# Notes on the Effective Use of UV Radiometers and Radiachromic Films

R. W. Stowe
Fusion UV Systems, Inc.
Gaithersburg, MD USA

RADTECH
THE ASSOCIATION FOR UV&EB TECHNOLOGY

FUSION UV
SYSTEMS, INC.

# Radiometry:
# Process Design and Process Monitoring

**Radiometry is used to evaluate the optimum exposure required for a photo-curable material to develop its ideal properties.**

**Radiometry is used to specify the minimum exposure condition required in process design.**

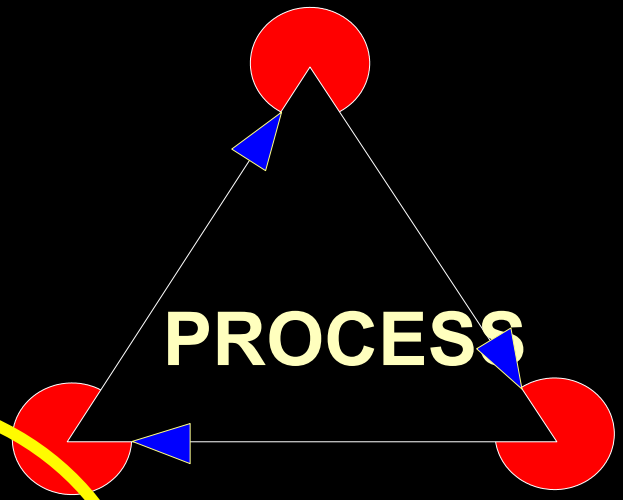
**Radiometry is used to verify the process design.**

**Radiometry is used to monitor the process over time**

FUSION UV SYSTEMS, INC.

## Product

Application Method
Film Weight
Process Speed
Substrate
Target Properties



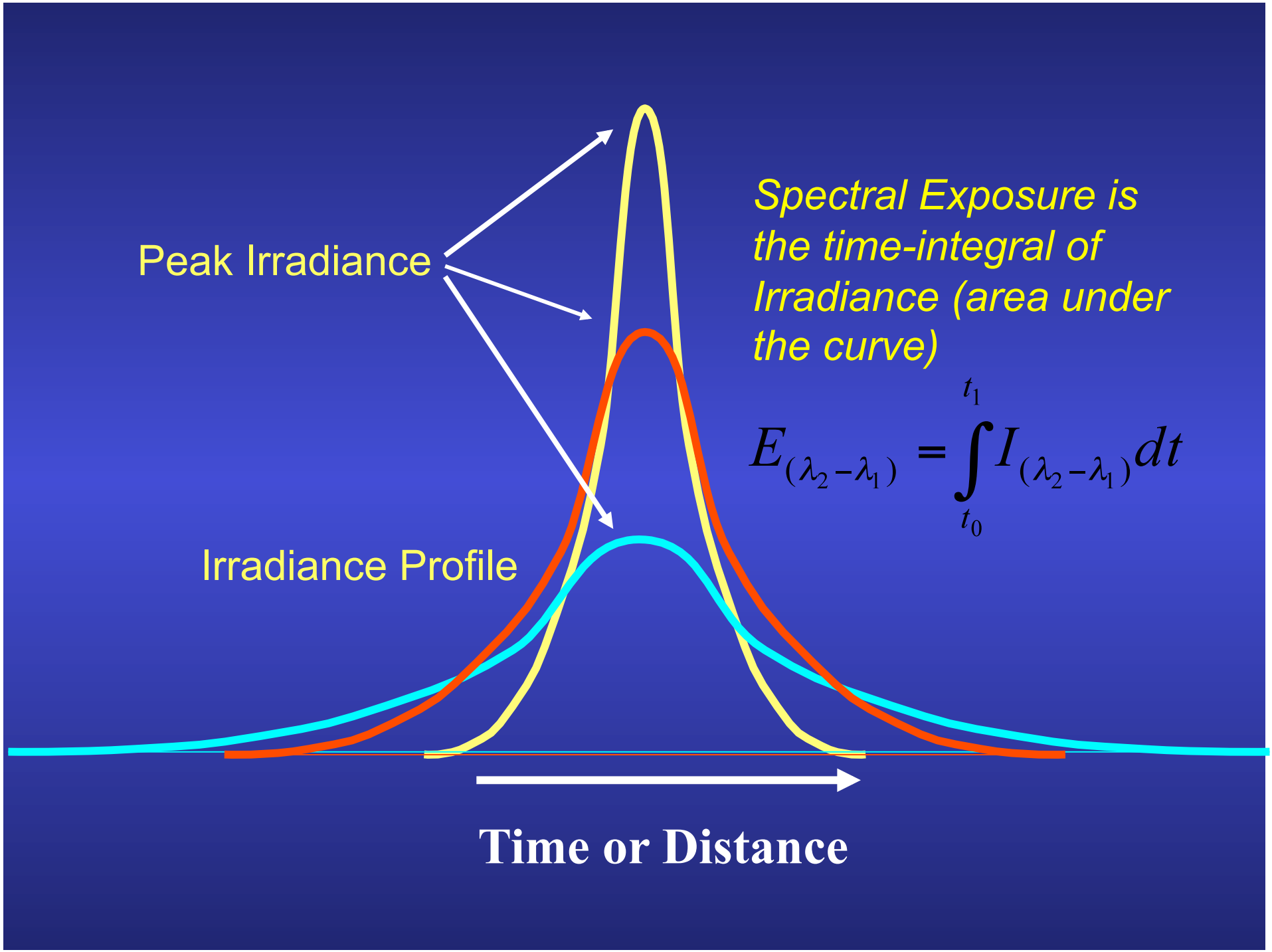

## Exposure

Spectral Distribution
Irradiance or Profile
Time
Temperature

## Formulation

Chemical Components
Spectral Absorbance
Spectral Response
Optical Thickness

# Irradiance


Peak Irradiance
Irradiance Profile
Spectral Exposure is the time-integral of Irradiance (area under the curve)
$E_{(\lambda_2-\lambda_1)} = \int_{t_0}^{t_1} I_{(\lambda_2-\lambda_1)} dt$
Time or Distance

# Irradiance

VERY LOW: 1 to 100 $mW/cm^2$
LOW: 100 $mW/cm^2$ to 1 $W/cm^2$
HIGH: 1 $W/cm^2$ to 10 $W/cm^2$
VERY HIGH: Over 10 $W/cm^2$

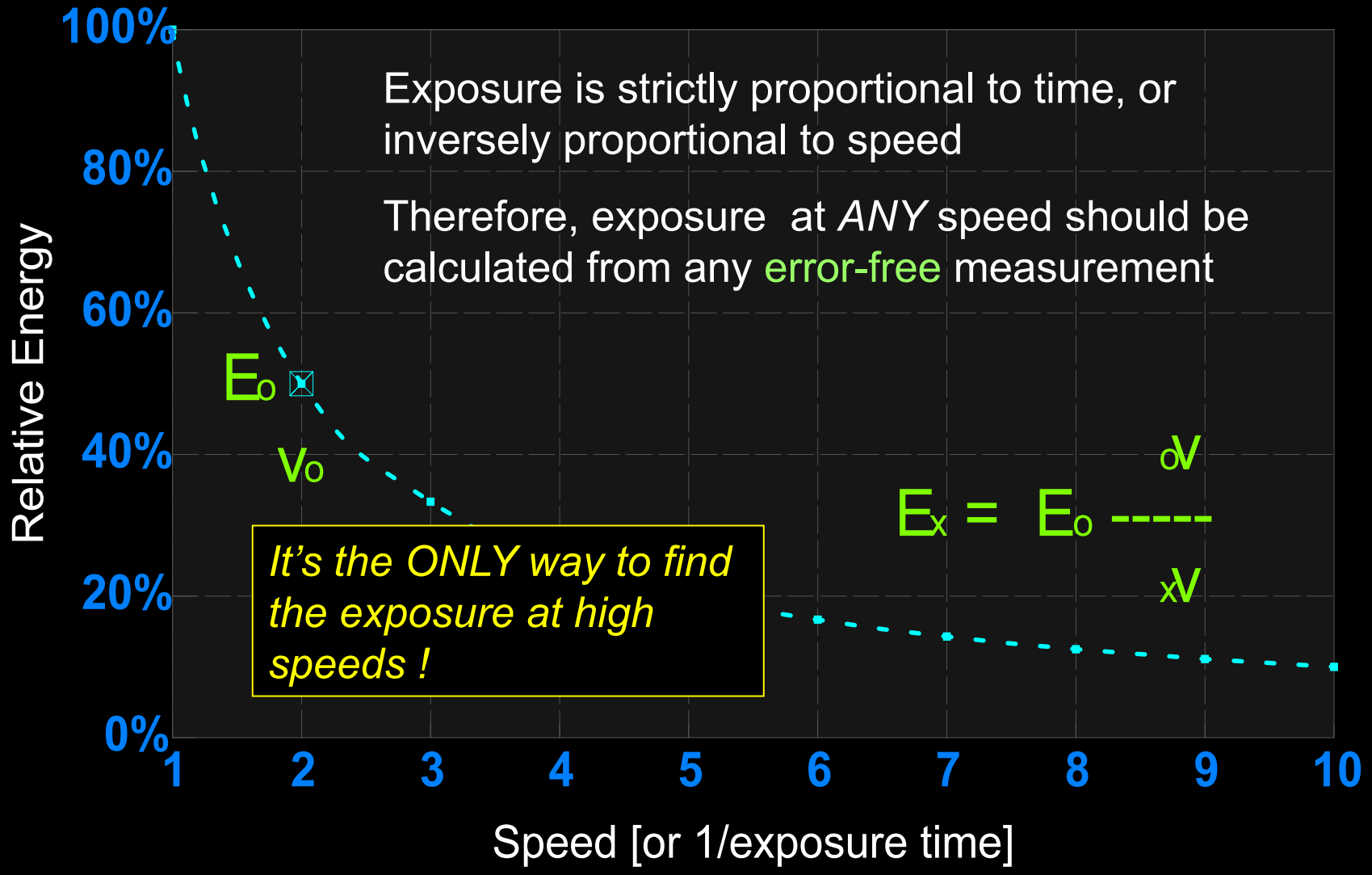
# Exposure

Note that “exposure” is the correct optical term for the time-integral of irradiance. Variations such as “energy density” or simply “energy” are acceptable.

“Dose” is actually an E-beam term, and applies only to ionizing and high-energy radiation.

Reference: IUPAC, CIE and RadTech

# Exposure


100%
80%
60%
40%
20%
0%
Relative Energy
1
2
3
4
5
6
7
8
9
10
Speed [or 1/exposure time]
Exposure is strictly proportional to time, or inversely proportional to speed
Therefore, exposure at ANY speed should be calculated from any error-free measurement
Eo
Vo
Ex = Eo ----- oV xV
It's the ONLY way to find the exposure at high speeds !

# The Simplest Possible DOE:

1. Determine the "marginal failure" point

1x 2x 4x 8x 16x

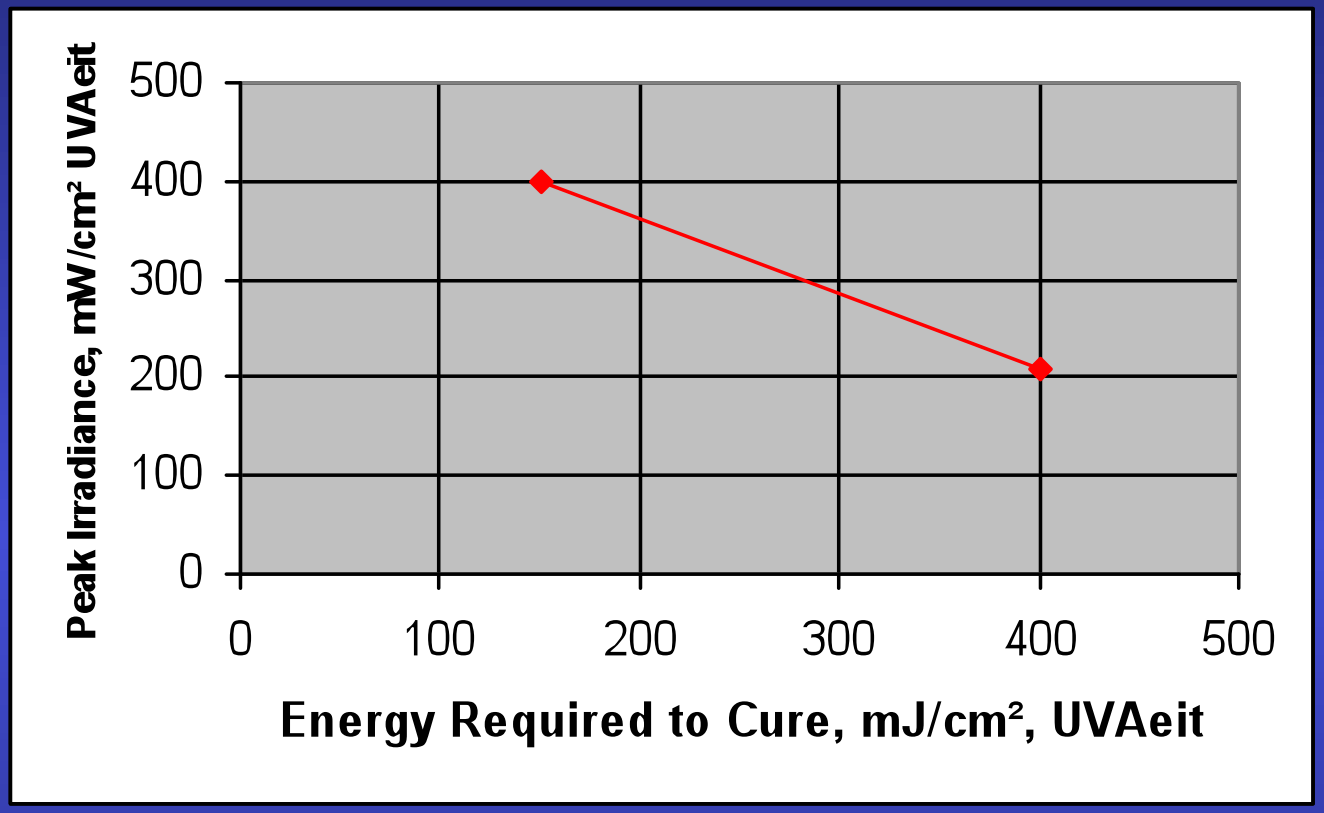
1.2x

1.5x

1.7x

2. Then change the irradiance profile.

# Typical Effect of Irradiance on "Cure"




**"Cure" of a clear coating on wood, based on equal chemical resistance (MEK rubs). (Two data points only -- the shape of the curve between these is not known).**

*For Most UV Curable Materials, Energy (alone) is not an adequate specification of Exposure*

# “Reciprocity Failure”

*A low irradiance exposure for a long time does not yield the same result as a high irradiance exposure for a short time, even though the energy may be the same.*

*TIME and IRRADIANCE are independent variables. The area under the irradiance profile is equivalent to energy (exposure).*

# A Lab "Quick Method":

# Measure the Spectral Absorbance of a Coating or an Ink

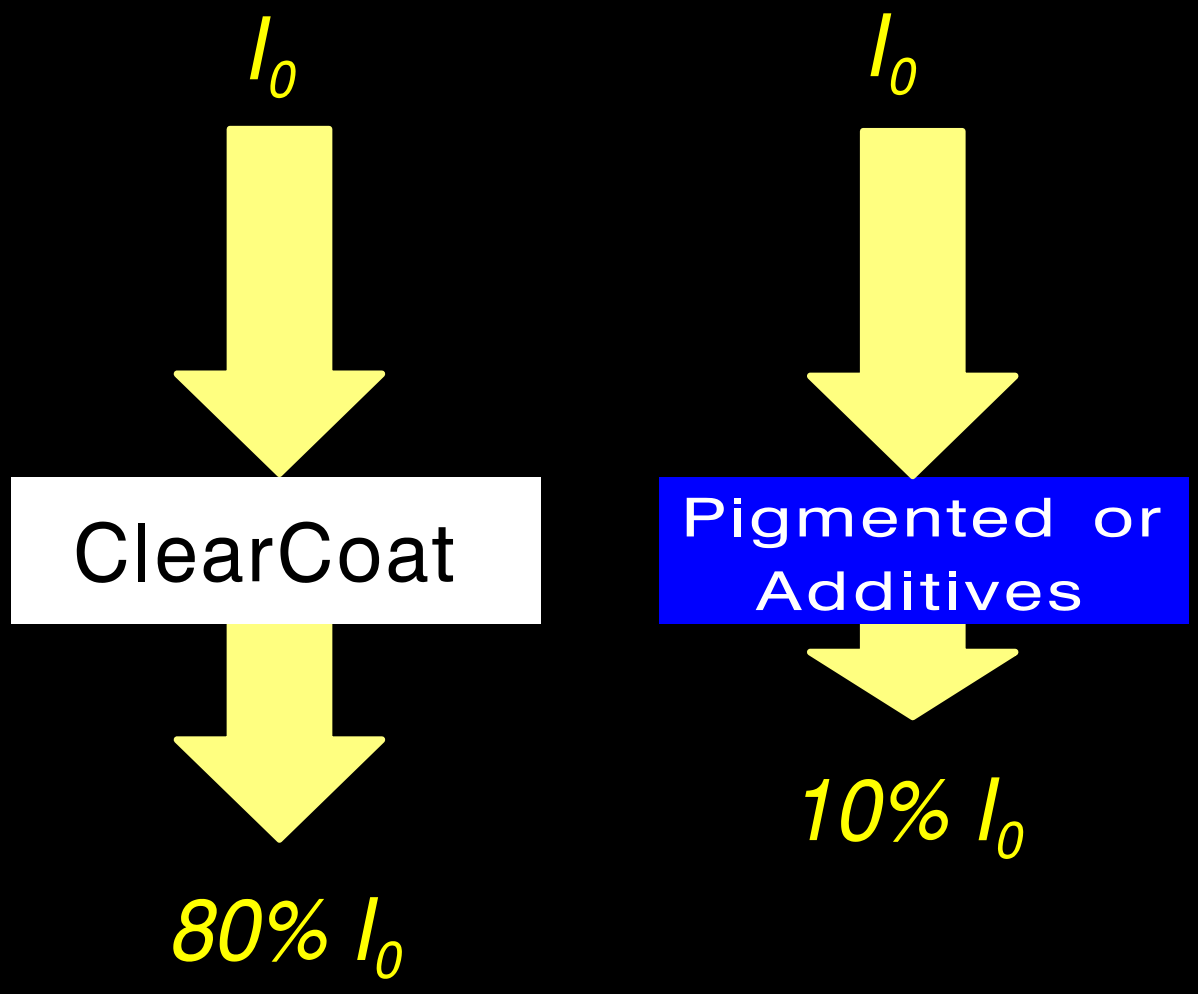
## Bouguer-Lambert Law

By resolving a Taylor Series, we get the expression:

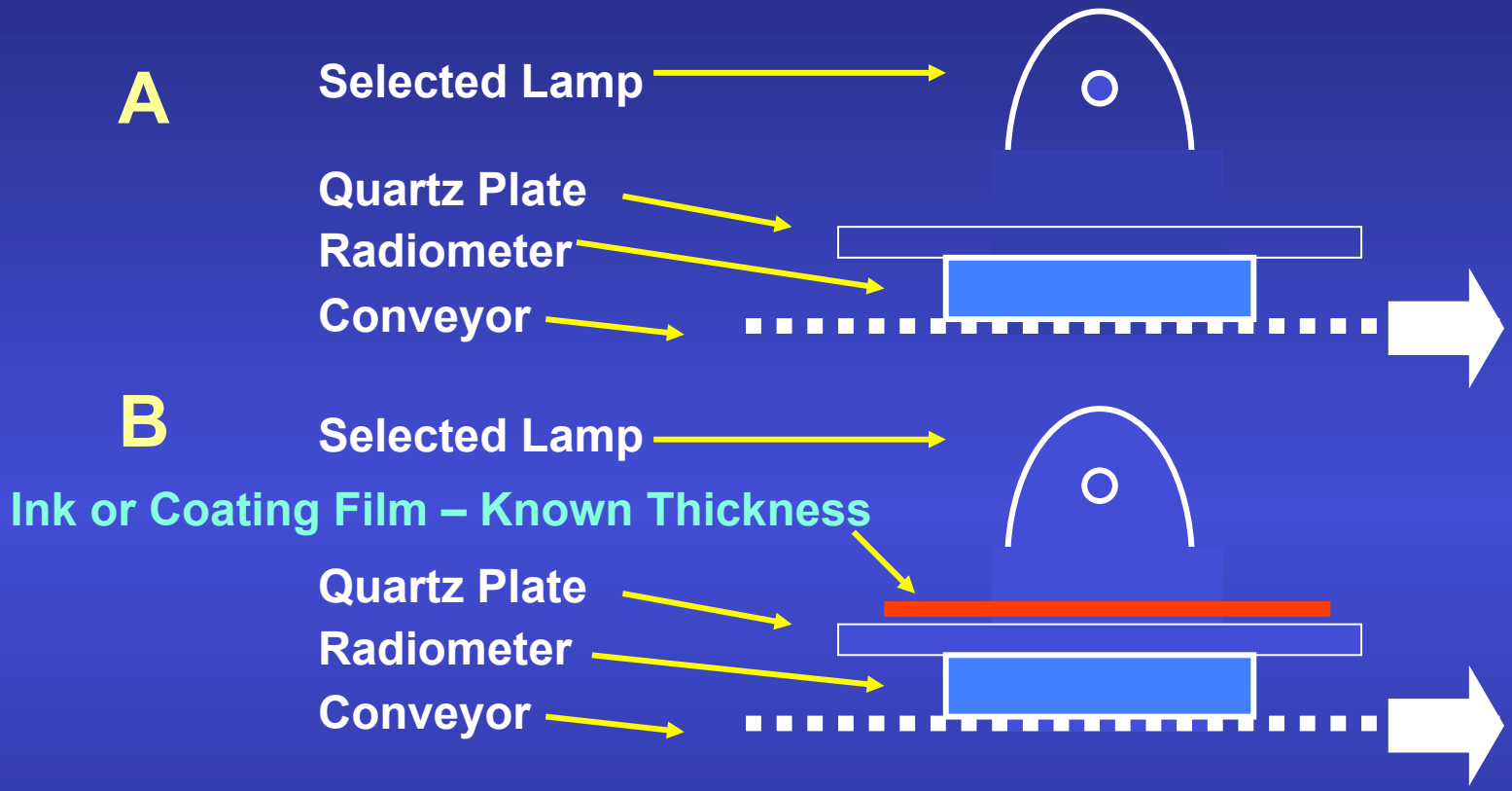
***The photon flux ($I_a$) at any depth (d) within a material is a function of its absorbance (A) and the incident flux ($I_0$) at a specific wavelength (λ).***

FUSION UV SYSTEMS, INC.

## Transmission of Radiant Energy Through "Optically Thin" and "Optically Thick" Materials



## Measuring the Opacity or Absorbance of a UV-Curable Material




We can determine the effective optical thickness of the film in any radiometer wavelength band.

# Temperature

Infrared thermometers measure the IR emitted by a “blackbody” (or “greybody”) surface.

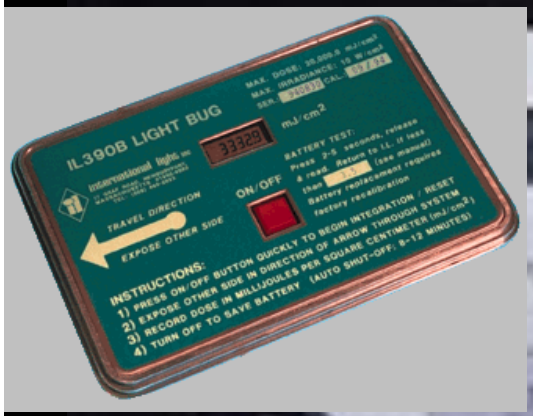
The common IR thermometer has a response in the 8-14 micron wavelength range, and can measure almost any opaque surface.

It cannot measure clear plastic films

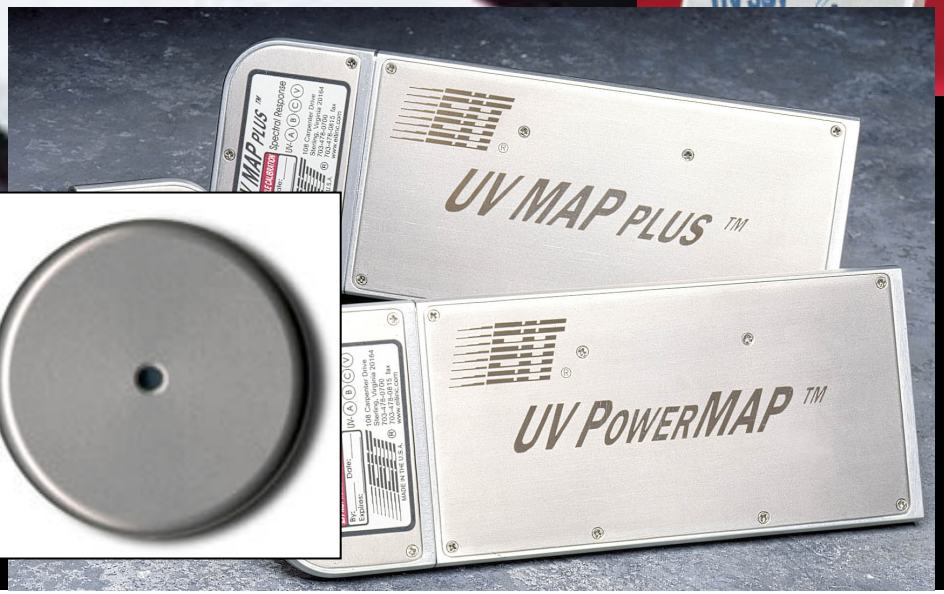
The beam is only a “laser-pointer” to indicate the location of the surface being measured.

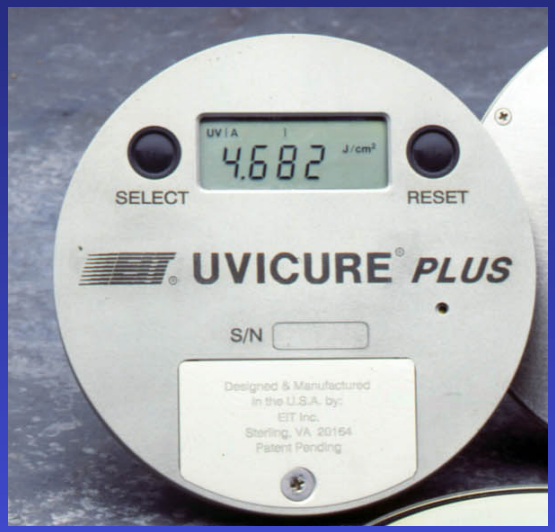
# Characteristics of Radiometers

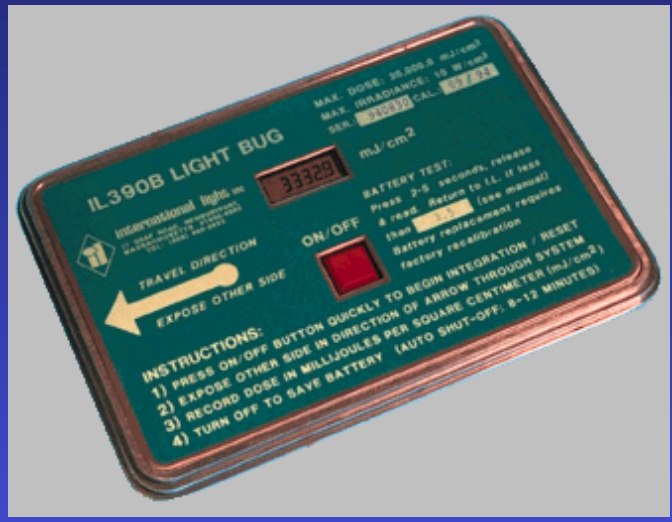
# Portable, or Dynamic Instruments





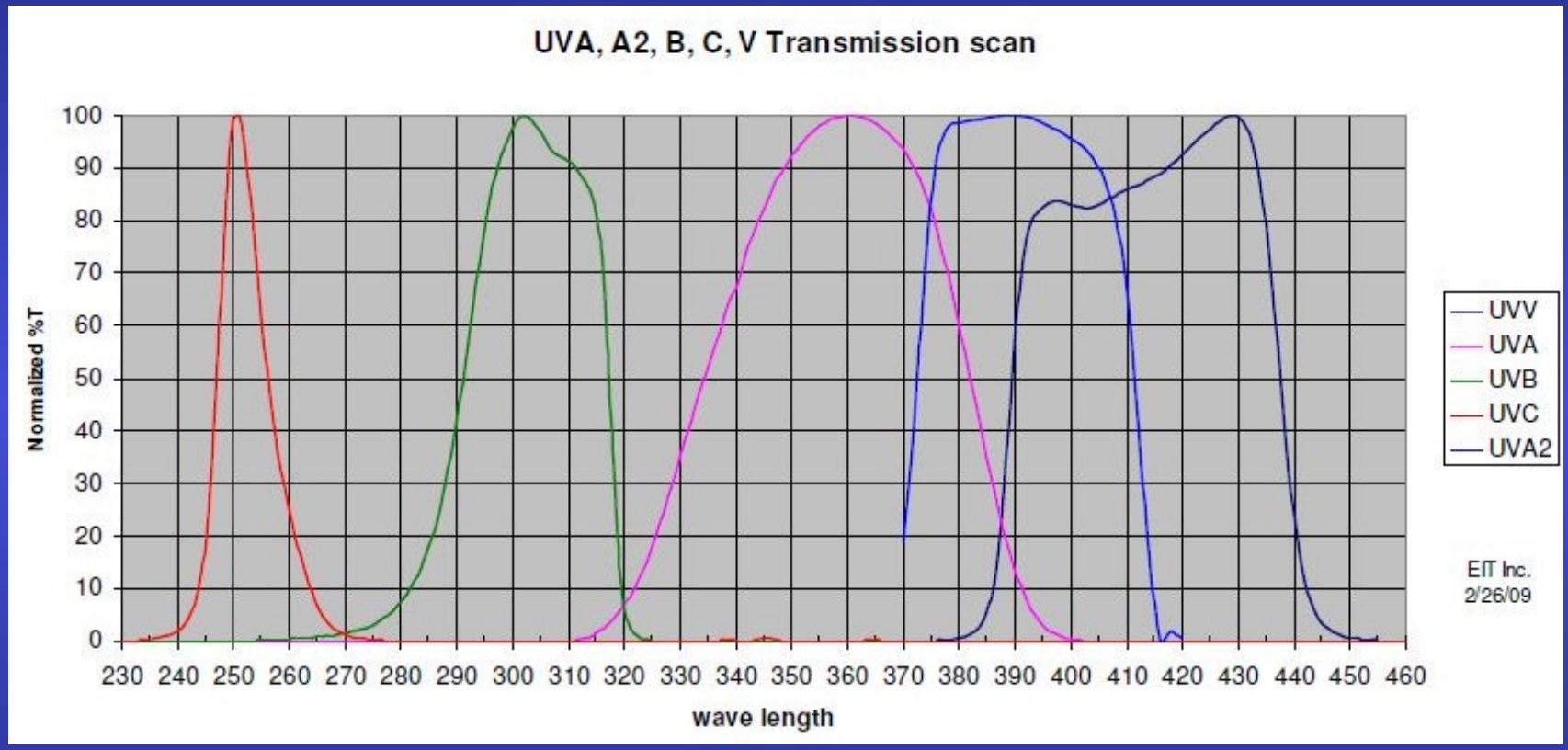
**Portable, or Dynamic Instruments**

**Typical for conveyors and lab use**

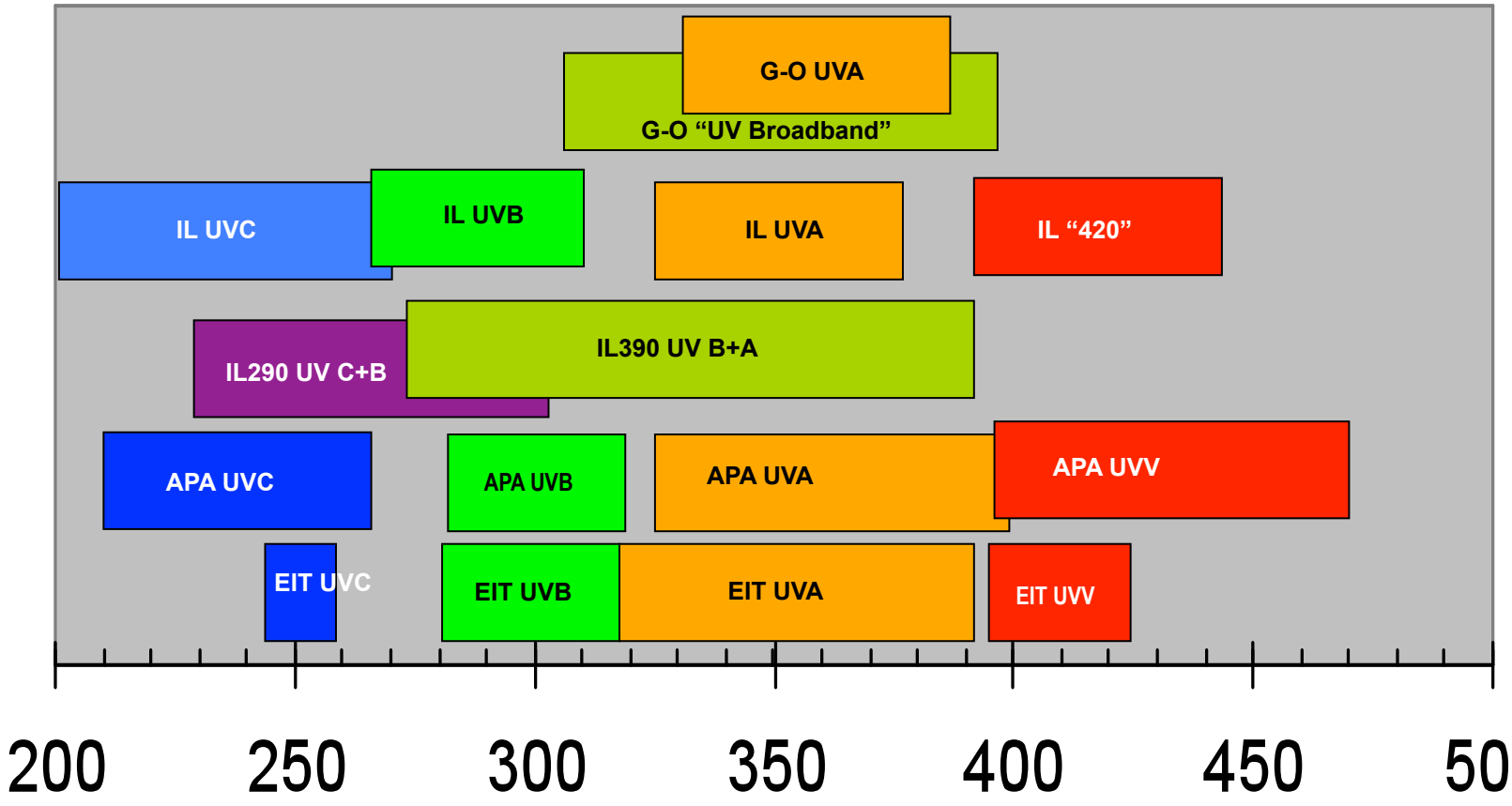
# Probes


# Responsivity

# Radiometer Response Bands




*The general definition of response band is the wavelengths where the response is 50%*



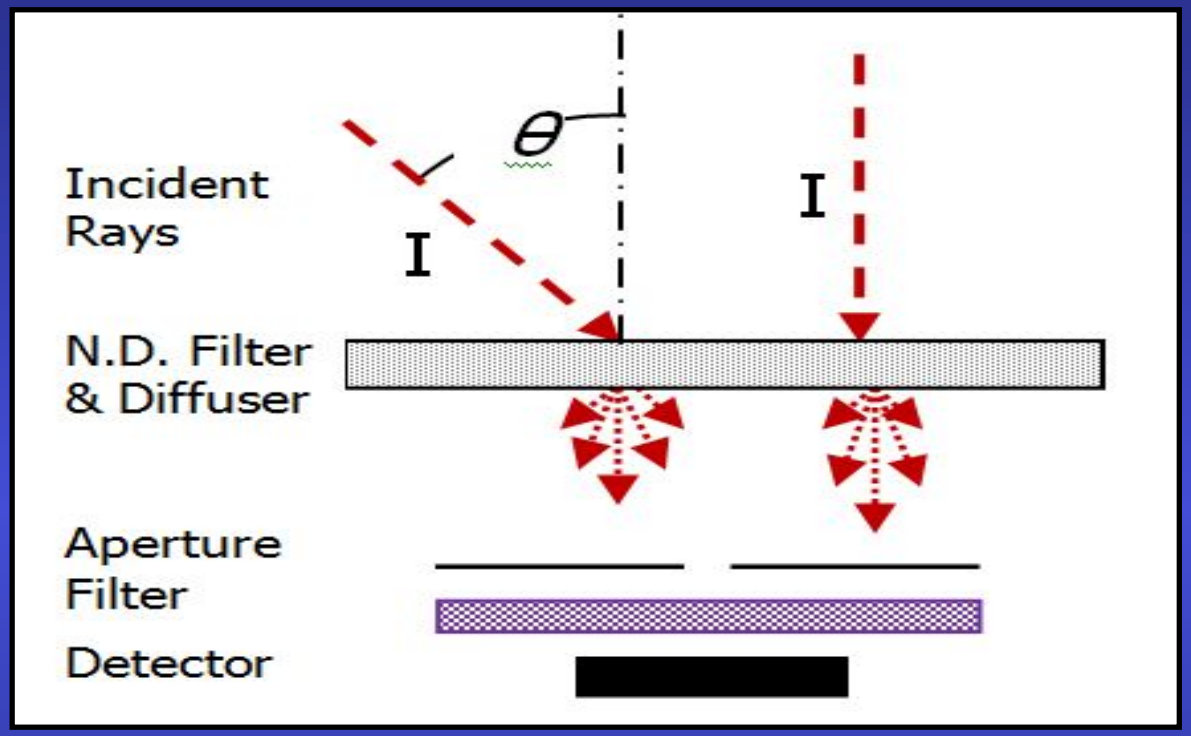

**Wavelength Bands of Various Radiometers (nm)**

[All represented at the 50% response points]

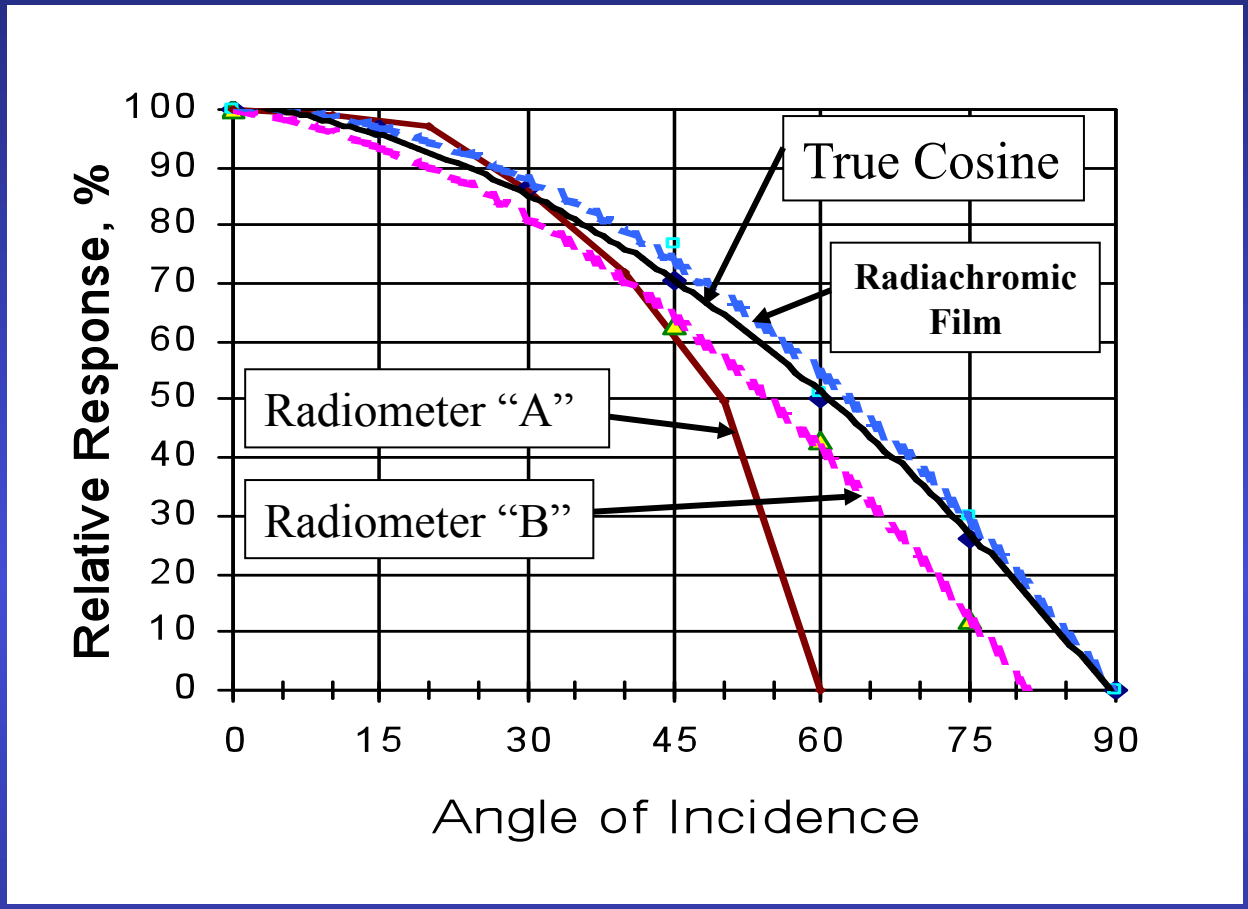
FUSION UV SYSTEMS, INC.®

# Cosine Response

# Filter-Detector Type Radiometer




Incident energy is integrated over a finite area of the diffuser and energy arriving at an angle is integrated over a smaller subtended area. The net result is somewhere between cosine response and cosine$^2$ response

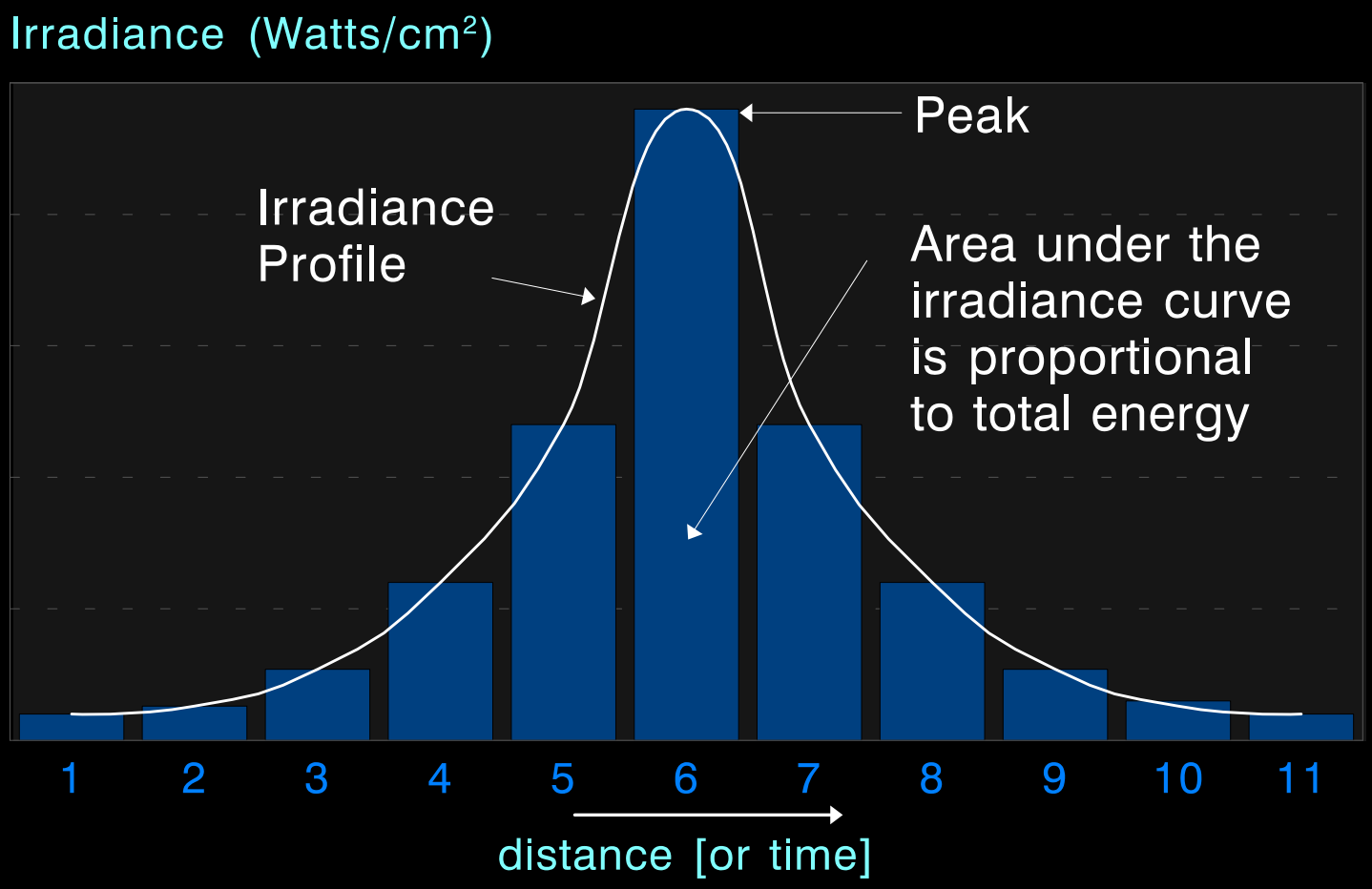



Cosine response of several commercial UV radiometers, radiachromic films, and ideal response.

# Electronic Sampling and Integration

# Radiometers

## Sampling and Integration



## Distance between samples:
## $D = V/R$

D: Distance between samples, inches

V: Speed in inches/second

R: Sample Rate in samples/second

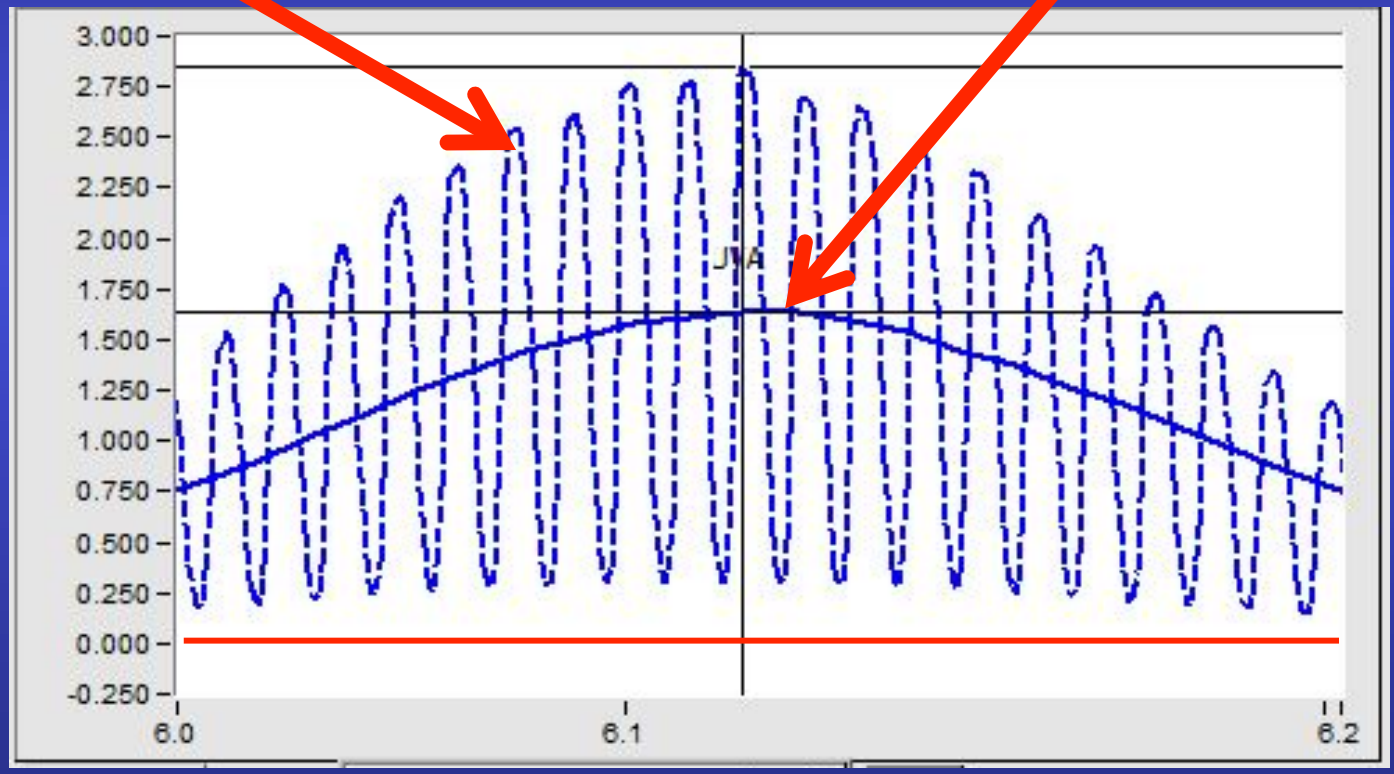
If the measurement speed is too fast, in combination with a sampling rate that is too slow, successive samples can actually MISS the peak !

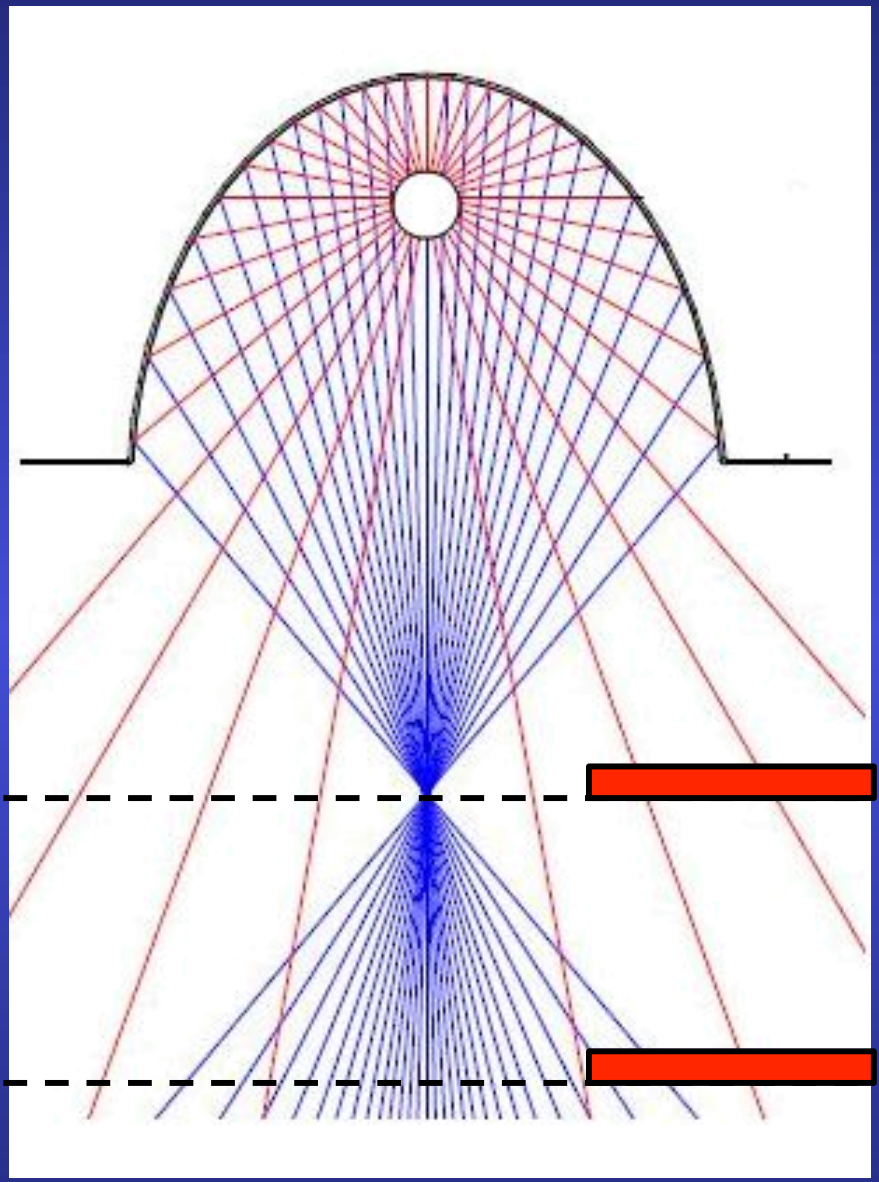
If the sampling rate is too fast, the radiometer may respond to the peaks of the output ripple!

# Sampling Rate and Output Ripple = Error

2048 Samples/second

128 Samples/second OR“Smooth ON”





## *DISTANCE ?*

**Q:** Where should a radiometer be placed with regard to the surface of interest?

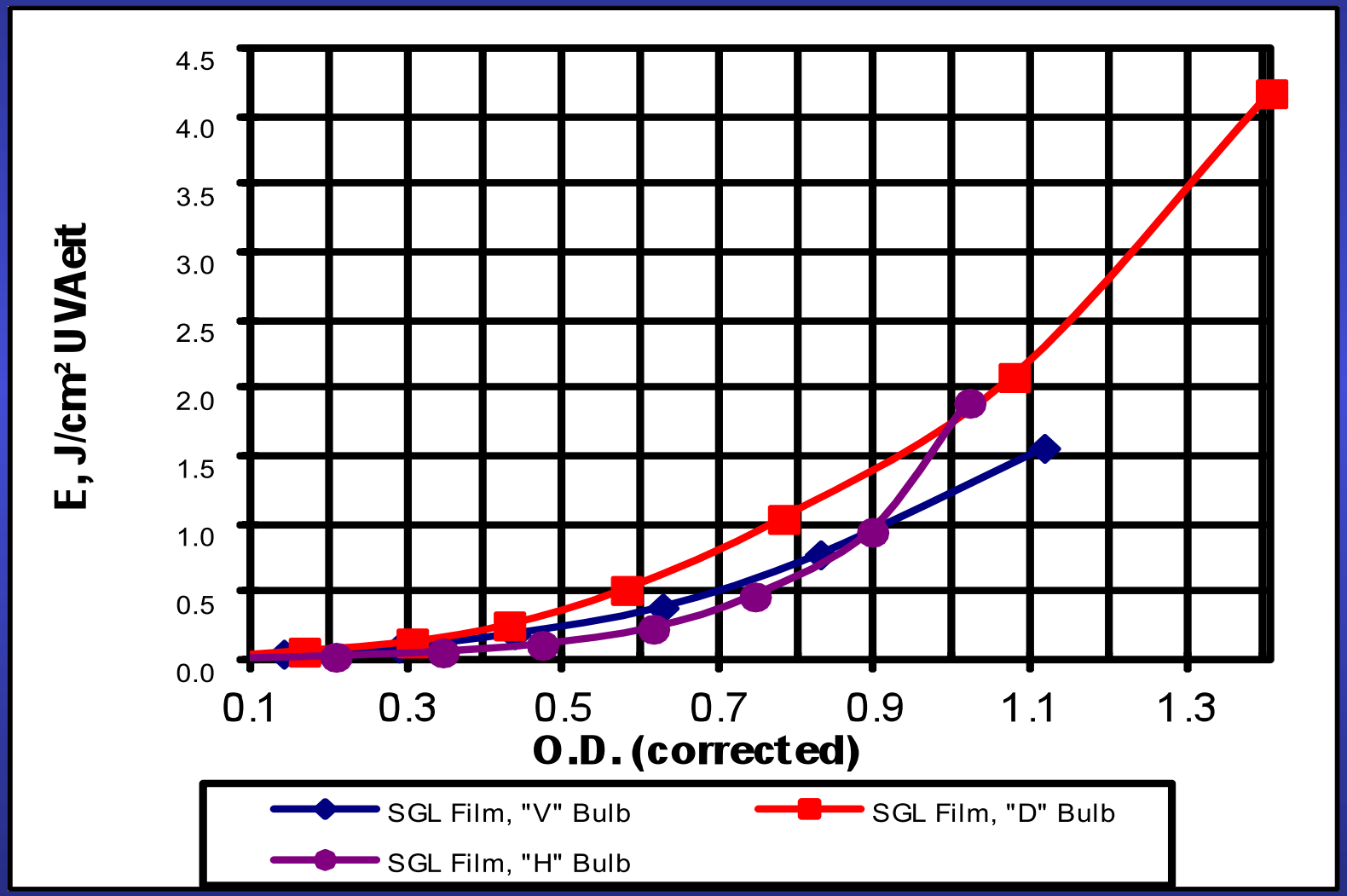
**A:** Place the radiometer ON the surface of interest.

This compensates slightly for the internal optics of the radiometer, but more importantly, provides a ***reproducible procedure*** for measurement.

# Radiachromic Films

IHARA Color Reflection Densitometer

# Radiachromic Correlation



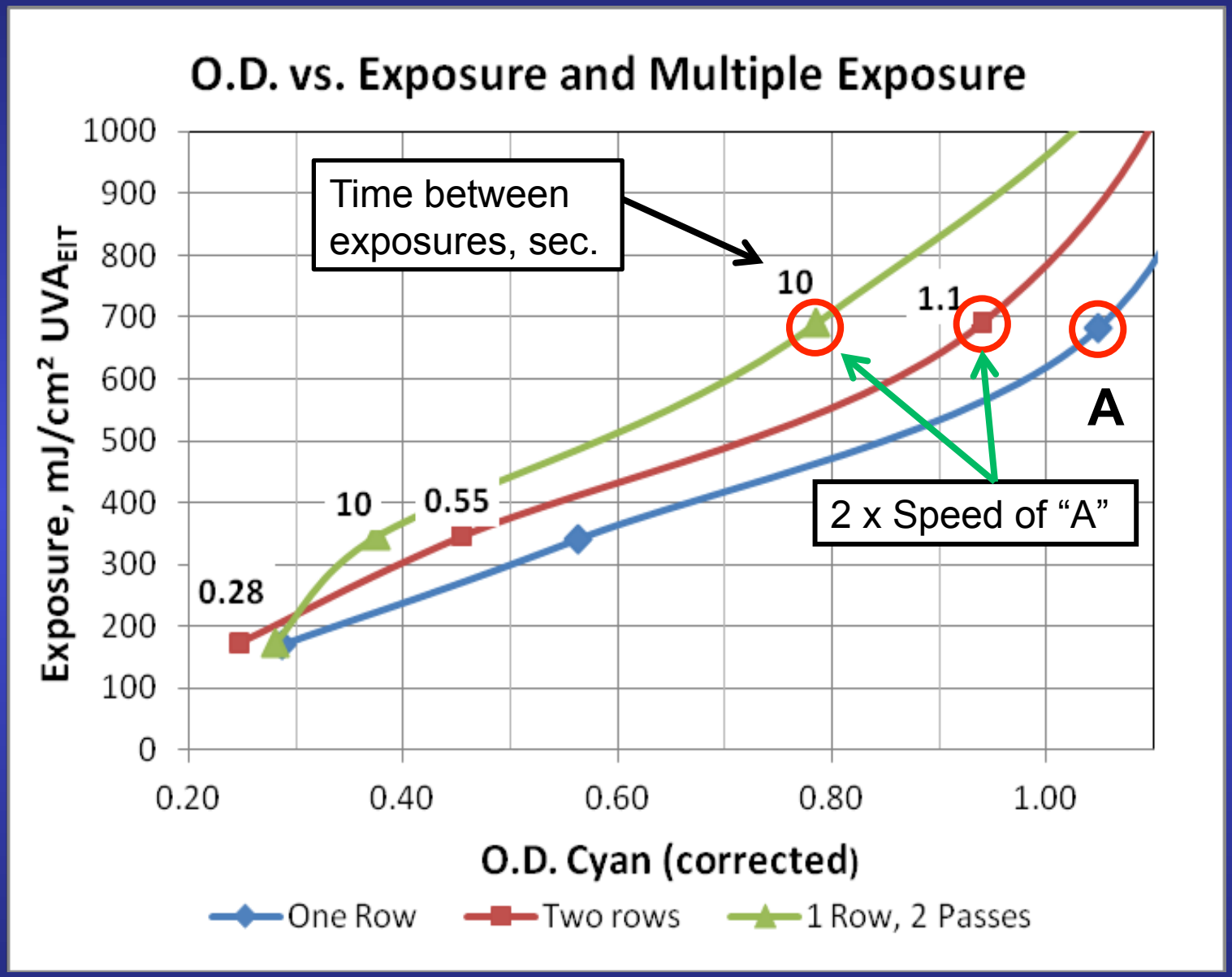
## A caution of using radiachromic films:

Radiometers will add the exposure of multiple passes or multiple rows linearly.

Radiachromic films do not. **1 + 1 ≠ 2**

It is essential to correlate a film with the same exposure schedule that ultimately will be measured.

Radiachromic films are chemical films. Consequently, they are subject to the same *reactive species depletion* that UV-curable materials are.




SG Reflective Film

# Conclusion:

# RECOMMENDATIONS

- ✓ *Always identify the UV band of measurement data*
- ✓ *Always identify the instrument (radiometer) used for measurements*
- ✓ *Report the speed and peak irradiance with any exposure measurements*

## Conclusion:

## So why don't formulators provide adequate exposure specifications to cure their material?

- Because they don't know what film weight you will put down
- Because they don't know what substrate you will put it on
- Because they don't know what lamp spectrum you will use
- Because they don't know what peak irradiance you will apply
- Because they don't know what radiometer you will use

# Thank You

RADTECH
THE ASSOCIATION FOR UV&EB TECHNOLOGY

FUSION UV®
SYSTEMS, INC.

FUSION UV
SYSTEMS, INC.

www.fusionuv.com