A New Approach to UV LED Measurement for Printers: Total Measured Optic Response

UV LEDs have evolved from being viewed as an "experimental novelty" to a mainstay technology for curing UV inks. Many of the same techniques and instruments developed to measure conventional broadband, mercury-based UV sources are mistakenly used to measure UV LEDs. The thinking is that if the radiometer displays a value, then it has to be a good value. This has led to problems with accuracy and repeatability in measuring UV LED output. It seems as though every day, there are new UV LED suppliers entering the market, introducing a wider range of wavelengths and output quality. There are also more printers, especially with digital applications, now using UV for the first time. This article describes a new approach to measuring UV LEDs that addresses this variation in commercial UV LED arrays. Total Measured Optic Response, developed specifically for UV LED sources provides printers with a more accurate and repeatable tool for maintaining a high quality process.

Measurement is vital if you want to set process parameters and verify whether your print process is running within those parameters. When things change, measurement provides the evidence that helps locate the source of the problem. Without measurement, you cannot optimize your print shop for greatest profit and efficiency. Measurement facilitates communication within your company (single or multiple facilities) and with your suppliers; especially your ink/coating suppliers.

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The Fundamental Paradox of Measurement

Suppose you want to accurately measure the air pressure in your car's spare tire: How can you measure the pressure inside the tire without changing the pressure itself?

By Paul Mills and Jim Raymont, EIT Instrument Markets

Figure 1

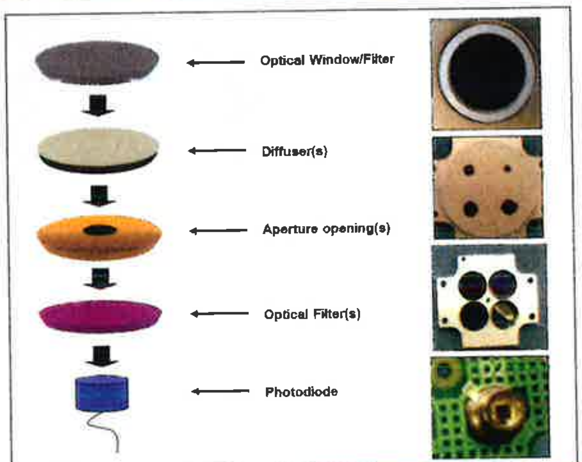

Figure 2

Figure 3

Opening the tire's valve stem opens a can of worms sometimes called the fundamental paradox of measurement (see Figure 1). Scientists call the problem of altering something's properties by trying to measure it, "the observer effect." The measurement engineer's challenge is to devise an instrument that produces the least distortion of whatever property we hope to measure.

The Challenges of Measuring UV

To measure UV energy, we must capture the source's output and transform its "optical" energy into an electronic signal that be stored and displayed. Figure 2 illustrates a generic, simplified chain of components needed to perform this task.

The energy from a UV source (including UV, visible and IR) that arrives at the surface of the radiometer is 'conditioned' (wavelengths, intensity) for the optics stack. There is an engineering tradeoff; a good instrument lets enough energy in to get a good measurement while also protecting the sensitive optical components in the stack to extend their lifetime. The energy passes through a series of diffusers and apertures. Since the detector is capable of measuring energy outside the desired UV band, filters are used to remove unwanted wavelengths such as visible or infrared. As a result, only conditioned (uniform and filtered) UV energy is presented to the surface of an electronic photodiode detector. This sensitive photodiode converts the UV energy into an electronic voltage proportional to the UV energy intensity. This signal is processed, stored and displayed.

Importantly, the accuracy of a device depends on the response characteristics of each component in the chain. Anything and everything between the original signal, and the final display influences the value reported. The challenge for a UV radiometer engineer is to design a product that is easy to use, affordable, and that can stand up to the harsh conditions encountered in an industrial UV print environment.

UV radiometers have evolved to meet the technical and commercial objectives of the graphic arts industry. Instruments are available to measure the output of UV sources used on commercial presses. Some radiometers rely on a single set of optical and electronic components to capture the entire (200nm to 450nm) range of UV wavelengths. Imagine trying to get crisp, clean beautiful audio from an inexpensive boom-box speaker. You simply cannot capture the range of bass to treble with a single speaker. A more faithful tactic is the 'woofer-midrange-tweeter' approach that uses separate speakers optimized or tuned to smaller portions of the sound spectrum.

The same approach has been applied with narrow band radiometers. The optics used in narrower spectral "bands" are generally more uniform. Figure 3 illustrates data gathered using this multi-band approach from a radiometer designed to measure UV output that has been segmented into the distinct UVA, UVB, UVC and UVV bands. These designations were originally established by the International Commission on Illumination based on the health effects of various wavelengths.

Most printers have come to recognize the effect each of these bands might have on their products. For example to obtain proper adhesion of highly pigmented inks, longer wavelengths (UVA, UVV) may be important, while shorter (UVC) wavelengths have a more pronounced effect on surface properties. Comparing the values in multiple UV bands allows users to identify bulb types, spectral changes in the bulb, and when press maintenance is required. For example, by comparing readings and the ratio of values between the different UV bands, an experienced printer can detect whether the correct lamp was installed in the lamp housing.

This multi-band approach allows the radiometer designer to select devices with a predictable, repeatable, and more uniform spectral response within each band. This avoids a "one size fits all" solution that compromises accuracy over a wide spectrum. This multi-band approach has served the print industry well for decades by measuring the UV energy from arc and microwave UV sources.

Almost all instrument manufacturers have adopted the practice of publishing the response of just the optical bandpass filter for instruments designed for broad band sources. In truth, the overall spectral response of the instrument is a combination of all optical components. This combined response is not always flat and can lead to slight variations when taking measurements from unit-to-unit, source-to-source and run-to-run.

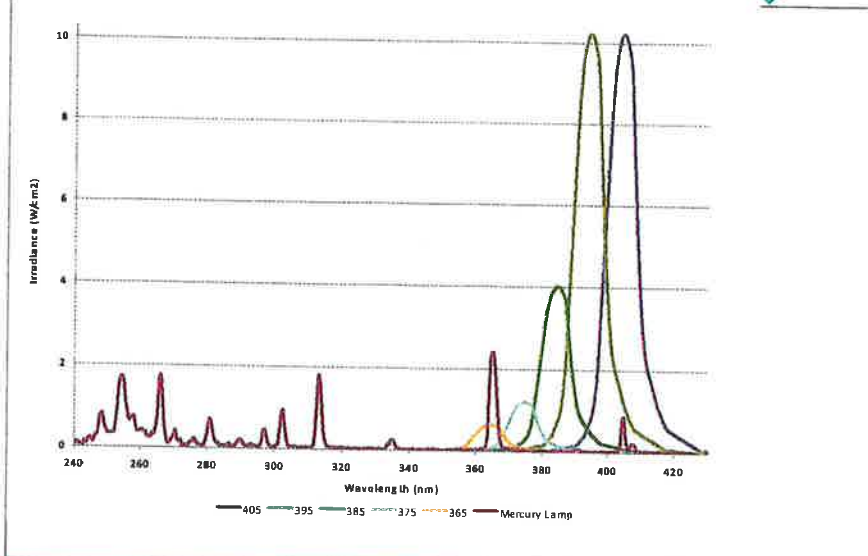

Figure 4

UV LED Light Sources are Different

The landscape for UV curing has been changing for printers over the past ten years as UV LED sources have become commonplace in commercial graphic arts applications. These UV LED light sources have substantially different spectral characteristics than traditional broad band mercury-based lamps. Figure 4 illustrates the output of a traditional mercury light source compared with the output of a UV LED array. Mercury lamps emit a continuous broadband spectrum comprised of many sharp peaks. By contrast, UV LEDs produce a relatively narrow, single peak, centered at a specific wavelength.

Although development is progressing at many wavelengths, most commercial UV LEDs used for curing print inks are monochromatic in one region output ranging from 365nm to approximately 405nm.

Commercial UV LED sources are arrays that contain hundreds, even thousands of individual, small diodes (or dies) arranged in rows and columns to provide uniform irradiance over a wide surface. These arrays can take many shapes and sizes ranging from a few centimeters to over a meter in length. To assemble arrays, UV LED source manufacturers purchases diodes in large quantities. For example, to build a commercial 2in. x 12in. 395nm UV array the manufacturer must purchase, mount, and connect hundreds of individual 395nm diodes. In practice, the output of any of these individual diodes may vary from one another depending on the exact semiconductor chemistry and manufacturing. Diodes are sliced from complex layers of semiconductor materials whose exact size and geometry can vary, affecting the spectral output of individual diodes. Thus, a 395nm array will contain diodes with central peaks at 390nm, 400nm, or any of a range of other possible wavelengths within a range. The diode suppliers often price their components according to how tightly they control the tolerance of individual diodes within any batch (called "binning"). Diodes are also binned on intensity and the (forward) voltage required to drive them.

Since the diode manufacturer must reject more non-conforming diodes, the tighter the binning specification, the higher the price. Each manufacturer of an LED array establishes their own internal binning standards. Some manufacturers will hold their arrays to a tighter standard than other manufacturers. Using more relaxed binning standards and manufacturing an array made with a wide range of spectral outputs, intensities and forward voltage values could lead to a lower-cost source. And, while LEDs may still be sold and promoted as a "single wavelength (e.g., 395nm)" source, the measured output of such a 395nm array may vary considerably from the expected CWL (Center Wave Length) by +/- 5 nm.

The difference between the theoretical and actual CWL can present a measurement challenge. It is desirable to keep the spectral response of the radiometer flat over a wider range of wavelengths. With "good" binning, the variation in the CWL from 390–400 nm on a 395 nm source, the output of

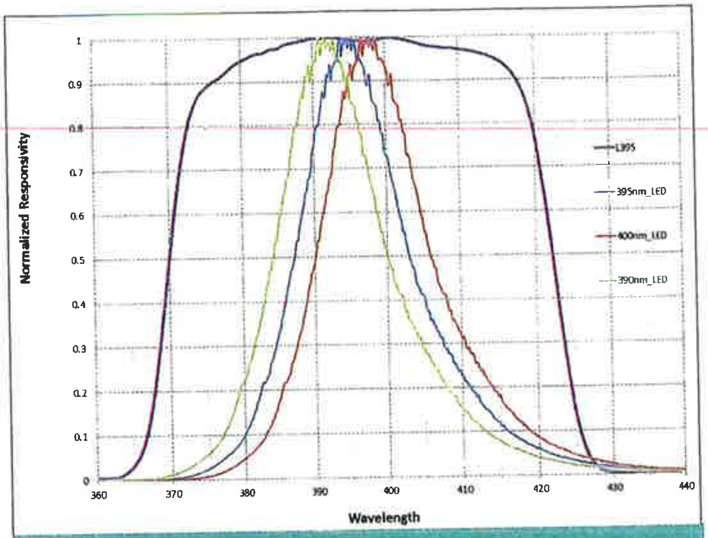

Figure 5

Table 1: Proposed EIT LED Bands

EIT Band	Wavelengths, Cp	Measurement Range
L405	400-410 nm	380-430 nm
L395	390-400 nm	370-420 nm
L385	380-390 nm	360-410 nm
L365	360-370 nm	340-390 nm

the energy may be as low as 370 nm and as high as 425 nm. The effects of poor LED binning may have the energy even further outside of the ideal instrument response shown in Figure 5 for a 395 nm LED array.

Using a narrow-band approach helps solve this problem. The LED bands proposed in Table 1 capture almost all but a very tiny percentage of the energy from popular, commercial UV LEDs. Keeping these "L" bands narrow has advantages. Each L-band is constructed by considering a central peak wavelength that might vary by ±5nm. Thus, each band is 50nm wide as shown in Table 1. Thus, an L395 radiometer is equipped to measure diodes whose center wavelength vary between 390nm and 400nm using an optic stack that captures all of the energy emitted between 370nm and 422nm at the 50% power responsivity point. The widths of the L bands were chosen to balance flatness of the overall instrument response, (and not just the filter), with the performance and cost of the instrument.

Total Measured Optic Response: A Different Approach

A Total Measured Optic Response approach incorporates the overall response of the instrument considering the influence of each component including the optical window, diffuser, aperture, spacers, filters and detector. Each of these components as its own response characteristics, as shown in Figure 6. The top and bottom illustrations show individual optical component responses. The middle panel shows the impact of off-axis energy to the instrument response. In practice, optic stacks can have two or three times this number of components.

This Total Measured Optic Response results in a flat overall instrument response. While conceptually straightforward, until now, radiometer designs did not play up technical challenges or consider the Total Measured Optic Response of the instrument. One reason is that the mercury spectra is very broad, and the consequences of cutting off a few nanometers of output are not as consequential as with the sharp spectral output that characterizes the output of LED light sources. As can be seen in Figure 5, a filter that cuts off at 410 nm instead of 405nm would have substantial impact on the measured UV output, since much of the energy would be cutoff.

By considering the total optical response, not only are readings highly accurate within each designated L-band, but there is vast improvement in the correspondence of measurements made from instrument to instrument. This means that a process measured in the lab with one instrument may be replicated in the field with little error. Figure 7 shows the overall total measured optic response achieved for the popular L395 band. Notice that the achieved response is exceptionally uniform over the desired region. (EIT [SGIA Expo Booth #2800] has been granted a patent for the Total Measured Optic Response approach.)

The Results

Why does using an instrument with a Total Measured Optic Response mean for someone measuring UV? Figure 8 illustrates the accuracy and reliability of two production radiometers. The pair of radiometers made 20 successive laboratory measurements of a single 395nm UV LED array.

The variation in absolute UV output from run to run, which averages substantially less than 1.0% may even be due in part to small fluctuations in the applied electrical power or light source itself. The difference between instruments, approximately 0.2% overall, is extremely narrow, and significantly better than results with traditional, filter-only designs.

The performance benefits of this new UV LED radiometer design are already being seen in field tests by LED manufacturers. Phoseon Technology found good spectral response in testing done using 385nm, 395nm and 405nm light sources with an L-395 band instrument. The lamps were calibrated using a 3rd party meter with a known (measured) spectral response. When exposed to a 365nm UV LED lamp the L-395 radiometer measured very little UV energy, indicating that L395 spectral response has a sharp response in the L-395 band. The radiometer also demonstrated consistent peak irradiance and energy density measurements at various scan speeds varying from 1.2 to 6.0 meters/min. Finally, when measuring watts, there was a strong correlation with a NIST traceable radiometer from another manufacturer. The L-395 instrument provided better measurements of expected joules (Figure 9A and Figure 9B, data courtesy of Phoseon Technology.)

A spectral radiometer using an integrating sphere and primary standard is a very accurate tool for

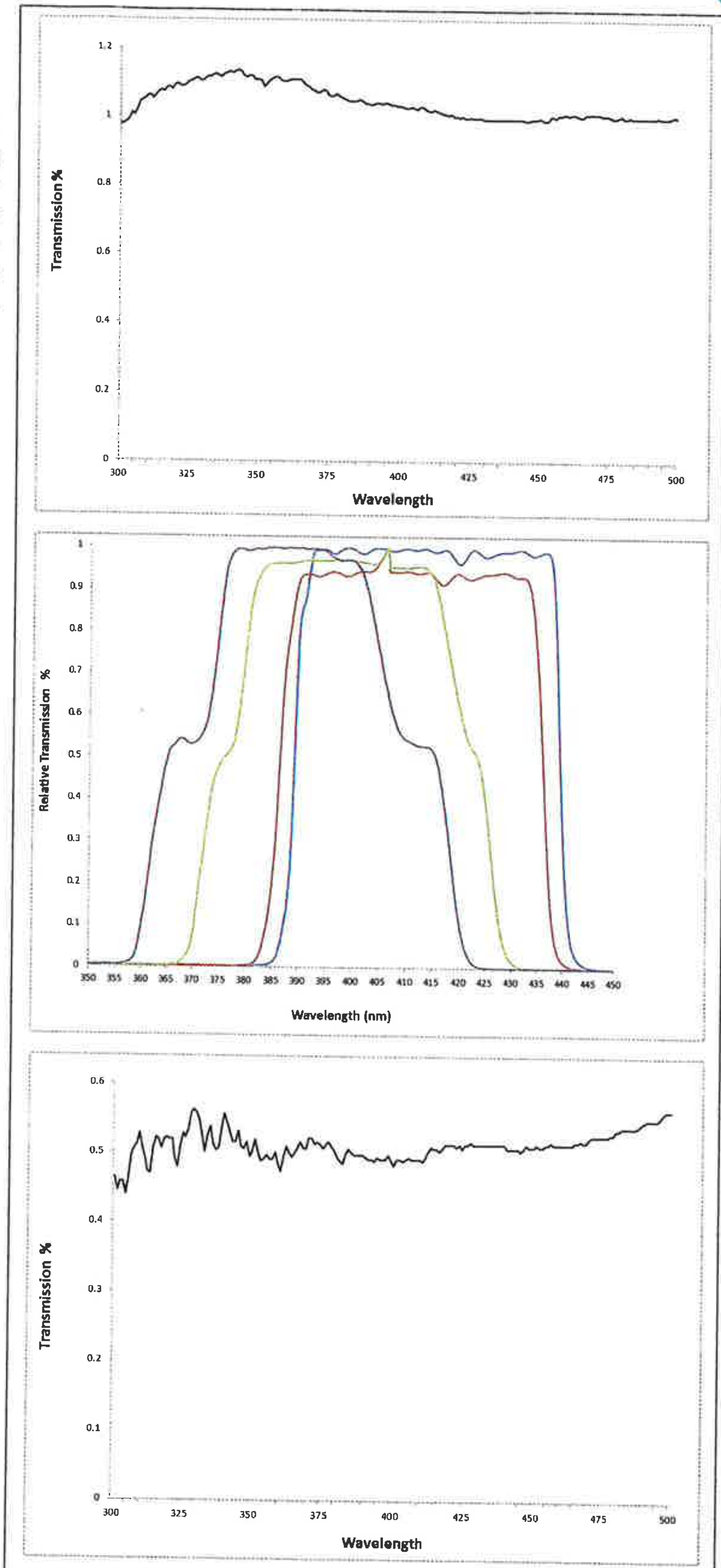

Figure 6

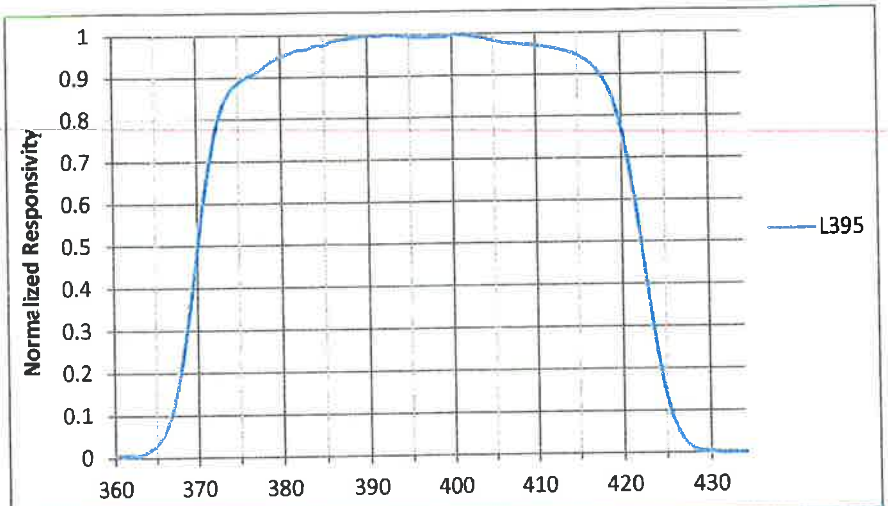

Figure 7

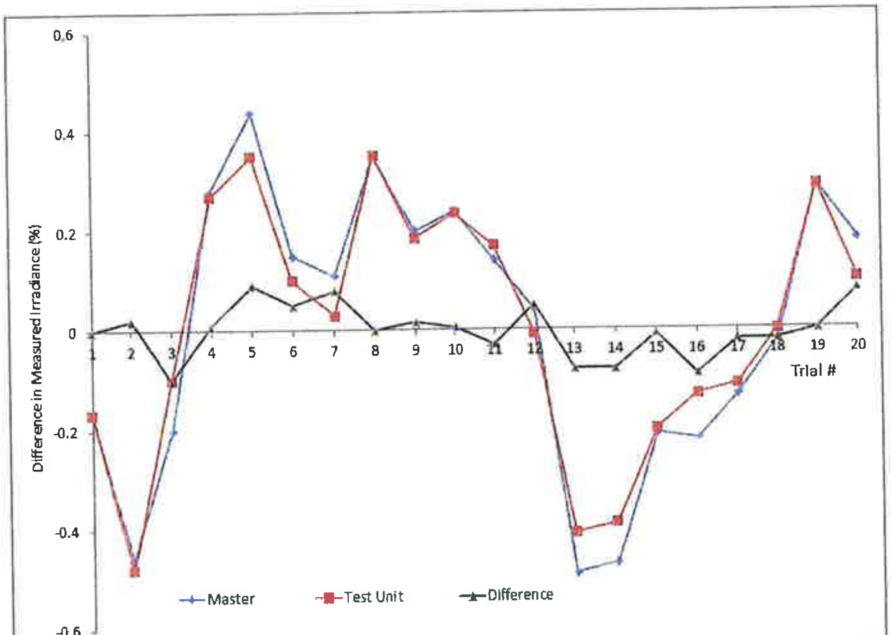

Figure 8

Table 2: Performance Results LEDCure vs. Standard

Working Distance (mm)	Primary Standard Integrating Sphere Irradiance (W/cm²)	LEDCure L395 Irradiance (W/cm²)	Difference (%)
5	9.01	9.23	2.4%
10	7.74	7.74	0.0%
15	6.66	6.63	-0.5%
20	5.74	5.83	1.6%

taking measurements in a controlled lab or research setting. In a production environment, this approach is not nearly as practical. Table 2 illustrates how closely the absolute measurements of an L395 LEDCure radiometer match a national, traceable, primary standard at various light source-to-radiometer working distances when measuring a 395 nm LED source. (Data courtesy of Excelitas Technologies).

Other manufacturers including Ushio America Inc. and Integration Technology Ltd. have tested the LED Cure L395 with similar, positive results. These results demonstrate the success of re-engineering the UV radiometer to meet the demands imposed by semiconductor light sources that can vary considerably within a single array. Until now the effects of the overall variation have been ignored. The development of L-bands that have exceptionally flat response across the each optical and electronic component have produced a new generation of radiometers with the predictable and repeatable response needed by printers to characterize the UV LED curing processes of the future.

Paul Mills is an industry consultant specializing in UV curing applications for inks, coatings and adhesives. Paul has been one of the leaders in the development of UV powder coating and UV LED curing technology. He also serves as the senior editor of the UV LED Curing Community, an online website focused on developments in UV LED applications in the graphic arts.

Jim Raymont has been with the Leesburg, Virginia-based EIT for more than 24 years, and has presented seminars worldwide on UV measurement and process control. He is a member of ASDPT and has written a number of articles with the same focus, and co-holds four patents on UV measurement. He has worked with a variety of customers in several different industries, all of whom share the common need to measure, maintain and control UV in their process. Prior to joining EIT in 1993, Jim spent ten years in technical sales, marketing and management and six years as a high school science educator. He holds a BS in Science Education from The Ohio State University.

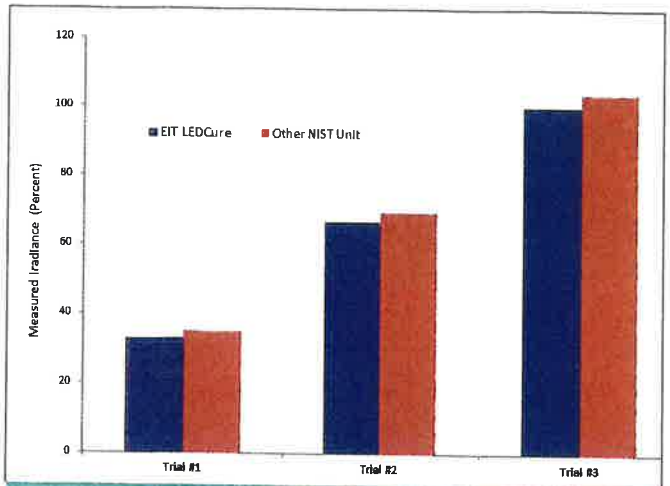

Figure 9A

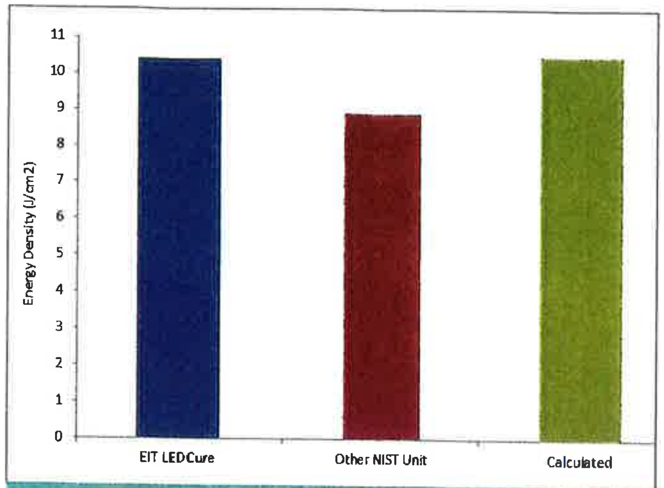

Figure 9B