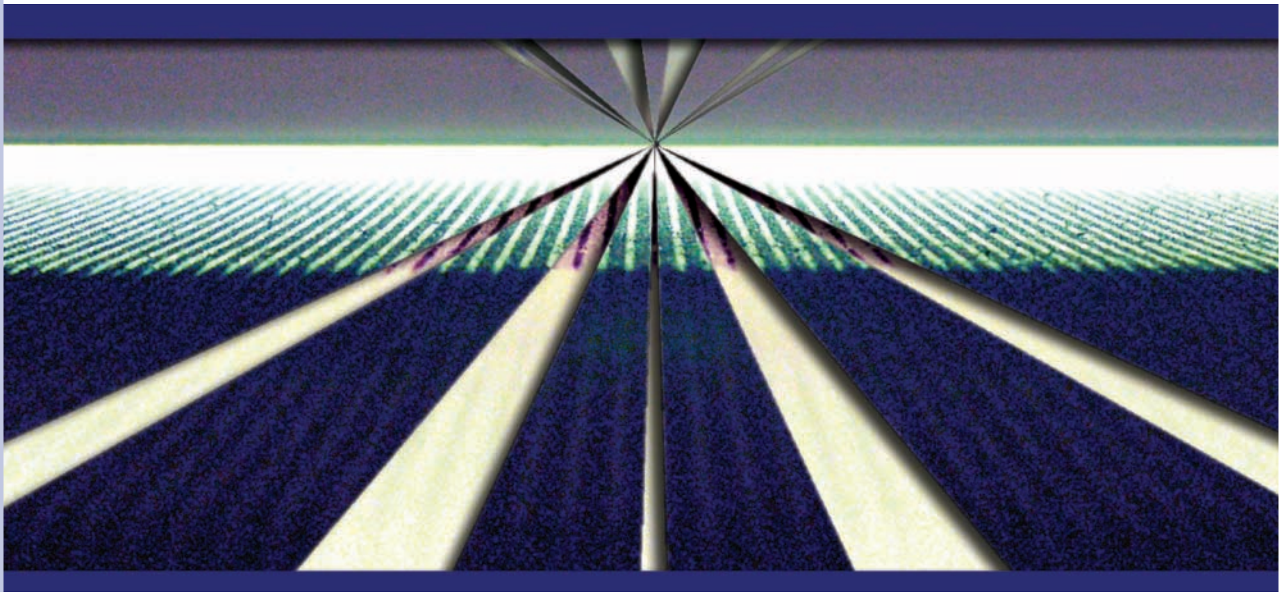
Radiometers — The Best of Intentions



When outlining and writing this article, my thoughts kept coming back to the Travis Tritt song, Best of Intentions. Written and performed by Travis, the following lyrics are part of his song, Best of Intentions.

I had big plans for our future
Thought I'd be so much further
by now
Now some people think I'm a loser
'Cause I seldom get things right

No matter how much I do wrong

That I had the best of intentions
all along

So here I am asking forgiveness

And praying that you'll understand
Don't think I take you for granted

'Cause I've had the best of intentions

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The lyrics also seem to apply to UV curing, process control and proper radiometer use. Do/did you have big plans for UV curing in your company? Are things not going as well as you would like? Did you start with the best of intentions when it came to UV? Have you wound up in a situation where you feel like a loser? Are you also praying and trying to understand what is going on with your UV? What do you do when your inks or coatings are not curing? What drives your maintenance programs? What kind of scrap rate will your profit margin support?

This article will concentrate on radiometer basics. A radiometer to measure and document your UV system(s) is part of an overall process to establish and maintain control. Information on the other variables in your process and the basics of UV measurement/process control were covered in an article Life After the Honeymoon: Getting to Know, Understand, Respect and Live with your UV System and Process in the SGIA Journal, Third Quarter 2001. The article is also available from EIT.

Did you have big plans for UV curing in your company? Are things not going as well as you would like? Here are some tips to get your "Best of Intentions" back on track.

Understanding the Process

Establishing, maintaining and understanding your UV process will save your company time and money through:

- Increased yields,
- Reduced scrap and time needed to change over and get a run going,
- Increased "up time" of your UV systems through a preventative maintenance program, and
- Better communication with your suppliers.

While your chosen field of work is called Graphic Arts, UV curing and the control of the UV process is an area that benefits when it is approached as a science. If you are

By **Jim Raymont**, *Director of Instrument Markets Group*, E.I.T. Inc.

Learning to use your radiometer properly and understand the information from it is the second step to saving money

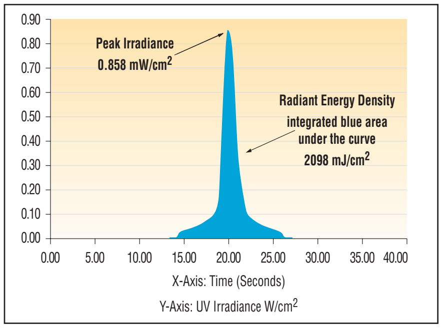

Figure 1: Measurement Terminology – Irradiance Profile

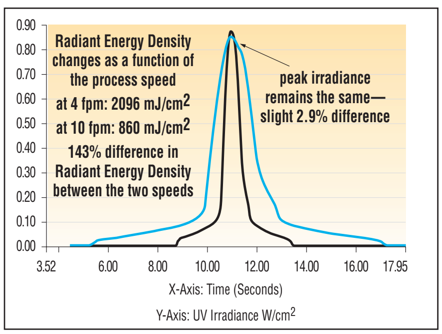

Figure 2: Effects of varying the process speed from 4 fpm (blue) to 10 (black) fpm

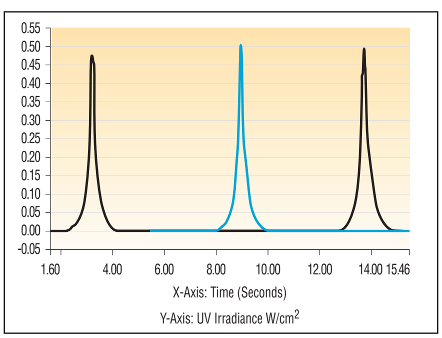

Figure 3: The effects of adding a second similar UV system to your existing configuration. The irradiance values (mW/cm2) are similar. The radiant energy density increases from 177 mJ/cm2 (one UV system) to 393 mJ/cm2 with the second UV system (122%).

not documenting process variables, it may be time to assess and determine if control of your UV process can help your company save time and money.

Congratulations if your company is already using a log or system to measure, document, record and track the variables in your process. You have taken the first step and have the best of intentions! A radiometer is an important part of this process. Learning to use your radiometer properly and understand the information from it is the second step to saving money and reducing costs.

Terminology Review

Irradiance

Irradiance is the radiant power arriving at a surface per unit area. With UV curing, the surface is most often the substrate and a square centimeter is the unit area. Irradiance is expressed in units of watts or milliwatts per square centimeter (W/cm^2 or mW/cm^2).

In UV curing, the term "intensity" is also commonly used to describe irradiance. Irradiance more correctly describes the concept of UV arriving at a two-dimensional substrate. UV irradiance is important in your process because it provides the "punch" to:

- Penetrate through opaque and pigmented coatings,
- Give depth of cure, and
- Allow adhesion to the substrate.

The average peak irradiance is the value most often reported from radiometers.

Radiant Energy Density

Radiant energy density is the energy arriving at a surface per unit area. A square centimeter is again the unit area and radiant energy density is expressed in units of joules or millijoules per square centimeter (J/cm^2 or mJ/cm^2). The radiant energy density is the time integration of the irradiance. In an exposure where the irradiance value is constant over time (square profile exposure), the radiant energy density could be estimated from the relationship of one watt for one second = one joule. Most exposures in UV curing and especially in graphics applications where the product is moving are not "square profiles." The product moves into the UV system, into the area of increasing UV, through the peak UV irradiance area and then exits through a decreasing area of UV irradiance. To determine the radiant energy density in this type of profile, the area under the irradiance curve needs to be measured and calculated. *(See figure 1)*

In UV curing, the term "dose" is also commonly used to describe radiant energy density. The radiant energy density is important for total and complete UV cure.

Other Measurement Terminology

Irradiance Profile — an irradiance profile is a plot of the irradiance on the y-axis as a function of time on the x-axis. This is extremely useful for determining the focus of a system and for analyzing multi-lamp systems. An irradiance profile is also good for illustrating measurement concepts. Many of the graphics in this article were generated with information collected by a radiometer that profiles the irradiance over time.

Spectral Radiometer — a spectral radiometer is able to profile the irradiance on the y-axis as a function of spectral distribution on the x-axis. Depending on the instrument, the distribution may be measured in units as small as 0.5 nm.

Temperature Profile — a temperature profile is a profile of the temperature measured by a thermocouple on the y-axis as a function of time of the x-axis. The profile may help in curing situations with temperature sensitive substrates. **A Glossary of Terms** — The UV Measurement Focus Group of RadTech has prepared a glossary of terms used for Ultraviolet (UV) Curing Process Design and Measurement. The purpose of the glossary is to assist those involved with UV curing and to allow communication in the same language. The glossary can be found on the RadTech website: www.radtech.org.

Process Control Targets

UV monitoring on the production floor usually means confirming that the UV irradiance (W/cm^2) and UV radiant energy density (J/cm^2) values remain above the levels that have been identified to cause rejects or produce poor quality product. With temperature sensitive substrates, the user may also have to monitor and maintain the temperature below a certain point. Often this means keeping the UV below a certain upper level to minimize ambient temperature increases from infrared energy.

Reducing the amount of UV will eventually induce a failure and needs to be identified. The minimum level of UV required for your process needs to be determined through testing. This minimum amount of UV can be found by:

- Increasing the process speed and
- Reducing the amount of power applied to the UV system.

Once you have found the failure point, mark it as the absolute minimum amount of UV required for your process. Build in a safety margin and set your monitoring/log system up to run at the absolute UV minimum plus a safety margin.

The amount of UV needed to cure a coating is a function of the equipment, process, substrate and ink/coating formulation. The amount of "cure" information available from a formulator varies.

Some formulators will supply minimum cure guidelines that you can use as a starting point with their products. For those that supply guidelines, they can vary from useless (product cures with a medium powered UV source) to extremely helpful and detailed (ink series, substrate, application method, bulb type, suggested minimum irradiance and radiant energy density values to use as a starting point). Historically, the UV radiant energy density (dose) has been the favored UV exposure guide number supplied by formulators. This provides only part of the needed information to cure an ink or coating. Imagine trying to make cookies with a recipe that tells you to "expose" the cookies 100 ºF degree hours. How will you bake your cookies: 100º for an hour, 200ºF for 30 minutes or 400ºF for 15 minutes? Many formulators have researched the minimum irradiance values required for a particular coating.

Some formulators are reluctant to publish or share guidelines because they do not want to be responsible if the process and cure guidelines are not followed exactly as tested in their lab.

I think that the technical staff at formulators would make excellent police detectives. Listening, the ability to observe, question a customer (suspect) and solve a problem (crime) are their most important skills. Imagine a phone call to a formulator from one of their customers:

- **The customer point of view:** I have the 800 mJ/cm² of radiant energy density and 600 mW/cm² of irradiance of UVA 320-390 nm as specified on your tech sheet but your ink will not cure. It can't be my process or the operator. It has to be a bad batch of ink.
- **The formulator point of view:** When was the last time maintenance was done on the system? How were the UV numbers collected and with what instrument? What is your ink thickness? Type of UV bulb? What has changed? Process or mesh parameters? Ink characteristics? Substrate changes?

Formulators who are reluctant to supply or publish cure guidelines may prefer to work with a customer on a one-on-one basis to establish targets based on the customer's process and equipment. Formulators also work to keep all information proprietary about their products.

My suggestion is to find a formulator(s) with whom you are comfortable working, and who also knows your business and application. Communicate with the formulator on a regular basis and not just when you are having problems. Involve and use their sales and technical support staff in your facility when you are looking to make changes, evaluate new equipment or formulations. Is that UV system that you are considering buying matched to the applications and formulations that you would like to work with? Factor in the value of support and technical help that you receive from a formulator when making your decision on which products you will use. Patronize the formulator who offers your company the products and support you need at the best overall value. Do not confuse value with the lowest dollar cost-per-unit quote.

Measurement Fundamentals

Knowing what to expect when changes are made to the controls and variables on your UV system are an important part of using and understanding your radiometer and UV system. The following examples illustrate what happens to the joules/cm²and watts/cm² when variables in the UV process are changed. It is a good idea to also check how these changes affect your particular formulation.

Process Speed/Dwell Time

Most UV systems used in graphics applications allow the conveyor speed or dwell time to be adjusted independently of the screening operation. Changing the conveyor speed will change the time (more or less) that the work piece is exposed to the UV source. When the conveyor speed is increased, the time that the work piece is exposed to UV decreases. When the conveyor speed decreases, the time increases. The UV measurement value that is a function of time is the radiant energy density. The radiant energy density is inversely proportional to the process speed. If I double the process speed, I cut in half the radiant energy density. If only the conveyor speed changes on the UV system, the irradiance value will stay the same. Information on calculating radiant energy density values for different process speeds can be found later in this article in the discussion on instrument sample rates. *(See figure 2)*

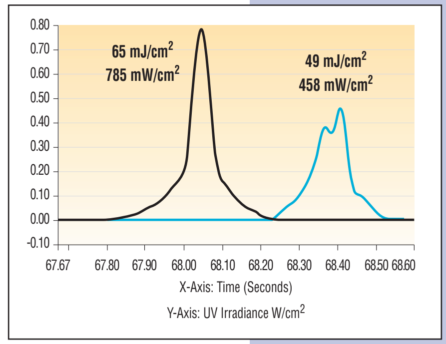

Figure 4: Adding a second UV system (blue) of less power to your existing configuration. The added system has less irradiance, is slightly out of focus and the energy density does not double as expected.

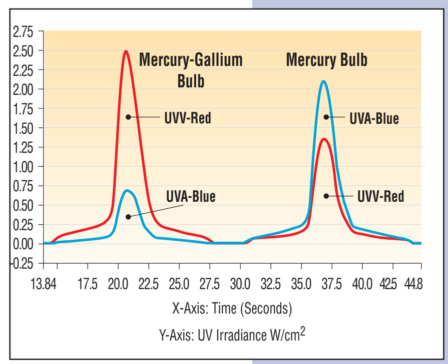

Figure 5: The effects of adding a UV system or lamp to your existing configuration of different spectral output. The addition of a second system may or may not produce UV in the spectral bandwidth favored (required) by the photo initiators in your formulation.

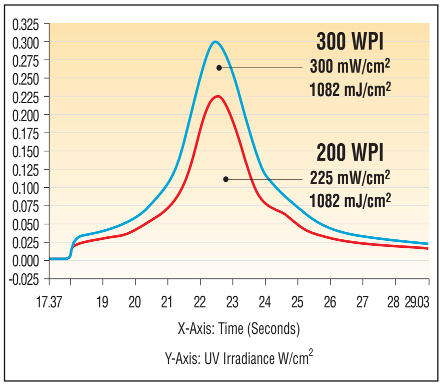

Figure 6: The effect of increasing the power on the same system from 200 WPI to 300 WPI.

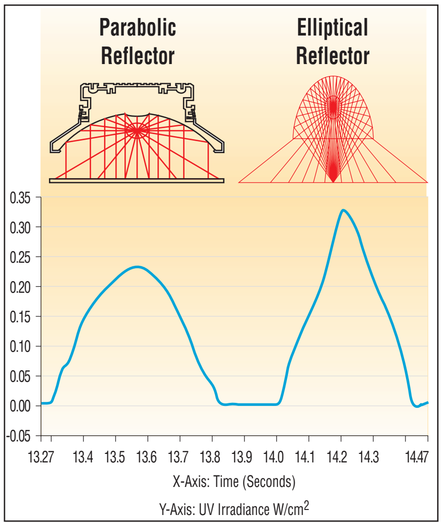

Figure 7: Parabolic vs. Elliptical reflectors

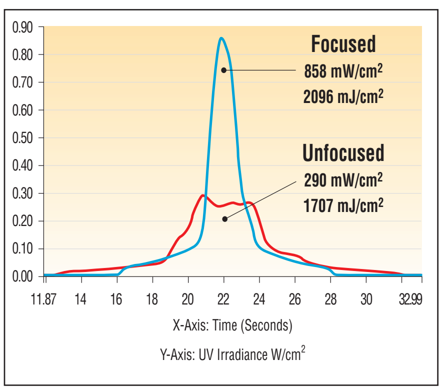

Figure 8: The effect of moving the UV housing away from the cure surface.

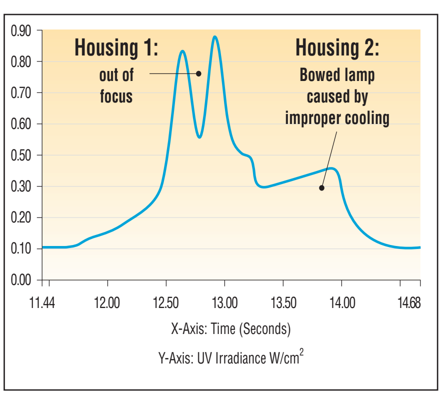

Figure 9: Two Lamps-first lamp out of focus, second lamp bowed from improper cooling. Data collected and courtesy of Miltec UV.

Knowing what to expect when changes are made to the controls and variables on your UV system is very important

Adding Lamps

The effect of increasing the number of lamps will depend on the type of UV system or lamp added. *(See figure 3, 4 & 5, page 38 & 39)*

Increasing Applied Power

The electrical power applied to the UV system is described in units of either the watts per inch (wpi) or watts per centimeter (wpcm). The numbers are calculated by multiplying the volts x amps (watts) applied to the system and dividing it by the arc length of the bulb in the system. Typical wpi numbers range from 200-600+ wpi (80-240 wpcm). Generally, with more power applied, more UV is generated. There are wide variations between manufacturers on systems with the same "applied power rating" in both the amount of UV generated and the amount of effective UV (that reaches the substrate and is the correct spectral type) delivered to the substrate. Compare carefully if you are evaluating a UV system.

Many power supplies have the ability to increase or decrease the power applied to the UV system in either a step or step less (variable) configuration. For a step configuration, the user typically has a choice of three settings- 200, 300, 400 wpi (80, 120, 160 wpcm) are common numbers. For step less power supplies, the user is generally able to generate UV from approximately 50-60% of available power up to 100% in small steps, sometimes as little as a few percent. Communicate with your UV system supplier if you have questions about your power supply. *(See figure 6)*

Reflector-Lamp Height Variations

The mechanical design of the system (reflector shape, bulb position, bulb diameter, distance to the cure surface, cooling) impacts how UV is delivered to the substrate. Choices are made to optimize the UV for your particular application. The key to successful curing is to maintain the system as it was designed for your application. Adjusting the height of the reflector assembly or bulb position in relation to the cure surface can move your process in or out of the "cure zone." Changes in the reflector height and the way that UV is delivered to the substrate can occur through lack of maintenance, incorrect reflector reassembly after maintenance, operator adjustment error or the jamming of material in the housing. *(See figure 7,8 & 9)*

Across the Width of the Lamp

On wide systems, it is important to measure across the conveyor in several points. Changes can be found at the ends of the bulbs as they age. Changes can also be found as a lamp bows or changes over time. *(See figure 10 & 11)*

Multi-Lamp Systems

It is important to identify which bulbs in a multi-lamp system need maintenance. In systems with two or three lamps, it is easy to measure each lamp individually with a radiometer after giving each lamp system time to warm up. On systems with more than three lamps, a profiling radiometer will save time by giving you a "look" at all the lamps at once instead of waiting for each lamp to warm up to be measured individually. Profiling the contribution from each lamp individually will allow you to target the lamps that need work (cleaning, adjustment, maintenance) as your UV values drop and start to approach the minimum level established for the process. *(See figure 12)*

Changing/Aging Bulbs

Multi-band radiometers are available that allow you to look at multiple areas of the UV spectrum with one pass. Multi-band radiometers are especially important when additive type bulbs (mercury-gallium, mercury-iron) are used. If your formulation is expecting to see UV in a certain bandwidth, it becomes important to monitor it to make certain that it has not changed. By looking at the ratio of the different bandwidths in a multi-band radiometer, the user can confirm that the correct bulb has been installed in the correct location in their system. *(See figure 13)*

Information collected over time can indicate aging of bulbs as the ratios of the different bandwidths change. *(See figure 14, page 42)*

Instrument Basics

Radiometers use a combination of optic and electronic components to collect,

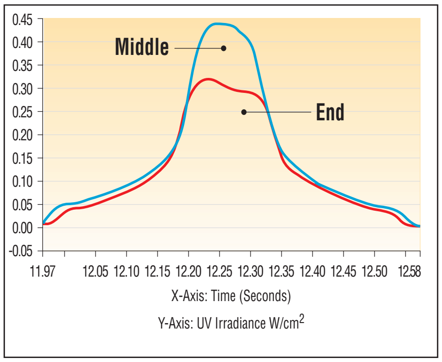

Figure 10: Comparison of middle (440mW/cm2) to end (317mW/cm2) measurements along the same bulb.

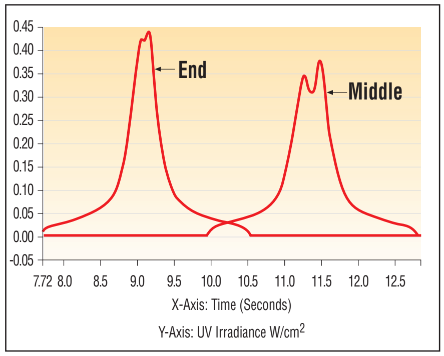

Figure 11: Sagging along the bulb, 15% difference in the irradiance levels middle to end.

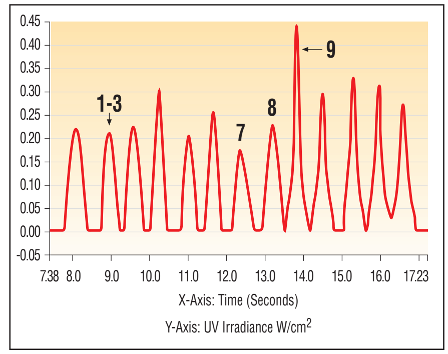

Figure 12: Irradiance Profile of a multi-lamp line Lamps 1-3: Parabolic reflectors; Lamp 8: Out of focus; Lamp 7 to Lamp 9: 173 vs. 440 mW/cm2, 58 vs. 93 mJ/cm2

process, calculate and display their information. Expectations of UV measurement instruments often exceed their actual performance with users sometimes expecting performance to be within a small fraction of a percent — similar to a precision thermometer or voltmeter. The combination and interaction of the optics/electronics and how the instrument is used determine how well it performs.

It is important to select the right instrument for your measurement needs and then use it properly. It is also important to use data collection techniques consistent with design of the instrument.

Understanding the proper use and inherent limitations of both the optics and electronics helps the user to get the most out of his/her radiometer. Our discussion here is general — for specific questions about a particular radiometer, it is best to contact the manufacturer of the instrument. When making comparisons between instruments, make sure that you are making "apples to apples" and not "apples to oranges" comparisons.
(See figure 15, page 42)

The EIT PowerMAP is a four-channel instrument and will actually have four separate optic stacks with detectors. Information on this unit is transferred to a computer instead of using a display.

Optical Considerations

Instrument Dynamic Range

Truck scales are designed to measure large heavy objects and do not work well for small packages. The dynamic scale is wrong. Radiometers are designed to balance the amount of light reaching the optical components with the output from the detector. Too much light can solarize and change the optical components; not enough can lead to a noisy detector signal. A single instrument can't always cover every single UV irradiance level found in a graphics facility. Instruments designed for low intensity sources like exposure machines will not always work on high intensity sources used for curing coatings. Make sure the dynamic range of the instrument matches the irradiance levels of the system on which it will be used. Watch for signs that you are over ranging the instrument. If you have any questions, check with the instrument manufacturer.

Instrument Angular or Spatial Response

The angular or spatial response of an instrument describes how the instrument handles light coming from different angles and is measured by the optics in the unit. Most instruments try to approximate a cosine response in the optics as it is thought that most coatings respond in a cosine manner to the UV reaching their surface. Some instruments are specialized or have unique optic designs that do not permit simulation of a cosine response. *(See figure 16, page 42)*

Temperature

Wide swings in the internal temperature of the photo detector(s) used in instruments may lead to small differences between readings. Check with your instrument manufacturer — the response of detectors varies as the temperature increases. Repeated, long, slow data collection runs under intense multi-lamp UV sources tend to increase the temperature of the detector and may cause small variations in the amount of UV measured. Let the radiometer cool for a few minutes between runs and try to be consistent when making repeated, long, slow readings under very intense sources.

Filter and Detector Specifications

Making of the optical filter, detector and other components is an art and it is normal to expect small variations in the optical performance between two filters. How close to specified center wavelength (CWL) is the actual filter? What is the repeatabil-

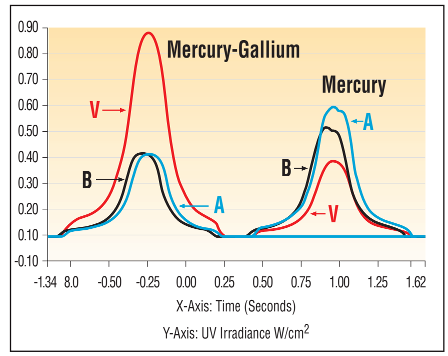

Figure 13: Comparison of the ratio of UVA-UVB-UVV in mercury and mercury-gallium bulbs

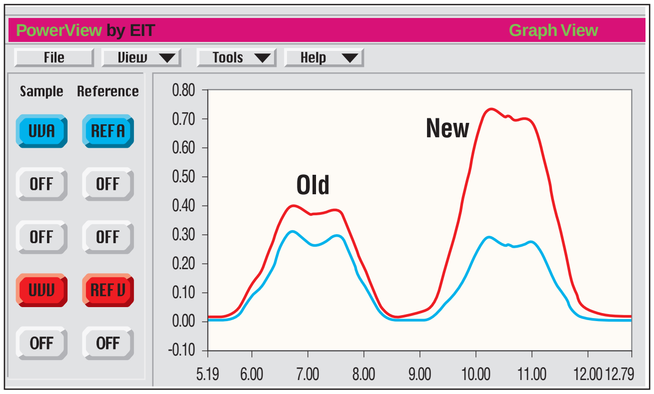

Figure 14: Aging effects in a Mercury-Gallium bulb UVA values remain steady while the UVV has changed significantly after 600 hours. Energy Density comparison: 737 to 1331 mJ/cm2 UVV Irradiance: 397 to 734 mW/cm2 Data collected and courtesy of Efsen Engineering.

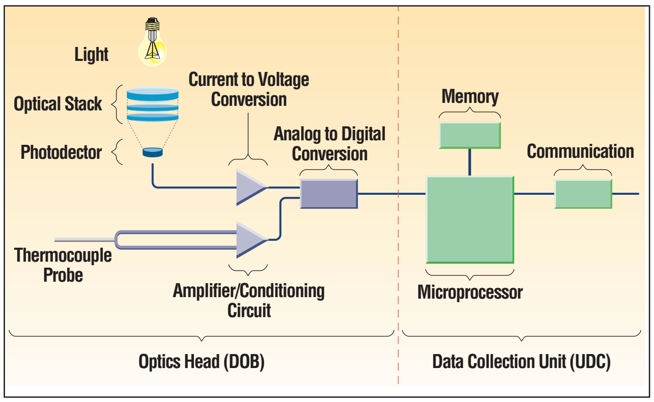

Figure 15: A block diagram for the EIT PowerMAP.

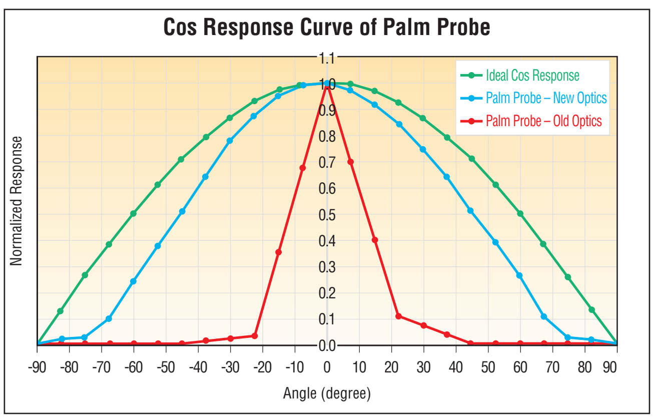

Figure 16: Comparison of the cosine response for various optic stacks during the development of the PALM Probe

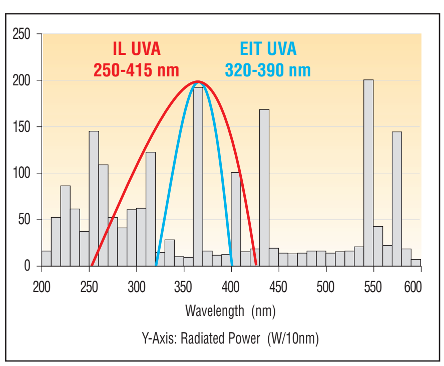

Figure 17: UVA bandwidth comparisons between EIT and IL

ity between filters on either side of the CWL? The slight differences between two filters can lead to slight variations between two instruments. How well does the instrument reject UV that is out of specified bandwidth? The way your instrument deals with energy outside the band you are looking at (out of band rejection rate) can also influence the readings. How well does the unit deal with infrared or visible energy? Most instrument manufacturers test individual optical components and accept only those that meet their criteria. Requiring even tighter specifications or tolerances on optical components could easily price the instruments out of the range of all but a few users.

Bandwidth Differences

Manufacturers have different spectral bandwidths in their instruments and it is often hard to directly compare one brand of instruments to another because of these differences. Some instruments are classified as narrow band while others are broadband instruments. The EIT UVA bandwidth measures between 320-390 nm with the CWL response centered at 365 nm. The International Light (IL) UVA bandwidth response is also centered at 365 nm but measures UV light between 250-415 nm. The UVA spectral response chosen by each manufacturer is different. Users need to note the differences, understand them and pick the bandwidth that best meets their needs. Different is not wrong — it is different.

Because of the bandwidth differences between manufacturers, it becomes important to not only communicate a number value (900 mJ/cm^2) but also the instrument by which the data was collected. Dick Stowe of Fusion UV Systems has suggested adding either the bandwidth and/or manufacturer to assist communication and avoid misunderstandings. A radiant energy density measurement that is stated as 900 mJ/cm^2 (EIT UVA) or 900 mJ/cm^2 (320-390 nm) is much more specific and descriptive than 900 mJ/cm^2. *(See figure 17)*

Calibration Sources

Calibrating an instrument to one type of spectral source (mercury) and then using it under a second source (additive bulb) can lead to small differences in the readings. If you will consistently use the radiometer under a specific lamp source, ask the manufacturer to calibrate the instrument under that type of source.

Electronic Considerations

Thresholding

Instruments are set-up with a start threshold to avoid picking up stray UV from ambient sources such as sunlight streaming in a window. Once an instrument reaches its start threshold, it normally counts all UV past that particular point. Differences in the electronics between instruments can cause one instrument to reach threshold and start counting UV while another instrument needs a higher irradiance value to reach threshold and count. If the optics and electronics in one instrument are set up with a threshold of 40mW and another instrument has a threshold of 2mW, slight differences can be expected between the two readings, especially when the process speed is very slow and the UV system is of low intensity. *(See figure 18)*

Sample Rates

Many people mistakenly believe that their UV instrument has to collect data at the same speed as their production process in order to get useful results. When the production speed is relatively slow, this is not a problem. When production speeds increase, the instrument can be fooled. Imagine trying to predict the outcome of a national election by sampling only a few voters at one voting location. There would be times when the small sample pool correctly predicts the election outcome and there would be times when it was wrong.

The relationship between line speed and the radiant energy density (joules/cm^2) reaching your substrate is inversely proportional. Doubling the line speed will cut in half the radiant energy density or dose. This inverse relationship between radiant energy density and belt speed allows UV measurements to be made at slower line speeds and extrapolated out if needed to faster production speeds.

To estimate the radiant energy density at different speeds use this formula:

$E_x = E_y \times V_y/V_x$

Ex is the energy level you would like to estimate for the new velocity (Vx). Ey and Vy are the energy density and velocity values collected at a speed, which allows adequate sampling.

The linear distance that a product travels through UV is relatively small compared to the total distance it may move on a production line. The total linear travel distance under a single reflector from a single UV lamp system generally does not exceed 12+". Often times, it is less, especially if the system is set-up as a focused system. On a highly focused UV system with an elliptical reflector, the most intense linear band of UV radiation is no more than an inch, maybe two in length. For repeatable, reliable results, a UV instrument needs to collect an adequate number of samples, including the area in the most intense region under the bulb. Some production speeds have moved to the point where the instrument collects samples under the most intense peak one run but just misses the most intense point on the next run. This can lead to wide variations in the reported irradiance values for a system.

Sample rates in UV Instruments have increased with advances in electronics. Older instruments with slower sample rates have given way to a new generation of

Instruments are set-up with a **start threshold** to **avoid** picking up **stray UV** from **ambient sources**

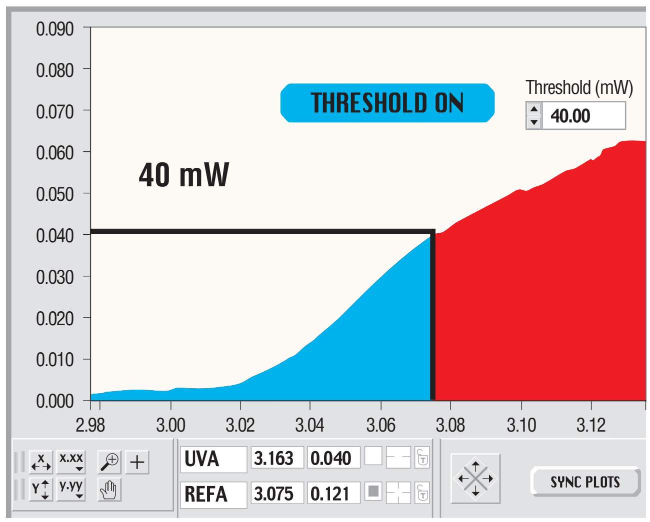

Figure 18: Comparison of the start threshold for two EIT instruments. The older unit does not "start" until the irradiance reaches 40 mW/cm2, while the newer unit "starts" at values in the 1-2 mW/cm2 range.

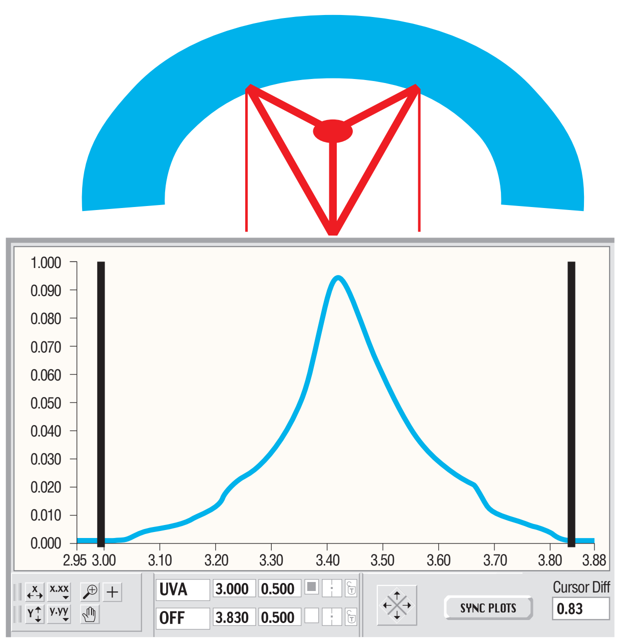

Figure 19: Estimation of the number of data points that an instrument would collect between the lines at 33 fpm
Speed: 33 fpm/10 mpm
Total Time under UV reflector: 0.83 seconds

Time under Peak irradiance: 0.30 seconds

Sample Rate (#/sec)	Data pts
25	20
40	33
128	106
256	212
1024	850
2048	1700

Establishing and maintaining control of your UV process through the use of measurement equipment and a job log will allow you to start saving time and money.

products that can sample up to 2048 times a second. Slower sampling instruments can still be used as long as you observe their "speed" limits. Check with the instrument manufacturer. *(See figure 19, 20 & 21, page 43 & 44)*

Unit Values

The lights in your office that you are using to help you read this article are cycling on and off very rapidly at 50 or 60 Hz. The cycling is too fast for your eyes to see and for practical purposes we assume that the lights are "on" instead of cycling "on and off" very rapidly. The development of radiometers that sample at 2048 samples/second has enabled radiometers to "see" the UV bulb cycling on and off as the alternating power supply cycles. The faster collections rates have enabled the instruments to capture this cycling of the power supply at its peak moment. Based on the sampling rate and data conditioning in the instrument, some radiometers can report this "peak-peak" or instantaneous irradiance value in addition to or instead of an "RMS" or "average peak" value that is obtained with instruments that sample more slowly.

Communicate clearly so that everyone understands what is being reported. *(See figure 22, page 45)*

Ten Tips for Maintaining Process Control

(And Using Your Radiometer Properly)

1. Establish, document and maintain your UV process window to save time and money.
2. Maintain a job log and establish/assign ownership of the UV equipment, process and measurement in your facility.
3. Select an instrument suitable for your application and monitor the UV bandwidths that are important to your process.
4. Use your UV measurement equipment properly and in the manner in which it was designed. Educate your staff on the variables in your process, which need to be monitored.
5. Set your frequency of measurement depending on your process window, application, product, equipment, maintenance program, quality control requirements and experience at tracking and identifying changes. (It is much easier to start out measuring frequently until you get to know your process and establish your production parameters than it is to try and correct problems later because not enough measurements were made. Control your process, then reduce the frequency of readings.)

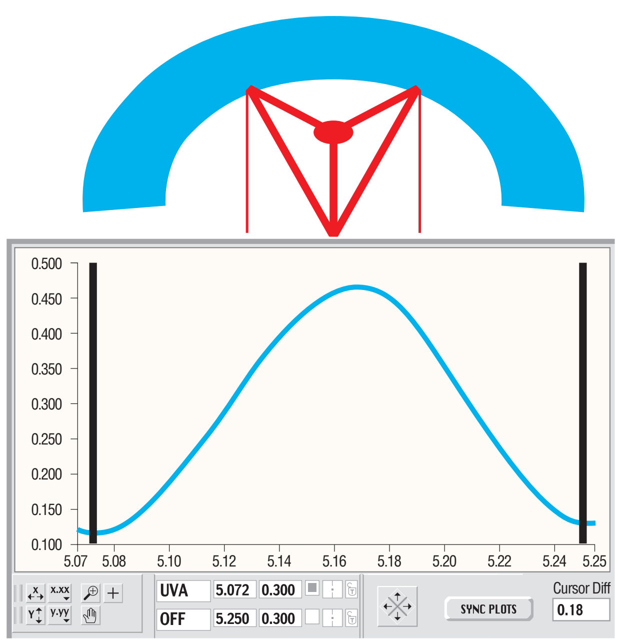

Figure 20: Estimation of the number of data points that an instrument would collect between the lines at 240 fpm

Speed: 240 fpm/74 mpm
Total Time under UV reflector: 0.18 seconds

Time under Peak irradiance: 0.08 seconds

Sample Rate (#/sec)	Data pts
25	4
40	7
128	23
256	46
1024	184
2048	368

6. Establish a preventative maintenance program and schedule for your UV related equipment.
7. Plan a course of action on what you will do when your readings fall outside of your acceptable values.
8. Handle your radiometer with care to avoid letting it drop off the end of your conveyor. If the unit is dropped or damaged and you notice changes in the readings on your job log, it is time to get the instrument serviced.
9. Have your instrument calibrated to account for slight changes in the optics that are caused by exposure to UV. Manufacturers set up recommended calibration intervals. The actual performance of your radiometer is going to depend on the amount of use and the irradiance levels that the unit encounters.
10. Decide how you will communicate both in your facility and with your suppliers. Communicate with your suppliers on a regular basis, not just when you are having problems.

Summary

Everyone starts or goes into UV curing with the Best of Intentions. Establishing and maintaining control of your UV process through the use of measurement equipment and a job log will allow you to start singing a new song in addition to saving time and money. The words are below; you will have to make up your own music to go with it.

I learned the error of my ways
Wow, a job log really pays!
Keeping track of joules and watts
Can really help process yield lots.
I've reduced scrap and life is good
My stuff is curing like it should.
Start or stop? Relamp or not?
These are things I now can spot.

Acknowledgments

Thanks to the following people that provided input, assistance, graphics or data used in this article:

Sue Casacia, Mam Ratovohery — EIT
Dick Stowe — Fusion UV
Michael Efsen — Efsen Engineering
Bob Malone — Miltec UV

The data in figures 1-13 and 14, 17, 18, 19, 21, were collected with an EIT PowerMap.

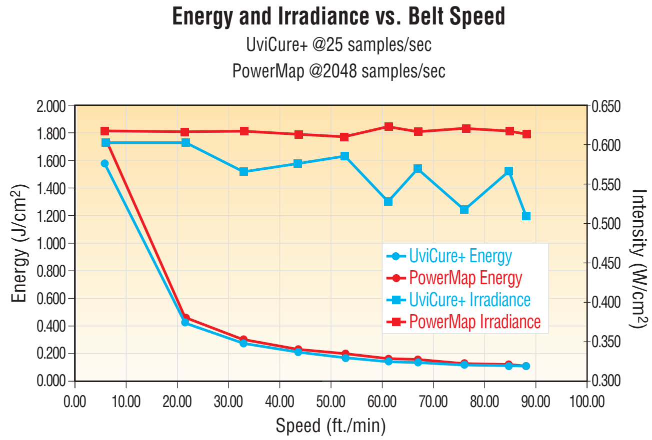

Figure 21: Energy and Irradiance compared to belt speed

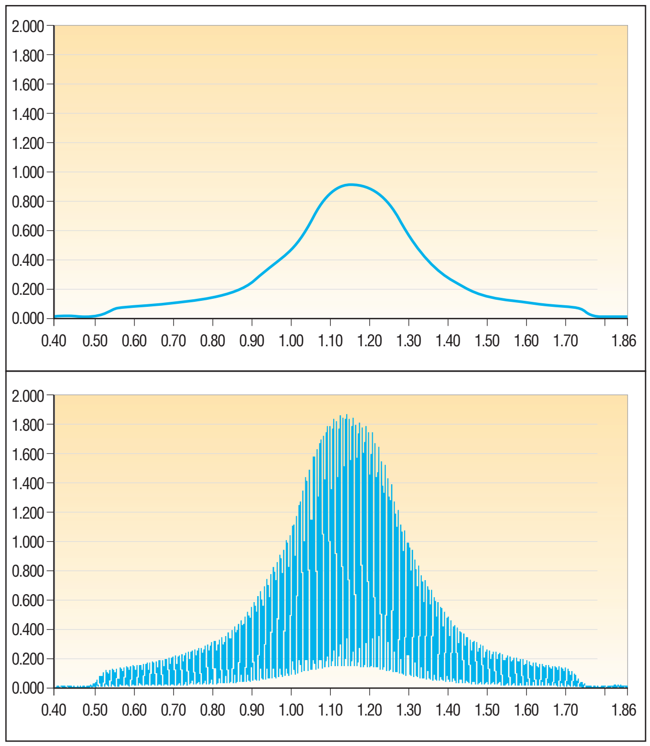

Figure 22: Average peak irradiance compared to Peak-Peak irradiance
The same irradiance profile shown both top and bottom. In each case the radiant energy density is the same. In the top profile the RMS or 'average peak' irradiance of 910 mW/cm2 is shown. In the bottom graph the 'peak-peak' or instantaneous irradiance of 1866 mW/cm2 is shown. With a sample rate of 2048/second, the user can actually see the UV respond to the cyling on the power supply.