STG AEROSPACE

The harmonisation of protocols and standards for high-performance photoluminescent way guidance systems in commercial aircraft.

A technology review paper

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Rev B – July 2007

1 Acknowledgements:

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STG Aerospace:

STG Aerospace Ltd is a UK based company with subsidiaries in the USA and Australia. It has been in the photoluminescence business since 1986. In 1995 STG developed and patented products and protocols for high performance photoluminescent products in aircraft emergency evacuation. STG has been FIRST in every aspect of the application of this technology on aircraft. It has won worldwide recognition for this innovative pioneering, most recently with a Queens Award for Innovation – the UK's most prestigious business award. STG has built its business and reputation on innovation and the practical development of products based on that innovation.

STG's SafTGlo is the leading photoluminescent brand in the aviation market, with over 3000 commercial aircraft currently using its products worldwide.

2 Table of Contents:

3 Abstract:

Photoluminescent (PL) materials research has now matured to provide a well-established and controllable technology, widely used in floor proximity emergency escape path marking systems (FPEEPMS) on aircraft.

FAA Advisory Circular AC25.812-2 has been the cornerstone guidance material in the approval of photoluminescent FPEEPMS in aircraft for the past 8 years. Design, installation, operating protocols and continued airworthiness are all critical aspects in the successful use of PL FPEEPMS, but due to the scope of AC25.812-2, all of these are open for interpretation.

This review document provides an understanding of photoluminescent technology, the relevant regulations governing its use in aerospace, and how they are currently being implemented. Different interpretations of the regulations are examined, reviewed and best practice techniques defined. The author aims to demonstrate that differences in the application of the guidance material suggest the need for a review of the regulations.

It is recommended that there should be an amendment to the scope of AC25.812-2 to include product luminosity performance, installation, operation and continued airworthiness standards. These new regulatory standard should be harmonised across global aviation authorities, to ensure that all manufacturers, design authorities, installers and operators are working to an equivalent level based on best practice techniques.

4 Introduction:

Photoluminescent floor proximity emergency escape path-marking systems (PL FPEEPMS) are well established as an excellent means of providing low maintenance, highly dependable cabin way guidance in an emergency. However, the effectiveness of the system in providing this is not only dependent on the quality of the product supplied but also in the installation, operation procedures and continued airworthiness of the system. This review examines the applicable regulations, the current means of compliance and best practice approaches to the design, installation, operation and ongoing maintenance of photoluminescent FPEEPM systems.

The objective of floor proximity escape path marking is to allow passengers who have become familiar with the cabin layout, to find their way to exits unassisted, in the event that the overhead illumination becomes obscured by smoke. This objective is stated in FAA regulation FAR 25 as two separate requirements:

1. The emergency escape path marking will enable each passenger to visually identify the emergency escape path along the cabin aisle floor after leaving the cabin seat.
2. The marking will enable each passenger to readily identify each exit from the emergency escape path by reference only to marking and visual features not more than four feet above the cabin floor.

In both cases it is assumed that all sources of illumination more than four feet above the cabin aisle floor are totally obscured and that it is dark [1]. Current systems are a hybrid. The non-electrical photoluminescent floor path marking is combined with electrical vertical exit identifiers at the exits.

This review aims to provide an understanding of photoluminescent technology, the applicable regulations and how they are currently being implemented. Different interpretations of the regulations will be examined, reviewed and best practice techniques discussed. The author aims to demonstrate that differences in the application of the guidance material are sufficient to precipitate the need for a review of the regulations.

5 The Science and Technology of Photoluminescence:

Section Summary
Photoluminescence occurs when a material absorbs light and emits the stored energy as light up to tens of hours after the source has been removed. PL works effectively in tandem with the human eyes ability for dark adaptation and the principle of continuous cueing to create an effective way guidance system in aircraft.

Photoluminescent products use inorganic pigments that can be incorporated into a number of materials such as paint, coating solutions, varnishes, films and plastic parts. There are many novelty products on the market today, which profess to "glow in the dark", but these should not be confused with the formulations used for emergency way guidance. Typical safety products include screen-printed signage, self adhesive tapes and rigid PVC products.

5.1 Photoluminescence Explained

Luminescence occurs if a material exposed to a source of excitation absorbs energy, and then emits that energy as visible or invisible light. The energy can be derived from a number of sources, including electrical, chemical, tribological or electromagnetic radiation. Electromagnetic radiation, visible, UV and IR light, can cause two phenomena: photoluminescence and fluorescence. Many people confuse the two.

Fluorescence is a phenomenon in which the electron transition back to the ground state occurs within a millisecond of excitation. Because of this timescale, the emission from a fluorescent material ceases the instant the excitation source is removed.

Photoluminescence also occurs by electromagnetic excitation and the material also emits while the energy source is present. But with photoluminescence the relaxation of the electron back to the ground state and subsequent emission of photons of light continues long after the excitation source is removed. Photoluminescent materials can emit a glow tens of hours after the light source has been removed. This is termed the "afterglow".

Stokes' Law states that for a photoluminescent material, the emitted light is at longer wavelengths than the excitation source applied. The emission wavelength is dependent on the chemical composition of the material rather than the excitation source applied. Ordinarily, pure materials do not show photoluminescent effects. Impurities need to be introduced in very controlled concentrations to induce a metastable state for the electrons and generate the photoluminescent effect. Doped Strontium Aluminate is currently the highest performing photoluminescent material readily available. It has a peak charging sensitivity at 360nm, in the ultraviolet region, with an emission spectrum peak at 520nm in the visible region (green/yellow light). The afterglow decays rapidly after the excitation source has been removed, with the rate of decay reducing over time. The electrons in the metastable state can remain there from seconds to many hours after the charging source has been removed, before relaxing back to the ground state with a photon emitted.

5.2 Human Eye Receptivity and Dark Adaptation

The intensity of light emitted from PL systems decays immediately after removal of the energizing light. However, the eye adapts extremely quickly to darkness. With a high output Strontium Aluminate system this decay is slowed, and combined with the dark adaptation of the eye, gives an extremely long perceptive capability.

How the eye adapts to light and darkness is extremely important in understanding the efficiency of photoluminescent technology in emergency evacuation. The eye has the ability to see detail and perceive contrast in both very bright and very dim environments. The physiology of adaptation is complex and is to an extent dependent upon the individual viewer. In its simplest form, it is a fact that a viewer's ability to perceive light changes improves if the eye is allowed to remain in the dark for some time. Typically, the eye can increase its sensitivity to light by as much as 250 times. This is a huge improvement, but brief exposure to bright lights can compromise this improvement and require a period of re-adaptation, although the time to re-adapt varies according to degree of light exposure.

The eye sees because of light impacting on, and being sensed by, receptors on the retina. These receptors are of two forms, cone receptors which see detail and colours, and which have limited dark adaptation capability, and rod receptors which do not perceive detail or colour well, but which adapt well to darkness. The eye adapts to increasing light by 'bleaching' of the surface receptor pigments, which makes them less light sensitive, combined with a decrease in neural sensitivity to reduce optic nerve transmission.

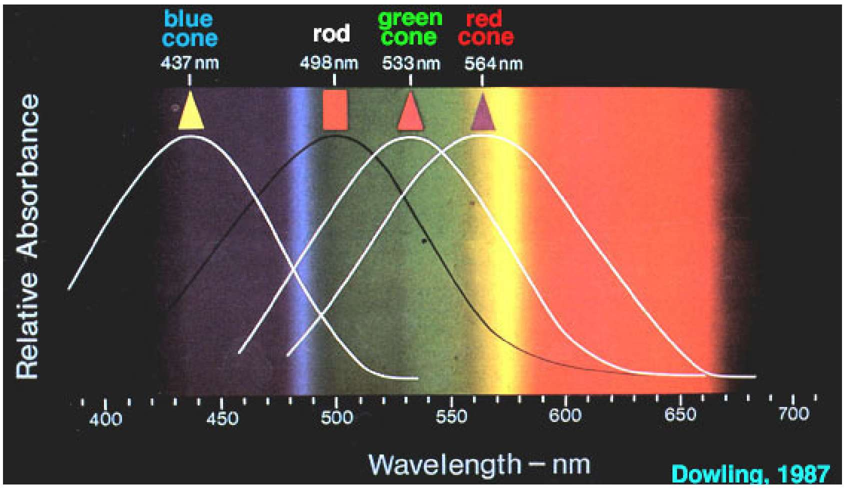


Figure 1: Relative Absorbance of the human eye rods and cones. (Taken from Dowling, 1987).

When light is removed from the eye, such as in an aircraft power failure, there is a progressive effect of dark adaptation. First there is a reverse neural effect, where the optic nerves become more receptive. This effect happens almost immediately, and is very significant. Following this, and within 1 minute, the retina cone detectors replace their surface pigments, and start to adapt, doing so very quickly for around 6 to 7 minutes, after which the rod receptors start a rapid increase in adaptation by a similar chemical process, which reaches a peak at around 25 - 30 minutes. This effect is illustrated in Figure 2 below.

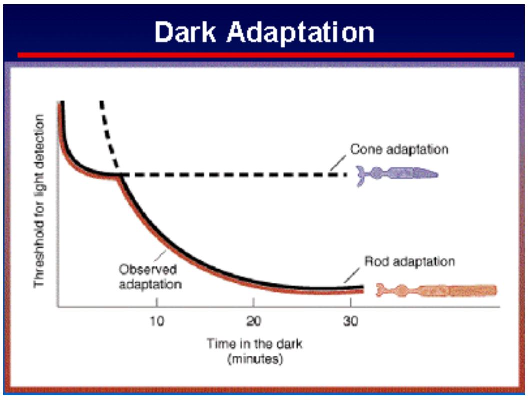


Figure 2: Dark adaptation of the eye.

In practical terms the eye 'dark-adapts' far quicker than the decay in light emissions from PL FPEEPMS. As a result, when light is removed from an aircraft cabin, the PL system appears to get brighter for approximately 10 to 15 minutes. This property is a key safety factor as most evacuations occur very quickly after an emergency. There is a long period of stable perception where the decay characteristics of the PL FPEEPMS mimics approximately those of the adapting eye, giving effective and safe escape path indication for periods in excess of 12 hours.

An additional benefit in the use of photoluminescent materials for way guidance is that the PL progressively conditions the eye to possible post-exit darkness conditions. This is a major factor in some of the current R&D efforts investigating the human factor issues to improve safety even further in aircraft evacuation. The transition from a lit cabin to complete darkness leaves the evacuee almost blind for a few seconds. This may cause a hesitation in exiting the cabin reducing the effective speed of evacuation and can cause disorientation.

5.2.1 What is the Dark Duration Limit For Photoluminescent material?

The maximum dark duration limits for PL FPEEPMS in aircraft are defined by the naïve evacuation from an aircraft, using FAA Advisory Circular 25.812-2 "Floor Proximity Emergency Escape Path Marking Systems Incorporating Photoluminescent Elements"[2] as the means of compliance. The pass/fail criteria are based on successful evacuation, not the output of the photoluminescent material. Using this method, the influence of the aircraft type and any other safety components, such as the electrical vertical exit identifiers (VEI) are also taken into account.

British Standard BS5266-6:1999[3], states that a photoluminescent material is no longer able to offer way guidance at the point at which the excitation decreases below 0.3mcd/m^2. European DIN standard 67 510 Part 1[4-7], also states that the period of light decay is determined by the point at which the output drops to 0.3mcd/m^2. Both standards also refer to the fact that this level is set at a conservative value of 100 times the limit of human eye sensitivity.

Measurements performed by STG Aerospace [8] have shown that the output of PL materials at the point of evacuation has always been in excess of the limits as defined by the DIN and British Standards. There are also ASTMs [9-10] for photoluminescent way guidance, but no minimum output limit has been proposed.

5.3 Continuous Cueing

Electrical illumination of the floor path provides general illumination of the seats and monuments to guide the evacuee. PL systems do provide a low level of illumination, but function primarily by guiding the evacuee along the aisle by a process called "continuous cueing". Continuous Cueing happens when the continuous line of glowing material either side of the aisle repeatedly triggers our orienting response – the instinctive reaction to pay attention to any sudden or novel stimulus.

Kubey and Csikszentmihalyi[11] stated that this orienting response evolved in the species because it helps us identify potential threats and react to them. In short, the system is designed to exploit basic psychological and biological "instincts" to get and keep our attention. Once between the lines it becomes very easy to follow the evacuation path. Any significant break in the line produces the same response and again triggers us to see what is at the break; this can be an emergency exit identifier at an over wing exit or a turn in the path to guide you to a type 1 exit. This feature utilized in PLFPEEPMS also defines the MEL critical aspects of the system. Any significant break in the continuous line will direct the evacuees to see if there is an exit.

6 The Regulatory Environment:

Section Summary
Advisory Circular AC25.812-2 gives clear guidance on the scenarios in which photoluminescent way guidance systems need to operate. Regulatory authorities are meeting the guidance of AC25.812-2, but have interpreted the installation and operation of the system differently leading to different operating protocols. Aspects of AC25.812-2 that may be open to interpretation include:

- *product design and its impact on reliability and longevity*
- *advice on safe installation protocols*
- *guidance on charging and discharging scenarios*
- *Life performance issues specific to photoluminescent materials*

The role of PL in aircraft is governed by FAA regulations FAR25 Subpart D – Design and Construction, section 25.812 Emergency Lighting [1]. This was written at a time when only electrical systems were available. The introduction of suitable high performance Photoluminescent floor path marking systems in 1995 needed a means of demonstrating compliance with the regulations. PL systems were approved in the UK and the USA and are ideally designed to fulfil the performance requirements, as shown in the extract below.

6.1 Extract from FAR25.812 Emergency Lighting

(e) Floor proximity emergency escape path marking must provide emergency evacuation guidance for passengers when all sources of illumination more than 4 feet above the cabin aisle floor are totally obscured. In the dark of the night, the floor proximity emergency escape path marking must enable each passenger to--

(1) After leaving the passenger seat, visually identify the emergency escape path along the cabin aisle floor to the first exits or pair of exits forward and aft of the seat; and

(2) Readily identify each exit from the emergency escape path by reference only to markings and visual features not more than 4 feet above the cabin floor.

As this new technology was introduced, the level of understanding and therefore, the scope of the approvals led to different designs and some confusion in the market. Advisory circular AC25.812-2 [2] was written in 1997 following a research study undertaken at the FAA's CAMI facility, and with the collaboration of the UK CAA and STG Aerospace. The AC was introduced to bring together the best practice understanding at the time, and remove differences in the approval and application of this new technology across authorities. The approval requirements were clearly defined, with the application of the requirements left more open for interpretation.

6.2 Advisory Circular AC25.812-2 What it does and does not say

AC25.812-2 has been the cornerstone guidance literature in the application of photoluminescent floor path marking. Like all ACs, it is not regulatory but it does provide guidance for applicants in demonstrating compliance with the objective safety standards set forth in the rule. The AC gives very clear guidance on the scenarios in which the system needs to operate:

"The first scenario may be referred to as the "first flight of the day" scenario. In this scenario the airplane is assumed to have been without power overnight thereby discharging the photoluminescent elements beyond the point at which they are useful. For purposes of evaluation trials the elements should first be discharged for at least 16 hours in total darkness. The elements should then be charged using the lowest level of cabin lighting allowed by the normal cabin lighting system controls. The charging time should be conservatively limited to the minimum time consistent with preparing an airplane for the first flight of the day."

"The second scenario may be referred to as the "maximum overnight flight" scenario. In this scenario the airplane is assumed to fly at night for the maximum time allowed by the performance characteristics of the airplane. During that flight duration, it is assumed that the passenger cabin will be either dark or in a subdued lighting environment for a significant portion of the flight to allow passengers to sleep. During this darkened cabin period, the photoluminescent elements will be discharging. Then prior to landing, an in-flight emergency is assumed, which will prevent normal cabin lighting from illuminating, thus preventing any recharging of the photoluminescent elements. The emergency is also assumed to include dense smoke in the upper areas of the cabin thereby preventing the overhead emergency lighting from partially recharging the floor level photoluminescent elements."

AC25.812-2 also gives clear guidance on how the installed system can be assessed to meet the requirements of FAR25. This assessment is done by means of a naïve evacuation, using a demographic range of participants in a blacked out aircraft. This was designed to assess the specific requirements of the two scenarios stated above.

AC25.812-2 was written with an underlying assumption that the bodies implementing the guidance materials understood the technology well enough to interpret the intent as well as the more prescriptive aspects of the guidance. Now that the technology is established and our understanding has grown, we see there are situations where different authorities are meeting the guidance of AC25.812-2, but have interpreted the installation and operation of the system differently. This has led to different operating protocols and subsequent standards. The author believes that this lack of harmonisation has been caused by the potential to interpret the guidance material, possibly combined with a lack of understanding regarding how photoluminescent materials need to be installed and operated to function as designed.

The key areas of AC25.812-2 that may be open to interpretation:

- Consideration of product design and its impact on product robustness and longevity
- Advice on safe installation protocols
- Guidance on charging and discharging scenarios
- Life performance issues specific to photoluminescent materials

In this review, each of these key areas will be assessed in relation to best practice and harmonisation of protocols across aviation authorities.

7 Design:

Section Summary

Material selection, manufacturing methods and product design all play a significant role in the performance and robustness of floor path marking strips. When selecting a photoluminescent FPEEPMS, it is important to remember that not all systems are the same.

The photoluminescent strip needs to be designed to give the optimum luminous performance and stability. It also needs to be well protected in order to withstand the harsh operating environment of the cabin floor. Many aggressive materials can be spilt on the assembly, it can be exposed to very high point loads and as one product design in the market today has shown, the very material that makes it perform, UV light, can damage it.

7.1 The Photoluminescent Coating

Photoluminescent design variants give rise to altering levels of initial light output and long duration performance. The photoluminescent pigments in the coatings have to be tailored to the particular requirements of the application. Aircraft cabin way guidance is not a typical operating environment. As with most other commercial or transportation way guidance systems it needs to give sufficient initial output, where the evacuee can see the strip the instant the lights go out. The second scenario, which is very specific to aircraft cabin systems, is where the passenger may have to evacuate many hours after the charging light source has been removed, with the evacuee dark-adapted.

PL pigments are produced as very fine powders, and are extremely susceptible to damage by environmental factors such as humidity, fluids and strong UV light. In their powder state they are practically unusable. They require expertise and the appropriate technology to provide a reliable product able to withstand the considerable environmental problems associated with use on an aircraft. To achieve this required performance and stability, the pigments are suspended in resin-based coating layers. This can give excellent performance, but can also deteriorate with age if material selection is poor or the product is not sufficiently protected. Discolouration and embrittlement of the coating are the two most likely failure modes for this type of coating. These defects can lead to the track turning brown or the coatings cracking and exposing the pigment to environmental effects leading to performance loss.

Particle diameter and thickness of the coating layers determines the luminous performance. This performance reaches a maximum level at a certain thickness and no further performance can be gained by making layers thicker or adding more layers [12]. Even if this "saturation thickness" is achieved, one cannot design a coating that will give the best initial output in combination with the best long duration performance. Achieving these two aspects with a single design is always a trade off. Pigment density within the applied layers, pigment suspension, particle size distribution and layer thicknesses are all variables that need to be well understood and closely controlled to optimise the resultant performance of the coating. Figure 3 shows that with equal pigment concentrations and coating thicknesses one can alter the discharge curve significantly. Luminous Output of the two product designs contrasts high initial output and short dark duration (red line) vs. lower initial output with a longer dark duration (magenta line). Both have acceptable initial performance, but the sample with the lower initial output has the better long term and therefore overall performance.

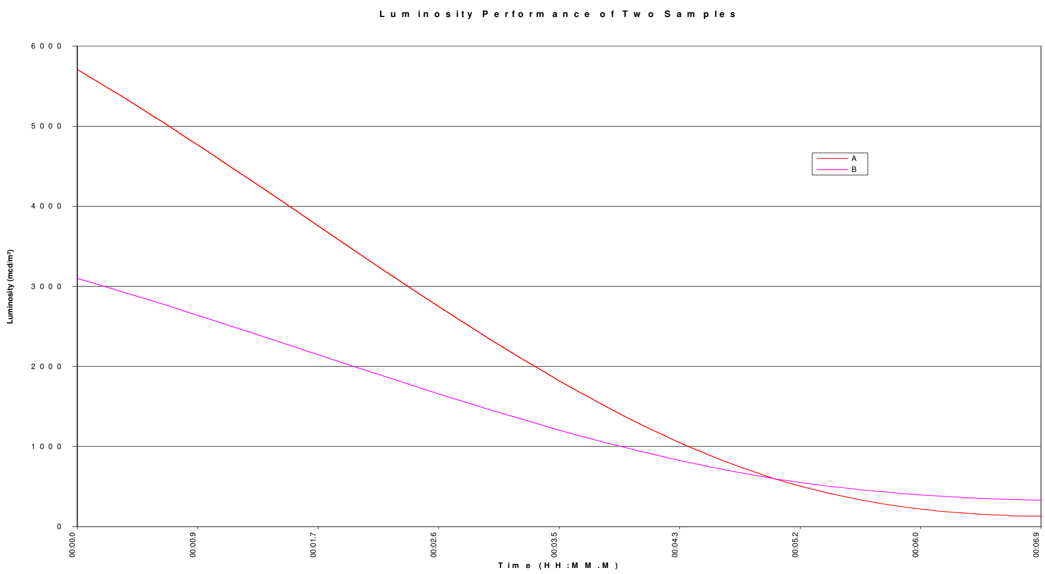


Figure 3: Luminous Output of two product designs.

7.2 Track Assembly – Protecting the Photoluminescent materials

Floor Proximity Systems, by definition operate in arduous conditions, where exposure to mechanical damage, cleaning chemicals and many other environmental factors are the 'norm'. Even with the protection of resin layers, the photoluminescent coatings are not robust enough to withstand the normal wear and tear they would encounter being placed in a cabin aisle. Therefore, the products in the market today use a variety of means to protect the PL coatings and increase the product life.

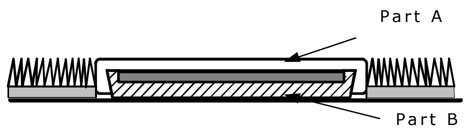
These track systems, designed to protect the PL insert component from mechanical damage, are the result of R&D combined with 'in service' experience. As in most areas, compromise, through experience with operators, is extremely relevant, and while the polycarbonate materials used are not ideal for excitation efficiency, they are ideal to give the products extreme toughness, durability and reliability, all of which are essential to users. These properties have been extensively specified and tested.

A 1.5mm thick layer of polycarbonate covering a photoluminescent strip will reduce the excitation light reaching the pigment by approximately 10% [13]. Therefore, best practice is to design the track covering the PL, so that it is kept to a minimum thickness while still protecting the materials underneath.

Systems can be made up of a base track and a protective top cover, or a single piece sealed system. Both systems are manufactured using flame retardant polycarbonate, to meet the aerospace flammability requirements.

Figures 4 and 5 show examples of track design. Figure 4 shows models that have a top cover protecting the PL insert and the base part for firm fixing to the floor. Figure 5 shows that a one-piece system can be designed to completely seal in the photoluminescent components, ensuring protection from chemical damage. The top track is sufficiently thick to withstand normal wear and tear while still giving the required luminous performance.

A)



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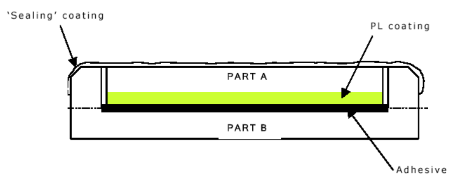

Figure 4: Two Piece track assemblies: Designs A is refurbishable, whereas B is not. Design B also has issues with cracking when flexed due to the "sealing coat". Both are susceptible to fluid ingress.

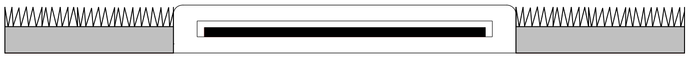

Figure 5: Sealed track assembly showing best practice techniques for protecting the photoluminescent strips/coatings.

7.2.1 Product Durability

Minimum performance requirements are defined and tested at the Minimum Equipment Limit of the aircraft lighting and the PLFPEEPMS, as part of the Naïve evacuation assessment to demonstrate compliance with FAR25. The products need to perform at or above this required level for their service life.

One would hope that all suppliers' products are designed and manufactured to the highest standards, but once they arrive at the installation site, manufacturers have little or no control over the quality of installation or the operating environment the product is used in. The products' designs have to take into account all of these requirements to ensure fitness for purpose. One must design to negate all envisaged potential failure modes that may occur through the product life cycle.

As the through-life operating environment is unknown, it is best practice to ensure that regular maintenance and more importantly, regular luminosity performance monitoring be used to determine if any in-situ issues arise. The operator cannot be expected to notice subtle changes in the material light output over a long period of time and there needs to be a high level of confidence that the system will operate many years after installation. There are systems in place that are now over ten years old, which are still operating as well as a newly installed system. However, there may be systems far younger than this, which could have insufficient luminous performance due to through life design or usage issues.

7.3 New Product Developments

7.3.1 Coloured Films

There have been a number of new developments in the field of photoluminescent way guidance. The two main ones in the past 12 months are altering the cabin lighting colour and the introductions of coloured films to improve the product aesthetics in ambient light. It is well understood that anything that reduces the incident light intensity on the photoluminescent strip will reduce the charging efficiency and therefore, the luminous performance. As stated earlier in this review, photoluminescent pigments charge in UV and visible light. The peak absorption sensitivity is at a wavelength of 360nm, which is in the UV region of the spectrum. The introduction of colours has been achieved by the use of carefully selected coloured films, placed above the PL strip. The use of an additional polycarbonate cover may also be needed to hold the film in place, and it should be remembered that a layer of polycarbonate would reduce the light transmission by 10% [13]. The products have had to be designed to ensure that the introduction of a coloured film does not reduce the incident light to the PL and the emitted light from the PL so significantly that the performance deteriorates to an unacceptable level.

The choice of materials for the coloured film is critical to ensure that the light, and therefore the charging and subsequent emission are not blocked. In the STG product the substrate material selected for the film is a thin optically clear grade of flame retardant PET or PC laminate structure. These do not significantly block UV or visible light. The colour pigments on the film also cannot significantly block the light of suitable wavelength from reaching the photoluminescent pigment. This is more difficult as the colorant characteristics mean that light will be reflected rather than absorbed, hence appearing coloured. The coloured film assembly has to be closely specified and tightly controlled at manufacture to ensure reliable performance and reproducible functionality. Figure 6 below, shows the transmission characteristics of one filter. The light transmission at the ultraviolet end of the spectra has been reduced by only 20% whereas the effect on the viewed colour is dramatic.

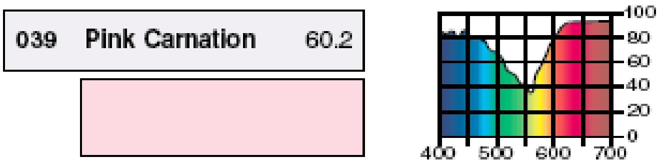

Figure 6: Example film transmission characteristics.

In addition to not significantly blocking light from reaching the PL strip, the film design has to take into account the emission characteristics of the photoluminescent material in an emergency. The emission profile of the photoluminescent strip is well defined. The peak emission for Doped Strontium Aluminate is at 520nm, close to the optimum wavelength for the most receptive part of the eye in dark adaptive conditions, the rods. Therefore, the film cannot block the 520nm peak emission, as this would render the product useless. The plot above shows that in the pink film, approximately 60% of the light transmitted by the PL passes through the film. The remainder is reflected back into the coating, and will further charge the PL. This means that the initial discharge characteristics are significantly reduced but the effect on the long duration performance is far less. The combination of prudent film choice and tailoring the materials to optimise transmission of light has resulted in products that significantly improve the aesthetic appeal of the product without deteriorating the product performance in an emergency.

7.3.2 Coloured Cabin Lighting

As cabin ambience is becoming more important to airline marketing the use of coloured filters on the lights and coloured LED lighting is becoming more common. The introduction of coloured lighting gives a reduced overall light level as it blocks a proportion of the visible spectrum. Measuring the light level using a Lux meter only measures the total light in the visible region. It does not distinguish between wavelengths (colours) and does not measure the UV component. For example, a blue filter on a fluorescent tube will block all colours in the spectrum except for blue light. In this case, the portion of the visible spectrum blocked is at the longer wavelengths, which do not play a major role in charging PL materials. As the light that is needed to charge the sample is still present an 80% overall reduction in light level leads to only 20% reduction in the luminosity of the PL FPEEPMS.

The inverse of this finding is also true. If a filter blocked the UV and blue portion of the electromagnetic spectrum, there may still be a good total level of light present. If the light were white, acceptable charging would take place, but if the peak charging wavelengths were blocked, for example with a red filter, insufficient charging would take place.

Commercial need for product launches have resulted in coloured PL track designs being approved by the use of AC25.812-2 and naïve evacuation. The understanding of the material output or the human perception had not been fully taken into account in this test regime that was implemented in 1997. Changes in product design combined with a much fuller understanding of the technology have lead us to the conclusion that the regulations as they stand, may not be sufficient. At the time the regulations were written, new product designs could not be foreseen and the level of understanding needed for appropriate implementation of any design could only be seen with hindsight. AC25.812-2 may need to be modified to cope with the type of changes people are proposing.

8 Installation – Protocols and Best Practice:

Section Summary
Correct installation of a PL way guidance system is vital to ensure they charge and emit effectively. Interpretation has led to authorities allowing differing placements of track and charging regimes, which could compromise safety.

The supplier, who issues the Supplemental Type Certificate (STC) kit on a Form 1 or an 8130-3, has validated the product design. Therefore, the installer is assured that the product performs to the required standards as received. The supplier cannot ensure that the installation follows their guidance.

At first impression, the installation of photoluminescent way guidance in aircraft is a simple procedure. This is because only one fundamental question needs to be considered: Is there sufficient light to charge the photoluminescent FPEEPMS? Ever since the first products were approved in conjunction with the FAA, it has been understood that the installation is an important component in ensuring the system will operate as designed. AC25.812-2 states, "Continuous photoluminescent marking strips must be installed at floor level along both sides of the main passenger aisle(s)". The AC clearly states the need for a twin track system along the aisle, but not where the tracks have to be placed in relation to the seats or monuments. The guidance assumes a level of knowledge about PL systems and how they need to be placed to achieve the same baseline level of performance, as tested and approved.

8.1 Track placement

The twin track system has to be placed in a location where the incident light level is kept in mind. A good example of how this principle should be interpreted is that the strips have to be placed within a certain distance of the seat edge. Too far into the aisle and the assembly will receive a higher level of wear, too far under the seat, the PL will not receive sufficient light to charge.

Interpretation has led to authorities allowing differing placements, such as strips so far under the seats, there is little chance an evacuee would see them. This is not only dramatically reducing the incident light level, but also destroying the ability of the system to provide the continuous cueing needed for PL systems to operate effectively. Placement under the seats can also be construed as a sufficient enough break in the continuous track to be considered an exit or a cross-aisle. This could cause confusion, disorientation and lead to a delay in evacuation.

Figure 7 shows a good example of how to ensure that the PL FPEEPMS placement is appropriate for way guidance. This positional tolerance stops the floor path marking strips being too far into the aisle and too far in under the seats. This regulation guarantees a clearly visible twin track PL FPEEPMS. Appendix A shows some "real world" installation photos giving examples of appropriate placement and inappropriate installations that give safety concerns.

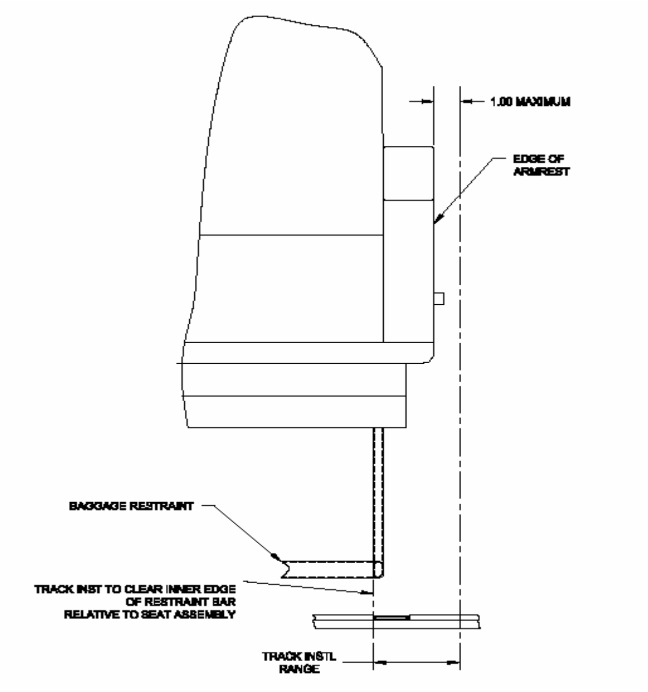

Figure 7: Lateral placement tolerance of PLFPEEPMS [14]. Dimensions shown in inches.

8.2 Minimum Light Levels

Prior to installation, the company performing the installation needs to prove that the light level reaching the photoluminescent strips is greater than the minimum required. The FPEEPM kit supplier always provides the minimum allowable light level in the STC for the aircraft type derived from the naïve evacuation testing. It is a simple test performed prior to the installation of any photoluminescent FPEEPMS and is the responsibility of the company performing the installation. Figure 8 shows the simple inspection test to measure the incident light levels at the PL FPEEPMS.

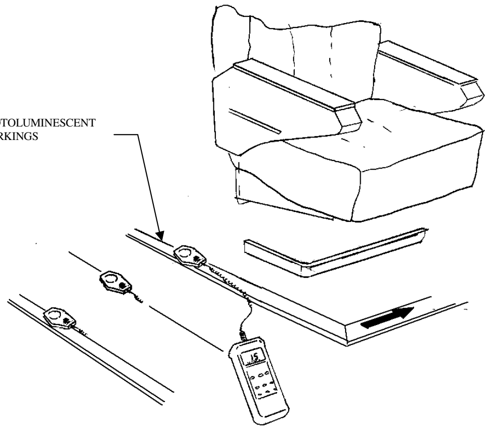

Figure 8. Interior Light Level measurement guidelines to ensure placement of FPEEPMS is appropriate [14].

Material placement and incident light level are two clear examples of how the regulations have been interpreted during the installation phase, resulting in different approval authorities allowing different standards. Only best practice approaches follow the intent of the regulations as well as the details laid down. Standard installation protocols should be applicable to all product variants, all aircraft types and under all authority approvals. These practices should follow the intent of the advisory circular giving a clear set of harmonised standards.

One installation of PL FPEEPMS provides an interesting example of some of the issues raised. An Airbus aircraft had a seating configuration, which could be moved from 3 seats in a row for economy to 2½ seats for business class travel. This meant that the edge of the row moved a number of inches into the aisle. Continuous lines of PLFPEEPMS were installed correctly in the aisle when configured as a 2½ seat wide row. When the class was changed to economy, the seats rows were wider. This placed the PL too far under the seats, making it difficult to charge and see. The solution was to place additional strips of PL on the sides of the seats, leading to cueing along a dotted line. The breaks in the line could appear to be an exit, thus causing un-necessary confusion in an emergency scenario, where time saves lives.

8.3 Minimum Equipment Levels

As many operators with electrical systems will lament, floor proximity evacuation lighting is an MEL item. PLFPEEPMS practically remove the risk of MEL failure. As the systems are charged, and approved, by using cabin lighting, this does require that these lights be also covered by MEL requirements. The PL systems should be designed to have large redundancy factors, which means that typically, over a specific defined length 10% of cabin lights can be inoperative and the system still function reliably.

When a PLFPEEPMS test on an aircraft type has been performed, the minimum light level, charge duration and dark duration performance are all well defined by the naïve evacuation scenarios tested. These findings should be the building blocks of any STC/TC approval.

9 Operational and safety perspectives:

Section Summary
Operators need to ensure that operating protocols guarantee that a PL system is receiving the light necessary to charge it. Any reduction in the quantity of light reaching the material will cause a reduction in luminous performance. Variables such as passengers boarding, position of bin doors and charging duration need to be tightly controlled. The operator also needs to demonstrate continued airworthiness by confirming that the performance of the system is still acceptable after many years of service.

When a system has been installed, the operator needs to ensure that the operating protocols **guarantee** that the system is receiving the light necessary to charge it. Simply stating the system has received light is easy; proving it has been charged sufficiently is far more difficult. It needs a controlled charging environment and regime. Unfortunately, system charging and discharging protocols do vary. It is the opinion of the author that not all of the current regimes can prove that the First Flight of Day (FFD) charge cycle guarantees performance.

The key requirement to guarantee that the photoluminescent materials have received enough light is the level of control designed into the FFD charging regime. Any reduction in the quantity of light reaching the material will cause a reduction in luminous performance.

There are currently two main FFD charging scenarios, before and during boarding. As stated previously, a key determining factor in performance is whether there is enough light reaching the PL. This can only be achieved if the system operator performs the charging in a controlled environment using controlled procedures. The operator has to remove all potential sources of variability, such as:

- Passenger traffic
- Bin doors open or closed
- Approved minimum light levels are reached
- Charge occurs for the duration as required in the STC

Without these simple measures in place, variability will be introduced and the standards at which the product was approved will not be met. As an example of what not to do; if passengers are boarding while performing the FFD charge, passengers will be queuing in the aisle, they may place their bags on top of the strips and leave the bin doors open. All of these things are probable occurrences and would dramatically reduce the photoluminous output of the floor path marking at the specified charge duration. The only way to enable charging while passengers are on board is to implement a very strict set of rules ensuring control. E.g. no passenger traffic in the aisle, no baggage on the floor and a controlled light level.

Best practice would dictate a set of rules, ensuring that the material is charged as controls are in place to remove the potential for variability, that is, before passengers board.

Once the system is properly charged, the photoluminescent FPEEPM has a defined "dark duration" corresponding to the charge duration applied. This dark duration is determined by the naïve evacuation data. It begins when the lights are turned off, not when the flight takes off. If the lights do not go out until 2 hours after take off, the dark duration begins two hours after take off.

9.1 Continued Airworthiness

Continued airworthiness is a major consideration for the approval bodies, both potential manufacturing failures and in-situ failures need due consideration. Performance of the FPEEPM system is determined by naïve evacuation at the product design stage, as required in AC25.812-2. To demonstrate continued airworthiness it is necessary to prove that an aircraft kit that was installed many years earlier is still performing robustly. The simple premise that if the strip is there, it will work, is not sufficient to demonstrate continued airworthiness.

STG Aerospace, in conjunction with the lead FAA certification office for photoluminescent materials and the NATD developed a range of measures to ensure continued airworthiness [14]. Requirements include visual inspection on a regular basis, a cleaning regime and a luminosity test at regular intervals, using a "test piece". The luminosity test for the photoluminescent materials is a necessity. There could be a drift in the material performance due to operational, environmental or design issues manifesting themselves over time. The level of operational confidence in the product design, the supplier, and the operating environment, determines the frequency of this test. If there is deterioration in performance, necessary action can be taken.

A test piece can be installed as part of the a/c FPEEPM installation, thus being exposed to the same operating environment as the remainder of the aircraft system under test. The test piece is then removed from the a/c at regular intervals and tested for luminous output in an approved test house. This confirms that the performance is still acceptable without any drift in the output over time. Based on knowledge of the systems that are in the market place today, the author recommends that this should be carried out at least every three years.

10 Proposals for Harmonisation of Protocols and Standards:

Section Summary
The author recommends that there should be an amendment to AC25.812-2 to include product luminosity performance, installation, operation and continued airworthiness. These standards should be applied and harmonised across all regulatory authorities,

The goal of the national and international aviation authorities is a strong partnership centred on harmonisation of aviation safety regulations [17,18]. This harmonisation is needed to ensure that all manufacturers, design authorities, installers, operators and regulatory bodies operate to the same best practice standards. Photoluminescent FPEEPMS is a good example of where authorities have interpreted the regulations slightly differently, resulting in a mismatch of standards within and across aviation authorities. With these issues in mind the authorities may wish to review the current position of the regulatory advice and update the guidance.

The current advisory circular gives clear guidance in approving the system design performance by demonstration, using naïve evacuation. In addition to this, the author believes that new additional standards for product design performance are needed to standardise a level of luminous output that is acceptable. By introducing this additional requirement, a benchmark level of luminosity is provided which can be used for future continued airworthiness tests. The design verification process would remain unchanged, but a performance level that has proven acceptable would be known and agreed.

Installation and charging protocols should be standardised by guidance from the authorities. This will stop the potential for installations that may meet the advisory circular as it stands today, but not the intent of the document as written, and which could be potentially unsafe in an emergency. The AC should be modified to reflect the overriding product design requirement; to ensure enough light reaches the material for acceptable performance and the system can continuously cue a passenger to the exits. Any variation in the installation and charging need to be understood and the effects assessed to ensure that the performance will be guaranteed at first flight of day and at long dark duration emergency escape scenarios.

Regulatory authorities can also define the requirements for ensuring continued airworthiness as an important part of the regulations. The current ambiguity in the application means that some operators are regularly testing material for performance and others are simply assuming that the performance has not deteriorated over many years service, without any history to back this assumption up. The operator need to guarantee that the material will perform to the design standards as defined at the point of approval and product installation.

The only way to do this is a regular testing regime as part of the continued airworthiness requirements.

To summarise, the author recommends that there should be an amendment to AC25.812-2 to include product luminosity performance, installation, operation and continued airworthiness. These standards should be applied and harmonised across regulatory authorities, to enable all manufacturers, installers and operators to work on an equal level, ensuring safety based on best practice techniques established since the introduction of the technology.

11 Conclusions:

- Photoluminescent materials research has now matured to a well established and controllable technology.
- Photoluminescent materials have proved to be a suitable technology for FPEEPMS, but a thorough understanding of the technology is important in the approval and implementation of the materials as FPEEPMS.
- AC25.812-2 has been the cornerstone reference material in the approval of photoluminescent FPEEPMS for the past 8 years. In this time the understanding of the materials and how best to utilise the technology for cabin safety has improved to a level where the material performance can be specified.
- Installation, operating protocols and continued airworthiness are all critical aspects in the successful use of PL FPEEPMS. Due to the scope of AC25.812-2, all of these are open for interpretation.
- Examples of differing interpretation of the AC have been presented, showing some of the risks and the need for expansion of the scope of the guidance material from the authorities.
- With the continuing drive to improve cabin safety, the advice for the installation, operation and continued airworthiness can be elaborated to include the best practice techniques from the market place.

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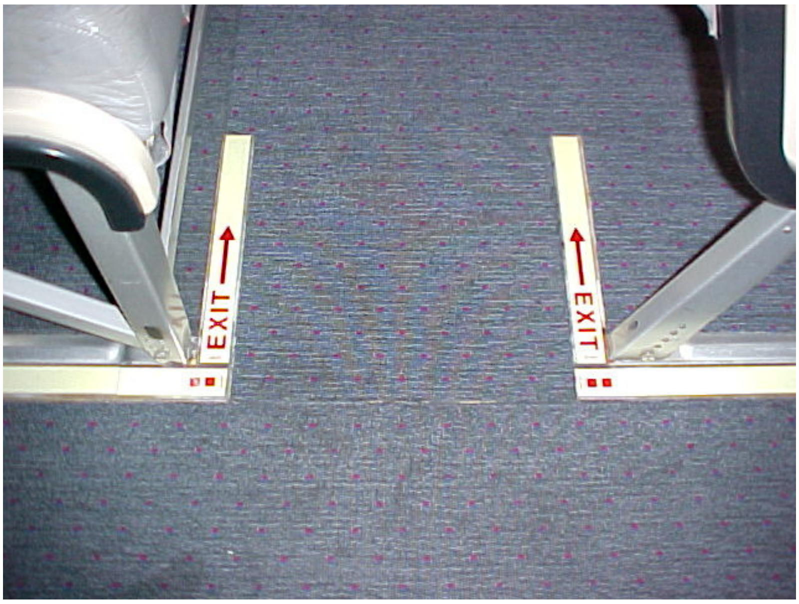
Appendix A: Example installation photos, best practice and poor installations

Best Practice Installations

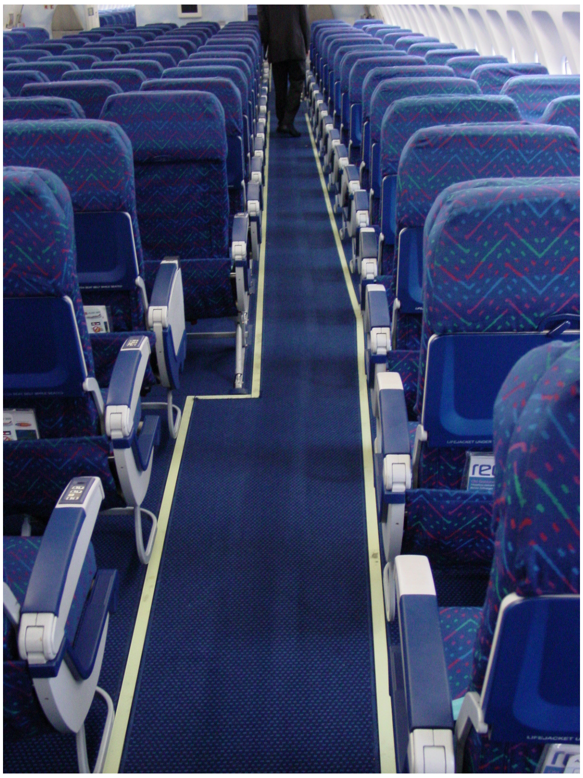
A good example of best practice is the Air Canada installation shown below. Both sides of the track are clearly visible to provide the way guidance path for an evacuee and the track is well illuminated by the cabin lighting to provide sufficient charging.

Correctly installed photoluminescent floor path marking system.

The other key areas that define a good installation for a passenger evacuation in darkness are the transition points, such as a spur to an over wing exit or a "jog" in the aisle. The figures on the next page show good examples of how these issues can be handled.



Correctly installed over wing exit spurs, provided a clear cue for the exits



Good installation to accommodate a step in the seating. Clear way guidance around the obstruction is provided

If a passenger was evacuating along the path shown above they could clearly see the step in the track indicating that they need to move around the object. This requirement has been born out in numerous naïve evacuation tests.

Installations that need improvement

FAA testing at the CAMI facility as part of the development of AC25.812-2[2] showed that for photoluminescent systems to provide effective way guidance, two lines of PL, one on either side of the evacuee, are needed to provide the guidance path. A single line was found to be ineffective. As a result of these findings, the FAA issued an AD to ensure that all installations followed this requirement for a twin track system and emphasised that both PL lines need to be visible in operation.

The photo below shows an installation where the passenger would have difficulty in walking safely down the aisle. If they were moving in darkness towards the rear of the aircraft, they would be walking, or running between the two glowing PL lines. Unfortunately, in this installation one of the lines goes under the second row of seats and disappears from view and any available charging light. The evacuee would simply see the line fade away and they would walk into that seat, either falling, potentially injuring themselves or at a minimum causing disorientation in an emergency situation. The author believes this installation should not have been allowed.

Installation providing way guidance into the seats rather than along the aisle. Photo reproduced courtesy of Ralf Stöckner.