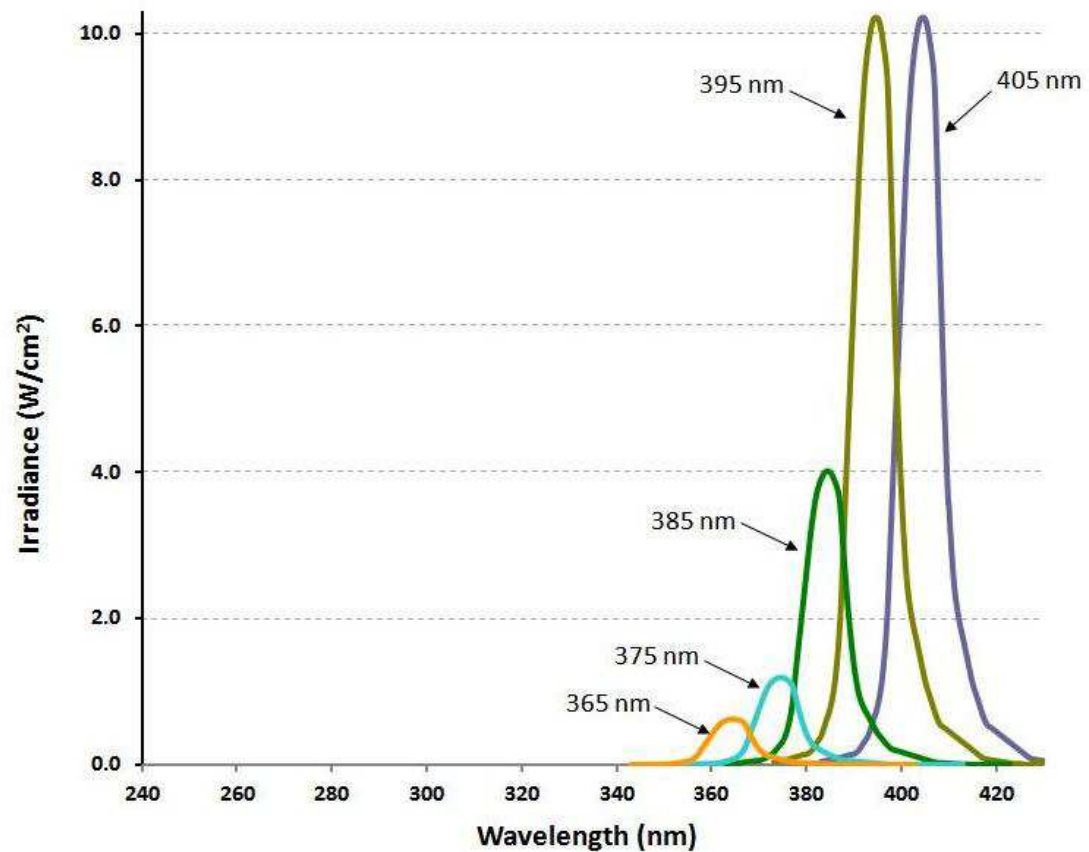
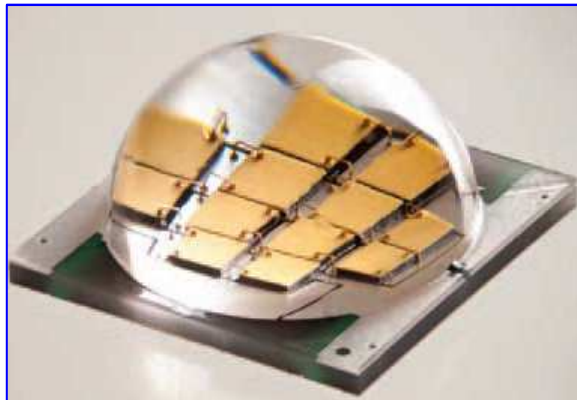
- Differences in materials, fill elements, pressure
- Useful life of lamp
- Buy on value, not the least expensive price
- “Purchasing Specials”

## Log

Date	Line Speed Dwell Time FPM/RPM		UV System: North Line Lamp: 2				Other	Signature
	Ind.	Actual.	Power WPI	Hour Meter	Irradiance (W/cm <sup>2</sup> )	Energy Density (J/cm <sup>2</sup> )		
10/4	25	22	400	780	0.859	1.45		

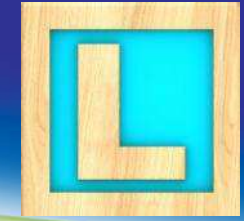


## (UV) LEDs



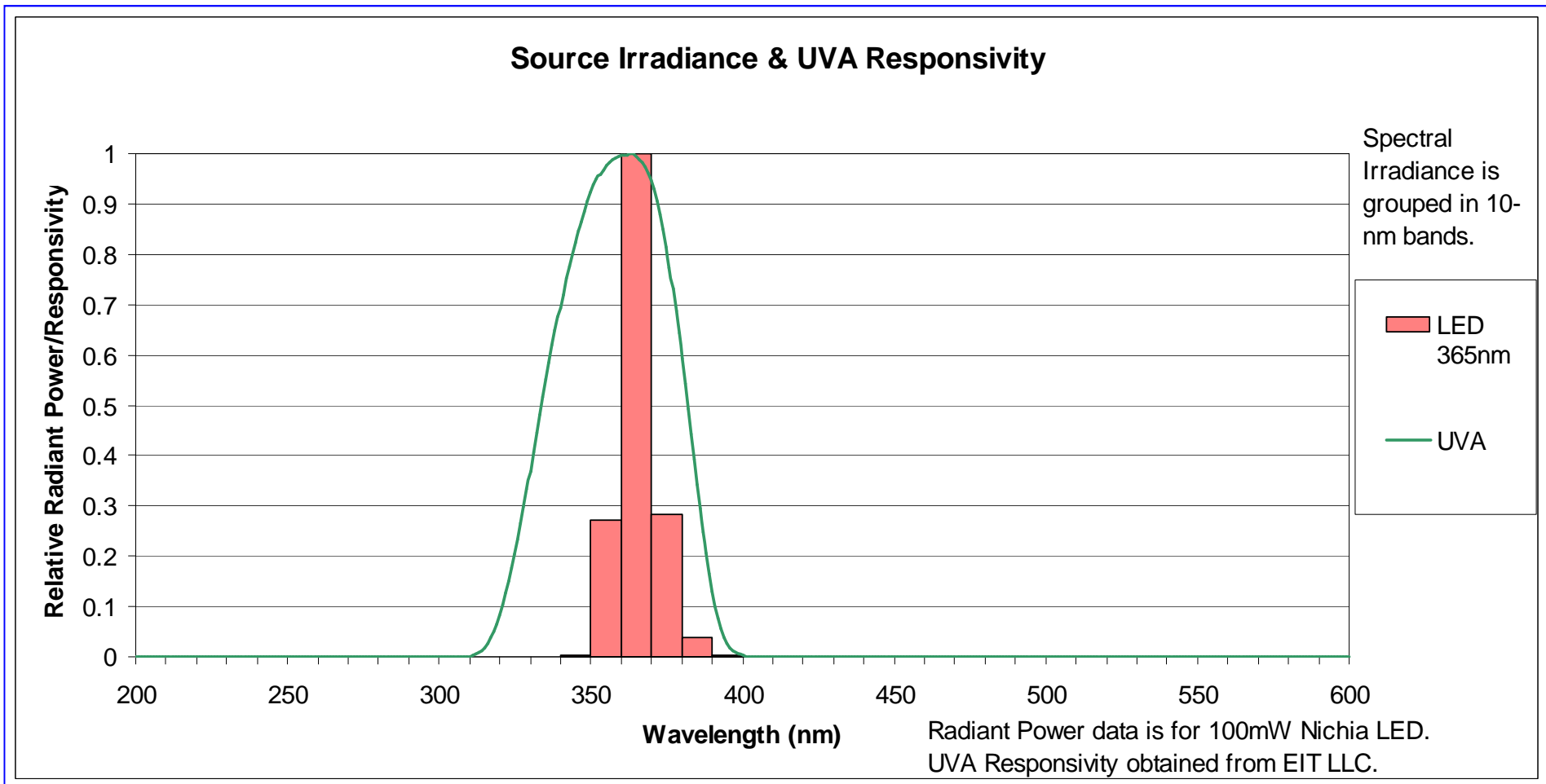
- Manufacturers use proprietary processes to select, bin (test) and assemble LED chips into arrays with optics
- Bin by spectral output, intensity and forward voltage



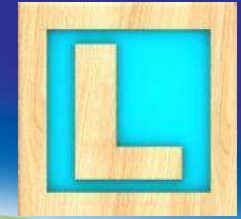


## (UV) LEDs

- Instrument Bandwidth Matched to Source
- Spectral Distribution from a 365 nm LED UV Source

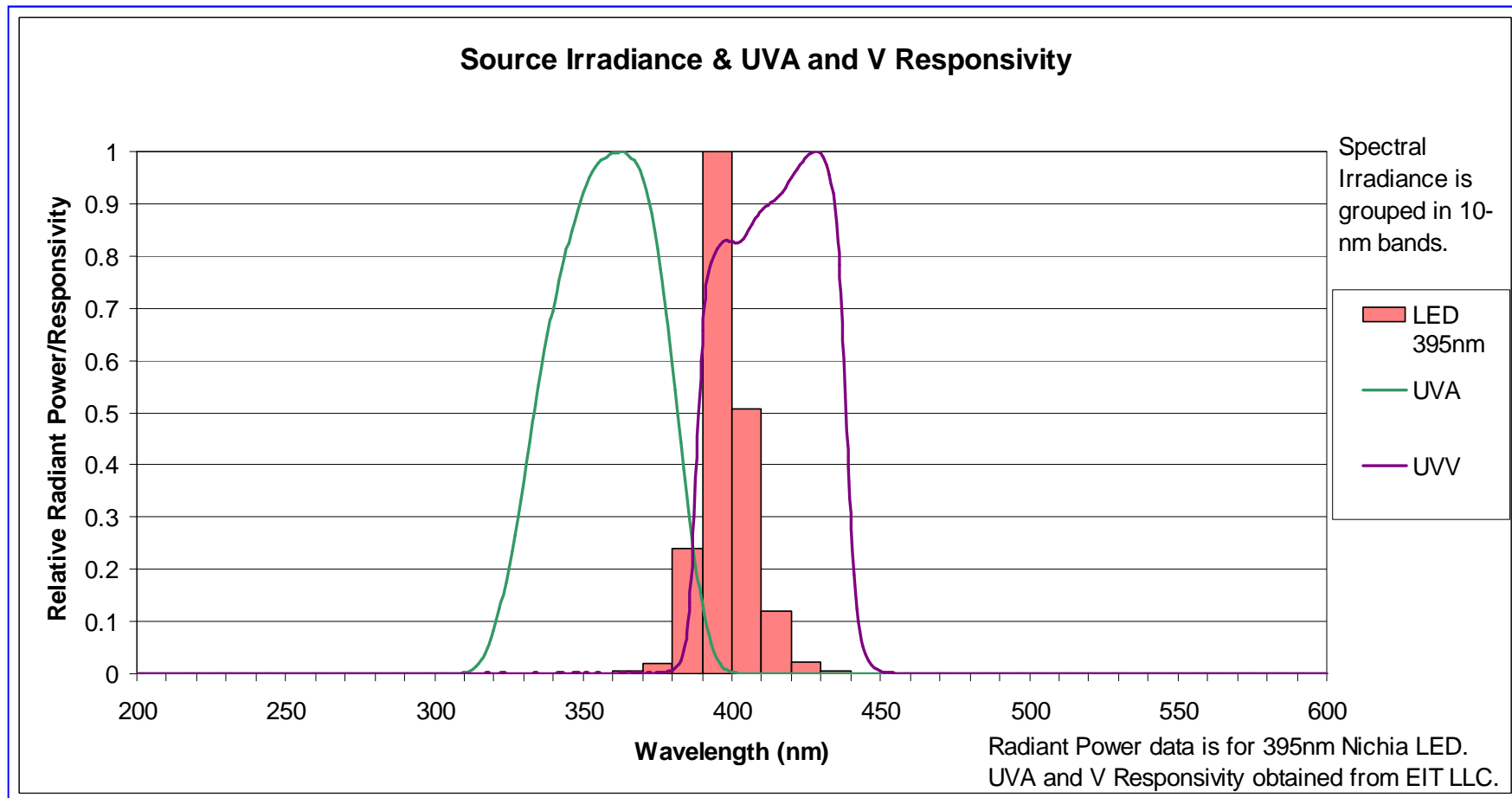


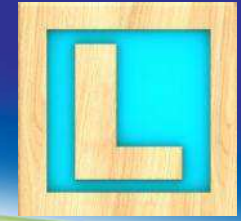
# Caution! I've Got Numbers



## (UV) LEDs

- Instrument Bandwidth Not Matched to Source
- Measurement of 395 nm LED with EIT UVA (320-390 nm) and EIT UVV (390-445nm)



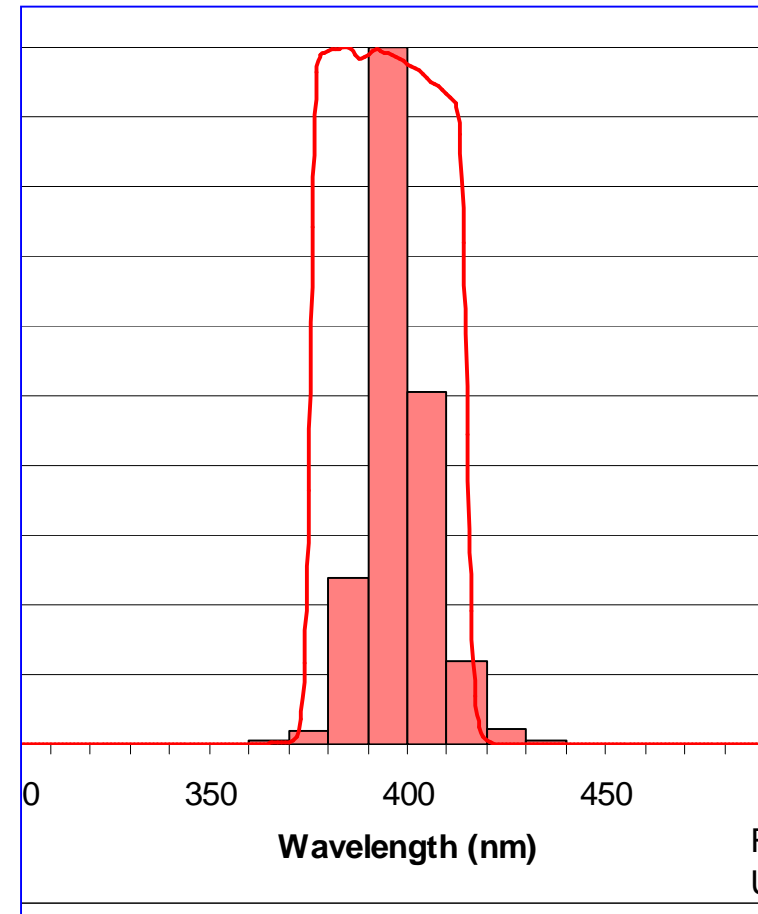


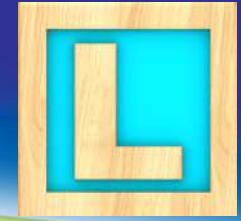
## (UV) LEDs

- 395 nm LED with EIT UVA2 (380-410 nm)
- Instrument Bandwidth Matched to Source

### UVA2 available in:

- Power Puck II & Power Puck II  
**Profiler** (UVA, UVA2, UVB, UVV)
- UviCure Plus II & UviCure Plus II  
**Profiler** (UVA2)
- Special order PowerMAP & UV Map  
Plus

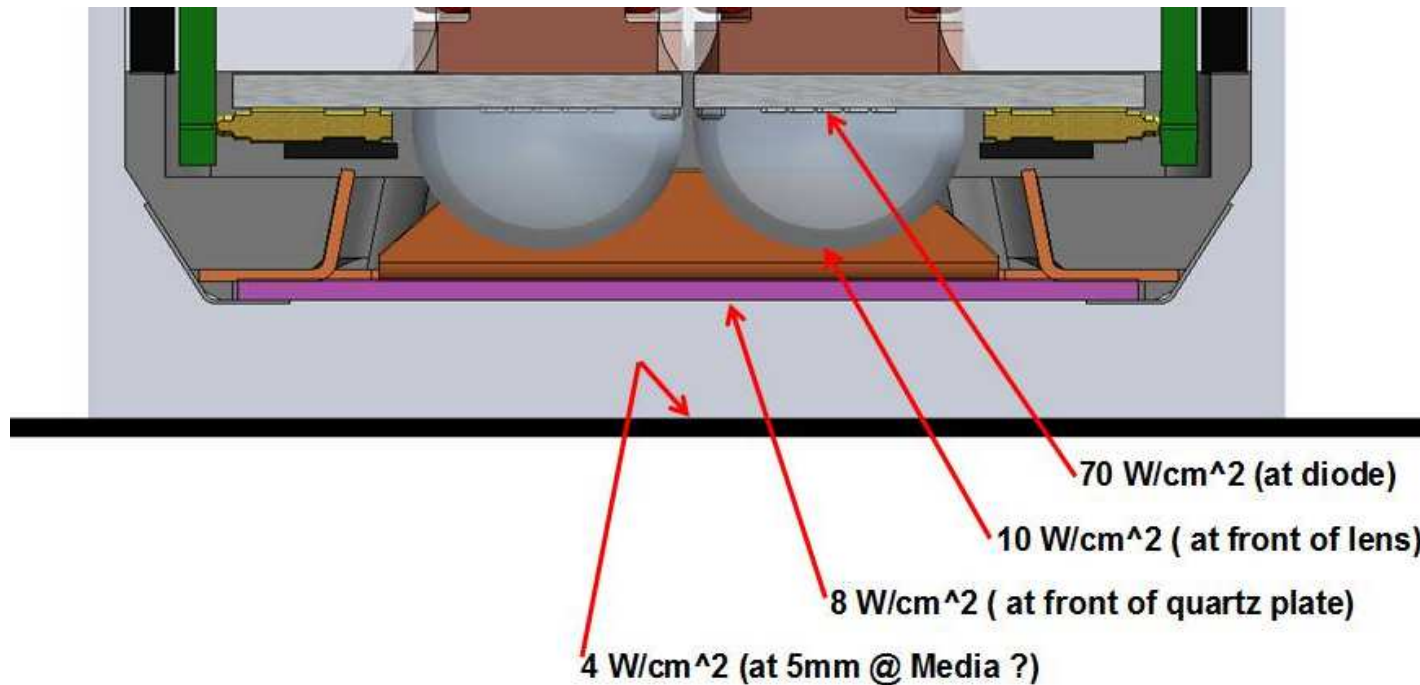




## (UV) LEDs

### Location of the UV LED Measurement

- Where is the proper location for the UV Irradiance Value?
- How do we compare systems and communicate values?



Courtesy of Integration Technology





## Measurement (Why)

- Save Time & Money



## Microwave



## Maintenance

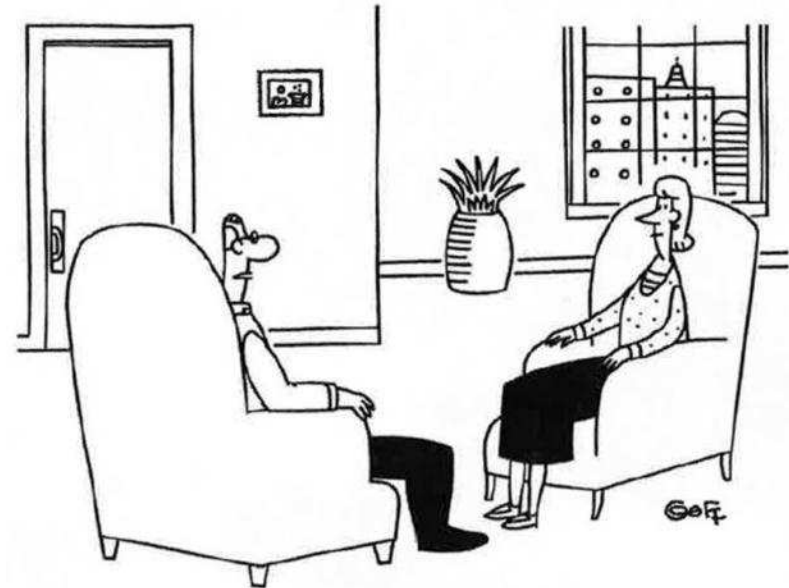
- Preventative, Simple & Major Maintenance
- Procedures & Training





## Nanometer

- A nanometer is equal to one billionth ( $1/1,000,000,000$  or  $10^{-9}$ ) of a meter
  - Water molecule is less than 1 nm
  - Typical germ is about 1,000 nm
  - Hair is about 100,000 nm wide
  - Shaquille O'Neal is 2,160,000,000 nm tall
- Non-vacuum UV: +/- 200 nm to 400-450 nm (visible light)
- Nanometers also used to describe instrument bands
  - EIT UVA response is 320-390 nm



**"I don't believe in micromanaging.  
What I do is nanomanaging."**

**From U.S. TECH July 2012 Issue**

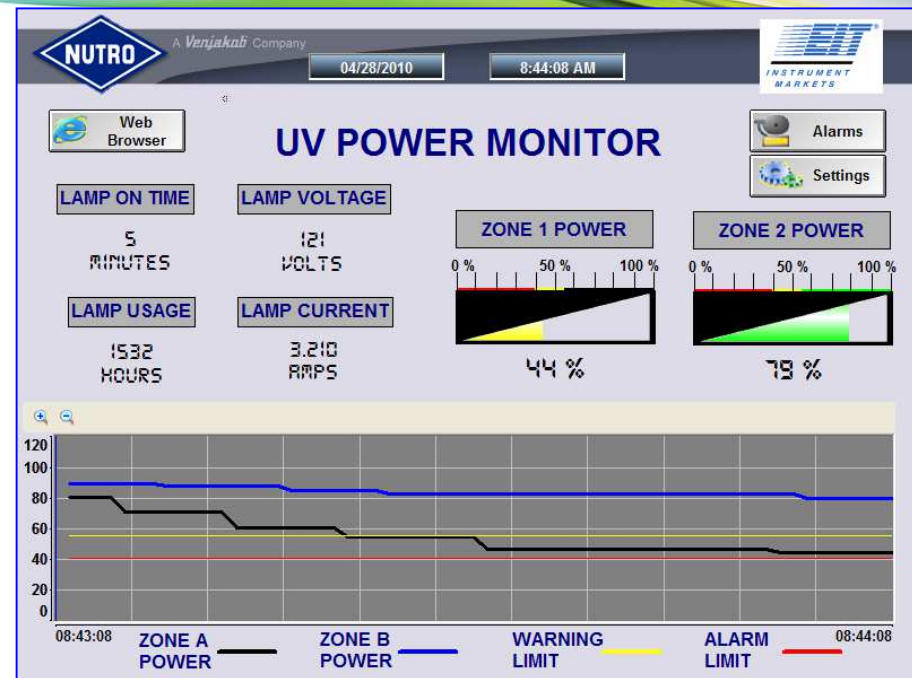
## NIST Traceability

- Process to transfer "NIST" traceable reading into customer instrument



## Online UV Measurement

- Continuous feedback & monitoring
  - Tight process windows/High \$ Products
  - UV changes with time
  - Feedback to display, PLC, Alarms
- Applications where a radiometer will not fit or is not practical
  - Web, Bank of multiple lamps
  - Lamps high off ground
- Communication
  - Percentage readings
  - Coordinate with absolute radiometer



EMI Hardened Sensor for Online measurements





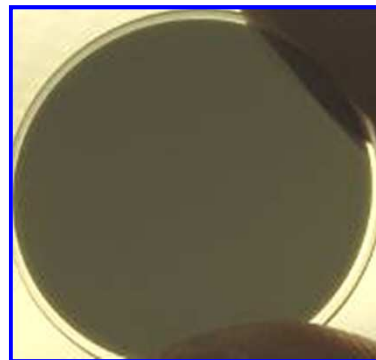


## Optics

- Filter and detector specifications
- Spatial response (Cosine)
- Design-Balance between optical stability & repeatable electronic signal level
- Proper care and cleaning

## Cleaning The Optics

1. LOOK
2. BLOW
3. FLOOD
4. WIPE



New Filter



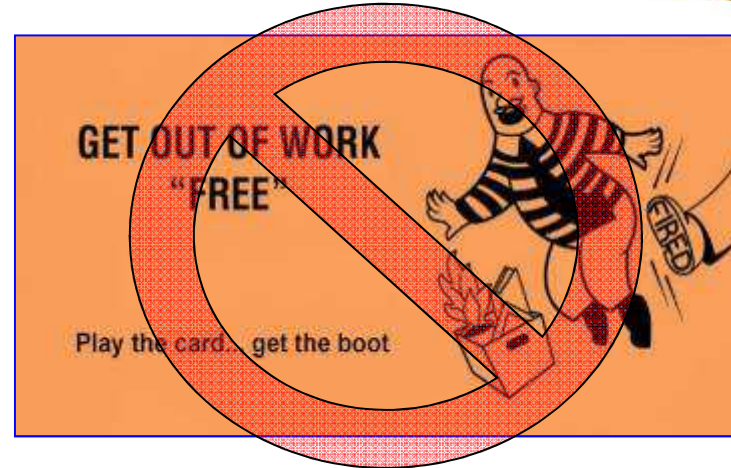
Customer Returns:  
**Left: Improper Cleaning Right: Scratch**





## Process Windows

- Require work to establish, document & maintain the process
- Require communication with suppliers, vendors, etc.
- Follow the Laws of Physics



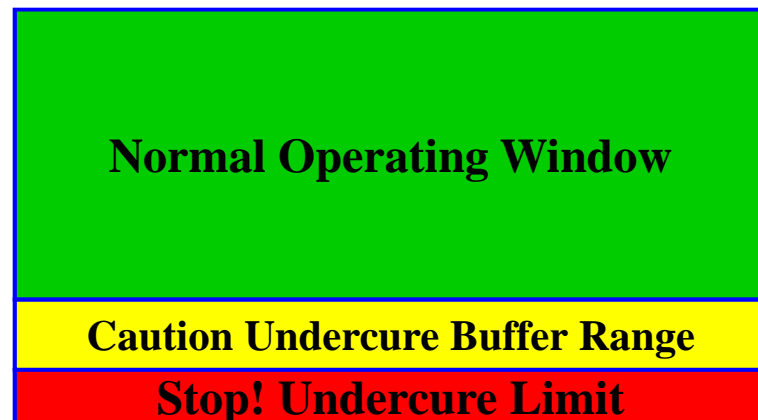
***Are we to believe that a UV (LED) photon soaks into a coating faster in your lab than anywhere else on the face of the earth? Well, I guess the laws of physics cease to exist in your lab. Are you using magic UV (LED) photons? Magic coatings? Did you buy them from the same guy who sold Jack his beanstalk beans?***

*Paraphrased from My Cousin Vinnie*

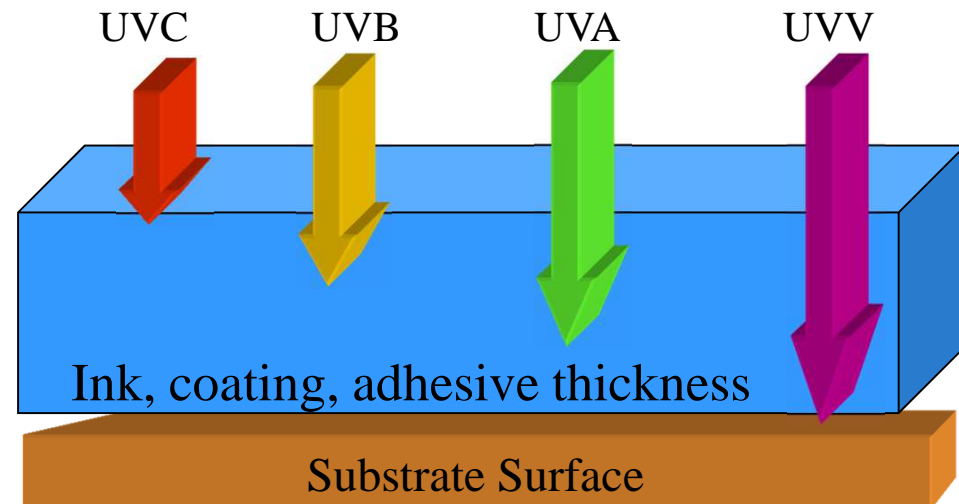


## Process Window

- The range in which a process will work with the desired results
- Adhesion, hardness, flexibility, gloss, texture, stain or scratch resistance, chemical rub, cross hatch, abrasion rub, color ID, registration



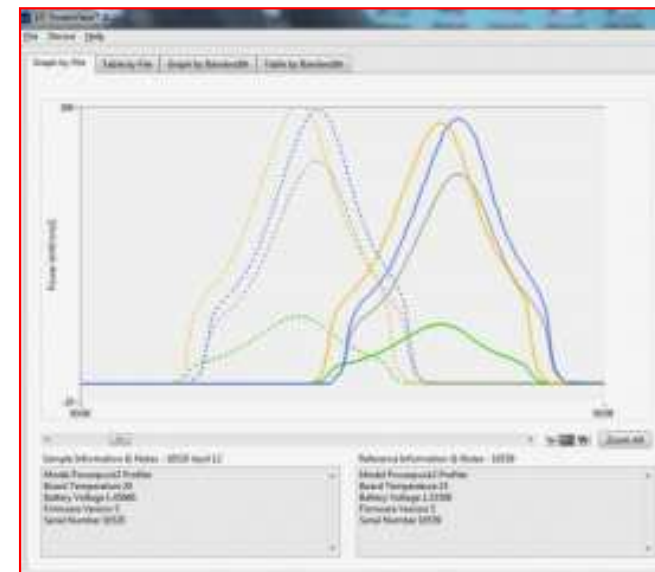
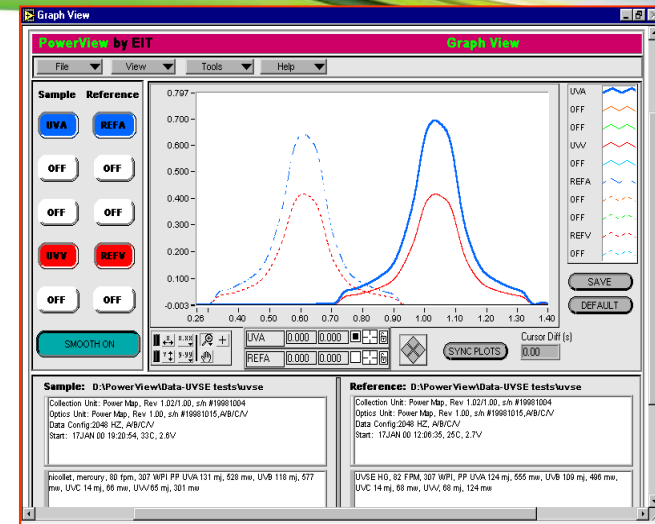
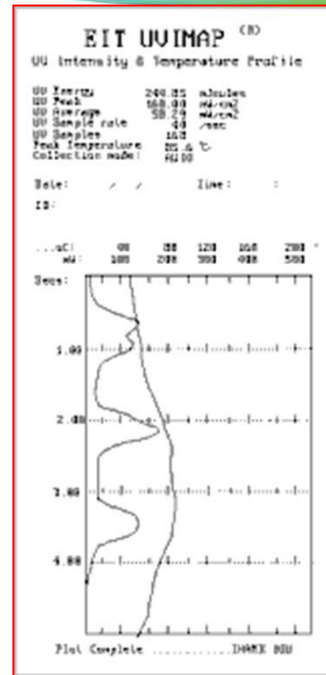
## Penetration (Adhesion)





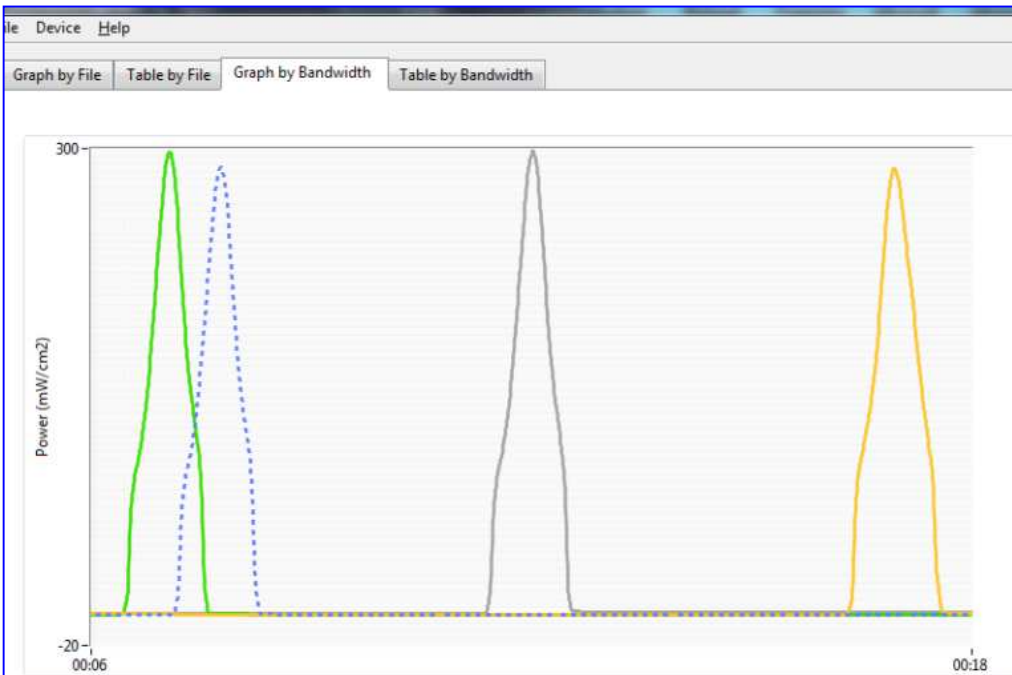
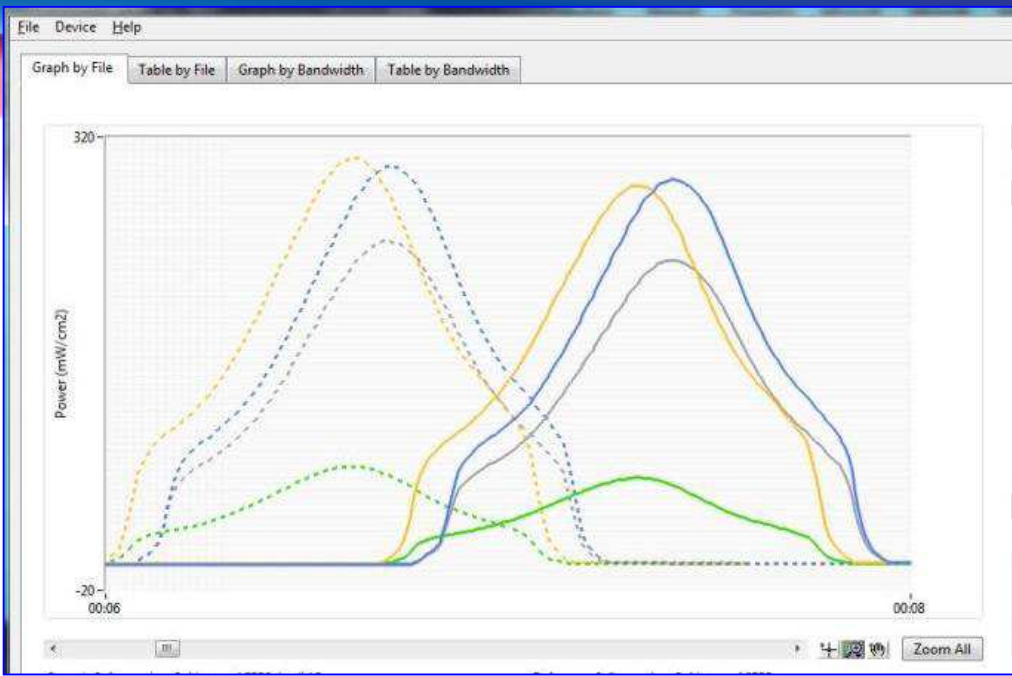
# Profiling Radiometers

- Measure the peak irradiance and total energy density
- Profile the UV irradiance (y-axis) as a function of time (x-axis)
  - Some also profile temperature
- Irradiance profiles useful to:
  - Analyze system changes over time
  - Compare multi-lamp systems
  - Trouble shoot lines
  - View lamp focus
  - Determine lamp type
  - Power supply analysis
- Software or Display





# Profiling Radiometers



EIT PowerView™ II

File Device Help

Graph by File Table by File Graph by Bandwidth Table by Bandwidth

Summary (by File)

	Sample File	Reference File	Difference
UVA - Power (mW/cm2)	290.559	297.844	(7.285)
Power (%)	(2.4)	100	(102.4)
Energy (mJ/cm2)	325.469	179.014	146.456
Energy (%)	81.8	100	(18.2)
UVB - Power (mW/cm2)	283.924	304.488	(20.564)
Power (%)	(6.8)	100	(106.8)
Energy (mJ/cm2)	351.577	186.268	165.309
Energy (%)	88.7	100	(11.3)
UVC - Power (mW/cm2)	64.573	73.067	(8.494)
Power (%)	(11.6)	100	(111.6)
Energy (mJ/cm2)	79.428	45.360	34.068
Energy (%)	75.1	100	(24.9)
UVV - Power (mW/cm2)	228.967	242.105	(13.138)
Power (%)	(5.4)	100	(105.4)
Energy (mJ/cm2)	282.214	147.816	134.398
Energy (%)	90.9	100	(9.1)
Cursors	Off		
Time	00:00.00		
Time - Ref	00:00.00		





## Qualify, Quantify & Quality

- UV Measurement & Process Control allows you to Qualify & Quantify a UV process
- UV Measurement & Process Control Allows you to Produce Good Quality Products



## Relative Measurement

- Electronic signal proportional to lamp brightness (% intensity)
- Sensor & Display



## Real Time Monitoring

- Situational awareness, into PLC display

## Reflectors

- 60-80% of energy reaching the substrate is reflected
- Optimize reflected energy, reflector focus and lamp position through design and maintenance programs
- Shape, type, material, coating of reflector matched to process
- Clean Reflectors are key to success



Event Time	Message	Comment
04/27/2010 16:34:17	28 % ZONE 2 Power Insufficient to cure part!	
04/27/2010 16:34:04	42 % Zone 1 Power Low	

Event Time	Message	Comment
04/27/2010 16:34:17	28 % ZONE 2 Power Insufficient to cure part!	
04/27/2010 16:34:07	34 % Zone 2 Power Low	
04/27/2010 16:34:04	42 % Zone 1 Power Low	
04/27/2010 16:31:59	44 % Zone 2 Power Low	
04/27/2010 16:31:19	44 % Zone 2 Power Low	
04/27/2010 16:31:13	11 % ZONE 2 Power Insufficient to cure part!	
04/27/2010 16:32:11	20 % ZONE 1 Power Insufficient to cure part!	Ordered New Lamp
04/27/2010 16:31:10	20 % ZONE 1 Power Insufficient to cure part!	
04/27/2010 16:30:51	46 % Zone 2 Power Low	Maintenance Scheduled
04/27/2010 16:30:31	46 % Zone 2 Power Low	

## Radiochromatic Strips

- Web press option
- Correlate to radiometer or color?

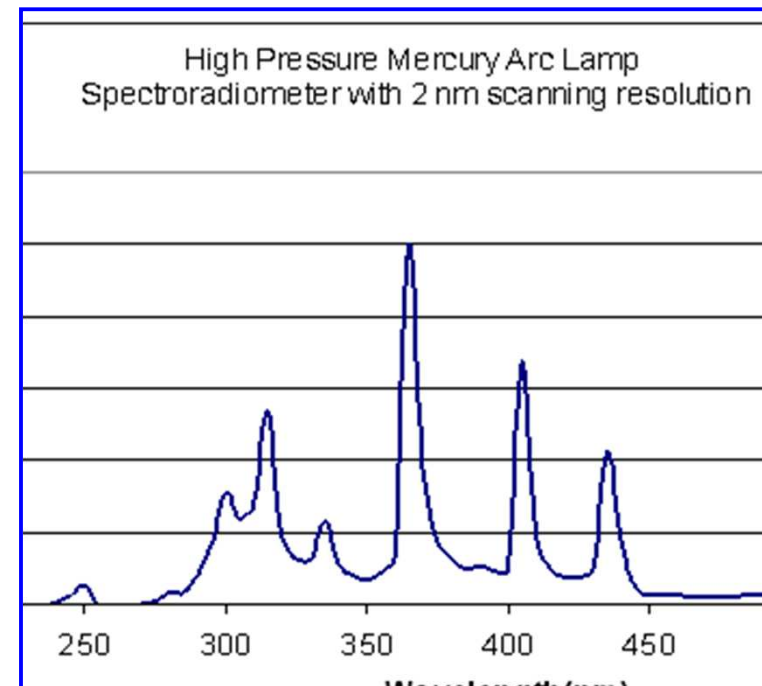


## Specification (Cure)

- Applied electrical power is not enough (i.e. 200 WPI lamp)
- Minimum energy density: 700 mJ/cm<sup>2</sup>, EIT UVA (320-390)
- Minimum irradiance: 650 mW/cm<sup>2</sup>, EIT UVA (320-390)
- Lamp Type, Reflector Type, Thermal, Coating Thickness

## Spectral Radiometer

- Irradiance as function of wavelength
- Available from UV bulb/equipment supplier
- R&D value vs. production value?



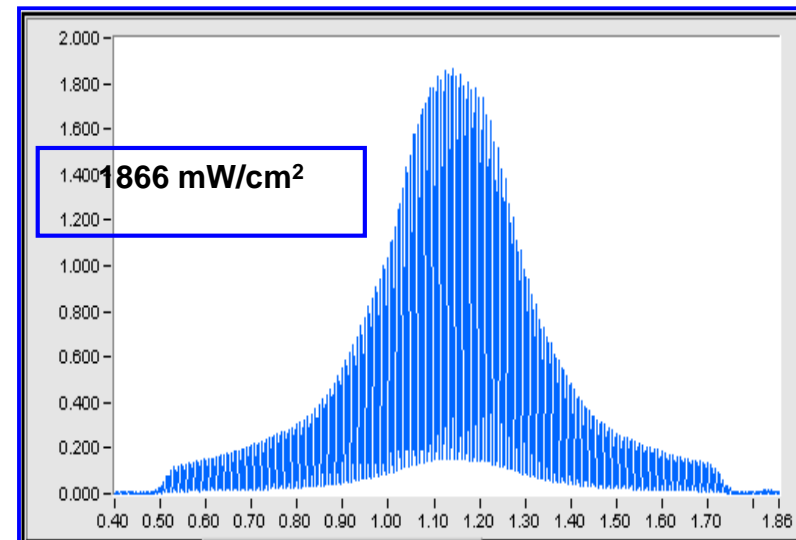
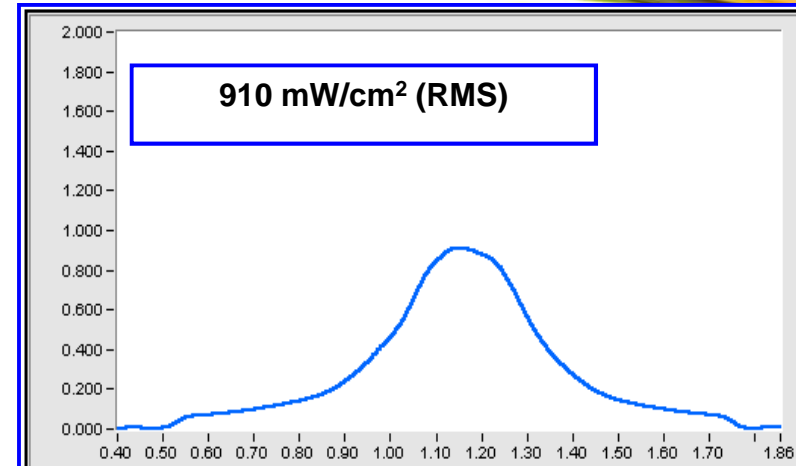


## Sampling Rate

- Did your instrument take enough samples to avoid errors and 'catch' the peak?
- Sample rates have increased in more recent instruments

## Smoothing (Data Filtering)

- Instruments have the ability to sample faster
- Peak irradiance: Report average (RMS) or instantaneous peak?
- 910 mW/cm<sup>2</sup> (RMS/Smooth On) or 1866 mW/cm<sup>2</sup> (Instant/Smooth Off)?







## Threshold (Start)

- Irradiance level which causes the unit to start measuring UV
- Varies due to dynamic range, electronic response, optics, design
- Use the right dynamic range instrument

## Temperature

- Avoid sending an instrument through rapid, repeated, long duration, high UV intensity/temperature runs
- Alarms on units
- If the instrument is too hot to touch – it's too hot to measure



## Three Dimensional (3D)

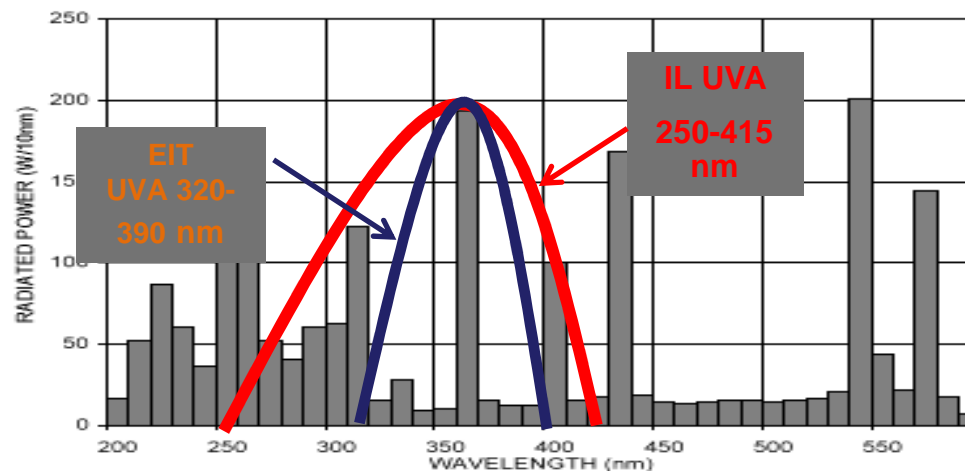
- Many UV applications are 3-dimensional & require measurement for uniformity





## Units

- Instrument Bandwidths are not defined and vary from manufacturer to manufacturer and how they are specified
  - EIT UVA 320-390 nm, Full Width Half Max (FWHM), CWL 365 nm
  - IL UVA 250-415 nm CWL 365 nm



- Specify units in measurement to avoid confusion
  - 300 mJ/cm<sup>2</sup> Start
  - 300 mJ/cm<sup>2</sup>-UVA Improvement
  - 300 mJ/cm<sup>2</sup>-UVA <sub>EIT 320-390 nm</sub> Best



## Variables (Process)

- UV Output ( $\text{W}/\text{cm}^2$ ,  $\text{J}/\text{cm}^2$  or Relative Intensity)
- Bulb Life/Bulb Type
- Reflectors
- Incoming Electrical Power (Volts, Amps)
- Applied Power (WPI)
- Process Speed ( $\text{J}/\text{cm}^2$ )
- Substrate
- Formulation
- Application Equipment
- Machine Equipment

## Verification & Validation

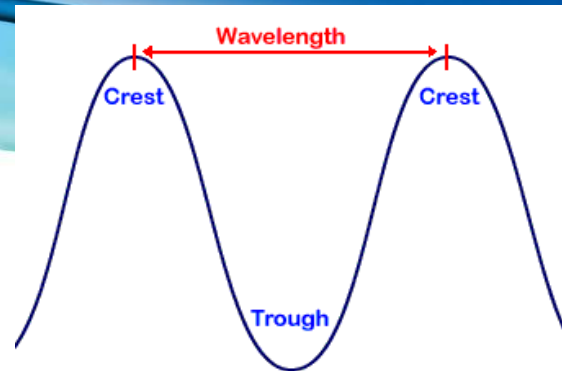
- Establish your process window during the design/development phase and start monitoring from day one in production
- Monitor your readings by job, hour, shift or day as required to maintain quality to avoid:





## Wavelength

- For UV, the wavelength is most often measured in nanometers (nm)



## Watts (For UV Curing)

### Irradiance Watts

- Units: Watts or milliWatts per square centimeter ( $W/cm^2$  or  $mW/cm^2$ )
- Total radiant power of (all) wavelengths passing from all incident directions onto an infinitesimally small area ( $cm^2$ )

### Total Applied Power to UV Source Watts

- Amount of electrical power applied to a UV source
- Total Watts: Voltage x Amperage

### Lamp Power Settings

- Voltage x Amperage/Arc length of bulb
- If bulb length is measured in inches: WPI
- If bulb length is measured in centimeters: WPCM



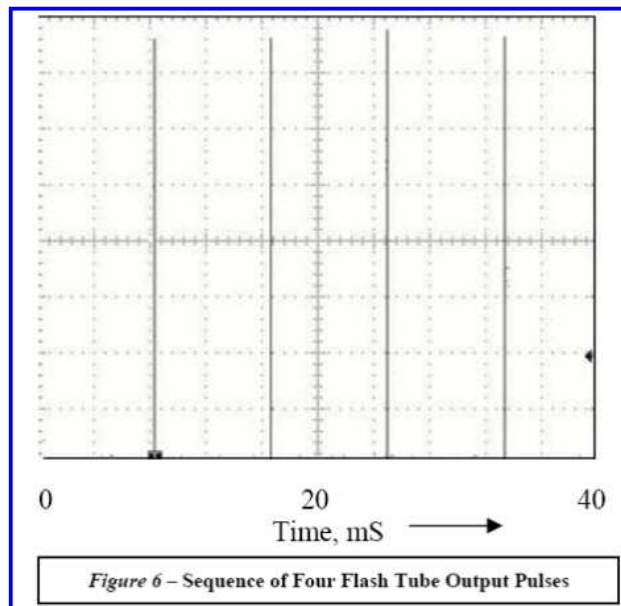
**Total power applied to the system or the lamp power setting is not the effective amount of UV generated or effective amount of UV reaching the cure surface**





## Xenon Sources

- Pulsed UV energy
- Not all instruments can measure short duration high energy pulses-need modified electronics for pulsed sources
- Coordinate with source and instrument supplier





## Yield

- At the end of the day, UV Measurement & Process Control is all about being able to produce good quality products at a profit





# Thank You

- **Zee Presentation available as PDF**
- **Zee Questions?**

**And now that you know  
your UV ABC's, won't  
you sing along with  
me...!**

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