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Photoluminescent Material Evaluation

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16. Abstract

The fundamental principle of photoluminescent technology is the ability of the photoluminescent material to absorb and store ambient ultraviolet light energy from its surroundings and then emit the stored energy as visible light. Two particular photoluminescent pigments have been used in the development of marking systems: zinc sulfide and strontium aluminate. Both afford a pale, flat, yellow-green color when viewed in lighted conditions; in darkness, the zinc sulfide material glows with a more yellow-tinged light compared to the greener emission of the strontium aluminate. While neither of these pigments provide significant levels of illumination, these markers are used for low-location lighting and escape route marking systems onboard aircraft.

As a result of these developments, manufacturers of the photoluminescent materials approached the Federal Aviation Administration (FAA) to allow these materials to be used for airport markings, reflectors, signs, and construction barricades as well. The manufacturers were asked to provide specific information about their products, such as suggested paint application thickness, area covered per gallon, useful light emission duration, serviceable life, and longevity/durability data. The luminance characteristics of the photoluminescent materials were evaluated at the FAA William J. Hughes Technical Center to assess their suitability in an airport environment.

The initial illumination, duration of useful light, and emission decay rate of the test samples were measured at predetermined intervals during photometric and subjective visual tests. The findings indicated that the luminance of all the samples decreased drastically soon after they were removed from the sunlight. During the tests, Manufacturer A's panel IV had an initial luminance of 8704 mcd/m^2 compared to Manufacturer E's panel 1 optimum initial luminance of 678 mcd/m^2. For all samples tested, the luminance dropped sharply to less than 50% of their initial value after 10 minutes, and then continued to decrease. Based on the results of this study, none of the test samples demonstrated a satisfactory ability to provide useful luminance from sunset to sunrise.

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LIST OF ACRONYMS

AC	Advisory Circular
FAA	Federal Aviation Administration
fL	Foot-lamberts
mcd/m^2	Millicandela per square meter
cd/m^2	Candela per square meter

EXECUTIVE SUMMARY

Airport operations in nighttime or during reduced visibility depend solely on lighting that is powered by electricity. Indispensability of electricity has made airport nighttime operations vulnerable to a variety of problems, such as failure of main electrical sources, breakdown of constant-current regulators, wiring or battery failure, and lamp failure. Attempts to overcome these problems have led to the development of alternative nonelectrical sources of lighting. These alternatives should enhance existing lighting systems and be able to provide visual guidance in absolute darkness in the event electrical power is lost. These alternatives must be cost-effective and capable of widespread implementation. One alternative is based on photoluminescent technology.

At the request of the Office of Airport Safety and Standards, the Airport Safety Technology Research and Development Visual Guidance Subteam conducted an initial assessment study on the use of photoluminescent materials in an airport environment.

The fundamental principle of photoluminescent technology is the ability of the photoluminescent material to absorb and store ambient ultraviolet light energy from its surroundings and emit the stored energy as visible light. Two particular photoluminescent pigments have been used to develop marking systems: zinc sulfide and strontium aluminate. Both afford a pale, flat, yellow-green color when viewed in a lighted environment. In darkness, the zinc sulfide material glows with a more yellow-tinged light compared to the greener emission of the strontium aluminate. They have been used in airport markings, reflectors, and signs, as well as applications such as low-location lighting and escape route marking systems in aircraft. These materials are environmentally friendly, nontoxic, nonradioactive, and have good adhesion and weather resistance.

The manufacturers were asked to provide samples and specific information about their products to evaluate the material's luminance characteristics and its suitability for use in an airport environment. In August 2001, the illumination, duration of useful light, and emission decay rate of the test samples were evaluated using photometric and subjective tests at the Federal Aviation Administration William J. Hughes Technical Center. Based on the results of this study, none of the test samples demonstrated a satisfactory level of luminance from sunset to sunrise.

In April 2008, another manufacturer provided photoluminescent material samples. A study was conducted to assess the viability of these samples. This study indicated that the luminance of the samples decreased drastically soon after they were removed from sunlight. The 2008 photoluminescent material sample measurements were compared to the 2001 samples. Of the 2001 samples, the highest valued initial luminance was approximately 12 times greater than the rated 2008 sample. The luminance values of all the samples dropped sharply to less than 50% of their initial value after 10 minutes, and then continued to decrease. The 2008 samples decreased at a slower rate compared to the 2001 samples, but it still was not adequate for an airport environment.

Currently, none of the photoluminescent samples emit enough luminance to be considered useful in an airport environment.

INTRODUCTION

PURPOSE.

This study was undertaken by the Federal Aviation Administration (FAA) Airport Safety Technology Research and Development Visual Guidance Subteam as part of on-going research to monitor state-of-the-art light sources for use on airports. The purpose of this effort was to evaluate the luminance characteristics of photoluminescent materials and to assess the materials suitability for use in airport environments.

BACKGROUND.

The fundamental principal of photoluminescent paint technology is the ability of photoluminescent material to absorb and store ambient ultraviolet light energy from its surroundings and then emit the stored energy as visible light. Photoluminescent paints have been used for applications such as low-location lighting for escape route marking systems to evacuate people from hazardous situations on ships, in airplanes, and hotels.

A preliminary effort to investigate the use of photoluminescent materials in transport category aircraft was conducted in February 1998 at the Oklahoma City Civil Aeromedical Center. This effort was undertaken as a performance demonstration of zinc sulfide and strontium aluminate photoluminescent pigments in Floor Proximity Escape Path Marking Systems in transport category aircraft.

To assess the viability of the materials, performance demonstrations were conducted of systems made with these pigments. As a result, strontium aluminate photoluminescent markings were found to be effective in providing aircraft egress guidance.

In 2001, a proposal was presented to the FAA stating that new photoluminescent materials may be beneficial for use on runways, taxiways, and other airport surface marking areas. In August 2001, Visual Guidance Research and Development personnel evaluated a prototype photoluminescent taxiway guidance sign in low-light conditions.

In addition to the initial sample, a variety of samples from other manufacturers were requested for testing. Photometric measurements and visual observations were made during low-light conditions immediately after prolonged exposure to sunlight. Based on the performance of those samples, it was concluded that the concept of using photoluminescence to enhance sign performance at night, while not to be dismissed entirely, was ineffective. The 2001 research has been incorporated into this report.

In 2007, new developments in photoluminescent paint technology showed promise in a number of areas, including pavement markings and retro-reflective markers, and in overcoming the deficiencies noted in the 2001 study. Developers proposed an emissive color change material as a potential replacement for retro-reflective marking materials. These developers proposed materials that could be sprayed on with similar application rates to those found in Advisory Circular (AC) 150/5370-10C, Item P-620.

The developer claimed that using current standards for application rates would result in visible light emissions for up to 12 hours, potentially eliminating the use of reflective beads in paint. In April 2008, the Visual Guidance Research and Development personnel evaluated the photoluminescent material at the FAA William J. Hughes Technical Center. The evaluation duplicated the 2001 test procedures.

SCOPE.

The research was limited to photometric measurements and visual observations of the photoluminescent materials during conditions of darkness, immediately after prolonged exposure to sunlight. In August 2001, the initial evaluation was performed on four manufacturer samples; the current evaluation was performed on one sample.

OBJECTIVES.

The specific objectives of this research included:

- Evaluating the effectiveness of photoluminescent technology as a replacement for water-based paint with reflective media.

If the technology was found to be effective, then:

- The capability of this technology to produce FAA-standard colors acceptable for both daytime and nighttime viewing would be evaluated.

- Human factors assessments would be conducted, as required.

RELATED DOCUMENTS.

1. Cyrus, H., “Paint and Bead Durability Study,” FAA report DOT/FAA/AR-02/128, March 2003.

2. AC 150/5345-44H, “FAA Specification for Taxiway and Runway Signs,” September 2007.

3. ASTM E 2072-00, “American Society for Testing and Materials Standard Specification.”

4. AC 150/5340-1J, “Standards for Airport Markings,” April 2005.

5. AC 150/5370-10C, “Standards for Specifying Construction of Airports,” Item P-620, “Runway and Taxiway Painting,” September 2007.

DISCUSSION

In July 2001 and October 2007, requests for photoluminescent paint samples were sent to the photoluminescent manufacturers. A list of the manufacturers, coded A through E, that responded to the request for photoluminescent paint samples are included in table 1.

Table 1. Manufacturers Providing Photoluminescent Test Samples

Manufacturer	Photoluminescent Product
A	MSS-SA-IV
A	MSS-SA-V
B	-----
C	-----
D	N-7795 (Florescent Yellow)
D	N-7794 (White Luminous)
E	Panel 1 (White)
E	Panel 2 (White)
E	Panel 3 (Yellow)

The manufacturers were asked to provide specific information about their products, which are listed in table 2. The manufacturers were also instructed to supply samples based upon specifications and anticipated potential use in airport markings. The manufacturers prepared the samples by applying their product to 12- by 12-inch panels. The thickness of the photoluminescent paint was in accordance with the manufacturers' recommendation.

Table 2. Manufacturers' Test Panel Data

Manufacturer	Application Thickness (millimeter)	Covered Area per Volume (sq. ft/gal)	Excitation Time (hours)	Duration of Light Emission (hours)	Duration of Durability (years)
A	10	130	1.0	91.67	10.0
B	5	144	0.3	18.00	0.5 – 1.0
C	3	N/A**	0.3	12.00	5.0
D	15	N/A	9.0	10.00	N/A***
E	N/A	N/A	N/A	137.63	N/A

N/A – Not Available
** Manufacturer provided area per unit mass in metric units of 2.5- to 3.0-sq.-meter per kilogram
*** Manufacturer provided a rating of "Excellent"

Figures A-1 through A-7 in appendix A show examples of the panels used in the evaluation.

EVALUATION APPROACH

The photoluminescent panels were tested using objective and subjective assessments. The objective assessments included photometric tests that examined the light degradation rate of each panel and comparative assessments of the photoluminescent panels versus each other and versus current waterborne, retro-reflective airport pavement markings when using an incandescent lamp. Subjective assessments included visual acquisition tests and assessments of comparative brightness versus distance.

PHOTOMETRIC TEST.

A photometric test was conducted on the photoluminescent panels. The samples were exposed to sunlight in an open area. Small pieces of opaque tape were attached to the sample surfaces before exposing them to sunlight to compare energized and nonenergized surfaces. After 5 to 6 hours of exposure to bright sunlight, the samples were quickly transferred to a darkened location. Measurements were taken with a Minolta LS-100 Luminance Meter, which was located in front of the sample at a distance of 10 feet, with the meter aimed at the center of the panel. The LS-100 luminance meter produces foot-lamberts (fL) readings. The foot-lamberts readings were converted to millicandela per square meter (mcd/m^2). Measurements were taken at 90- and 45-degree viewing angles. The luminance or photometric brightness is the amount of visible light leaving a point on a surface in a given direction. The laboratory test equipment setup is shown in figure 1.

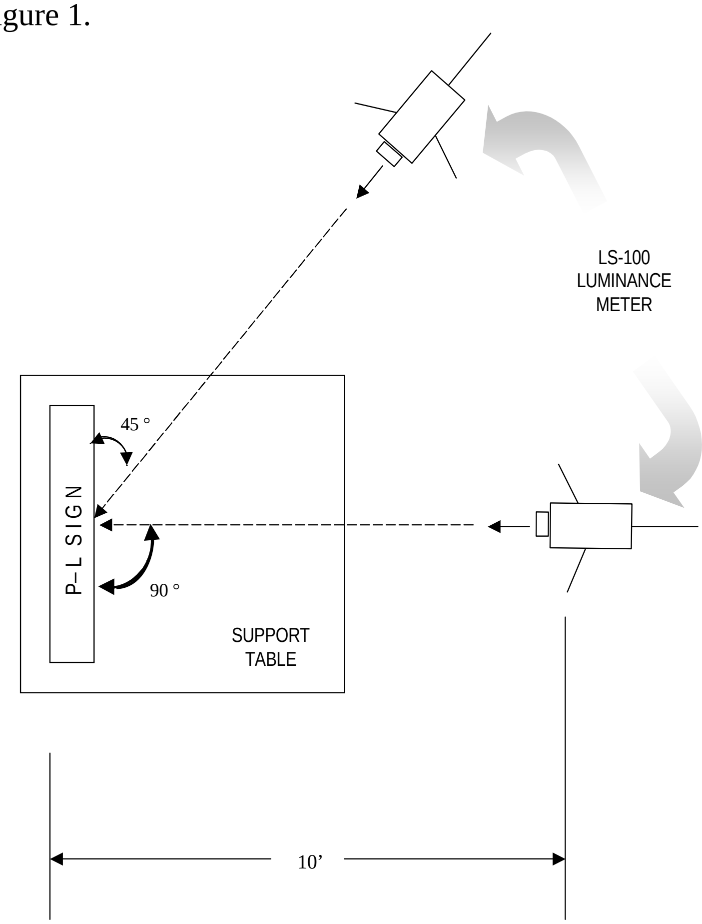

Figure 1. Photometric Test Setup

The luminance values were recorded at intervals of 0, 10, 20, 30, 40, 50, 60, 120, 180, 240, and 300 minutes.

SUBJECTIVE EVALUATION.

A subjective evaluation was conducted on the 2001 photoluminescent panels. In this evaluation, a 2-inch-high letter E was affixed to the samples prior to exposure to sunlight. The samples were exposed to bright sunlight for 5 to 6 hours and then quickly transferred to a dark room. The samples were observed in the dark from a 15-foot distance to check the visibility of the letter E. This test provided a subjective assessment of the material to provide sufficient contrast in optimal ambient low-light conditions. The dark-room simulation is equivalent to observing a standard 18-inch-high letter on an airport sign from a distance of 135 feet.

VISUAL ACQUISITION TEST.

This test was conducted on the 2008 photoluminescent sample to provide a subjective comparison of this material with the current waterborne, retro-reflective airport pavement marking with glass beads. To perform visual acquisition evaluation, the photoluminescent samples were exposed to bright sunlight for 9 hours. After exposure, the samples were quickly transferred to a dark location on a pavement surface with some direct external lighting. The photoluminescent sample was then placed alongside a retro-reflective test sample. The test subjects were asked to drive toward the samples in a vehicle, viewing the panels and judging which sample appeared brighter relative to the other and by how much. The distances at which the test subjects identified the test sign panels were also noted.

COMPARATIVE PHOTOMETRIC TEST.

A photometric test was conducted to compare luminance values of the 2008 photoluminescent material samples with the waterborne, retro-reflective airport pavement markings with glass beads. The photoluminescent sample was exposed to sunlight in an open area for 9 hours. The sample was quickly transferred to a darkened area. Measurements were recorded with the luminance meter. The measurements were collected at 10-minute intervals for 1 hour. Similar measurements were taken on the retro-reflective panels at the same location with an external light source with an incandescent lamp characteristic of those used in the airfield environment. A comparative analysis of the luminance of the panels was performed using the collected data.

DATA COLLECTION

Various types of data were collected during each test as described in the following sections.

OBJECTIVE EVALUATION.

Criteria were established to determine pass/failure of the data collected. Thresholds for illuminance have been established in the NBS monograph 159 “Visual Range: Concepts, Instrumental Determination, and Aviation Applications” [1]. Thresholds for illuminance versus background illuminance are listed in table 3.

Table 3. Illuminance Threshold Versus Background Illuminance

Horizon Sky	Location Known—Threshold (mcd/m^2)	Location Unknown—Threshold (mcd/m^2)
Overcast with moon	17	340
Clear, moonlight	170	3,400
Deep twilight	1,700	34,000
Twilight	17,000	340,000

The threshold values in the second column are applicable only when the observer knows precisely where to look for the visual cue. If the location of the viewed object is not known, the values in the third column are used.

The illuminance of the night sky in the vicinity of cities and airports seldom falls below the overcast with moon value because of man-made light sources. Thus, the visual cue needs to exceed 340 mcd/m^2, at a minimum, to be easily seen in contrast to the surroundings at an airport.

RESULTS

PHOTOMETRIC TEST.

In August 2001 and April 2008, photometric tests were conducted at a photometric laboratory. The luminance values were recorded at intervals of 0, 10, 20, 30, 40, 50, 60, 120, 180, 240, and 300 minutes. The luminance values of each sample are shown in table 4.

Table 4. Photometric Measurement Results

Year	Manu-facturer	0 min	10 min	20 min	30 min	40 min	50 min	60 min	90 min	120 min	180 min	240 min	300 min
2001	A-IV	8407	675	332	240	168	140	120	82	58	38	27	21
	A-V	5259	435	250	158	116	86	72	41	27	24	17	7
	D	552	38	21	17	10	10	7	3	3	3	3	3
	D	1686	120	48	38	24	21	17	14	10	7	3	3
	C	2713	291	147	106	69	51	45	21	7	3	3	3
	B	6492	254	127	93	65	55	48	27	21	14	10	7
2008	E- Panel 1	678	274	161	120	93	75	65	45	27	21	14	10
	E- Panel 2	394	188	127	99	77	69	58	41	31	21	14	10
	E- Panel 3	411	206	137	113	89	75	65	51	38	21	21	17

Unit of measure = mcd/m^2

The luminance values of all the samples are shown in figures 2 and 3. The visual cue needs to exceed 340 mcd/m^2, at a minimum, to be easily seen in contrast to the surroundings at an airport. The values indicate that the luminance decreased drastically soon after the samples were removed from the sunlight. In the evaluation, Manufacturer A's panel IV initial luminance was

8407 mcd/m^2 compared to Manufacturer E's panel 1 optimum initial luminance of 678 mcd/m^2. For all samples tested, the luminance dropped sharply to less than 50% of their initial value after 10 minutes, and then continued to decrease.

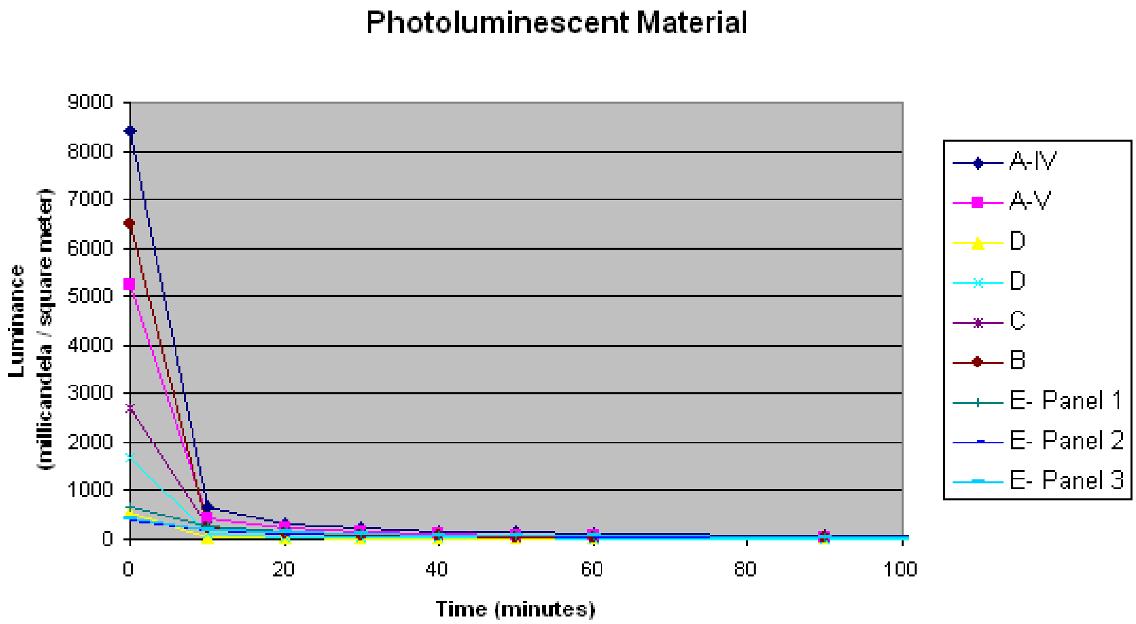

Figure 2. Photometric Evaluation Results

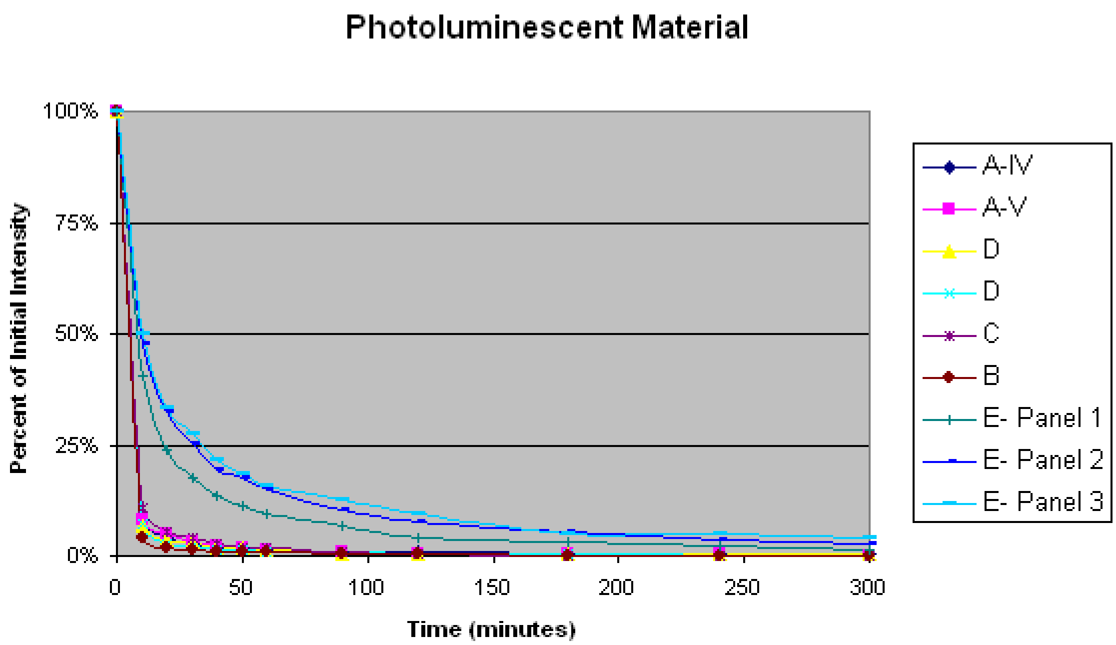

Figure 3. Light Intensity Decay Rate of the Photoluminescent Samples (Shown as Percentage of Initial Intensity)

Figure 2 shows that the manufacturer E panel 1 sample exhibited the highest initial emissions of the samples tested in 2008 at 678 mcd/m^2 and 27 mcd/m^2 after 2 hours in the darkened test laboratory. All E panels are from the 2008 study. In 2001, two samples from manufacturer A exhibited the highest initial emissions of 8407 mcd/m^2 and 5258 mcd/m^2, 120 mcd/m^2 after 1 hour, and 58 mcd/m^2 after 2 hours. The samples from manufacturers B and C provided lower initial emissions and lower decay rates. Of all the samples tested, E panel 2 (from manufacturer E) emitted the lowest initial luminance. Manufacturer E's photoluminescent material was engineered so the light would retain more of its initial luminance over a long period of time. It is likely that this engineered property reduced the amount of luminance the material was capable of emitting initially.

SUBJECTIVE EVALUATION.

During the initial evaluation in 2001, a subjective evaluation was performed on the three panels with the highest luminance characteristics from the six samples available. The test showed that sample A-IV from manufacturer A provided some visibility for up to 90 minutes, indistinct visibility after 120 minutes, and no visibility after 150 minutes. The other two samples provided reduced visibilities. The subjective evaluation results are shown in table 5. The subjective evaluation was not conducted for these samples due to the substandard performance of the samples during the photometric test.

Table 5. Subjective Evaluation Results

Manu-facturer	10 min	20 min	30 min	40 min	50 min	60 min	90 min	120 min	150 min
A-1V	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Indist. visible	Not visible
A-V	Visible	Visible	Visible	Visible	Visible	Visible	Indist. visible	Not visible	Not visible
B	Visible	Visible	Visible	Indist. visible	Not visible	Not visible	Not visible	Not visible	Not visible

VISUAL ACQUISITION TEST.

Test subjects observed the retro-reflective and photoluminescent materials from a vehicle proceeding toward the test samples and made judgments of which sample appeared brighter than the other. The test subjects were capable of acquiring the retro-reflective markers at much greater distances than the photoluminescent paint samples. In addition, all the test subjects commented that the retro-reflective panels appeared brighter than the photoluminescent panels, as shown in table 6.

Table 6. Visual Acquisition Results

Type of Material	100 feet	500 feet	1000 feet	2000 feet
Photoluminescent	Bright	Not bright	Not bright	Not bright
Retro-reflective	Very bright	Very bright	Very bright	Bright

COMPARATIVE PHOTOMETRIC TEST.

Comparative photometric measurements were taken on the retro-reflective and photoluminescent materials. Luminance measurements were taken on the retro-reflective panels to assess the retro-reflectivity of the samples. The luminance of the retro-reflective panels varied between 20,868 mcd/m^2 to 34,671 mcd/m^2, depending on the amount of ambient lighting. This was considerably brighter than the photoluminescent panels by an approximate 100:1 ratio. Table 7 shows the luminance values of the retro-reflective panels.

Table 7. Photometric Results on Retro-Reflective Panels

Elapsed Time (Minutes)	Luminance (mcd/m^2)
0	34,671
10	30,522
20	25,300
30	20,868

Because the photoluminescent samples failed to meet the predefined benchmarks for successful completion of the photometric and subjective acquisition evaluations, the Visual Acquisition Test and Comparative Photometric Test were the only additional tests conducted in the 2008 evaluation. No chromaticity or human factors assessments were conducted. In the future, additional evaluations may be conducted as necessary should newer, more effective photoluminescent materials be developed and become available.

CONCLUSIONS

To provide airport visual guidance, photoluminescent material must be able to render enough luminance to contrast with the background luminance in addition to the luminance from other light sources in the field of view. Based on the results of this study, none of the test samples demonstrated an ability to provide useful luminance due to the low-intensity initial luminance value and the rapid decline in intensity once the energizing light source was removed. Therefore, photoluminescent materials are not an effective replacement for waterborne paint with retro-reflective beads.

REFERENCES

1. Douglas, C.A. and Booker, R.L., "Visual Range: Concepts, Instrumental Determination, and Aviation Applications," U.S. Department of Commerce, NBS Monograph 159, Washington, DC, 1977.

Figure A-1. Test Panels Charging Under Sunlight

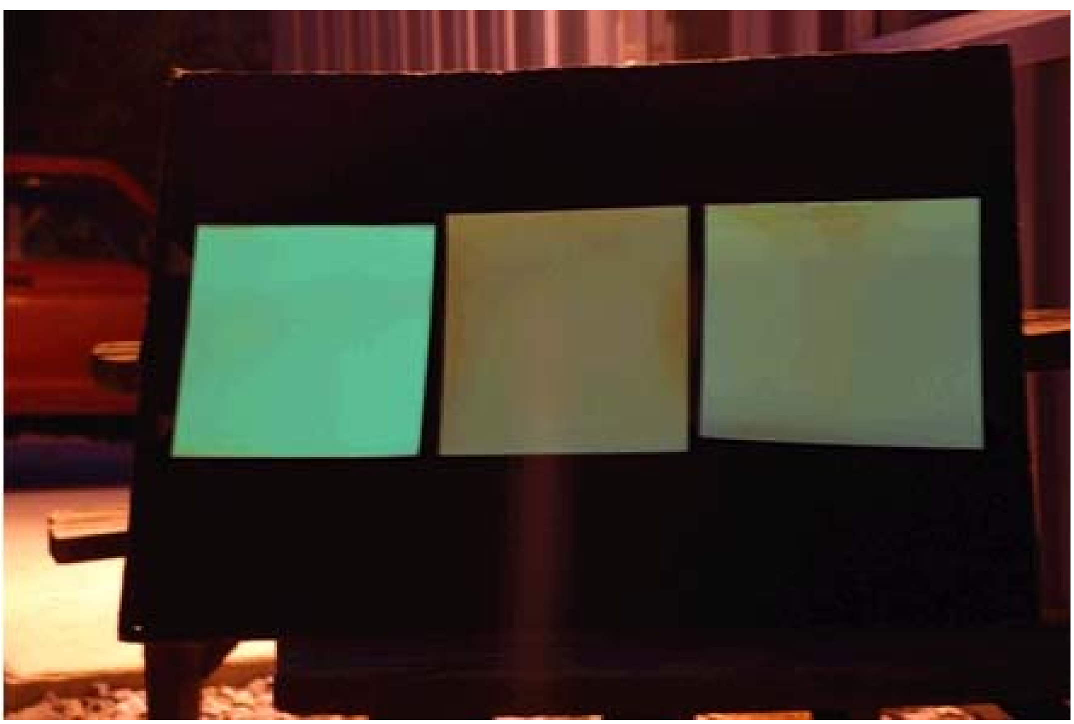

Figure A-2. Test Panels at Peak Luminance

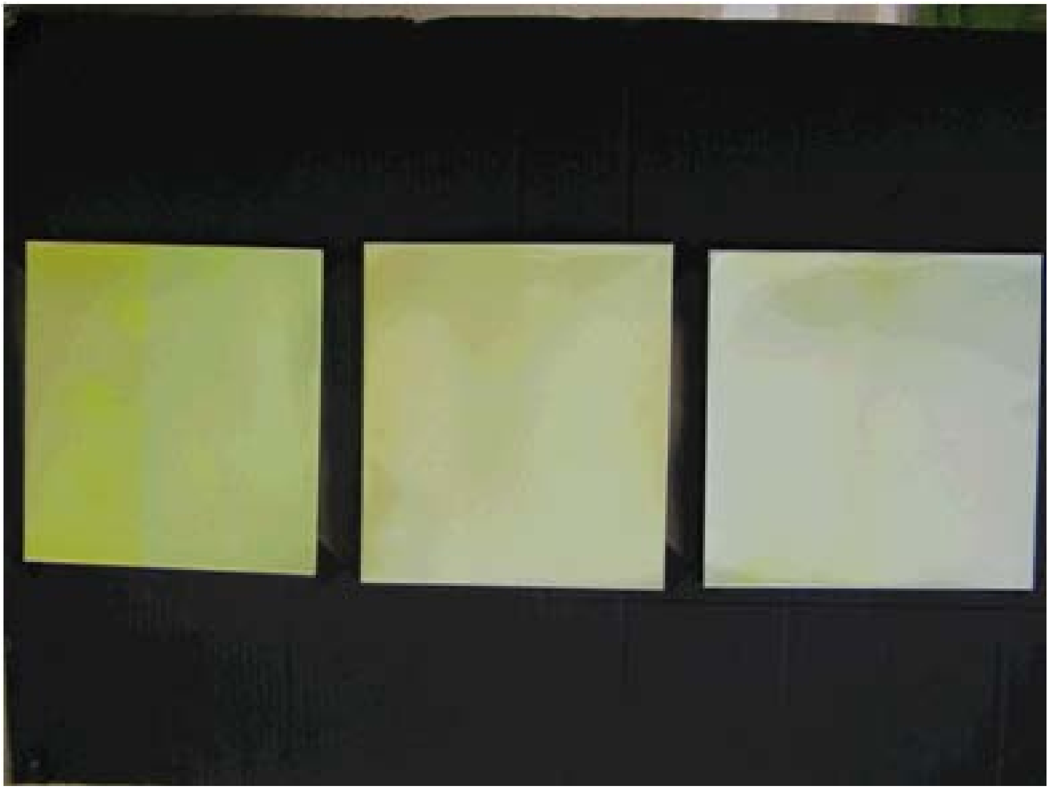

Figure A-3. Test Panels after 10 Minutes in Darkened Room

Figure A-4. Subjective Comparison of Samples With Retro-Reflective Panels

Figure A-5. Subjective Comparison With Retro-Reflective Panels at a Greater Distance

Figure A-6. Luminance Measurements of Retro-Reflective Panel Setup

Figure A-7. Luminance Measurements of Retro-Reflective Panels