Line 49 Inc.

Glo to Sleep™ - Interaction With Light

Technical Report No.GTS04

12.29.2008 - This technical report documents the characteristics of the absorption and subsequent remission of light by the phosphorescent pigment inside the Glo to Sleep™. The different light sources that can be used to charge the Glo to Sleep™ are examined, as well as their effects on the brightness and the duration of glow. A discussion on illuminance and melatonin levels concludes the report.

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INTRODUCTION

The light inside the Glo to Sleep™ serves one important purpose, to direct the gaze of the user upwards. This is the essence of the Glo to Sleep™ effect. Phosphorescence is used to supply the light source as only a low level of illumination is needed, and there is no need for the risk and complication associated with electricity. The Glo to Sleep™ only needs quick activation near a reasonably bright source of light and it is ready to work.

STRONTIUM ALUMINATE PHOSPHORESCENT PIGMENT

The phosphorescent pigment used in the Glo to Sleep™ is strontium aluminate($SrAl_2O_4$), a solid odourless non-flammable pale yellow powder that is heavier than water. It is chemically and biologically inert and non-radioactive. It is a new generation glow pigment, greatly superior to its predecessor, copper-activated zinc sulphide (the familiar glow-in-the-dark greenish color) in terms of illuminance levels from short charging times.

The Glo to Sleep™ has dual illuminance modes. White Mode: pale bluish-white to white glow, the dimmer middle-of-the-night mode for more light-sensitive eyes. Blue Mode: a calming, soft blue color. Blue glow pigment is used in the introductory model of the Glo to Sleep™ however the glow color has no bearing on the actual Glo to Sleep™ effect. In the future, green, also a relaxing color, and possibly white afterglow strontium aluminate phosphor, will be incorporated and a Glo to Sleep™ can then be chosen based on personal preference.

LIGHT ABSORBED BY THE GLO to SLEEP ™

White Mode and Blue Mode

Expose the Glo to Sleep™ to any reasonably bright light source, LED, incandescent or fluorescent for a very short duration and it will be in White Mode, exhibiting a pale bluish-white to white glow. As well, the Glo to Sleep™ can be placed, inside up, in a reasonably bright room and it will be in White Mode when required. Shifting the Glo to Sleep™ into Blue Mode requires more radiant energy, and some artificial light sources are more efficient at providing it.

Determining the Most Efficient Charging Source

Artificial white light sources can emit all colors of the visible spectrum in varying proportions as well as in some cases, small amounts of invisible ultraviolet light. Each part of the spectrum effects phosphorescent pigment differently. Red light actually discharges the glow pigment. Green light is neutral. Blue/violet light inefficiently charges the glow pigments. Ultraviolet light charges the glow pigments efficiently. If two artificial light sources are of equal illuminance, the source that emits more radiant energy in the blue/violet/ultraviolet end of the emission spectrum will be more efficient at charging the phosphorescent pigment.

Incandescent and Fluorescent Lights

To roughly determine the ratios of red, green, blue, violet and ultraviolet light from florescent or incandescent light, we need to make a visual estimate of colour whiteness or chromaticity. Chromaticity of white light is often expressed as Correlated Color Temperature (CCT) and measured in degrees Kelvin (□ K). The CCT for incandescent and fluorescent lights ranges from 2000 to 7500 □ K. Lower color temperatures, in the 2000 to 4100 □ K range, give the light a yellowish to slight yellow appearance, classed as Warm White (WW). This source emits more radiant energy at the red end of the spectrum and less UV light. Artificial light sources designated as WW (standard incandescent, halogen incandescent and some fluorescents) are not as efficient at charging glow pigments. It requires a longer exposure to a Warm White source for the Glo to Sleep™ to reach Blue Mode. At a higher CCT, 4100 to 6500 º K, light appears white and is classed as Cool White (CW) and Daylight (DL), emitting more radiant energy at the blue end of the spectrum. CW and DL sources are Compact Fluorescent Lights (CFL), standard fluorescents, and halogens. When CCT reaches above 6500 º K, the source will appear white with slight blue tones. CFL and standard fluorescents are sources of Cool Daylight (CD) lighting. Chemical and glass filters are used to reduce the UV emitted from CW, DL and CD sources to non-hazardous levels, however the minimal UV energy that escapes can quickly excite the phosphorescent pigment, making these artificial light sources more efficient, and thereby faster, at charging the Glo to Sleep™ to Blue Mode. See Table 1 for a more complete charging efficiency ranking.

Light Emitting Diodes (LEDs)

White light LEDs emit no UV energy so they require significantly more time to charge the Glo to Sleep™ to Blue Mode. CW LEDs are actually blue LEDs directly covered by a yellow phosphor and when the blue LED emits light, and then excites the phosphor coating, the glow appears white with blue tones. Recently developed WW LEDs use a blended phosphors coating and when energized they glow yellowish-white, a chromaticity comparable to standard incandescent bulbs. CW LEDs have a radiant energy peak centered at the yellow part of the spectrum, WW LEDs peak in the orange part of the spectrum. With this shift in radiant energy towards the red end of the spectrum, WW LEDs are a less efficient than CW LEDs at charging glow pigment. See Table 1 for a more complete charging efficiency ranking.

Table 1 - Ranking of artificial and natural light sources in terms of increasing phosphorescent charging efficiency.

Table 1. Ranking of light sources in increasing phosphor charging efficiency.

<<------ More Efficient Charging <<------

Type Of Source	Chromaticity	CCT ºK	Light Apperance	UV µW/lm*
Warm White LED	WW	3200	White with yellowish tone	none
Cool White LED	CW	6500	White with blue tones	none
Blue LED	CW	8000	Blue	none
Std. Incandescent	WW	2000-2700	Yellowish white	30-40 µW/lm
Halogen	WW	3500-4100	White with slight yellow	20-70 µW/lm
CFL	CW & DL	4100-6500	Pure white	50-140 µW/lm
Tube Fluorescent	CW & DL	4100-6500	Pure white-natural daylight	50-170 µW/lm
Halogen	DL	5700-6500	Natural daylight	40-200 µW/lm
CFL	CD	>6500	White light slight blue tone	50-140 µW/lm
Tube Fluorescent	CD	>6500	White light slight blue tone	50-170 µW/lm
UV LED	UV		Whitish violet	200-300 µW/lm
Black Light Tube	UV		Violet	200-300 µW/lm
Direct Sunlight	Daylight	5000	Sunlight	600-800 µW/lm

* UV levels in Microwatts/Lumen (µW/lm) range from shielded to unshielded for artificial white light sources

WW = Warm White CW = Cool White DL = Daylight CD = Cool Daylight

Conclusion

Any reasonably bright light will quickly charge the Glo to Sleep™ to White Mode – a pale bluish-white to white glow - however charging the Glo to Sleep™ to Blue Mode – a calming blue glow - can take significantly longer. Shifting to Blue Mode, in the shortest possible time, requires an efficient charging source. In choosing between sources of equal brightness, select a source with a higher CCT, which can be visually determined by its chromaticity. Warm White lights appear yellowish, emit more radiant energy from the red end of the spectrum, and are inefficient as red light actually discharges glow pigment. Choose lights designated Cool White, Daylight or Cool Daylight. Appearing white to white with blue tones, they emit more radiant energy from the blue end of the spectrum. Sources higher in UV light are more efficient. UV LED pen lights, widely available and inexpensive, are a very efficient way to charge the Glo to Sleep™.

LIGHT EMIITTED BY THE GLO to SLEEP ™

The basic principle of photoluminescence is simple: electrons orbiting atoms or molecules absorb energy through collision with photons during excitation. They then emit the excess energy as photons of visible light, at a later time. Strontium aluminate phosphor is used for its extended after-glow in response to minimum of charging. Normally, these phosphors are charged for up to 24 hours exhibiting 20 hours of afterglow. The blue formulation used in the Glo to Sleep™ emits light at a wavelength of 490 nm (Fig. 1). Future models of the Glo to Sleep™ will also incorporate green phosphorescent pigment emitting at 520 nm.

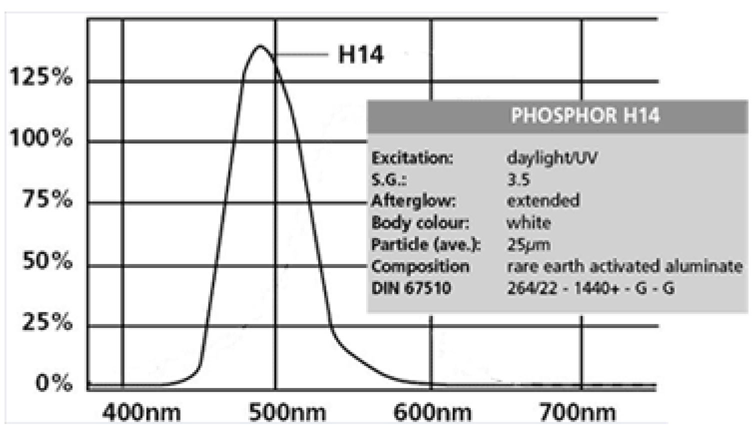

Figure 1. Spectral emission of Glo to Sleep™ blue phosphorescent pigment.

Units of Illuminance

The intensity of a light source is measured in lux. The lux is the SI unit of illuminance, measuring the brightness of light impacting a surface. One lux is equal to the illumination of a surface one meter away from a single candle. Brightness measured in lux increases proportionately as the distance from the light source to the surface of impact decreases. For example, the light impacting a surface one meter from a candle measures one lux, decrease the distance to two centimetres and the illuminance measures 1720 lux. Table 2 provides some examples of the intensity of natural and artificial illumination.

Table 2 - Measured illuminance from natural and artificial light sources.

Light Source	Illuminance
Glo to Sleep™ White Mode	0.01 lux (measured at a distance of 19mm)
Quarter Moon	0.01 lux
Glo to Sleep™ Blue Mode	0.13 lux (measured at a distance of 19mm)
Full Moon	1 lux
Book Light	10-15 lux
Office hallways	90 lux
Office Lighting	410 lux
Overcast Day	1000 lux
Candle	1720 lux(measured at a distance of 19mm)
100 watt incandescent bulb	4200 lux(measured at a distance of 16 cm)
Full Daylight	10,000-25,000 lux
Direct Sunlight	80,000 – 130,000 lux

Glo to Sleep™ Illuminance

The glow pigment pattern inside the Glo to Sleep™ functions only as a reference point, keeping the eyes raised, therefore only very low levels of illuminance are necessary. Significant amounts of information exist on phosphorescent pigment, however no data encompasses the short activation time and dependent rapid decay rates, low brightness level, and small glow pigment surface (0.64 $cm^{2)}$ of the Glo to Sleep™. Consequently, to report on the light-emitting specifications of the Glo to Sleep™, testing was required. The Glo to Sleep™ was tested for maximum illuminance as well as levels of illuminance after specified periods of charging under different household artificial light sources.

Illuminance Testing and Apparatus

Measuring Maximum Illuminance

The Meterman LM631 Digital Light Meter, with a range from 0.01 to 20,000 lux, a resolution of 0.01 lux and a precision of ±3%, was used for the testing. The LM631 was selected as it has a built-in CIE spectrum curve for accurate human eye response. The testing procedure for maximum brightness was straight forward - after exposure to direct sunlight for 5 minutes the illuminance was measured, using a shielding device to ensure no ambient light affected the measurements. All values were recorded with the photoreceptor of the LM631 at a distance of 19 mm from the plane of glow pigment (distance from the eye pupil to inside face of the Glo to Sleep™).

Measuring Illuminance Relative Charging Time

Using the Meterman LM631, four light sources were tested for maximum brightness dependent on charging time. All values were recorded with the photoreceptor of the LM631 at a distance of 19 mm from the plane of glow pigment (distance from the eye pupil to inside face of the Glo to Sleep™). The distances the Glo to Sleep™ was offset from the charging light source varied between two and 16 cm. This ensured light from each source impacting the inside of the Glo to Sleep™ was of equal intensity, approximately 4200 lux. This value was not arbitrary but corresponded to the illuminance from a 100 watt incandescent at 16 cm, the distance a Glo to Sleep™ should offset from a hot light source. The charging distances, from the source to the Glo to Sleep™, were as follows: CW Florescent tube - 4 cm, WW Compact Florescent - 14 cm, WW Standard Incandescent - 16 cm, CW White LED - 2 cm.

Illuminance Testing Results

Maximum Illuminance

After repeated tests, the maximum recorded brightness was 0.13 lux. After an extensive charging period, under intense ultraviolet light, the Glo to Sleep™ emitted only a fraction of the illuminance from a full moon (Table 2).

Illuminance Relative to Charging Time

Tests of maximum brightness dependent on charging time are presented in Figure 2. To determine the initial brightness of the Glo to Sleep™, after exposure to light for a specified time, select the curve that corresponds to the type of light source, note the charging time on the x-axis (time in seconds) and the corresponding brightness on the y-axis (brightness in lux). Artificial white light sources emitting more radiant energy in the blue/ultraviolet part of the spectrum are more efficient in shifting the Glo to Sleep™ into Blue Mode.

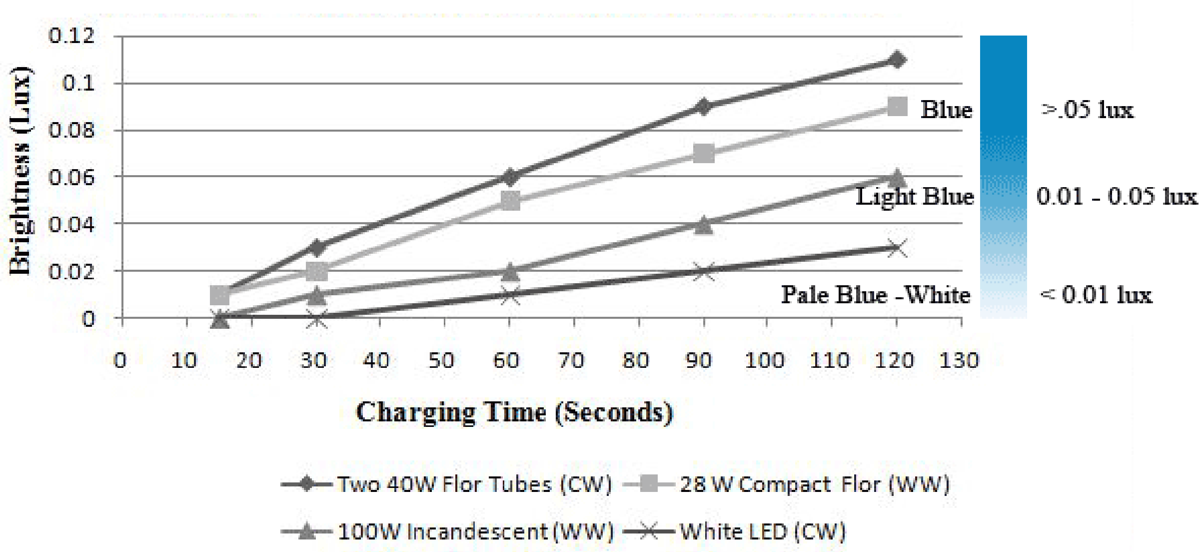

Figure 2 - Results of measured maximum brightness after charging with a white artificial light source for a specified duration. Following the recommendation to charge the Glo to Sleep™ for less than 30 seconds, under normal household light sources, results in an illuminance level of a fraction of a Lux.

Conclusion

Maximum Illuminance

The maximum recorded illuminance of the Glo to Sleep™, after a long exposure to a source high in UV light, was only 0.13 lux - an expected result considering the small total surface area (32 mm^2) of glow pigment inside the GTS. For a subjective determination of brightness, direct the inside of the Glo to Sleep™ in Blue Mode towards a surface at about a 25 cm distance, only a faint blue glow will be cast, whereas a single candle will light a surface meters away. Another example of relative brightness: the illuminance from a single blue LED, measured at 19 mm, is 1562 lux - 13,500 times the intensity of the Glo to Sleep™, measured at an equal distance.

Illuminance Relative to Charging Time

Results from Figure 2 show that after an extended charge of two minutes duration, Glo to Sleep™ brightness measures only 0.11 lux, a small fraction of the illuminance from a full moon. When charged for the recommended time of 30 seconds, illuminance does not exceed 0.03 lux. Only 30 seconds of charging time is necessary as the apparent brightness of the Glo to Sleep™ exceeds actual brightness. The reason is simple - blue light appears brighter at night, or indoors where ambient light is low – an effect known as the Purkinje Shift, because the rods, the sensitive monochromatic rod light detectors which our retinas rely on more at night, are most sensitive to greenish-blue light.

Duration of Illuminance

Using Figure 2, the decrease in brightness over time can be determined. The plotted curves for each light source are also functional as partial luminous decay rate curves, representing the time-dependent reduction in brightness of the phosphorescent pigment, after the charging light source is removed. (The reason the curves have a more linear characteristic than the expected hyperbolic decay for strontium aluminate, is the short activation times, which reduces the duration of measurable afterglow.) Charging the glow pigment under a 28 watt warm white compact fluorescent (CFL) for 30 sec will reach 0.03 lux (Fig 2) , charging it for an additional 30 seconds will reach 0.05 lux. Removing the Glo to Sleep™ from a charging light source decreases illuminance to 0.03 lux in 30 seconds. The increase in brightness, gained by activating the phosphor for an additional 30 seconds, is lost in an equal amount of time. In typical uses, phosphors are charged for hours exhibiting an extended bright afterglow. If excitation times are shorter, higher energy states quickly become unstable - the energy is not "locked up" and is rapidly released.

If a user charges the Glo to Sleep™ for an extended period of time, 90 seconds under two 40 watt fluorescents, they would be looking at glow brighter than 0.01 lux, for only a short time. Using the partial decay curve for the 40 watt fluorescents (Fig 2) - after charging the phosphorescent pigment for 90 seconds the Glo to Sleep™ would be emitting at > 0.06 lux for only 30 seconds, further decaying to 0.03 lux in 30 more seconds, and finally dropping to 0.01 lux after an additional 15 seconds. With an extended 90 seconds charging period, the user gazes at glow brighter than 0.01 lux for only 75 seconds.

The LM631 Digital Light Meter did not have the range or resolution for any empirical test results below 0.01 lux. Subjectively, it was determined that if the Glo to Sleep™ was charged to a light blue intensity, the blue would persist for approximately 45 minutes (most users are asleep in less than 10 minutes). The glow would further diminish to White Mode, becoming dim white over a period of hours. This protracted luminous decay rate below 0.01 lux is advantageous. If a Glo to Sleep™ user is awakened in the middle of their sleep period, there is no need to turn on a light to reactivate the Glo to Sleep™, they can open their eyes to a soft white glow. This middle-of-the-night White Mode is perfect for sensitive night-time eyes. If a person has little trouble getting to sleep, but may need their Glo to Sleep™ at some point during their sleep period, the Glo to Sleep™ can be left face up in a reasonably bright room and it will be in White Mode when required.

Most Efficient Charging Sources

Figure 2 shows that given enough time any reasonably bright source of white light can charge the Glo to Sleep™ to Blue Mode. If the phosphorescent pigment in a charged Glo to Sleep™ appears white when blue is desired, charging time must be increased or a more efficient light source, emitting more blue/ultraviolet radiant energy, must be selected.

NOCTURNAL ILLUMINANCE AND MELATONIN

Though there have been numerous studies conducted on the connection between exposure to nocturnal illumination and melatonin suppression, none could be found that directly experimented with very low levels of illuminance emitted by the Glo to Sleep™. Two recent studies which compiled data using relatively low levels of illuminance, can be used in comparison to conclude the Glo to Sleep™ does not have any measurable effect on melatonin levels.

Research

In late 1987, Richard G. Stevens hypothesized that night-time illumination interrupts the body's mainly nocturnal production of the hormone melatonin. Russel J. Reiter, a researcher at the University of Texas, Health Science Center in San Antonio, agrees. "People's behaviour after bedtime also counts. They should avoid even brief intervals of [bright] light at night. A nightlight is generally safe," he adds, "because dim light has relatively little effect on melatonin."(1). Researchers have spent the last two decades amassing data that supports this hypothesis and determines what level of "dim light" is safe. Initially, very high intensities of wide-band light were studied; later, tests were conducted with monochromatic light to determine which part of the spectrum affects melatonin levels more acutely. Most research has been conducted with luminous intensities in the 200 to 3000 lux range. Only two studies were found with data that could be compared with the low illuminance of the Glo to Sleep™.

Researchers at Sleep Research Laboratory in Toronto, experimenting with selective wavelength blocking goggles, used a light source of less than 5 lux as control. "Salivary melatonin levels were measured under dim (<5 lux), bright (800 lux), and filtered (800 lux) light at hourly intervals between 2000 and 0800 hours in 11 healthy young males and eight females. All subjects demonstrated preserved melatonin levels in filtered light similar to their dim-light secretion profile."(2) Assuming the "dim light" in the study was a Warm White source, emitting approximately 2% blue light, the 5 lux wideband light is equivalent to about 0.10 lux blue light. Subjects were exposed to the "dim light" for 12 hours.

Another study, by Glickman *et al,* provided experimental evidence that parts of the visible light spectrum effected melatonin levels more acutely. "Spectral characteristics of the light source further influence the amount of light needed to inhibit melatonin production."(3) Subjects were exposed to a range of monochromatic spectral emissions and the levels of illuminance that corresponded to a 50 percent suppression of melatonin were recorded (Table 3).

Table 3 - Radiometric and photometric equivalencies of light required to elicit the half-saturation constant (ED50) of the percent controlled adjusted melatonin suppression in humans at eight different wavelengths (3)

	440 nm	460 nm	480 nm	505 nm	530 nm	555 nm	575 nm	600 nm
Intensity (μW/cm^2)	2.42	2.41	3.43	3.28	6.75	27.7	46.6	110
Photon density (photons/(sec*cm^2))	5.35×10^{12}	5.59×10^{12}	8.28×10^{12}	8.33×10^{12}	1.801×10^{13}	7.75×10^{13}	1.35×10^{14}	3.33×10^{14}
Photopic lux (lm/m^2)	.39	1.01	3.29	9.21	39.3	188	290	475
Scotopic lux (lm/m^2)	13.5	23.3	46.2	55.2	92.4	192	132	67.9

The wavelength of the blue light emitted by the Glo to Sleep™, at maximum illuminance, is 490 nm. Figure 3 uses the data from Table 3 to illustrate the adjusted melatonin suppression value at 490 nm, which is 4.9 photopic lux.

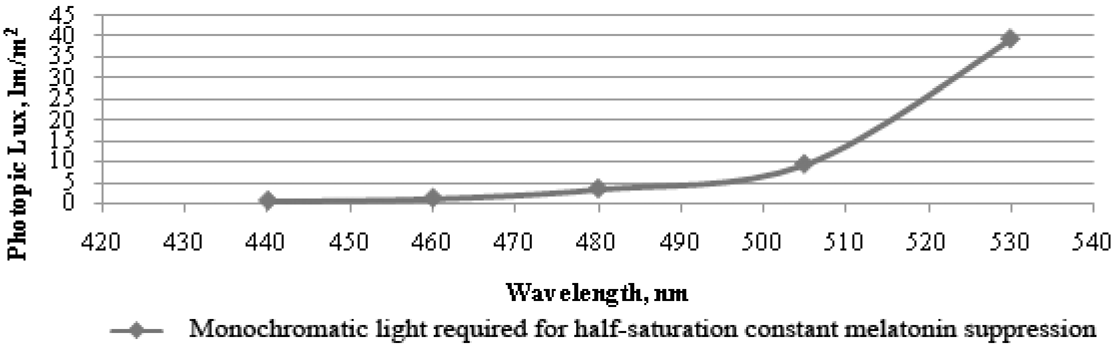

Figure 3 - Graph of results from Table 3. Photometric equivalencies of light required to elicit the half-saturation constant of the percent controlled adjusted melatonin suppression in humans at five different wavelengths.(3)

Conclusion

Without experimental data from tests using the very low levels of light emitted by the Glo to Sleep™, no quantitative conclusion can be reached as to whether the Glo to Sleep™ has any measurable effect on nocturnal melatonin levels. However, using the data from the Glickman *et al* and Kayumov *et al* research, a valid comparative conclusion may be possible.

Following the recommended charging time of less than 30 sec, the Glo to Sleep™ will emit only about 0.03 lux. Even if charged for an extended period of two minutes, the Glo to Sleep™ does not emit more than 0.11 lux, quickly decaying to 0.01 lux. Glickman *et al* results indicate 4.9 lux at 490 nm, distinctly suppresses melatonin - the Glo to Sleep™ emits only 2.2 percent of that value of maximum illuminance, quickly decreasing to less than 0.2%.

In direct comparison with Kayumov *et al,* the control source of < *5* lux, which is equivalent to approximately 0.10 lux blue light, had no effect on melatonin levels. Possibly pointing to an even more favourable conclusion, Kuyman *et al* subjects were exposed to levels of <5 lux for 12 hours, and though Glickman *et al* does not reveal the duration of illuminance exposure, it may be significantly longer than that of a Glo to Sleep™ user, as most are asleep in less than10 minutes.

Comparing the results from the studies, it may be possible to conclude that it is unlikely the Glo to Sleep™ has any measurable effects on melatonin levels. The dim glow emitted is far below levels demonstrated to affect melatonin levels, and secondly, a Glo to Sleep™ user's exposure to illuminance is for a significantly shorter period than test subjects in the studies.

Final consideration could be given to the increased health benefits of using the Glo to Sleep™. The user can charge the Glo to Sleep™ at bedtime and be asleep in minutes, without having to experience the stress and anxiety of sleeplessness. If awakened in the middle of the sleep period, the Glo to Sleep™ will be ready in White Mode with no need to turn on light. Without the Glo to Sleep™, the sleepless would have to choose between lying awake in the dark, turning on the light and reading, watching television, or other activity involving light - all unhealthy alternatives. As an added health benefit, wearing the Glo to Sleep™ all night would allow the user get those last hours of sleep in complete darkness. This contributes to good health as early morning light speeds the decline in melatonin levels.

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