

# UV Measurement & Process Control

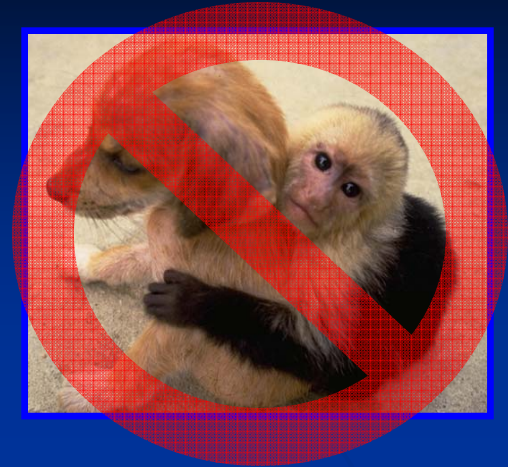
UV/EB West/Intro to UV/EB Technology

Jim Raymont

Director Sales, EIT Instrument Markets

# Presentation Content

- Why measure?
- Who's asking?
- Where do we measure?
- What should we measure?
  - Indirect UV-monitor
  - Direct UV-measure
- How do we measure?
  - Types of measurement?
- Process Control
- Understanding UV Measurement Instruments



# Are we speaking the same (UV) language?

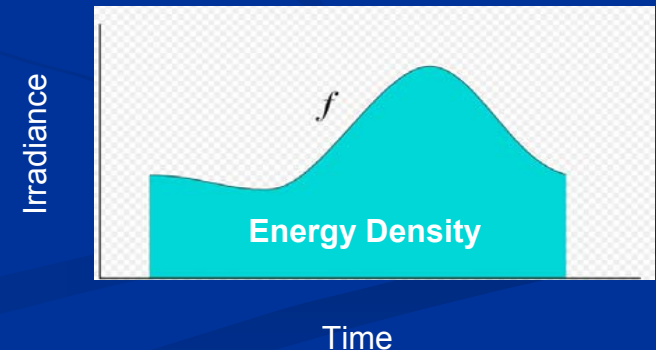
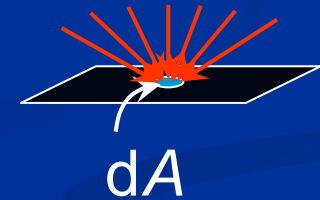
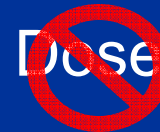
## Irradiance (Intensity)

- 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 ( $\text{cm}^2$ )
- Depth of cure, penetration through pigments and opaque colors, adhesion to the substrate



## Radiant Energy Density

- Expressed in joules or millijoules per square centimeter ( $\text{J}/\text{cm}^2$  or  $\text{mJ}/\text{cm}^2$ )
- 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
- Important for total and complete cure of material

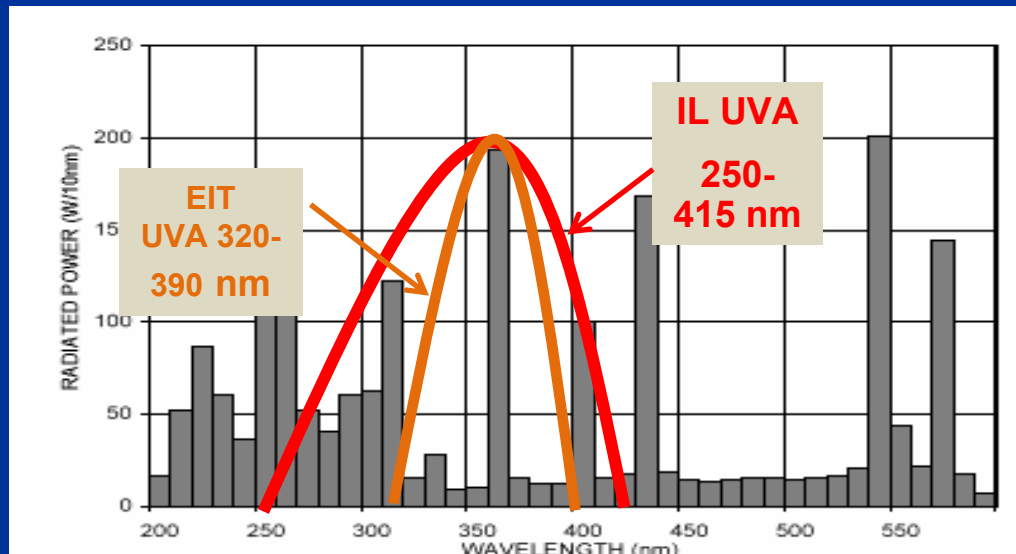


## Wavelength-Nanometers

UV Glossary & Terminology: [www.radtech.org](http://www.radtech.org)

# What 'dialect' of UV are you speaking?

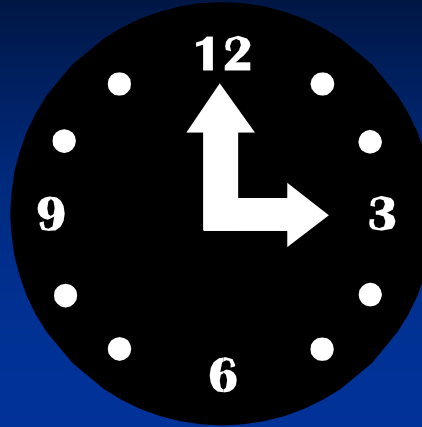
- Instrument Bandwidths are not defined and vary from manufacturer to manufacturer and how they are specified
  - EIT UVA 320-390 nm, Full Width Half Max (FWHM), CWL 365 nm
  - IL UVA 250-415 nm CWL 365 nm
- Specify units in measurement to avoid confusion
- UVA-University of Virginia
- 300 mJ/cm<sup>2</sup> Start
- 300 mJ/cm<sup>2</sup>-UVA Improvement
- 300 mJ/cm<sup>2</sup>-UVA<sub>EIT 320-390 nm</sub> Best



Be specific when communicating instrument values

# Why do we measure?

- Repeatability
- Reliability
- Verification
- Documentation
- ISO
- Training
- Quality
- Certificate of Conformance/Customer Requirement
- Establish, Document and Use Process Control Limits to avoid UV Curing by Guessing!
- Art vs. Science



**Waiting to measure until after you have a problem is  
guaranteed to cost you time and money!**

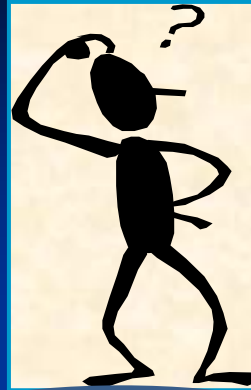
# Why didn't I think to say that.....

- 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
- *UV can be measured and it can be controlled. If UV is not measured & controlled it will cause mysterious problems*
- Not everything that counts can be counted, and not everything that can be counted counts.  
Albert Einstein
- *Document all process parameters initially and then decide what is important to continue counting, measuring, controlling and maintaining.*

# Who is measuring UV and what is their motive?

## Formulator/Chemist

- Establish a specification
- Determine a process window
- Optimize a process
- Acquire, service and maintain customer
- Tend to be **absolute** measurements.



## Customer/End User

- (Operator, Maintenance, Business, Quality)
- Maintain the process
  - Troubleshoot and operate in process window
  - Record keeping
  - Production costs, Scrap, Profit
  - Tend to be **relative** measurements.

UV Equipment  
Supplier

Communication

Substrate  
Supplier

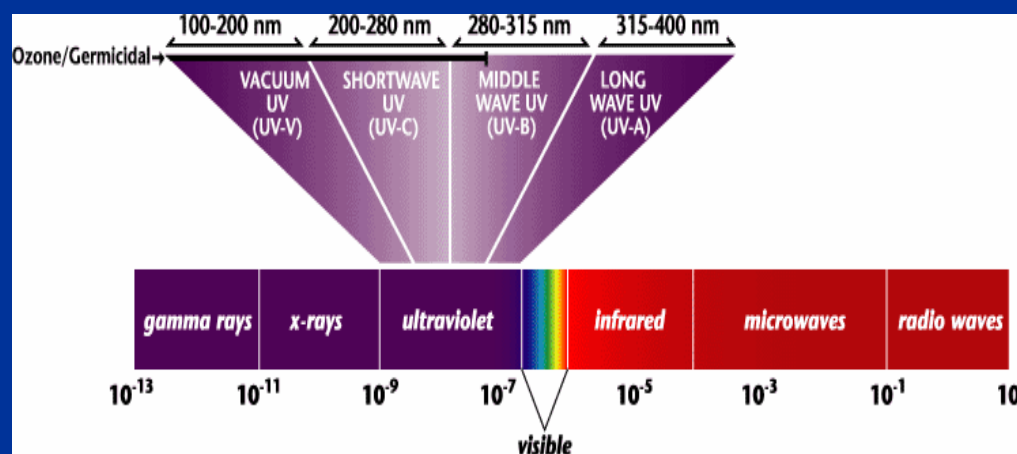
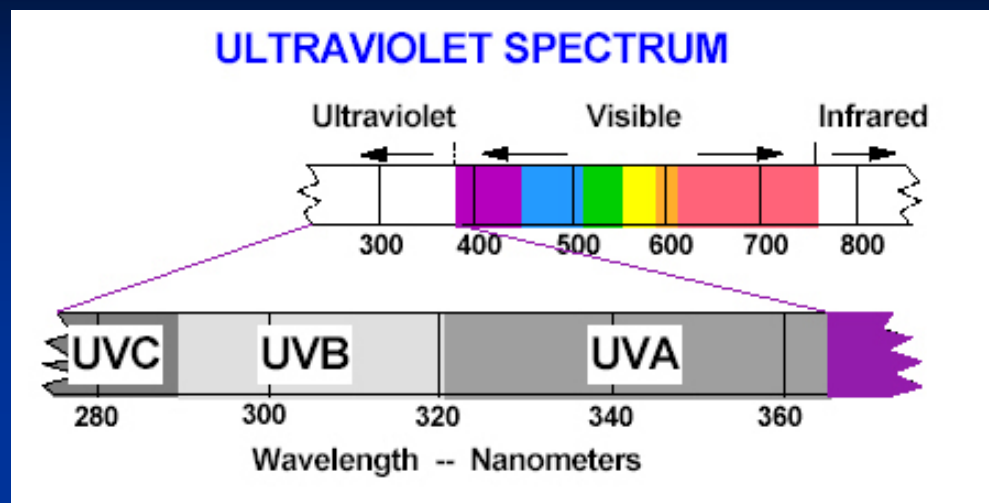
Manufacturing  
Equipment  
Supplier

Process Control & UV  
Measurement  
Instrumentation

Communicate and Work With Suppliers That Communicate!



# Where are we measuring?

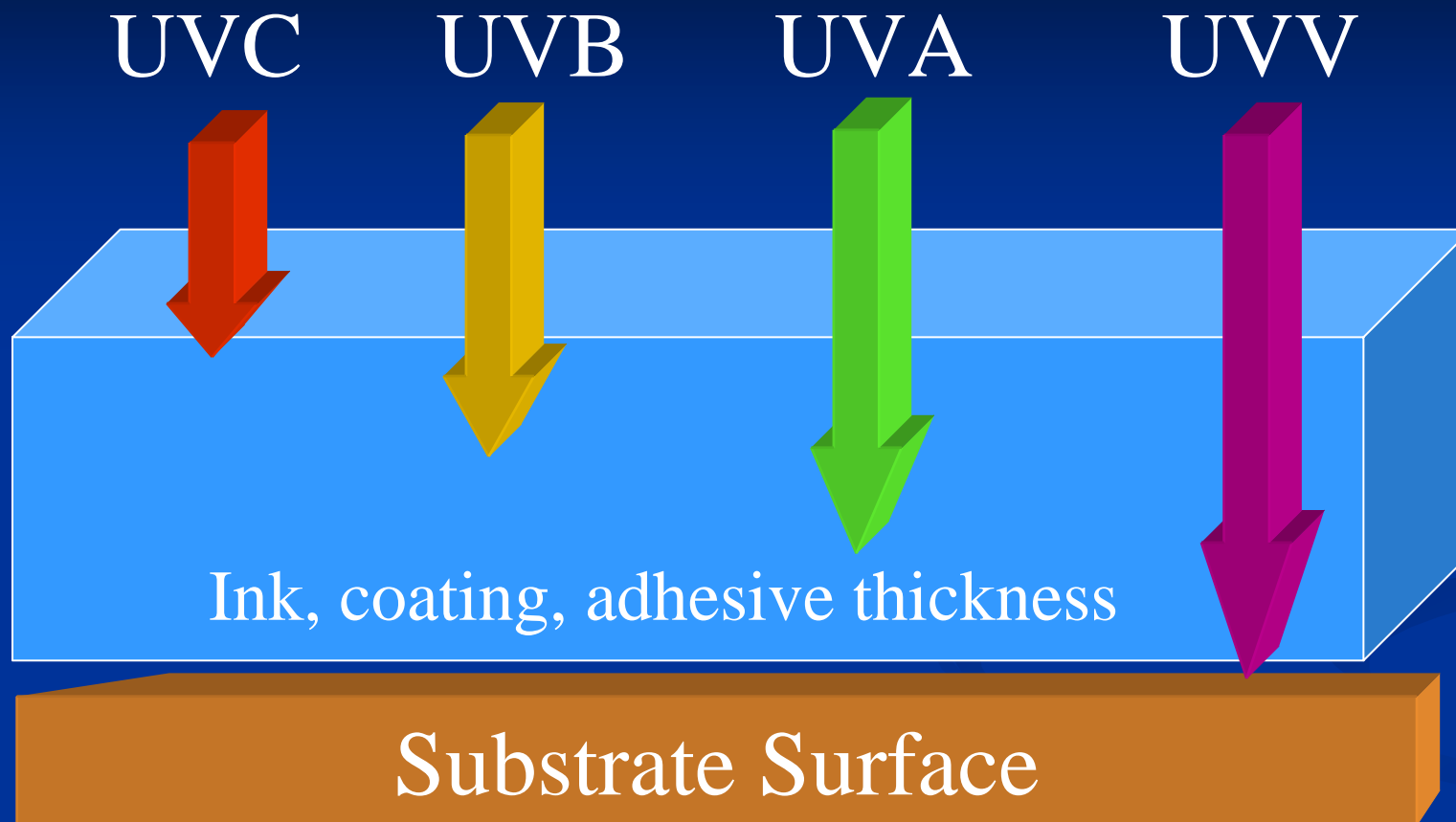


- UVA: 320-390nm Long-wave, blacklight, UV Inks,
- UVB: 280-320nm Middle-wave, erythral response, medical applications
- UVC: 200-280nm Short-wave, germicidal (254 nm), absorbed by DNA, clear coats, surface cure, tack, chemical or scratch resistance
- UVV: 395-445nm Ultra Long-wave, wood products, opaques/whites, thick coats, adhesion, depth of cure
- VUV (Vacuum UV): 100-200 nm, Ozone < 200 nm

Don't assume, clarify the UV bandwidth you are talking about



# Where the UV goes-relative penetration

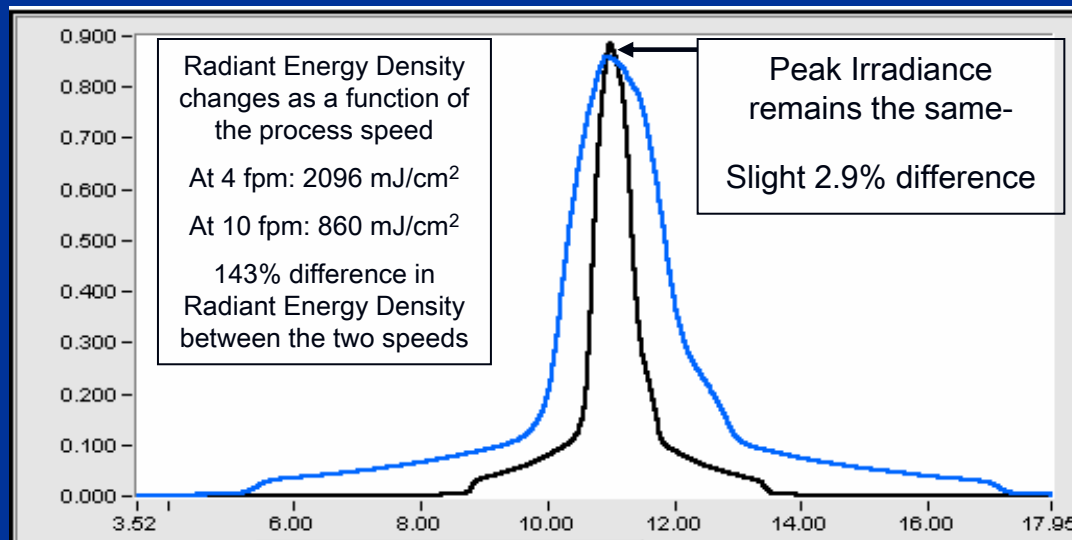


Understand what kind and quantity of UV your formulation needs to cure. Match the UV source and equipment to it

# What should we monitor?

## Dwell Time or Belt/Line Speed

- Affects the amount of energy reaching the substrate
- Actual speeds may vary widely from settings on the speed controller and may not be linear ( $\pm 25\%$ )
- Independently test and confirm dwell time or belt/line speed



Effects of varying the process speed from 4 fpm (blue) to 10 (black) fpm

## Hour Meter

- Number of hours on the current UV bulb
- Hour meter does not indicate the number of starts and stops on the bulb
- Hour meter does not indicate at what temperature the bulb was generating UV
- Hour meter does not tell you the amount of UV being generated
- Hour meter only gives you a rough indication of when you will need to replace the bulb
- Use a radiometer for confirmation



# What should we monitor?

## Electrical Power

### ■ Amp Meter

- Measures the input power applied to the system
- Variations in line voltage (up to 20%), system efficiency

### ■ Lamp Power Settings

- This is a measure of power applied **to** the “bulb”
- Watts per inch or cm (200-800+ WPI)
- WPI/CM estimate: Voltage x Amperage/Arc length of bulb
- WPI/CM settings-variations from actual, linearity of system
- Power applied to system, not the effective amount of UV generated or effective amount reaching the cure surface
- Describing lamp power is not the same as describing its output.
- A 600 watt/inch lamp does not produce 600 watts/inch of UV-it consumes it

### ■ Power Supplies

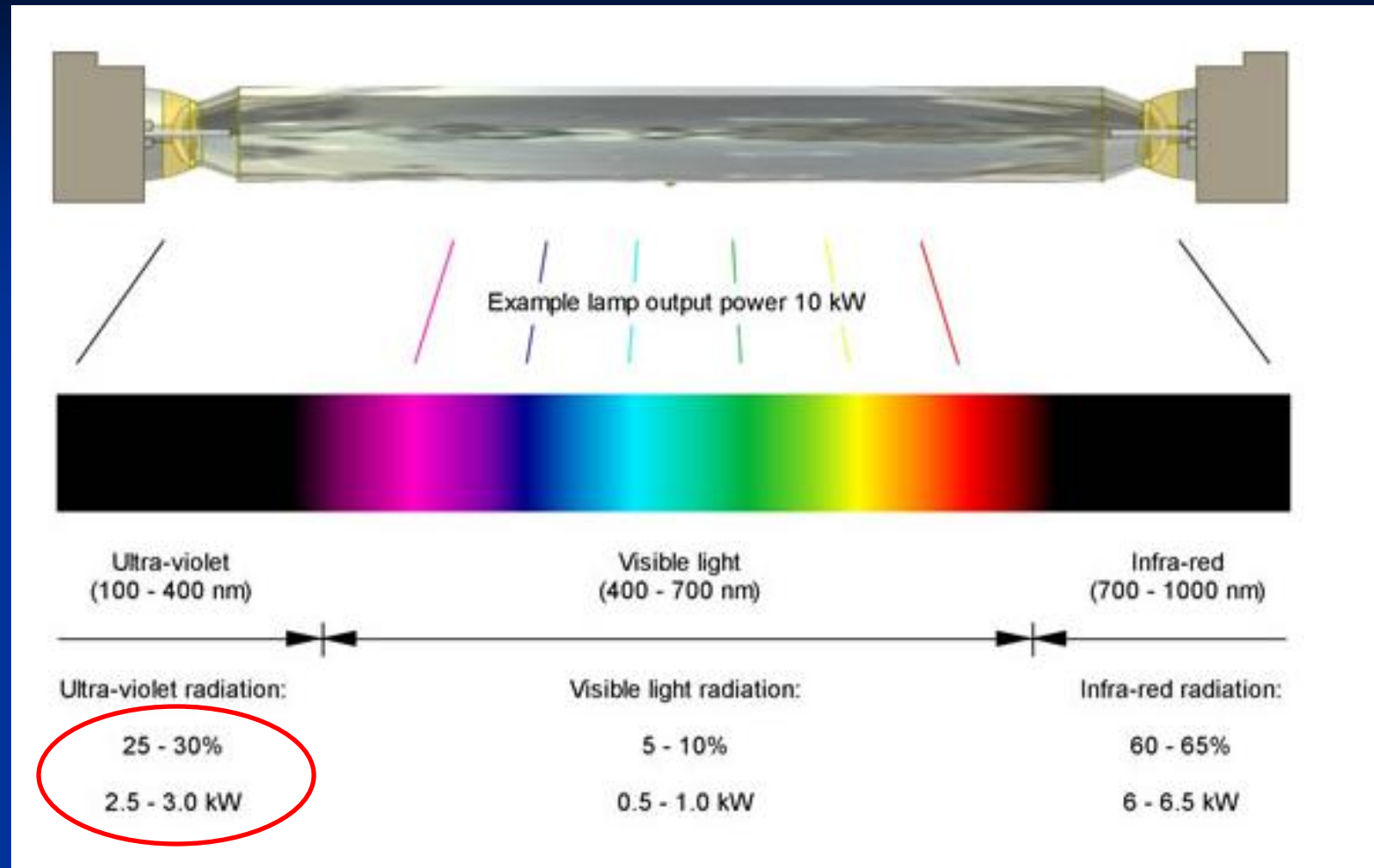
- Conventional, Solid State, High Frequency, DC, Square vs. Sine

Lamps with an applied input power of 600 W/inch vary in UV output from <0.5 W/cm<sup>2</sup> (arc) to > 6 W/cm<sup>2</sup> (microwave) of UVA (EIT 320-390)

Do not confuse electrical input power to effective UV output.



# Where the electrical power goes?



Only a small portion of the applied power generates UV

# What should we monitor?

- Before: Readings on a two lamp system
  - Energy Density:  $953 \text{ mJ/cm}^2$  (UVA EIT 320-390)
  - Irradiance:  $313 \text{ mW/cm}^2$  (UVA EIT 320-390)
- After: Readings on the same system
  - Energy Density:  $1203 \text{ mJ/cm}^2$  (UVA EIT 320-390) + 26%
  - Irradiance:  $449 \text{ mW/cm}^2$  (UVA EIT 320-390) + 43%
- Only one thing done
  - Reflectors were cleaned

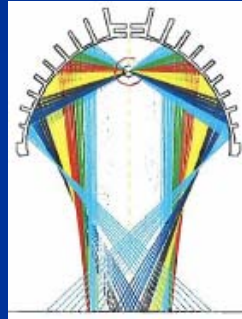
One little thing can have a big impact in the amount of UV reaching the cure surface

# What should we monitor?

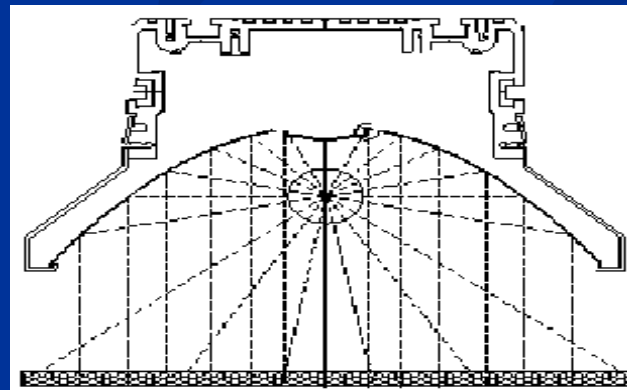
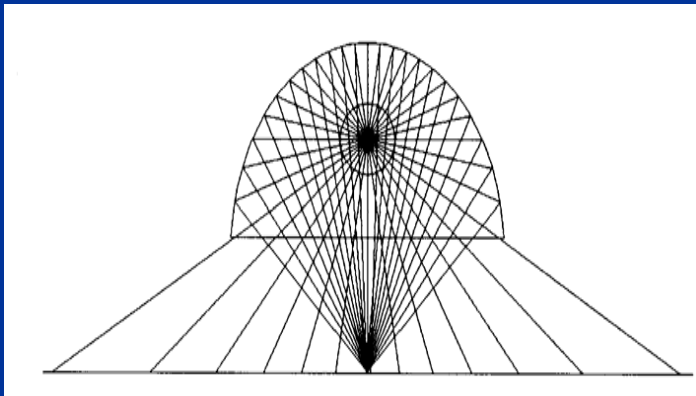
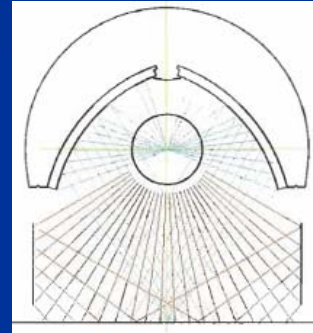
## Reflectors

- 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

Elliptical Reflectors

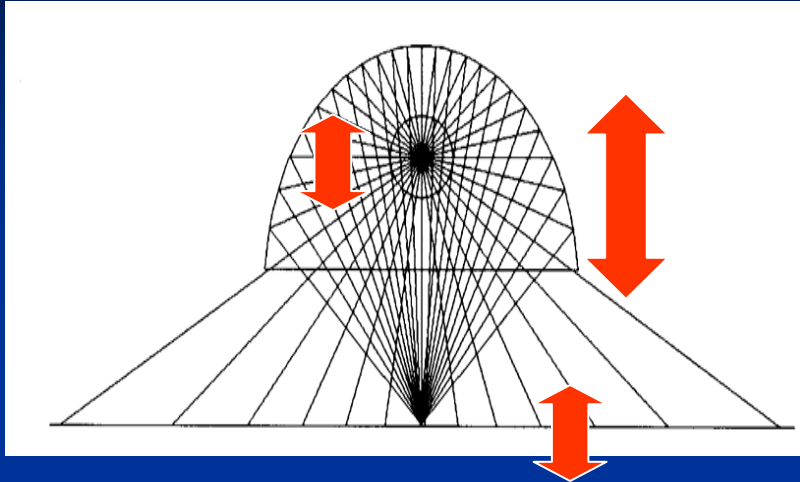


Parabolic Reflectors

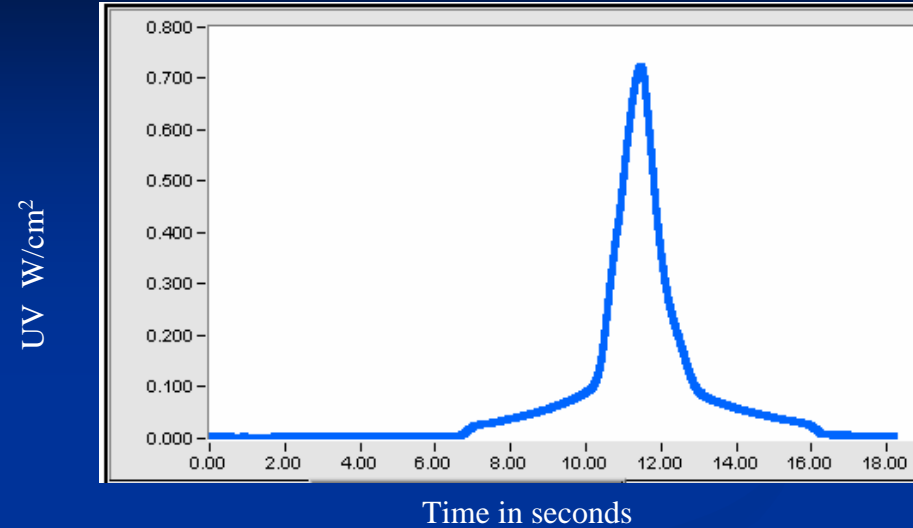


# What should we monitor?

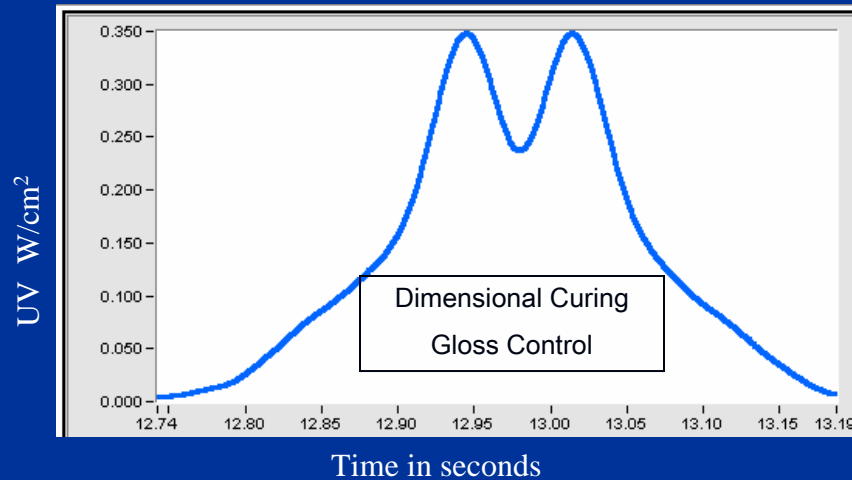
## Impact of System Changes



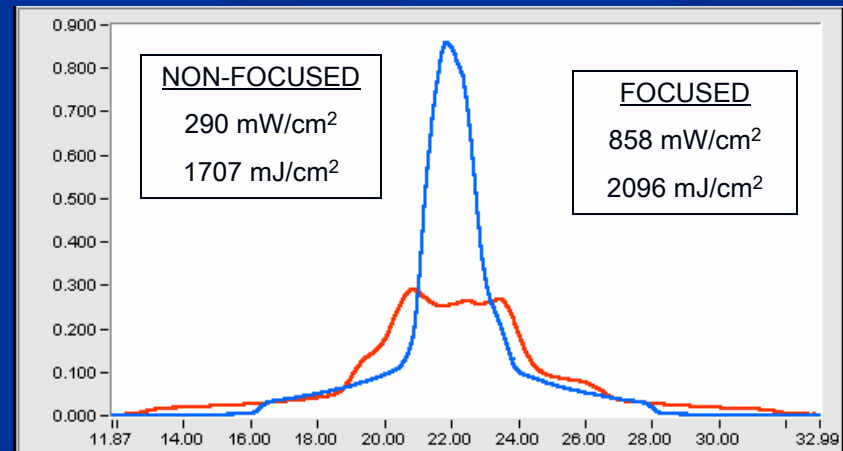
## Focused lamp



## Non-Focused lamp

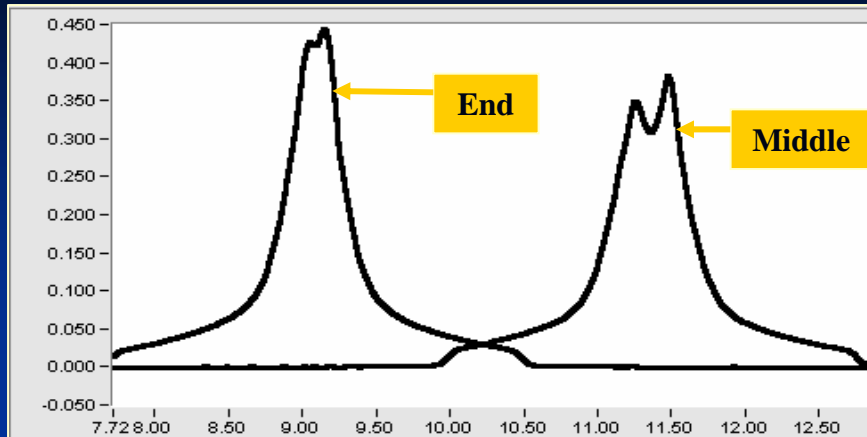


## Distance Change-Same lamp





# Life After The UV Honeymoon

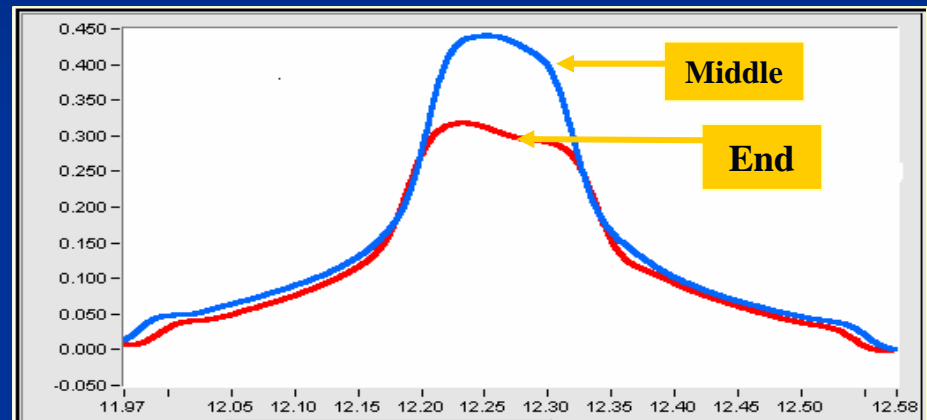


## Aging

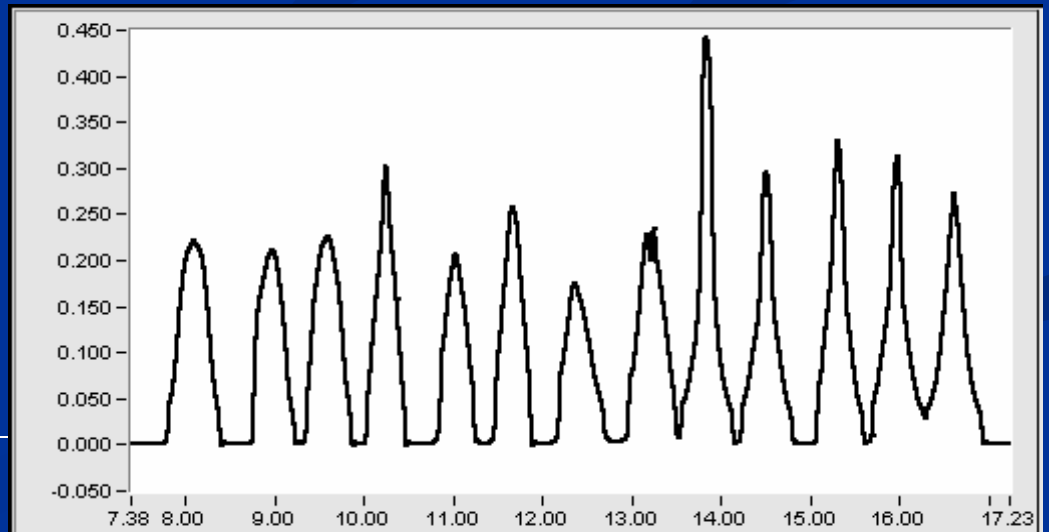
- Middle reading higher
- Arc bulb aging on ends
  - 440mW/cm<sup>2</sup> in the middle vs. 317 mW/cm<sup>2</sup> at the end
  - Width of source to width of product?
  - Time to replace bulb?

## Sagging

- Middle reading lower on middle to end comparison
  - 15 % difference in irradiance levels
  - Rotate bulbs
  - Cooling issues?

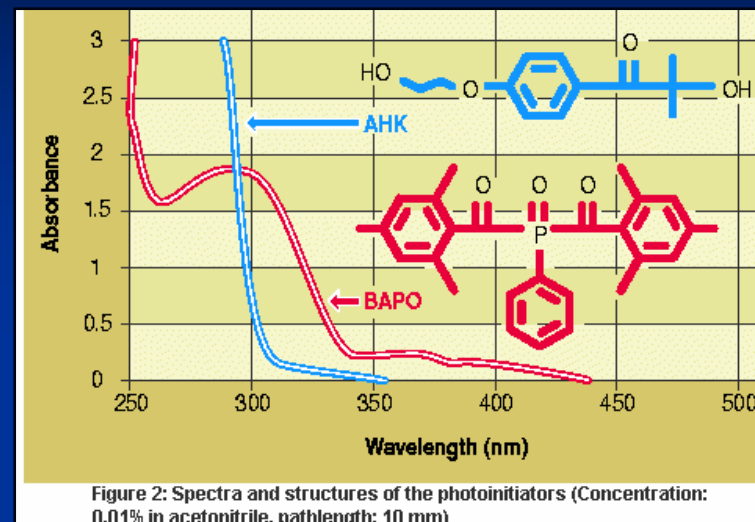


## Multi-Lamp Systems



# What should we monitor? UV Spectral Output

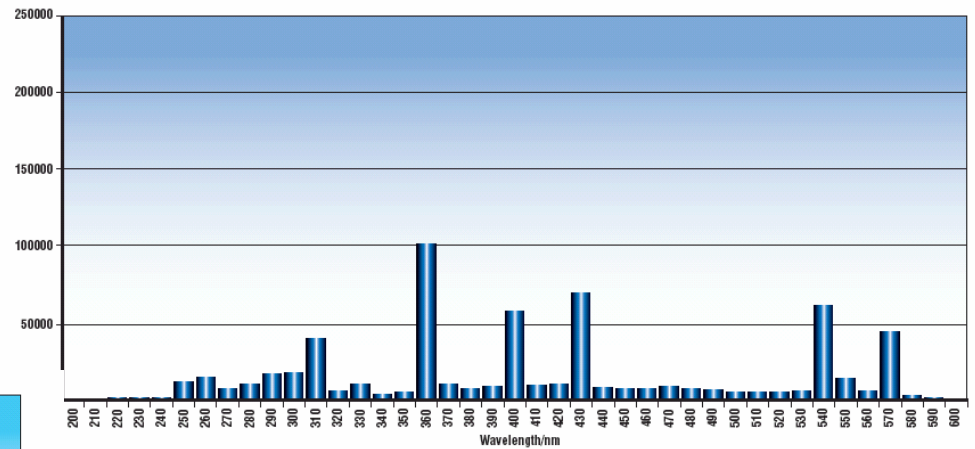
- Match the UV light to your process and chemistry Different types of bulbs, variations in the bulb over time and variations in the bulb with power, power supplies
- Diameter of bulb, cooling system and airflow in lamp housing
- System manufacturer can tell you what types of bulbs your system can use
- Not always interchangeable due to power supply-kicker
- Variations between manufacturers, match to process
- Ozone producing (more UVC) or Ozone free (material)
- Buy bulbs based on best value and not the cheapest cost. Watch purchasing staff getting 'specials'



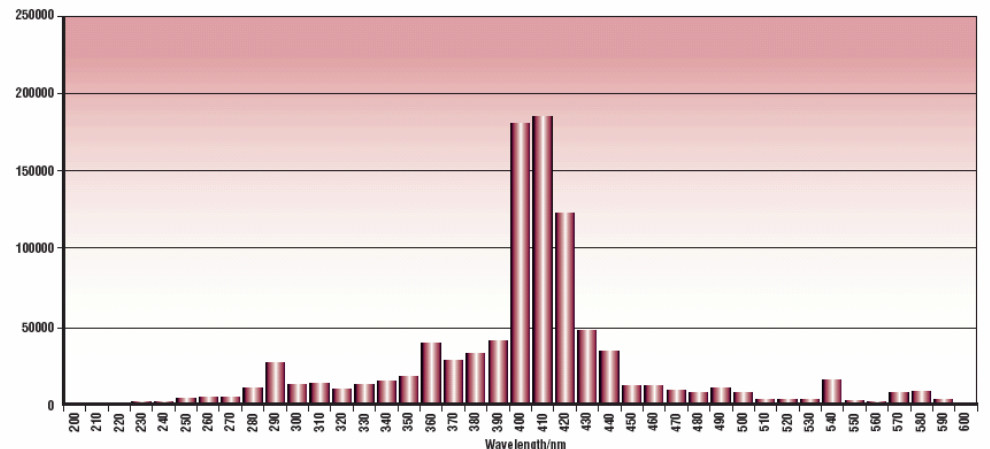
Bulb Type & Focus Indicator

# What should we monitor? UV Spectral Output

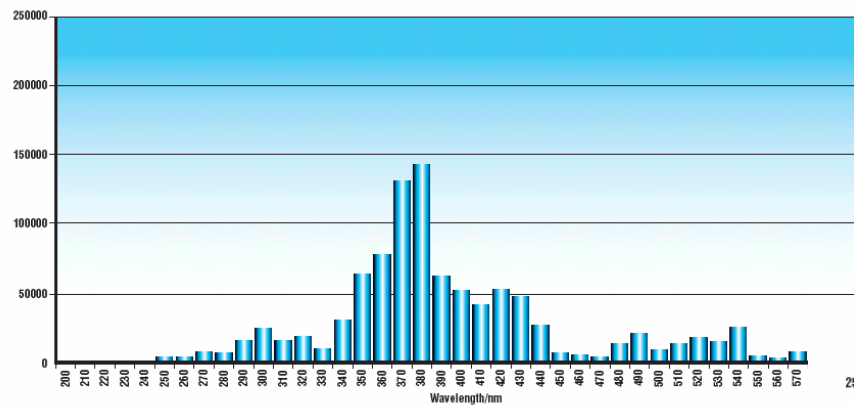
Mercury Lamp Spectra  
“H” Lamp



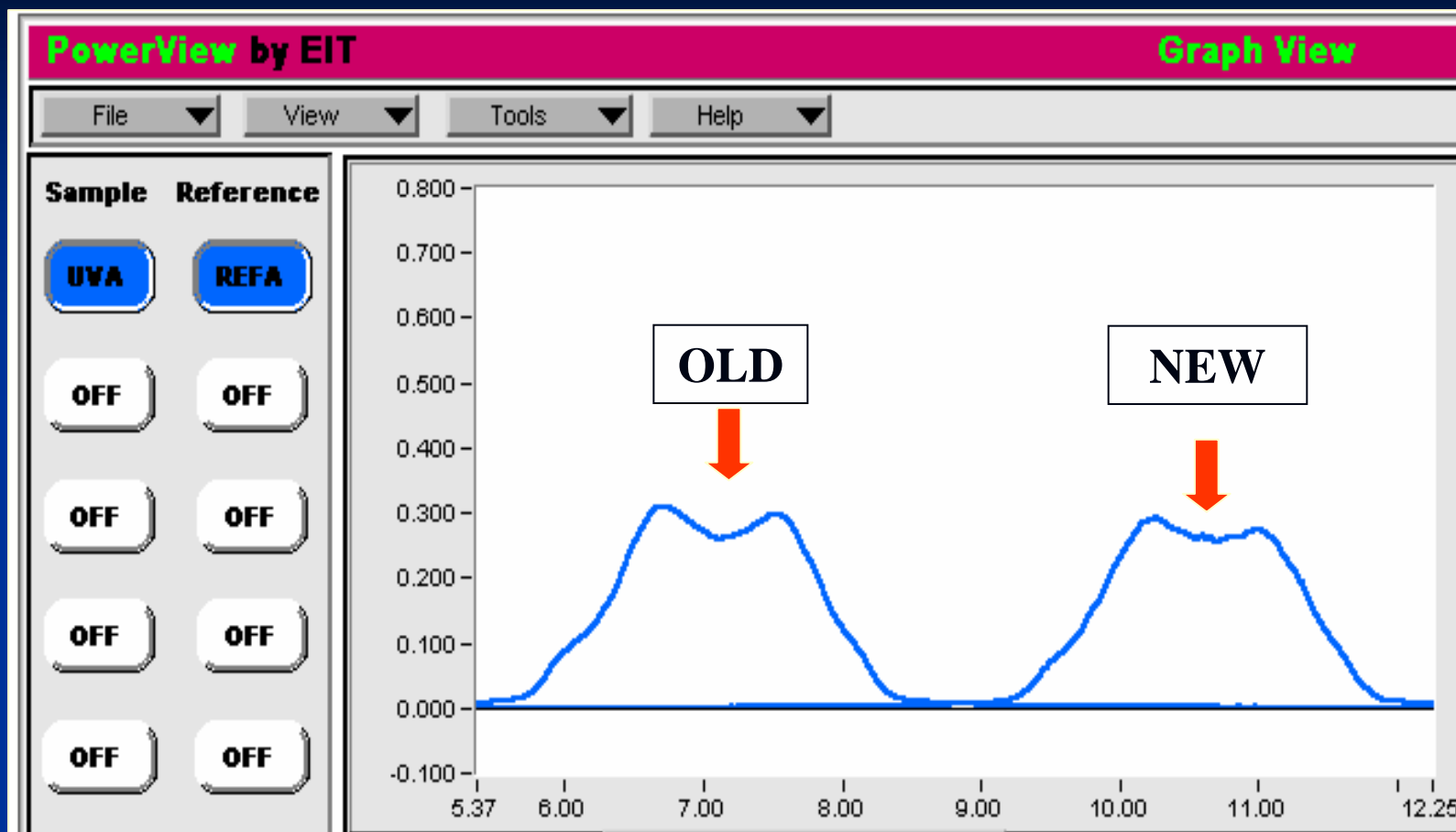
Iron Additive Lamp Spectra  
“D” Lamp



Gallium Additive Lamp Spectra  
“V” Lamp



With 600 hours of run time would you change this bulb?

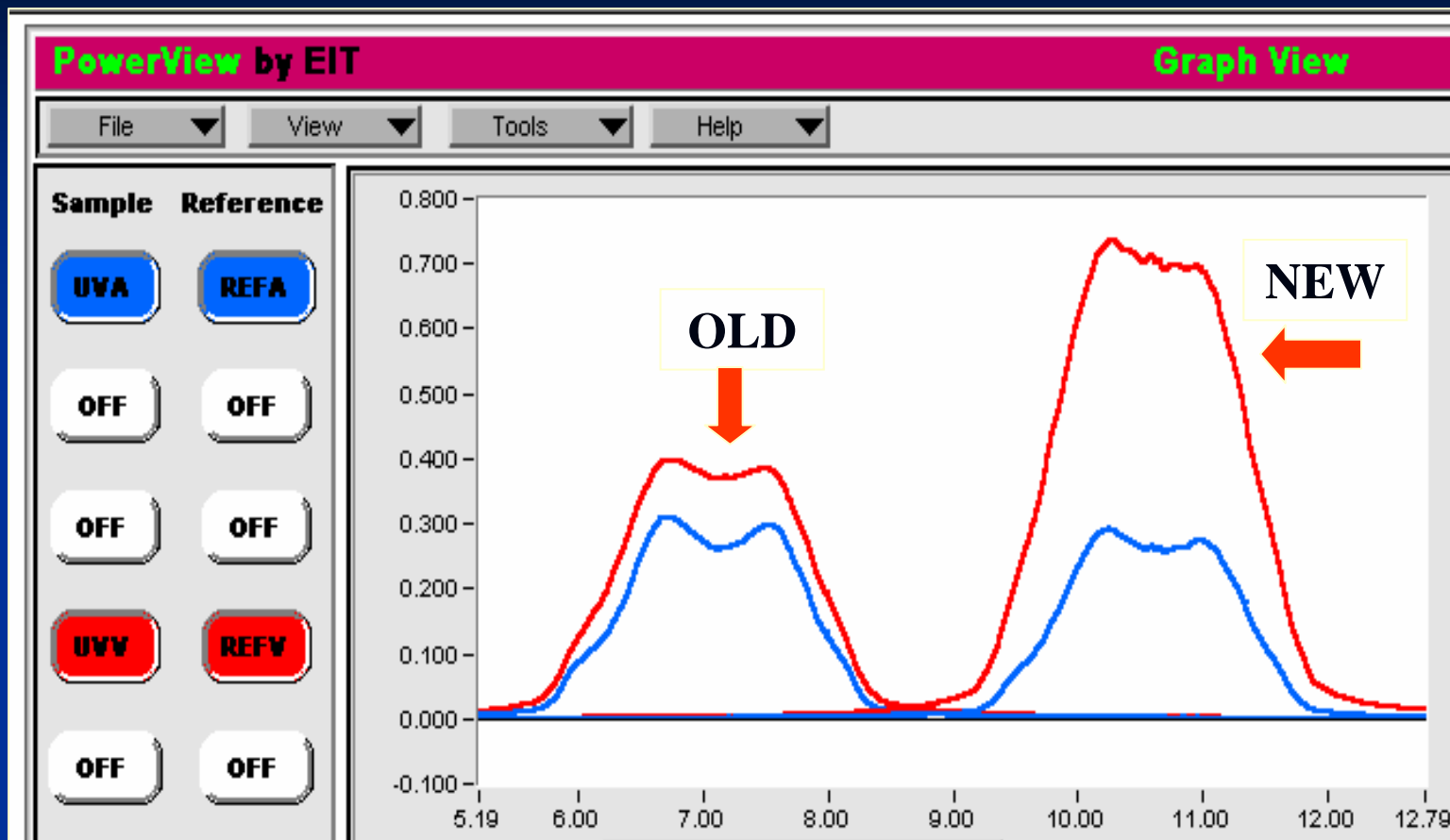


**UVA Energy Density: 537 to 487 mJ/cm²**

**UVA Irradiance: 309 to 290 mW/cm²**

UVA EIT 320-390

# Change Now?



**UVV Energy Density: 737 to 1331 mJ/cm<sup>2</sup>**

**UVV Irradiance: 397 to 734 mW/cm<sup>2</sup>**

UVV EIT 395-445

# What should we monitor?

Do you have any additional parameters unique to your process or environment?

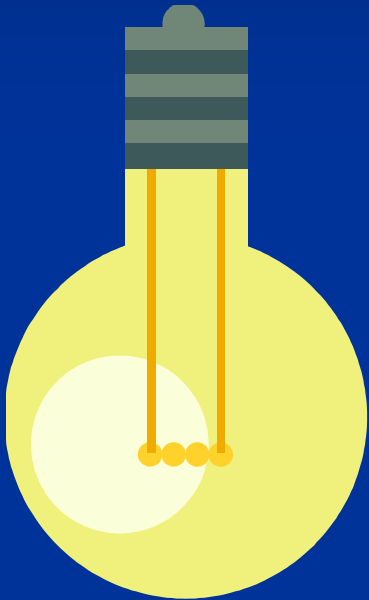
## Examples:

- Inert Curing-Nitrogen, Quartz Plates, Supplier Changes
- Temperature: Ambient, Exhaust, Water Cooled
- Humidity, Static, Handling, Storage

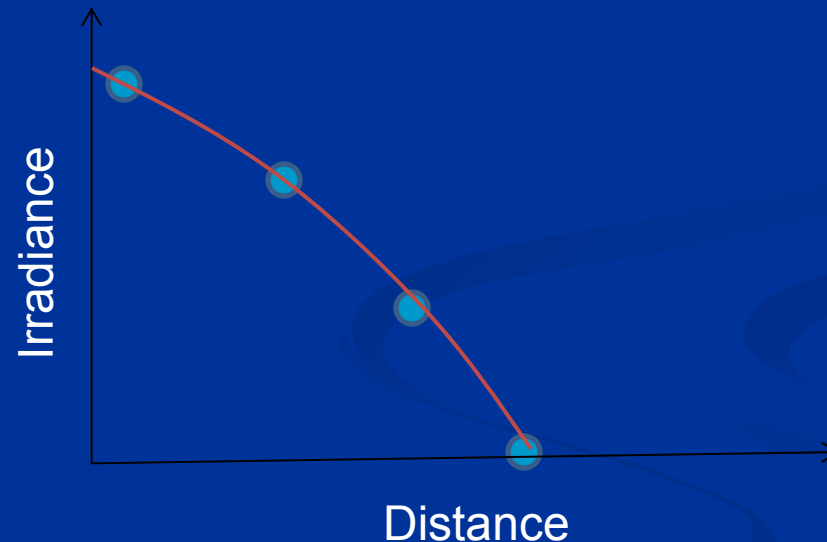


# Irradiance

- 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 ( $\text{cm}^2$ )
- Depth of cure, penetration through pigments and opaque colors, adhesion to the substrate



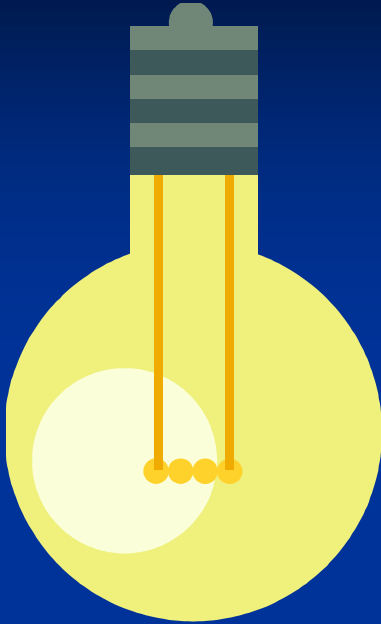
## Irradiance as function of distance



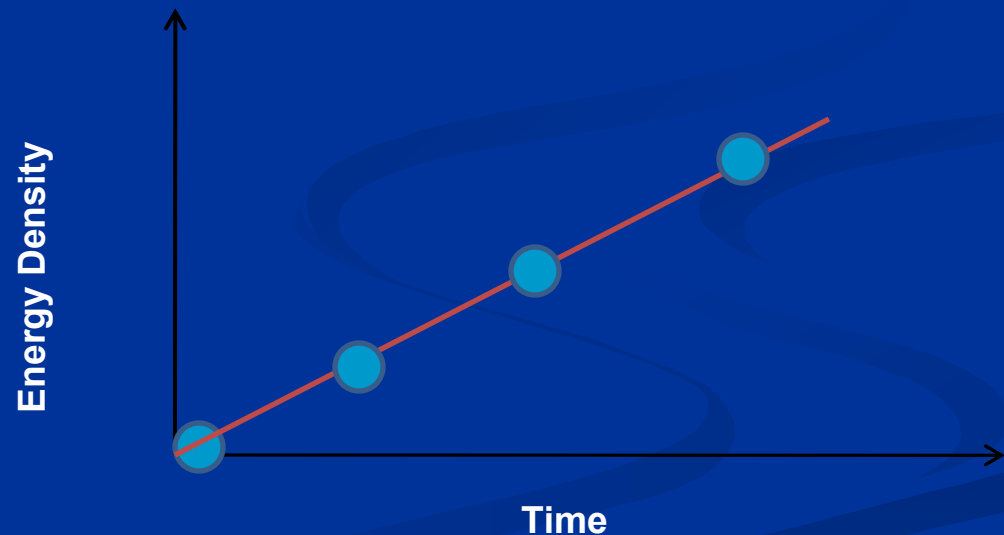
Readings Decrease with the Square of the Distance.



# Radiant Energy Density as a Function of Time

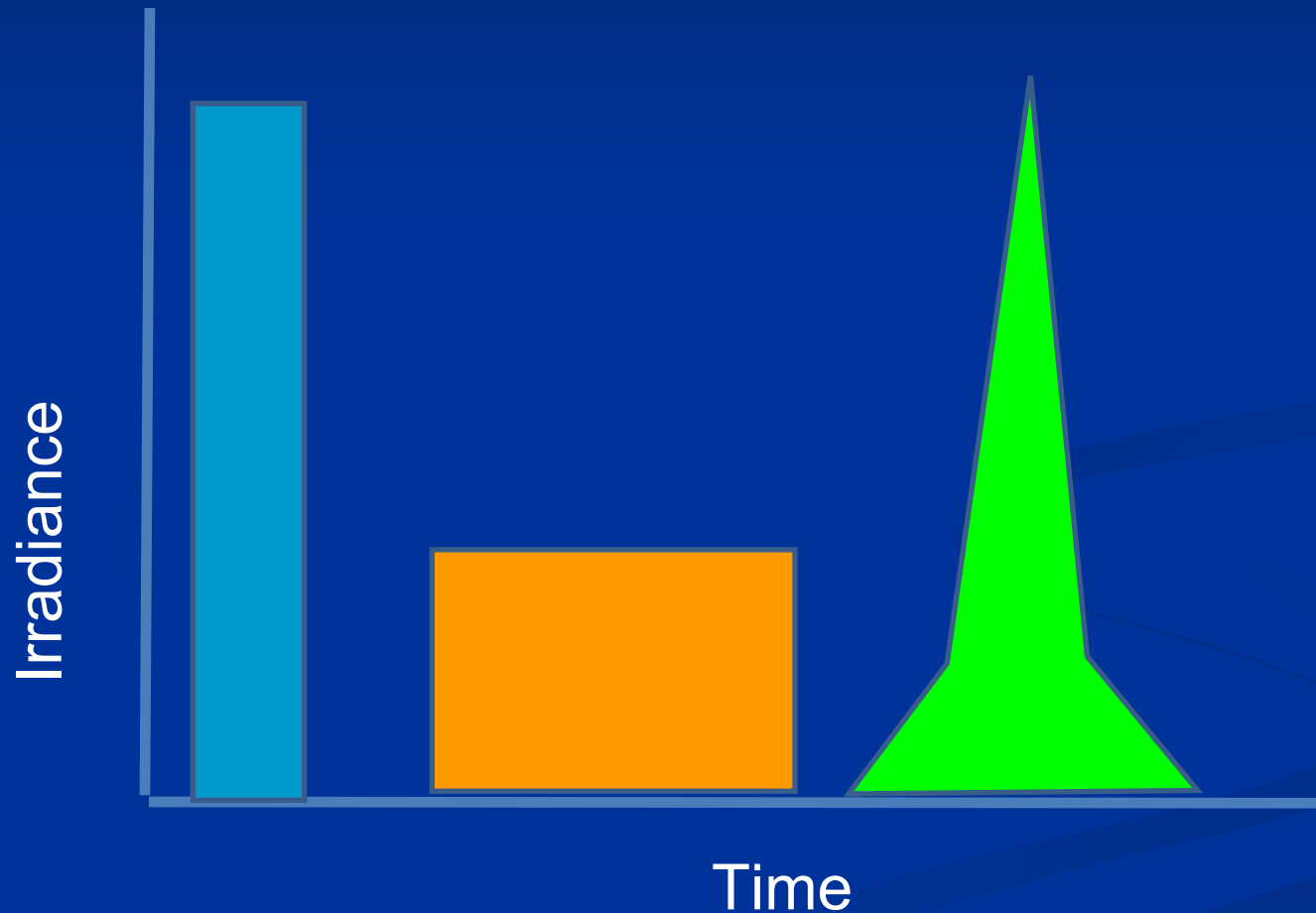


- Expressed in joules or millijoules per square centimeter ( $\text{J}/\text{cm}^2$  or  $\text{mJ}/\text{cm}^2$ )
- Incorporates time as part of the measurement
- One watt for One second = One joule
  - Area under the irradiance curve
- Often the only UV exposure guide number supplied
- Important for total and complete cure of material



## Equal Joules = Equal Cure?

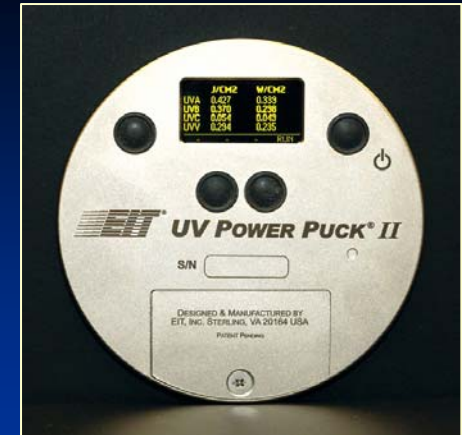
- Area in each figure approximately equal
- Represents the “area under the curve” or Joules/cm<sup>2</sup>
- Equal Joules  $\neq$  Equal Cure?



# How do we measure?

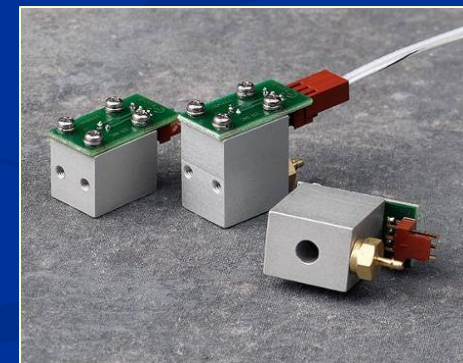
## Absolute Instruments

- Absolute units ( $\text{mJ}/\text{cm}^2$  and  $\text{mW}/\text{cm}^2$ ), compare readings between curing units and locations



## Relative Instruments

- Relative units, electronic signal proportional to lamp brightness (% intensity), on line continuous monitoring, feedback to display, PLC



# UV Instrument Selection

## Evaluate Application

- **Linear**
  - Linear travel, flat
- **Area Flood**
  - Flat or complex travel, lower irradiance levels, motion varies from timed exposure with no movement to complex
- **Spot**
  - Small areas, liquid or fiber guides
- **Other**
  - Germicidal

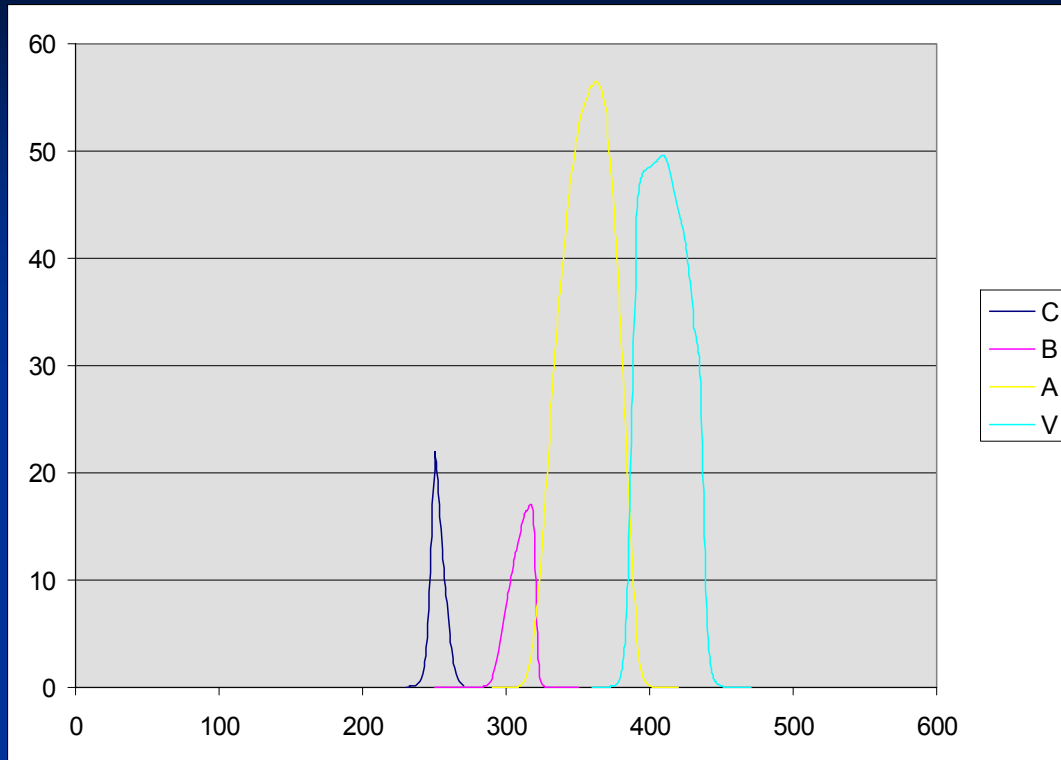


## Select Right Instrument For Application

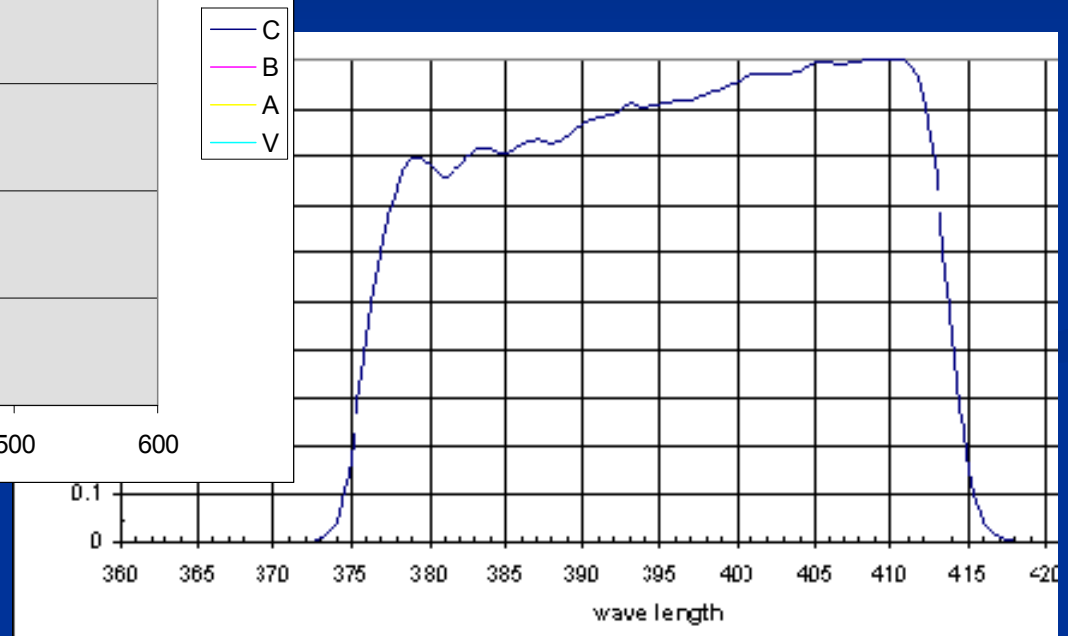
- **Reading Type**
  - Absolute or Relative
- **Size**
- **Product Type**
  - Continuous-online
  - Numeric Display of Irradiance & Energy Density
  - Profiling-irradiance over time
- **Source/Bulb Type**
  - Arc
  - Microwave
  - Pulsed (Xenon)
  - LED
- **Bandwidth(s)**
  - (UVA, UVB, UVC, UVV)
- **Dynamic Range**
  - Exposure vs. curing
  - But I get readings.....
- **User Expectations**



# UV Bandwidths



UVA, UVB, UVC, UVV (EIT)

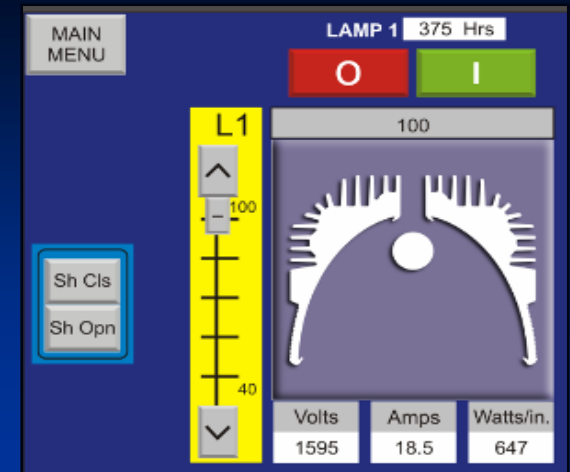


UVA2 (EIT)

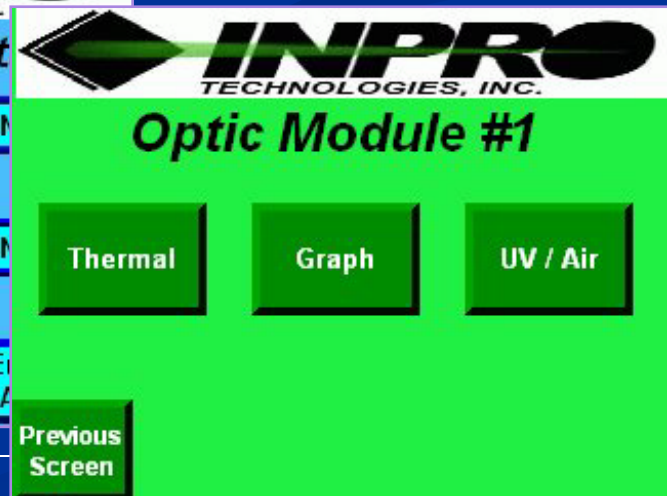
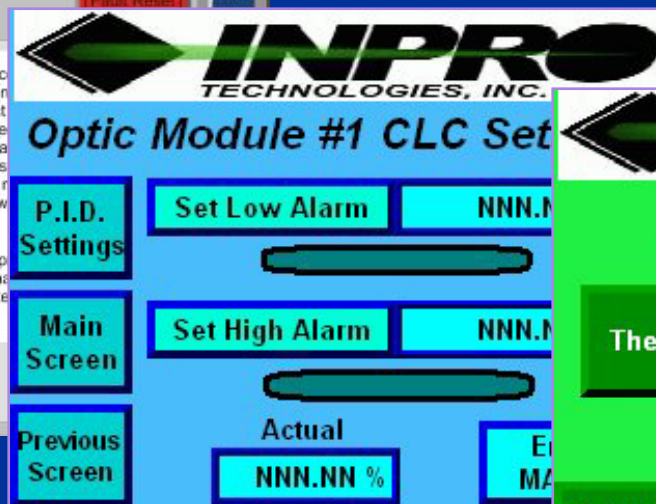
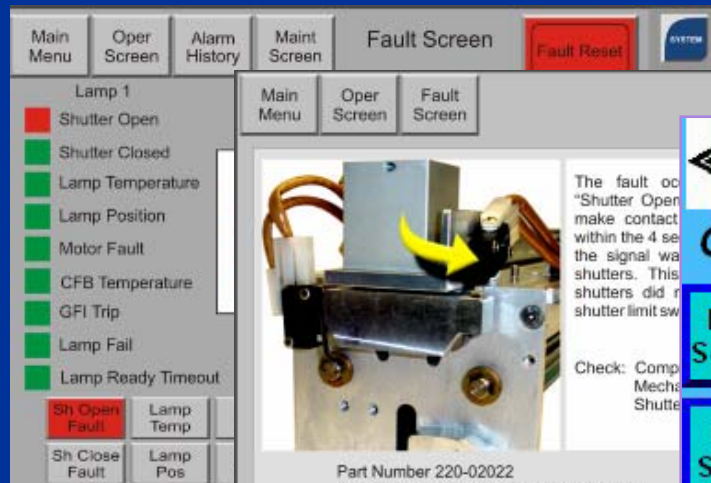
# State of the Art Equipment



- Touch screen PLC controller
- Focus Adjustment
- Image based controls
- Lamp status
- Trouble shooting guides
- On-Line Displays



Lamp 100%



# UV Measurement and Process Control

- We aren't smart enough to know what matters and what doesn't so we copy everything  
Brian Harrison-Intel
- ***Be as smart as the folks at Intel***
- Goals are deceptive-the unaimed arrow never misses  
Charles Knief (Kimo's Rules)
- ***Great advice for a vacation or beachcombers lifestyle***
- ***Know your process & process window, know you will have a job***
- UV measurement can't help you unless you document and record the readings!  
Jim Raymont-EIT
- **Where did I put those UV readings?.....**



# 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
- Ideal if the Process Window is forgiving and has a wide latitude. It takes work and time
- Invest before production & confirm when things are working!
  - Starting guidelines from formulator?
  - Operator Training, ISO/Procedure Documentation
- Define your lower limits and document the readings
  - Increase line speed/decrease applied power until you undercure, note readings and cushion by 20%
- Upper limits?
- Monitor your readings by job, hour, shift or day as required to maintain quality
- Establish your process window during the design/development phase
- Establish your process window when things are working

# Process or Cure Window

**Normal Operating Window**

**Caution 20% Undercure Buffer Range**

**Stop! Undercure Limit**

# Process or Cure Window for Temperature Sensitive Substrates

**Stop! Over temperature limit?**

**Caution 20% Over temperature Buffer Range**

**Normal Operating Window**

**Caution 20% Undercure Buffer Range**

**Stop! Undercure Limit**

## Sample Job Log

Date	Line Speed Dwell Time FPM		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> )		
2/17	25	22	400	780	0.859	1.45		

### Equipment variables

- Indicated vs. actual process speed

### For each UV lamp system

- Hour meter
- Power settings (WPI, Amps)
- Irradiance (W/cm<sup>2</sup>)
- Radiant Energy Density(J/cm<sup>2</sup>)
- Lamp matched to chemistry
- Focus/Reflector condition

### Other things to consider

- Date/job number
- Operator signature
- Mesh count
- Formulation type
- Pass/fail on specific QC tests-cross hatch, rub, registration
- Maintenance log of system
- Maintenance due date
- Radiometer type/bandwidths

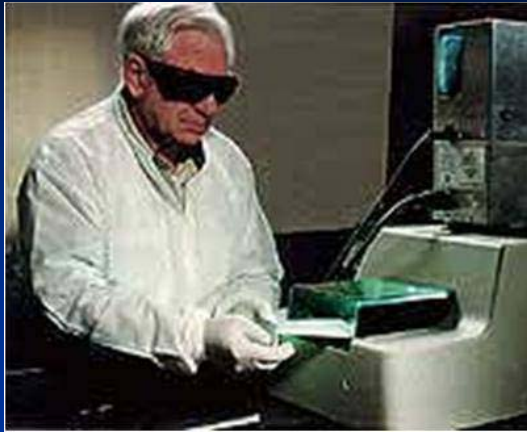
# Outside the Process Window?

- **PANIC!!!!!!! Call Formulator!!!! Point Fingers!!!!**
- Relax and breathe deep! You have the process window established! Right?
- Gradual change towards caution area?
- Which way do you have to go?
- Perform system maintenance
  - Measure, Clean, Rotate, Measure. Any Improvement?
- Replace lamps or adjust user controlled variables until you are back in your process window
- Work and communicate with suppliers in good times and bad times

**Get into “predict and perform preventative maintenance” routine  
vs. a “fix it when it breaks” routine**

**6 P's: Proper Prior Planning Prevents Poor Performance**

# UV Formulation Specifications



## Original Formulator Specification:

2x Hg lamps 80 W/cm, 5 meters/minute, forward feed



## Improved Specification:

- 2x Hg lamps 80 W/cm, 5 meters per minute, forward feed
- Joules or Watts more important?
- One 160-200 W/cm lamp work?
- Lamp Type? (H, D, V)
- Reflector type?
- Thermal?
- Coating Thickness (Mils?)

## Distance from the lamp

- Focus? Non Focus?

## Radiometer values

- Minimum irradiance
- Minimum energy density
- Instrument type
- Bandwidth
- 650 mW/cm<sup>2</sup>, EIT UVA (320-390)
- 700 mJ/cm<sup>2</sup>, EIT UVA (320-390)
- UVB?, UVV?, UVC?

# Understanding your instrument (and its limits)

- Treat and handle as an instrument
- Maintain on daily basis, calibrate & service as required
- Users expect the same accuracy as other instruments-current radiometer technology  $\pm 10\%$
- Optics
  - Filter and detector specifications
  - Spatial response (Cosine Response)
  - Design-Balance between optical stability (minimal solarization) and repeatable electronic signal level
- Electronics
  - Temperature sensitivity
  - Sample rates/Data collection speeds
  - Improvements in electronics since early instruments
- User induced errors and comparisons (real vs. perceived)
  - Comparison to other products

**Use your instrument within design specs**

**PICNIC errors: Problem in chair, not in calibration**



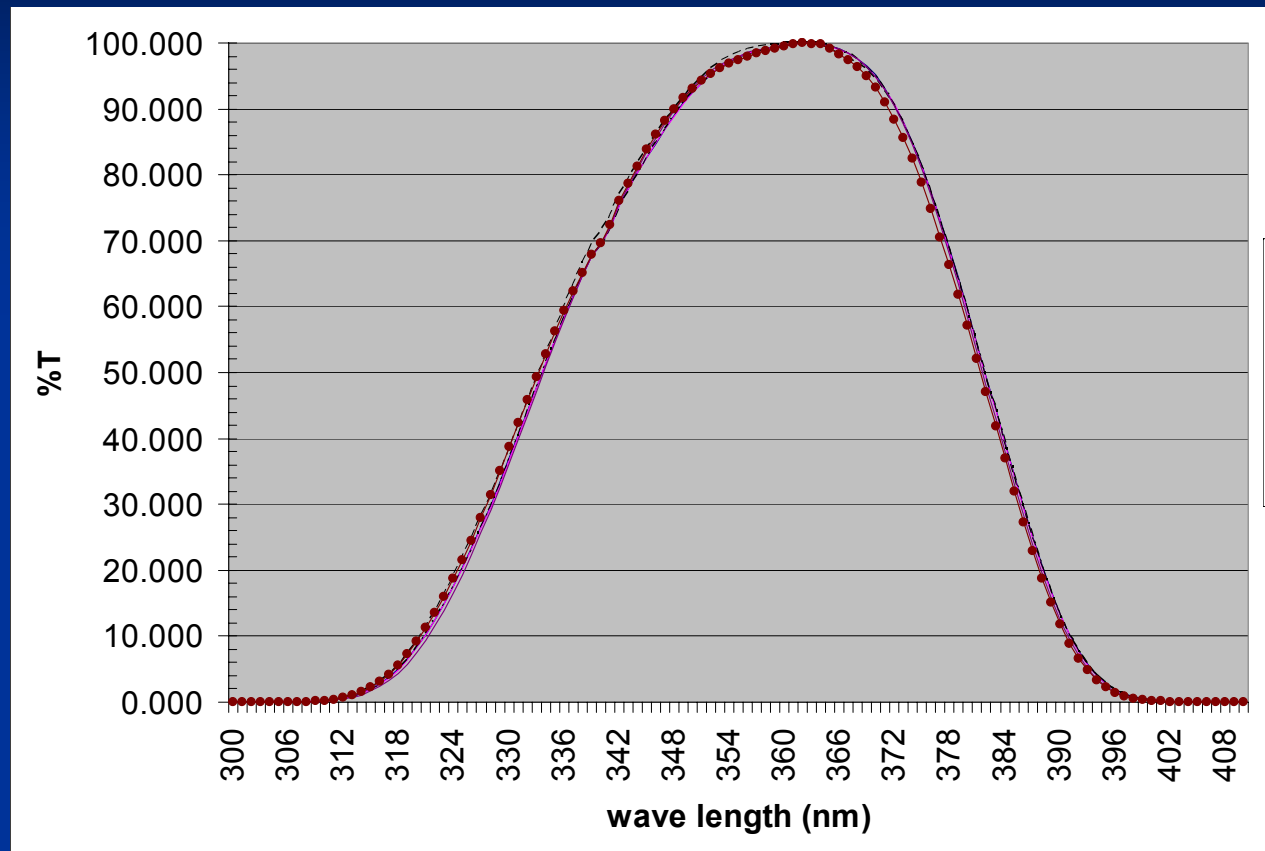
# Why Calibrate?

- Balance the amount of IR, Visible and UV the optics and detector “see” with the output signal from the detector
- Compensate for changes in the optics over time
  - Solarization
- Instruments used in harsh production & manufacturing environments
  - Irradiance levels:
    - Sunlight: +/- 20 mW/cm<sup>2</sup>
    - Production UV levels: 100's to 1000's mW/cm<sup>2</sup>
  - Physical damage to instrument
    - Drop, crush instrument, scratch optics
  - Optics/instrument coated with ?
- Electronics checkup
  - Physical and/or heat related damage



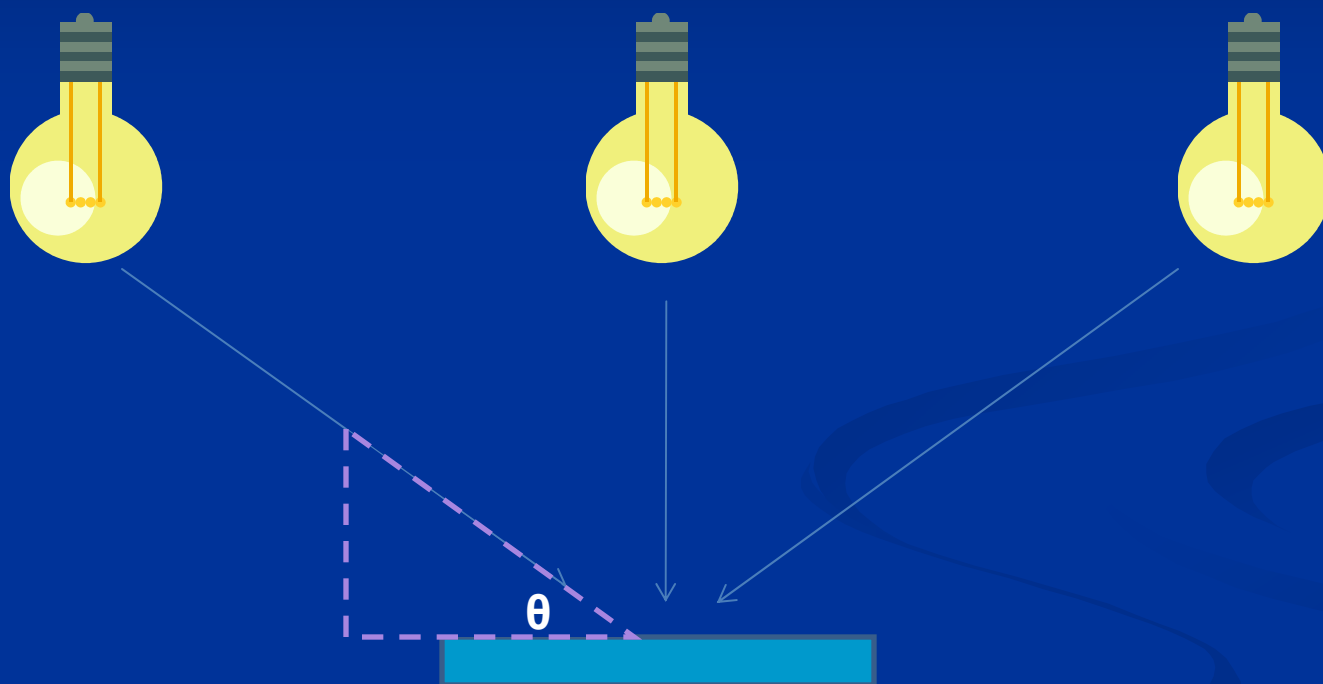
# Instrument Optics

- Normal to expect small variations between filters
- Test each optical component to avoid wide variations
- Tradeoff is \$ vs. performance
- Select & test the optics for better performance and unit to unit comparisons



# Instrument Optics: Spatial Response

$$E_{\theta} = E \times \cos\theta$$



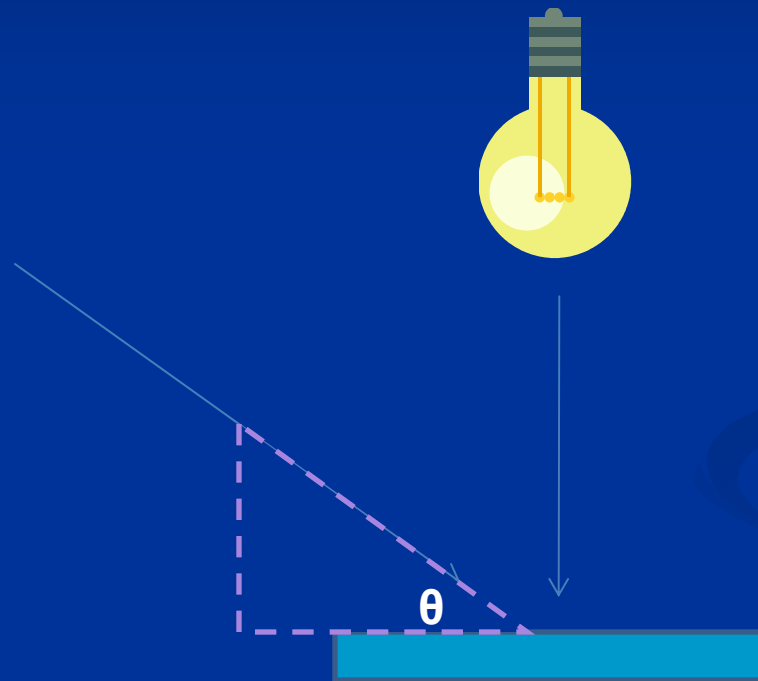
Cosine Response in Measurement

# Instrument Optics: Spatial Response

45° = .7 Watt

90° = 1.0 Watt

$$E_{\theta} = E \times \cos\theta$$

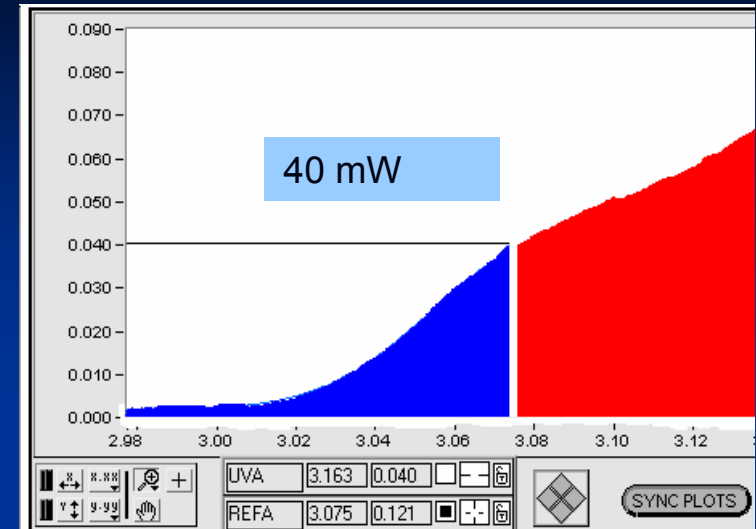


Cosine Response in Measurement

# Instrument Electronics

## Threshold

- Irradiance level which causes the unit to start measuring UV
  - Counts all UV past that point
  - Varies due to scale, electronic response, optics, design
  - Use right dynamic range (scale) of instrument



## Temperature

- Unknowingly introduce variations to readings based on the internal temperature of the unit
- As detector temperature raises, readings may drop
- Try to maintain consistent conditions and avoid rapid, repeated, long duration high intensity runs
- If it's too hot to touch – it's too hot to measure

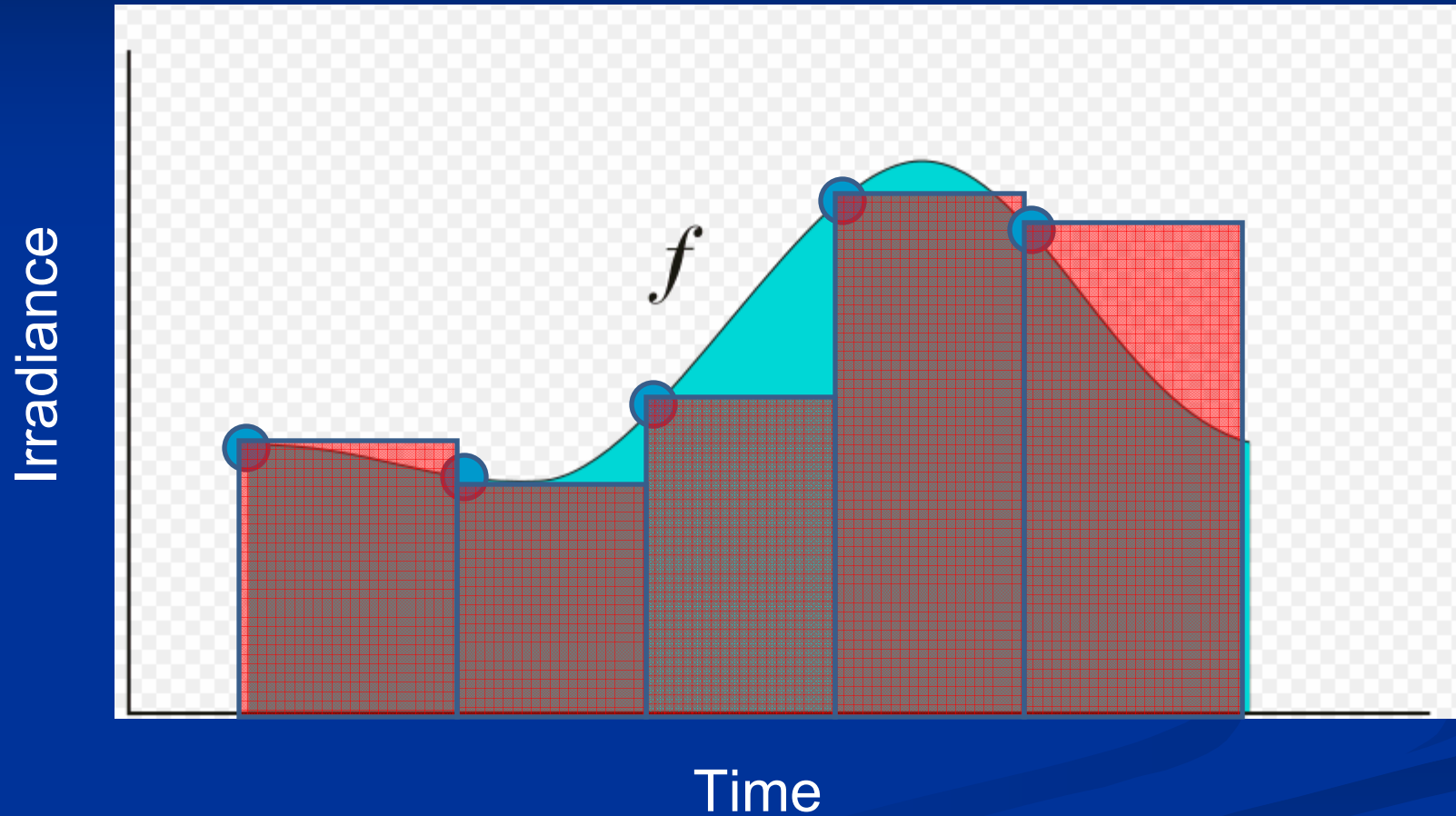


# Instrument Electronics

## Instrument Sample Rate

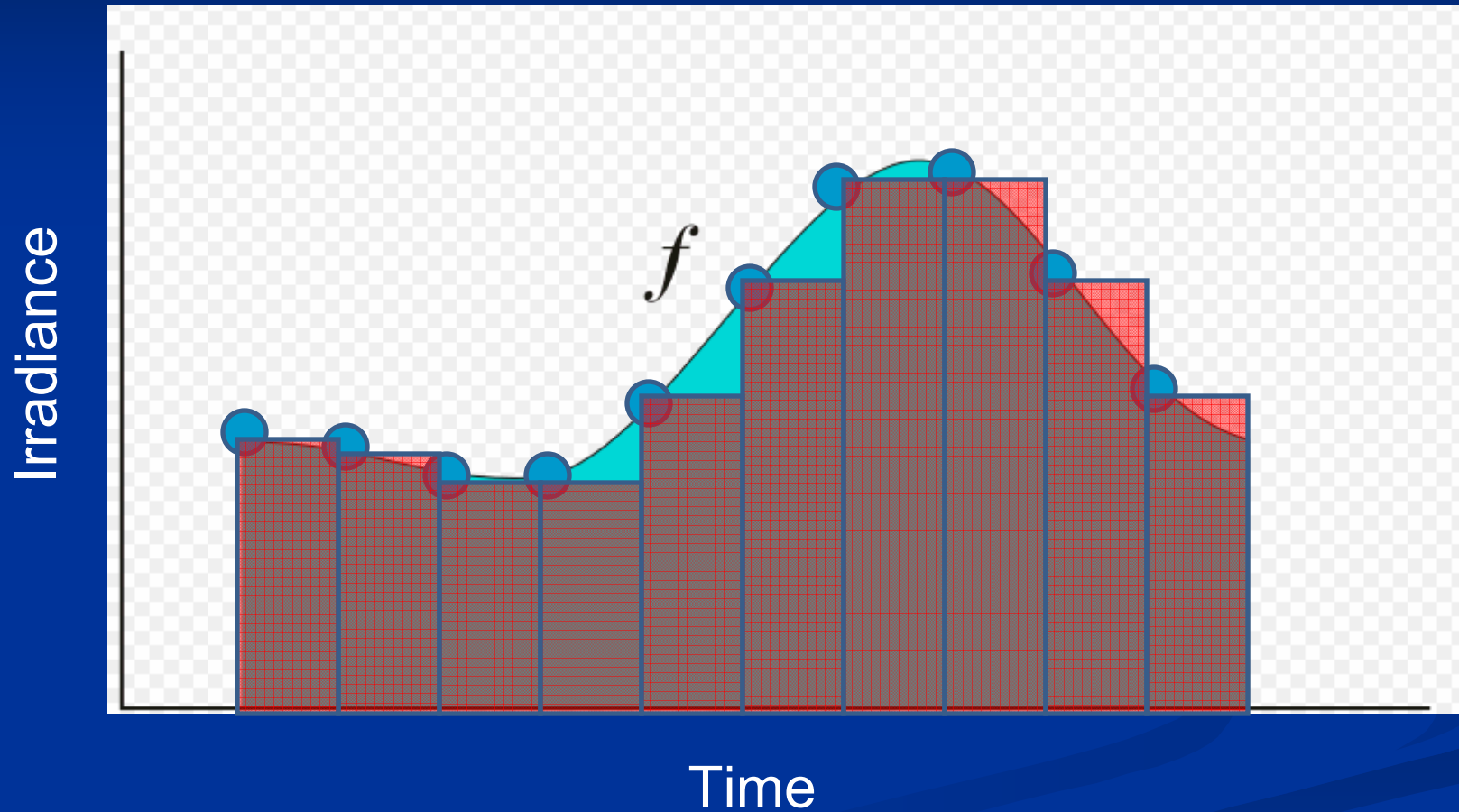
- Unknowingly introduce variations to reading based on the sample rate of the unit
- Did the unit collect an adequate number of samples to produce a number you can trust?
- Slower is better-irradiance values should be similar, calculate energy density information from the reading at a slow speed

## Instrument with Low Sampling Rate & Fast Belt Speed

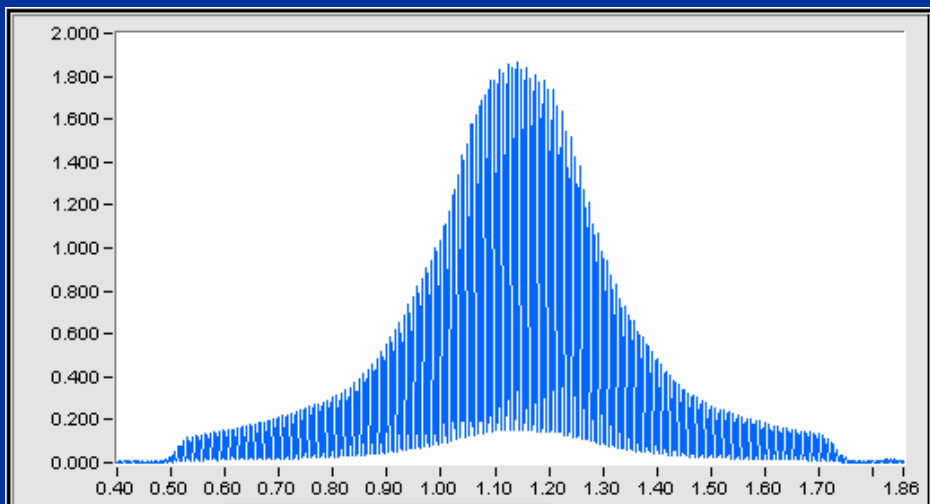
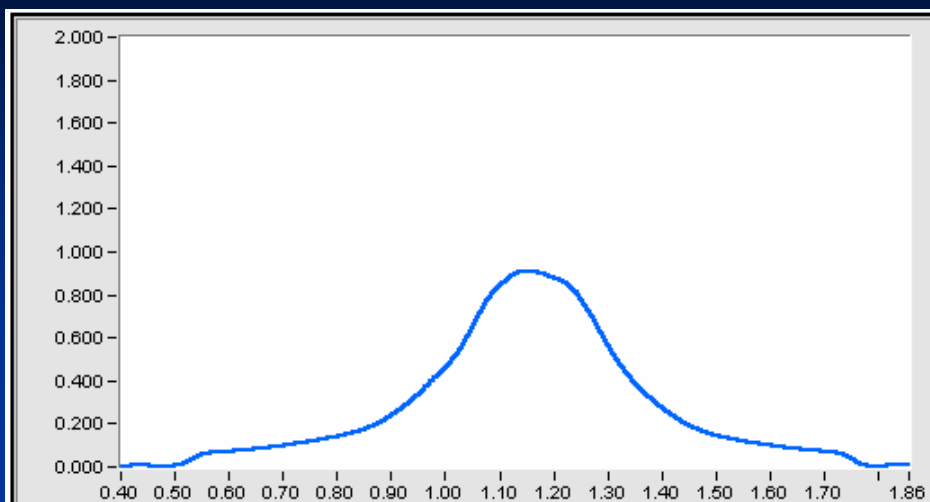




## Instrument with Faster Sampling Rate



# What 'dialect' of UV Watts are you speaking?



- Over head lights-on or on/off at 60/50 Hz?
- Sampling rate/electronics of the unit
  - Yesterday: 5-25 sample/second
  - Today: 128-30,000 samples/sec
- Average Peak irradiance: (Smooth On): 910 mW/cm<sup>2</sup>
- Peak-Peak irradiance: 1866 mW/cm<sup>2</sup> (Smooth Off)
- Energy Density: the same
- What is the impact?
  - Power supplies?
  - Speed limits to process?

Be specific when communicating instrument values



# Thank You Questions?

**EIT-Instrument Markets**

**108 Carpenter Drive**

**Sterling, VA 20164 USA**

**P:703-478-0700/F:703-478-0815**

**E:uv@eitinc.com**

**Web: eitinc.com**