**1.50** **Photometric Performance –**
**Evaluation of Pavement Markings and AWTA Product Testing Capability**

*David Teakle - AWTA Product Testing*

**ABSTRACT:**
Current photometric testing regimes are geared towards limiting chaotic or non-Newtonian behaviour, which is accomplished by using instrumentation for measurement rather than human perception.

Instrumentation to determine and quantify reflected spectra demonstrates greater and less variable Quantum Efficiency than the human eye which ensures the elimination of subjectivity enabling the reproduction of data using different equipment consisting of similar componentry and geometric sensitivities resulting in lower error and uncertainty levels.

The primary sources of error in current equipment are those associated with product and equipment geometric sensitivity; however other environmental variables also contribute to uncertainty of measurement

Testing does not take into account, Human Quantum Efficiency, angular change and movement, product deterioration, environmental chaos, illuminant source/type or difference in area and reflected spectra colour.

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## Introduction:

Photometric performance of substrates plays a large part in everyday human activity, where autonomic perception and physiological processing lead to the subjective evaluation of both emitted and reflected light spectra, providing us with the ability to discern highlighted spectra from background noise, which can be used to define the importance of the information we receive.

Reflective media and lighting both play integral parts in providing us information about elements required for everyday human social interaction.

The primary aim of this paper is to discuss and define commonly used Photometric terminology and measurement units, In addition to describing Photometric testing equipment pertinent to the evaluation of reflective surfaces, comparing to human physiological processes and environmental variability.

## Terminology and Units:

- **Photometry** – Measurement of the intensity of light. (1)
- **Flux** – The amount of energy Flowing through a given area in a given time ($Wm^{-2}$). (1)
- **Intensity** – The amount of energy per unit volume emitted in a given solid angle in a given range per unit time ($Wm^{-2}Hz^{-1}sr^{-1}$)***** sr = Steradian (Element of Solid Angle) (2)

- **Quantum Efficiency** – Q.E (%) = Detected Photons / Incident Photons

- **Illuminance** – The total luminous flux incident on a surface, per unit area. A measure of the intensity of the incident light, wavelength-weighted by the luminosity function to correlate with human brightness perception. (4) (Lux (lx)) [5].

- **Retro-Reflection** – Retro-reflectors are devices that operate by returning light back to the light source along the same light direction. [3] (Refer to figures 1a & 1b)

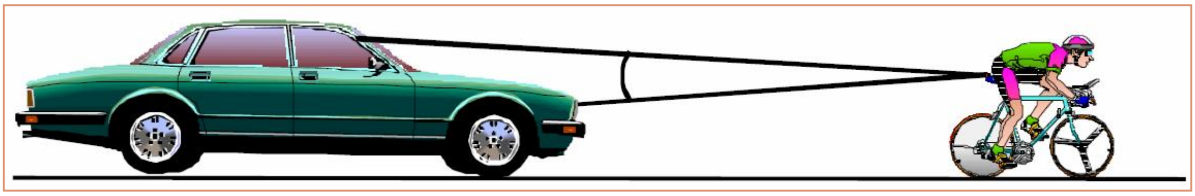


**Figure 1a**

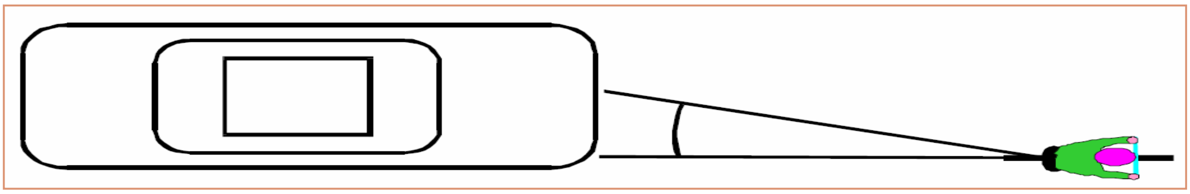


**Figure 1b**

**Figures 1a and 1b** show the path and applicable correctable angular geometries that can be associated with retro reflected light (Where trigonometric (Cos $\theta$) ) correction can be made to ensure that angle to and from the substrate are the same.

- **Coefficient of Luminous Intensity - (CIL)** – The ratio of Luminous Flux per unit of illuminance (candela/Lux)

- **CCD** – Charge Coupled Device – The same device used in a digital camera. Converts photon to electrons in accordance with the photoelectric effect. The amount of electrons produced relates proportionately with the amount of photons being detected. A signal processor measures the number of electrons associated with each pixel and converts the information to a digital code which is subsequently re-constructed by computer to re-construct and display the scene. [5]

- **Photomultiplier Tube (PMT)** - Measures the total light energy during the exposure period which is then converted to luminosity. PMT's are being progressively replaced by CCD's. [5]

- **Coefficient of Retroreflection – (CIL/m-2)** – Coefficient of Luminous intensity per unit area.

- **Gaussian** – The uniform radiation of flux from an axis of symmetry. [6]

- **Luminous intensity** - Unit of measure: Candela (cd) - The luminous intensity describes luminous flux emitted by a light proportionate to a solid angle source in a particular direction.

- **Luminance** - Unit of measure: Candelas per square metre (cd/m²) - Luminance is the amount of visible light leaving a point on a surface in a given direction. This "surface" can be a physical surface or an imaginary plane, and the light leaving the surface can be due to reflection, transmission, and/or emission. Luminance describes the impression of brightness the viewer experiences. The relationship between luminance and brightness is non-linear and very complex.

- **Illuminance** - Unit of measure: Lux (lx) -Illuminance (usually "E" in formulas) indicates the amount of luminous flux from a light source falling on a given surface. It is the quotient of the luminous flux divided by the area of the surface. Because illuminance is relatively easy to measure or calculate, it is frequently used in planning. Illuminance does not provide clear conclusions about subjective brightness.Illuminance can be weighted by the luminosity function to correlate with human brightness perception. [4] (Lux (lx)). [5]

## Discussion

## Apparatus

Apparatus used for measuring retro-reflected light consists of a projected light source, A Photocell (PMT) capable of being moved to various observation angles, and a Goniometer (3- Axis) capable of adjusting the angle of the reflector. (Refer to Figure 2a and b).

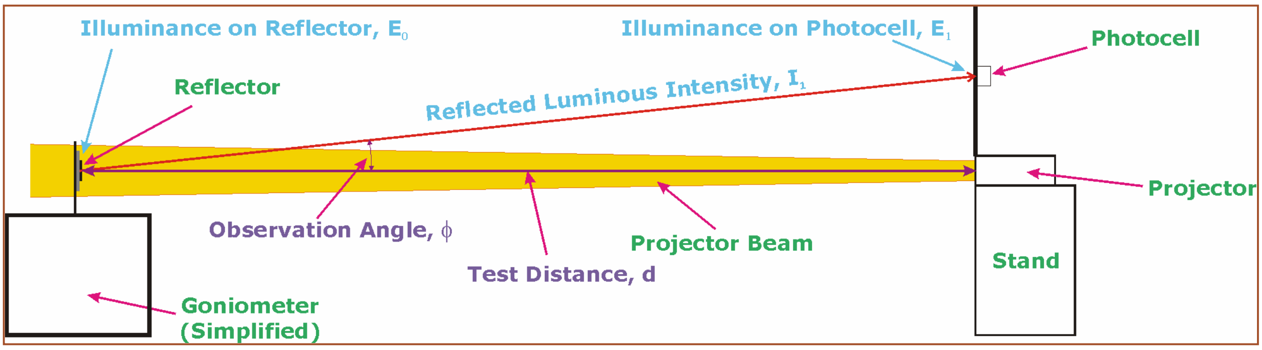



**Figure 2a** – Simple retro-reflected light apparatus describing geometry and test apparatus elements. [6]

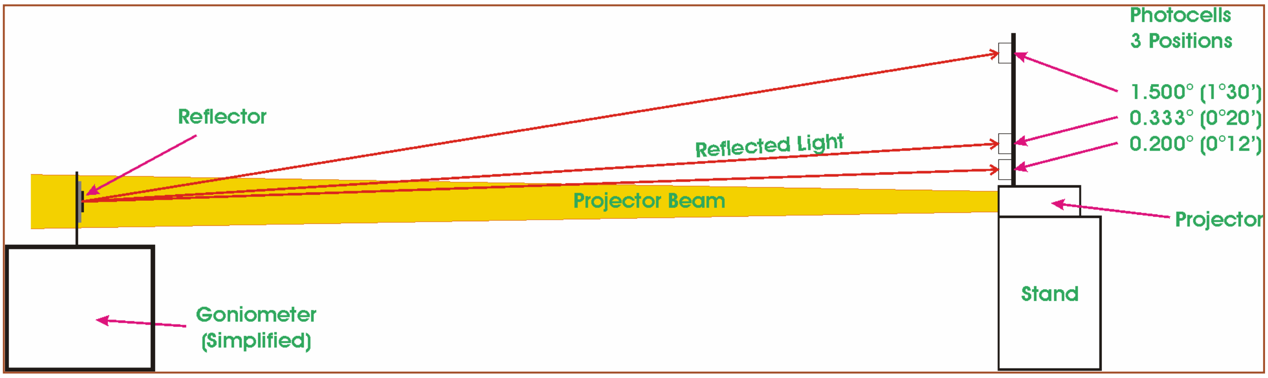
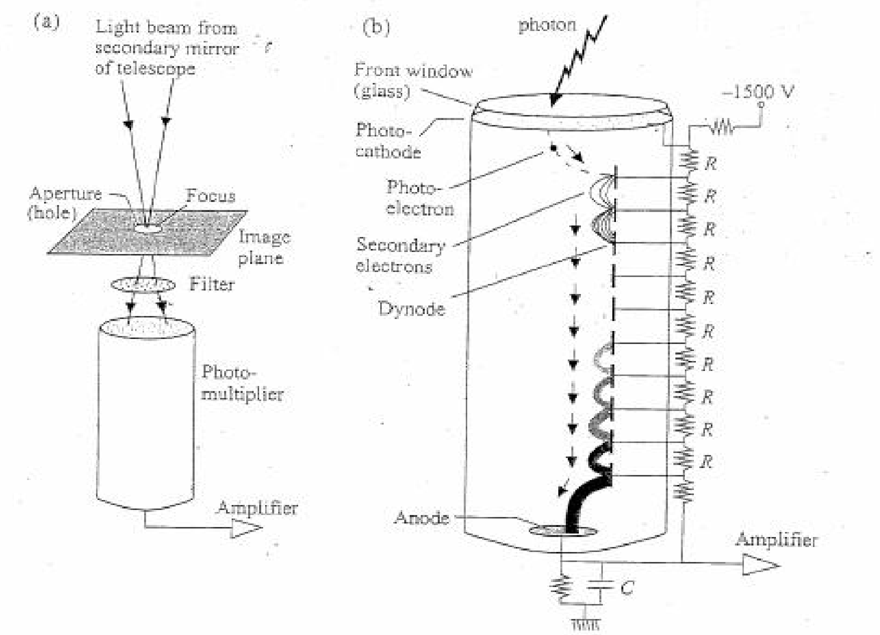



**Figure 2b** – Simple Retro-reflected light apparatus with variable photocell (PMT) receiver entrance angle geometries. (6)

### Photomultiplier & CCD

Whilst in PMT's are progressively being replaced by CCD's, they are still widely used in retro-reflective measurement. Figure 3 shows both types of detectors which demonstrate significantly more Quantum Efficiency (65 – 95%) than the human eye, additionally eliminating subjectivity and operating over a broader wavelength spectrum. The primary advantage that both instruments have, is the direct link to photon bombardment and the amount of electrons produced for image re-construction.




(a) Classic arrangement for quantitative measurement of flux of light from a star, known as photometry. CCDs are now used for photometry. (b) Operation of a photomultiplier. An incident optical photon interacts with the photocathode, ejecting a photoelectron which is replicated manyfold by the dynodes. The resultant large charge of electrons is collected at the anode. In real tubes, the dynodes are arranged to optimize the collection of electrons.

**Figure 3** [2] – PMT and CCD construction and comparison.

## The Human Eye

The human eye (Figure 4) provides relatively poor detection and conversion of photons into signal. The eye detects Visible spectra @ 400 – 700 nm with the maximum sensitivity corresponding to about 550 nm (Which is why tennis balls are Yellow-green in colour). [(5)] The eye splits white light into component spectra where it is converted into neural signal after being focussed onto pigmented receptors (Rods/Cones (Refer to Figure 5)) which is sent to the brain via the optic nerve. Perception of colour, intensity and distance all vary as function to the construction and physiology which differs from human to human. The primary difference between instrumentation such as CCD's or PMT's and the Human Eye lies in the Quantum efficiency of the detector. The eye does not convert faint light to signal as readily as instrumentation (Refer to Figure 6 (Eye @ approximately 7% QE vs CCD at approximately 65 – 95%)).

It is pertinent to note that irrespective of instrumental efficiency, retro-reflective, and colour measurement should ultimately be scaled to correlate with human visual perception.

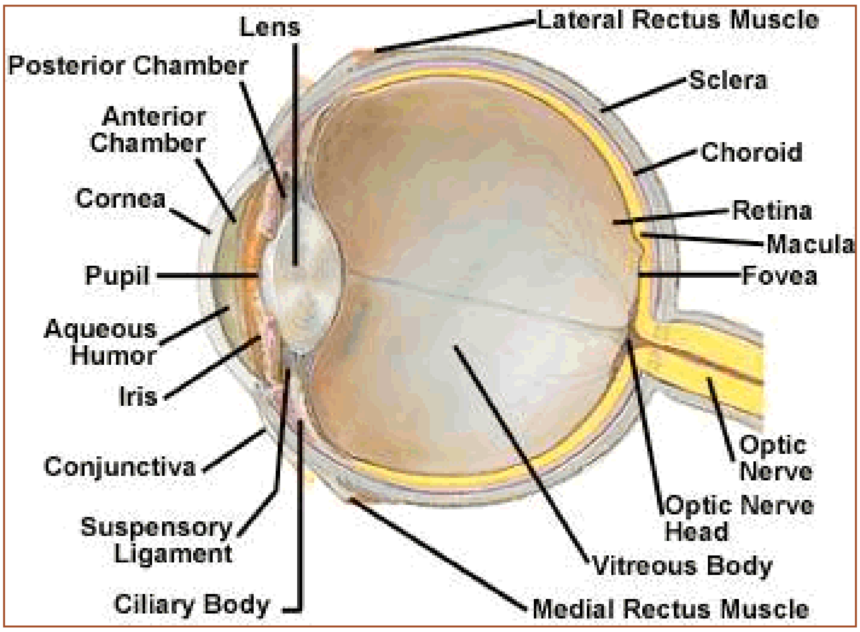



**Figure 4** [(12)] – The Human Eye – Typically 5% QE

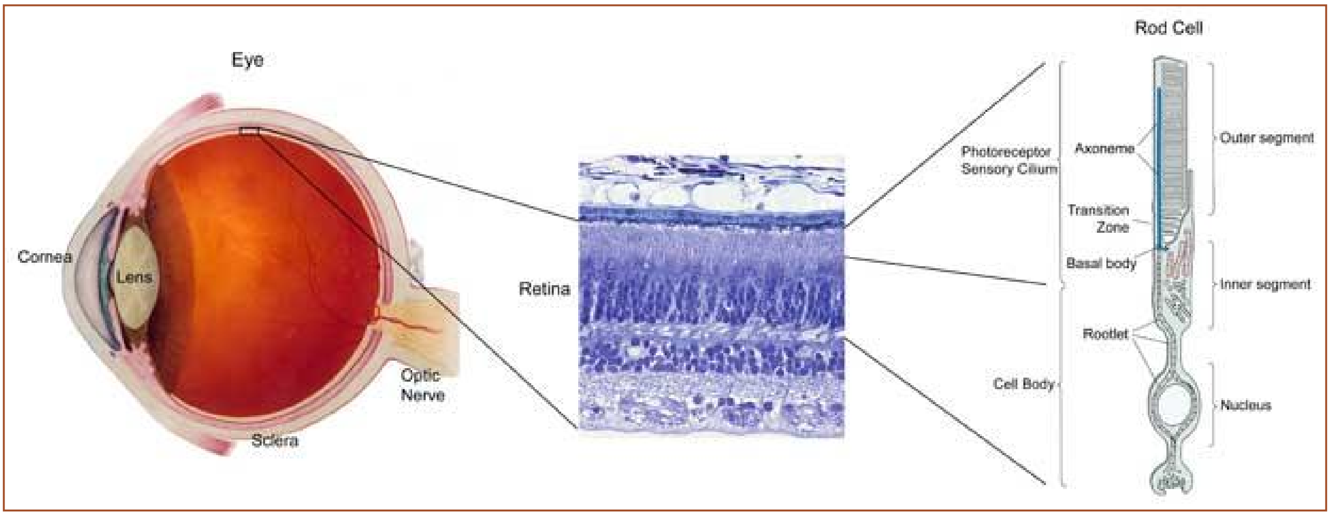



**Figure 5** (13) – The Human Eye – Converts visual spectra into neural impulses via pigment receptors.

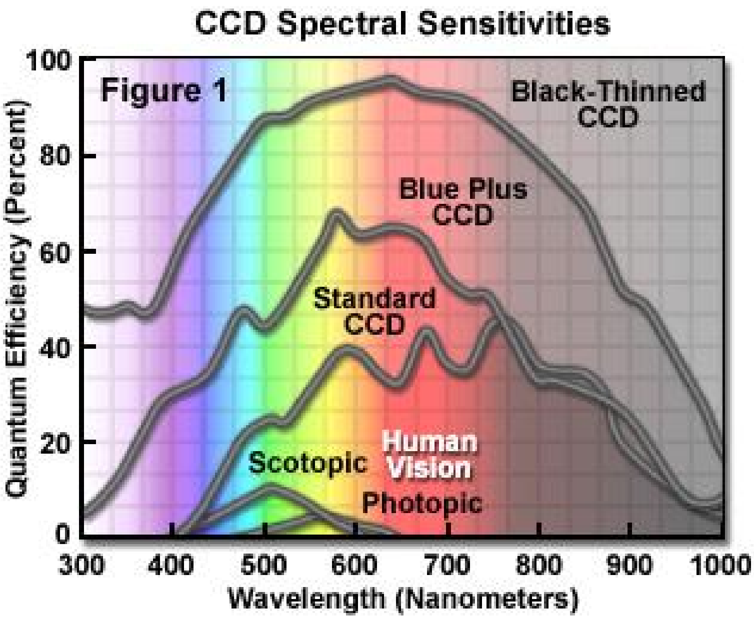



**Figure 6** (14) – Eye versus the Machine – Differences in QE between the human eye and CCD Detectors.

## Light Source

The light source used by AWTA Product testing equipment is optimised to run at a temperature of 2856K, producing a focussed circular image at the specified test distance (15m). The illumination is Gaussian to ± 5% over the test area of 250mm at the 15m test distance. (Refer to Figures 8a and 8b). The distribution of radiant light flux per unit area is a function of distance from the source due to atmospheric absorption and scattering.

Potential Light sources are wide and varied using many different radiators at many different temperatures. It is known that the characteristics of radiation depend on temperature and properties of the surface of the radiator. [5] Which is why we can obtain a variety of different emission spectra from a given radiators.

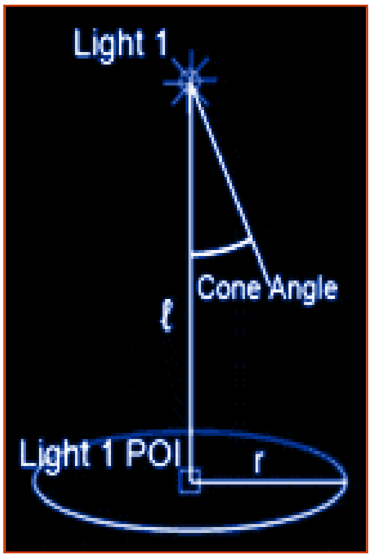


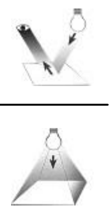

**Figure 8a** [7] – Geometric representation of a light Cone

**Figure 8b** [7] – Actual light Cone

## Measurement

Retro-reflective measurements currently provided for road marking substrates are expressed in units of mcd/m$^2$/lx (or candela x 10$^{-3}$ / meter / Lux), which is a ratio of Luminance per unit Illuminance. The main advantage of this measurement is the correlation and scaling to typical human perception as detailed earlier (Refer to Terminology and units). The primary disadvantage is that human physiology and perception are not readily quantifiable.

$$\frac{\text{Candela Per Unit area}}{\text{Lux}} = \frac{\text{Luminance}}{\text{Illuminance}} =$$



$$= \frac{\text{mcd m}^{-2}}{\text{lx}}$$

The measurement detailed above is a ratio between (Luminance) - the amount of visible light leaving a point on a surface in a given direction and (Illuminance) - the amount of luminous flux from a light source falling on a given surface. The measurement describes the quantity of spectra from a reflected spectral flux that is captured by the receiver.

## Reality

Human sight only interprets the visual portion of the electromagnetic spectrum as described in Figures 7a, b & c. The integral of the spectrum generated by a black body in Gaussian fashion encompassing the entire visual spectrum is perceived as white light which will vary in intensity commensurate with flux and colour due the distribution of visual spectra within it

Figures 7a – 7d describe the electromagnetic spectrum, the portion of spectrum that is discernable by eye, and the visual component of white light.

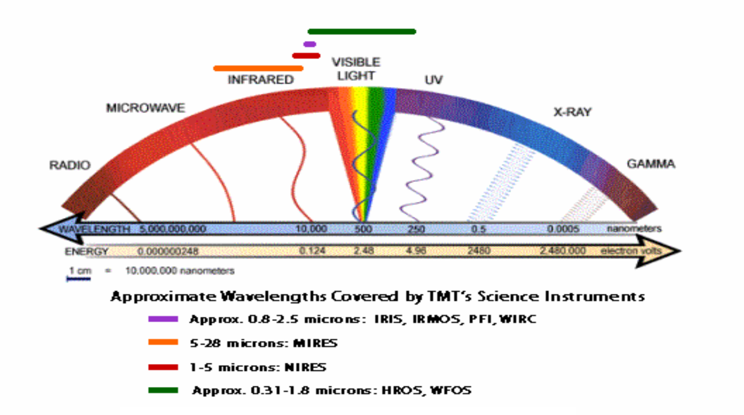



**Figure 7a** [9] – The electromagnetic spectrum

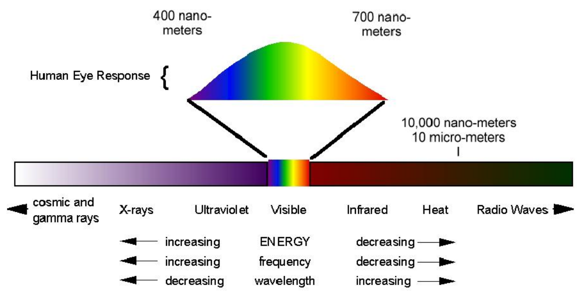



**Figure 7b** [10] – The electromagnetic spectrum and human perception

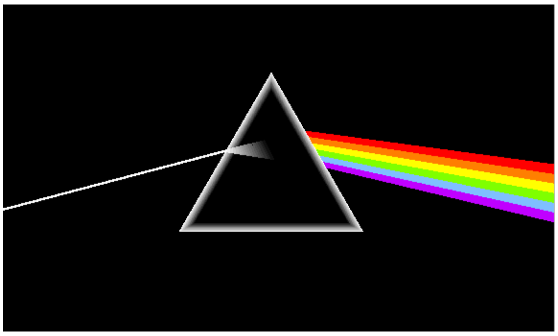


**Figure 7c** [10] – White Light Splitting into visual spectra

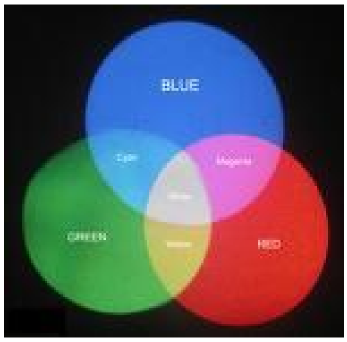



**Figure 7d** [8] – White Light - composition

## Variables & Potential Error Sources

In reality there are a number of components which will affect the individual and instrumental perception of reflected light from a substrate which may include the following…

- **Atmospheric extinction** – The diffusion, scatter and absorption of light focussed toward a substrate by atmospheric anomalies' including, rain mist, fog and temperature.

- **Sensitivity to angular geometry -** Constantly changing angles relating to a moving vehicle approaching and passing a retro-reflective substrates, in addition to the differences in car /truck/train headlight heights will all result in variation reflected spectra for a constant source of spectral emission, with intensity maxima and minima.

- **Type of substrate** - The reflection (albedo) characteristics of a substrate surface will result in different rates of absorption and scatter of light flux.

- **Interference** – interference from spectral sources from the surrounding environment will invariably contribute to changes in reflected spectral colour and uniformity of flux.

- **Colour of substrate -** (Remembering that the atmosphere scatters blue light better than red light, which is why the sky is blue. The human eye has its highest QE at approximately 550 nm (Tennis ball green-yellow) and lower QE lowers human perception at a given intensity).

- **Human physiology** - Basic human eye construction physiologies are the same, however our ability to detect, analyse, subjectively evaluate and discern the intensity and colour of reflected light, varies with the amount of experience, skill, deformity and the specific QE of the receptor which varies about a Poisson distributed standard for human visual acuity and perception, which may be applied and may vary with each colour of the spectrum – (This is a very complex dynamic.)

- **Type of illuminant** - The intensity, composition and radiation characteristics all affect the composition emission spectra.

- **Temperature** – The temperature of the radiator is closely related to the spectral emission.

- **Albedo of the retro-reflective substrate** – Defines the quantity of reflected spectra at the substrate surface.

- **Area and dimension** of the reflective substrate **-** Captures and reflect more flux per unit area back to the observer.

- **Condition of reflective substrate** – If the surface of the substrate changes during use, then reflectance and spectral characteristics will change as a result. Typical elements that will affect the reflectance characteristics of a substrate may include deposits on the substrate surface or substrate environmental degradation. (E.g. Surface deterioration, uv-degraded etc…)

- **Use and Application** – Is the substrate the best one for the Job? Determination of the relevance of a substrate or reflective media for a function must take all of the above variables and potential error sources into account

## Conclusion

Current photometric testing regimes are geared towards limiting chaotic or non-Newtonian behaviour, which is accomplished by using instrumentation for measurement rather than human perception.

The instrumentation used has far greater and less variable Quantum Efficiency than the human eye

This ensures the elimination of subjectivity enabling the reproduction of data using different equipment consisting of similar componentry and geometric sensitivities within estimated instrumental error and uncertainty levels

The primary sources of error in current equipment are those associated with product and equipment geometric sensitivity which.

Information obtained from testing is designed to be scaled to a standard degree of human perception eliminating physiological differences

Testing does not take into account, angular change and movement, product deterioration, environmental chaos, illuminant source/type or difference in area and reflected spectra colour.

## References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