

Title: **The Continuous Information Stream - Leading Occupants to Safety with Photoluminescent Safety Way Guidance Systems and Signage**

Author: James D Amy, Rolf Jensen & Associates

Subject: Fire & Safety

Keywords: Egress
Evacuation
Life Safety

Publication Date: 2003

Original Publication: CIB / CTBUH Kuala Lumpur 2003 Conference

Paper Type:

1. Book chapter/Part chapter
2. Journal paper
3. **Conference proceeding**
4. Unpublished conference paper
5. Magazine article
6. Unpublished

THE CONTINUOUS INFORMATION STREAM – LEADING OCCUPANTS TO SAFETY WITH PHOTOLUMINESCENT SAFETY WAY GUIDANCE SYSTEMS AND SIGNAGE

JAMES D. AMY, JR.

Rolf Jensen & Associates, Inc. Chicago, IL 60661 USA

Abstract

Presently, codes and standards address emergency lighting, safety way guidance systems, exits signs, and other signage as if they are unrelated. This is clearly not the case as the loss of one such component of the egress system can drastically affect egress. This does not have to be the case. The other components can, if designed in concert, compensate in whole or in part for the loss of one component. For example, when emergency lighting or an exit sign fails to operate or is obscured by smoke from a fire, safety way guidance systems can compensate, identifying the paths to the exits.

After the 1993 bombing, stairways in the World Trade Center were fitted with battery-powered emergency lights and a photoluminescent safety way guidance system, also known as pathway marking. Both of these components of the continuous information stream enhanced occupant egress on September 11th.

In a building, the egress information system as a whole should be capable, although it is not presently, of surviving a failure of one of its components. Just as fire resistive barriers serve as a backup to automatic sprinkler systems in preventing fire spread, so should three of the egress system components back up the fourth, allowing one failure without adverse impact to occupant safety. The use of photoluminescent pigments in safety way guidance systems, exit signs, and other signage will be discussed and the phenomenon of photoluminescence described.

This paper will identify the critical elements of the continuous information stream, recent code changes that point towards an understanding of the relationship between each, the means by which the failure of one component can be compensated for by the other components considering available technologies, and suggest conceptual code changes that would enhance egress.

Keywords: Safety way guidance, pathway marking, low-location lighting, photoluminescent, egress, evacuation

1. Introduction

John J. Fruin's *Pedestrian Planning and Design* was first published in 1971. Fruin, in speaking of the movement of people in urban environments broke the environment into five components: paths, nodes, landmarks, edges, and districts. Fruin was addressing the movement of people in streets and the ways in which people orient themselves to progress towards their destinations.

By classifying the components of the environment, Fruin was able to identify specific shortcomings in the environment that resulted in inefficiencies in people movement. For example, if landmarks, such as street signs, are not present, there may be a higher incidence of people taking wrong turns, stopping to ask for directions, or simply slowing down in their search for their destinations. Similarly, if street patterns are convoluted, such as may be found in the older parts of many cities, the duration of trips for pedestrians and drivers is longer, adding to congestion.

The classification system that Fruin developed can easily be applied on a smaller scale to buildings.

- Paths – the actual paths available to the occupants for movement (egress)
- Nodes – the transition point from a room, corridor, or stair to another, commonly through a door
- Landmarks – the signage seen along the path (exit signs, informational signs, instructional signs)
- Edges – the walls of the rooms, corridors or stairs
- District – the building

As with Fruin's, this effort can allow us to identify shortcomings in building design that result in longer travel and egress times. A lack of appropriate signage can cause confusion to visitors under normal conditions and to all occupants during an emergency, when unfamiliar paths may be used for egress. Anyone having trouble finding his or her way in an airport understands this. A poorly laid out building can frustrate visitors and long-time occupants alike under normal conditions and lead to congestion at constriction points during an emergency when all occupants are seeking to exit at once.

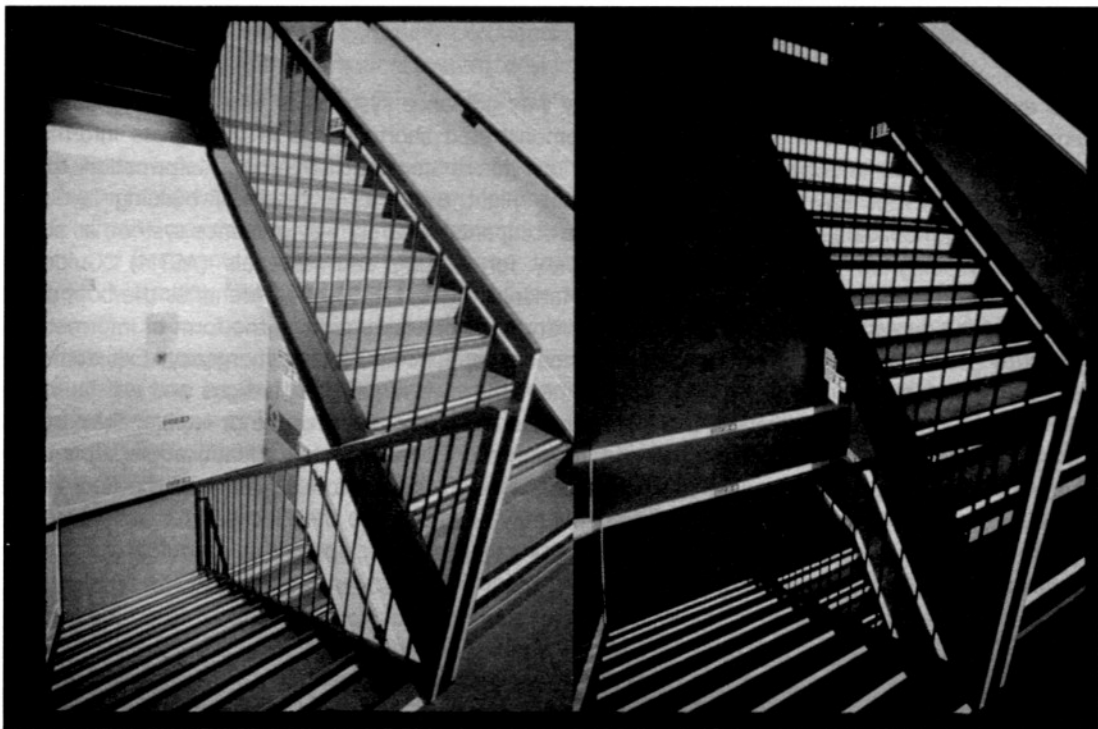
Another consideration is that under normal conditions, occupants make use of familiar paths. In fact, many occupants are well versed only in the portions of the building that they frequent, including only the path to and from main entrance to the building and the elevator that takes them to the floor on which their office is located. Occupants may never have been in the stairs or used all of the exits from the building even though they have been in the building for years. Part of the reason for this is the limits on time that the average person experiences, causing them to take only what they feel is the most expedient path to and from their office and elsewhere in the building. Another reason for this is that stairs, in particular, may be off-limits under normal conditions. Stair doors may be alarmed for security reasons, preventing occupants from becoming familiar with their location and arrangement. Thus, in emergencies occupants try to use the paths they know even if a much shorter path exists.

2. Evacuation Paths

When an emergency arises and occupants evacuate en masse, shortcomings in the design of the building or signage and lack of familiarity on the part of occupants can lead to significant delays in egress. In 1993, when the World Trade Center was bombed, problems with the ensuing evacuation were well publicized. These included loss of lighting in the stairs and the unfamiliarity of occupants with the stair layout. In several stairways there were stair transfer corridors, landings at which the stair shaft shifted with a horizontal passageway leading to the next flight of steps. With the lack of lighting, these transfer corridors caused delays and confusion. More importantly, the lack of ambient lighting prevented occupants from identifying the boundaries, or edges to use Fruin's term, of their path. The locations of handrails, the beginning and end of a flight of steps, the edge of each step, the doors at each floor were not clear and occupants slowed down to prevent missteps and falls.

Remedial actions were taken in response to these and other problems experienced in 1993. The stairs were fitted with emergency lighting units on every other landing. These units were battery-powered with electrical power keeping the batteries on a trickle charge. The units, should a loss of power be detected, were designed to power the lights off the battery for at least 90 minutes.

Additionally, the Port Authority of New York and New Jersey installed a photoluminescent pathway marking system, or safety way guidance system (SWGS). A SWGS, should power be lost and emergency lights fail or should smoke obscure overhead lighting, identifies handrails, stair treads and risers, exit doors, and the beginning and end of each flight with marking that glows in the dark (Fig. 1). The duration of this glow depends on the quality of the photoluminescent material used and the duration, type, and intensity of ambient light present prior to the onset of emergency.



Courtesy of NRC Canada

Fig.1 Safety Way Guidance System in Normal Lighting and Darkened Conditions

On September 11th, these two measures enhanced egress from the World Trade Center towers. Power was lost on some floors after the initial impacts and widely in the North Tower after the collapse of the South Tower. Additionally, there was smoke in the stairways that, according to at least one survivor from above the lowest floor impacted by the plane in the South Tower, obscured overhead lighting. As the event lasted in the North Tower for in excess of 90 minutes prior to collapse of the building, there may have also been emergency lights that were beginning to dim or lose power in the last 10 minutes.

The Pentagon, where egress was also required on September 11th as a result of the attack, survivors reported that they were unable to see high mounted, electrically-powered exit signs because they were obscured by smoke. Also, power was lost to emergency lighting, leaving portions of the complex in complete darkness. A decision was made since the attack to install a photoluminescent safety way guidance system and low-mounted photoluminescent exit signs to prevent a reoccurrence of the difficulties encountered with egress on September 11th. In fact, installation of the safety way guidance system and exit signs was deemed so critical that it was implemented throughout the Pentagon, even in areas not in the process of being renovated.

While September 11th does not represent the typical emergency, emergencies or false alarms requiring evacuation of a portion of or of the entire building are not uncommon. Emergencies commonly result in power loss and that power loss may last the duration of the emergency or much longer. During a heat wave in New York City in 1999, the local utility, ConEd, lost power for four days to a grid where a major medical complex was located. The complex had backup generators but they were not designed to power fire and other life safety systems, including emergency lighting. Thankfully, this event did not result in a need for immediate evacuation of all occupants because the stairways were in complete darkness. For the next four days, the lack of lighting in the stairways, which were frequently used by occupants to travel between floors, became a serious obstacle to travel within the building. It was realized by hospital management that a similar power loss during an emergency where evacuation was required could be a challenge to occupants. Subsequently, management considered the installation of either a photoluminescent safety way guidance system or battery-powered emergency lights in the stairways. Ultimately, battery-powered emergency lights were installed.

3. Safety Way Guidance Systems

Three examples have been provided where safety way guidance systems or emergency lighting have been installed as a result of an incident that demonstrated shortcomings in the egress information system design. This information system should provide a constant stream of information to the occupants to prevent any slowing in egress that might occur as a result of building layout or unfamiliarity with building layout on the part of the occupants. A safety way guidance system, as shown in the below diagram from the American Society for Testing and Materials (ASTM) "Guide for Recommended Uses of Photoluminescent Safety Markings" (ASTM E2030-99), identifies the boundaries or edges of the egress path in corridors and stairs and provides landmarks in the form of informational signage to assist occupants or emergency personnel in responding to the emergency. Exit doors are identified by low-mounted exit signs that complement the high-mounted exit signs and will be visible even if smoke or power loss prevent the high-mounted sign from being visible or legible. Stair treads, landings, and handrails are marked to ease movement. Floor and stair identification signs allow occupants and emergency personnel to orient themselves; It is easy to lose count of the floors while ascending or descending and emergency personnel may need to radio their location for assistance and need to be able to identify the stair they are occupying. Fire equipment is identified for use by emergency personnel.

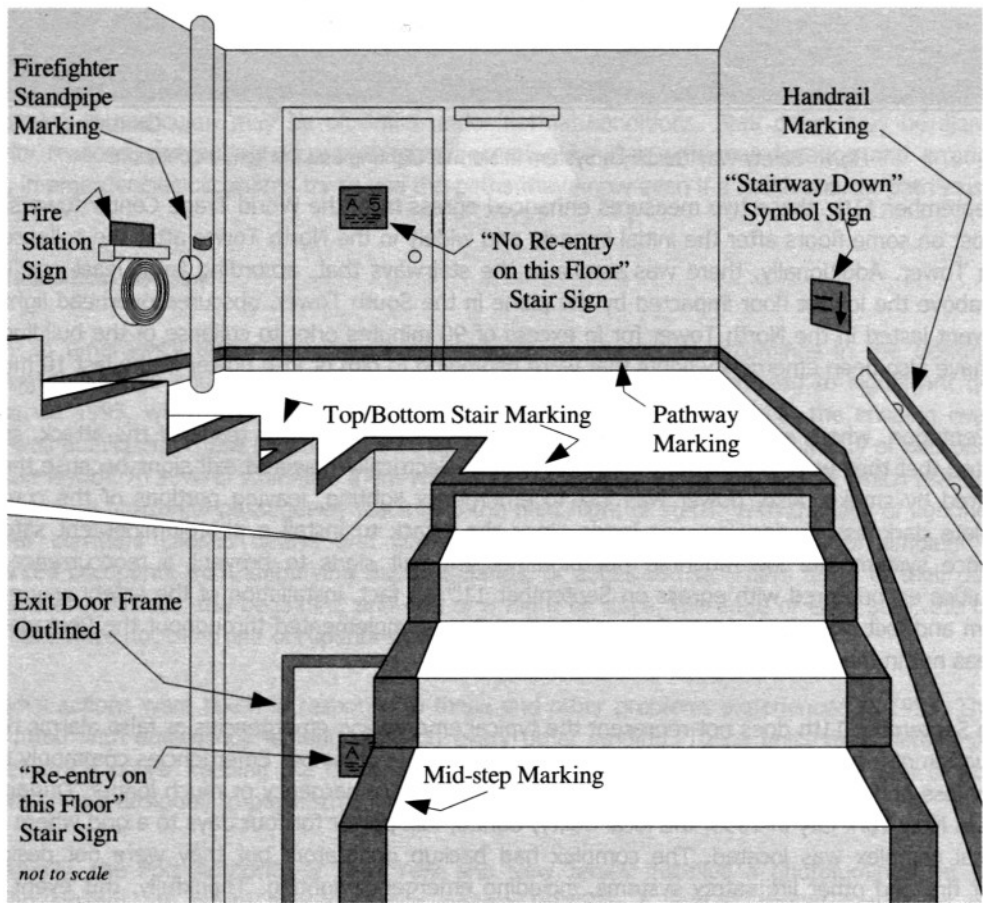


Fig.2 Diagram of Safety Way Guidance System marking from ASTM E2030-99

Safety Way Guidance Systems can compensate for a sudden loss of ambient or emergency lighting or an obscuration of that lighting from smoke. This is a critical facet of identifying how the egress information system as a whole lacks cohesion at present. Building and fire codes are written with emergencies in mind and redundancy that allows system or component failure without impact is integrated in many parts of the codes. For example, every effort is made to ensure that automatic sprinkler systems are in service at all times but there are cases of failure during emergencies. The redundancy built into most building codes covering high rise buildings is that other egress components, such as the egress corridors and stairway enclosures, are capable of withstanding fire for a certain period prior to failure occurring. This approach allows for the possibility of the sprinkler system failing

without immediate impact on egressing occupants. However, the lack of a similar redundancy in the approach to the egress information system design is only now being identified widely. The key to correcting this shortcoming is the safety way guidance system.

When an emergency occurs, if the emergency lighting and exit signage operate as designed and the building is fitted with appropriate signage, occupants can be expected to egress at a typical rate. The codes already mandate a minimum number and capacity of exits and the egress rate will relate to the number of occupants and to the number and capacity of the exits. However, if either exit signs or emergency lighting fails to perform, whether it be as a result of power loss or obscuration by smoke, the ability of the occupants to egress at the same rate as they would otherwise is challenged. Additionally, signage, such as stair identification signs or elevator signs directing occupants to make use of the stairs, may be illegible in such darkened conditions. The egress information system presently has no redundancy and its integrity falls apart with the loss of any one of the above components. How do occupants easily identify an exit door if no exit sign is visible? How do occupants navigate the stairs easily if no emergency lighting highlights its boundaries or edges?

Safety way guidance systems provide that level of redundancy, as demonstrated in the 1999 study by the National Research Council of Canada (CNRC). That study showed egress speeds using a safety way guidance system as being comparable to those under normal and emergency lighting conditions. But what of failure of the safety way guidance system? This is a question that bears scrutiny.

4. Photoluminescence

The previously mentioned safety way guidance systems were identified as being photoluminescent in nature. In 1859, the French researcher A. Becquerel described the first of many phosphors (photoluminescent materials) that absorb ultraviolet light and emit visible light. German submarine commanders during World War I reportedly rubbed inorganic zinc sulfide compounds on their hands to allow them to read documents during blackout conditions.

Zinc sulfide doped with copper (ZnS:Cu) became, between the early 1900s and the early 1980's, the pigment of choice for use in photoluminescent products, including novelty products (toys). The pigment can be integrated into plastics, ceramics and paints. Beginning in the 1980s, a series of tragedies identified a need for safety way guidance systems. These included fires or other accidents involving commercial aircraft, cruise ships, trains and buildings. As noted above, the failure of one or more components of the egress system, mainly loss of power to or obscuration of overhead lighting and exit signs were cited as contributing to fatalities. For example, smoke from the raging fire on the cruise ship *Scandinavian Star*, according to survivors, was so thick that the passageways were pitch black even though overhead lighting was still powered. 158 passengers and crew died, many having been unable to negotiate the path to safety or distinguish exit doors from cabin doors in the darkness. Subsequently, among other new requirements, the International Maritime Organization (IMO) adopted a new requirement for safety way guidance systems, known on cruise ships as Low-Location Lighting.

What the IMO requirement and others allowed was the installation of a system that was electrically-powered or photoluminescent. Several years before, the IMO had adopted a requirement that fire equipment signs be photoluminescent. It was recognized that photoluminescent signs, although not as bright as electrically-powered signs, could not fail to operate in an emergency. This acceptance of photoluminescent materials, even with the low luminance levels associated with zinc sulfide pigments, set the stage for a revolution in the use and performance of photoluminescent materials.

The means by which photoluminescence is accomplished is that in the presence of ambient light, photons, or light waves, from the ambient light source strike the molecules of photoluminescent crystals. The energy from the photons is imparted to ions in the crystals, where it remains for some time before the ions release the stored energy as light. The time that the energy is held by the ions depends on the characteristics of the molecule. It can be nanoseconds, as is seen with a fluorescent light fixture or with fluorescent inks and dyes. Alternatively, with a phosphorescent product, the energy can be retained for seconds, hours or even days. Both fluorescence and phosphorescence are

photoluminescent phenomenon, the only difference between the two being the time that the energy is retained.

There are other types of luminescence besides photoluminescence but they use a different means of charging the phosphor. Radioluminescence results when radioactive particles strike a phosphorescent pigment, similarly driving electrons up to higher shells for a time. Tritium, also known as self-luminous, exit signs make use of radioluminescence. Chemiluminescence results when a chemical reaction impart energy to the luminescent molecules, which they then release immediately as light. There are many chemiluminescent glow-sticks on the market, some targeting safety applications such as serving as a light beacon on a lifejacket. Electroluminescence results when an electric current is run through a layer of phosphor in a multi-layer film.

In the mid-1990s, a new photoluminescent pigment, strontium aluminate ($\text{SrAl}_2\text{O}_4:\text{Eu,Dy}$), was patented. The performance of products, such as exit signs, manufactured with strontium aluminate can be 2500% that of zinc sulfide in terms of luminance and duration of the glow. This allowed unprecedented uses. This high performance has ushered in safety way guidance systems and signage that can truly be considered to be of a safety grade. The Federal Aviation Administration (FAA) in the U.S. now allows photoluminescent aisle pathway marking systems on commercial aircraft if strontium aluminate pigments are used. Also, there are now photoluminescent exit signs that are accepted in many of the states of the U.S. as equivalent to electrically-powered exit signs. The American Public Transportation Association (APTA) developed a standard for aisle pathway marking on rail passenger cars that can be satisfied by either electroluminescent or photoluminescent marking. The luminance levels necessary for these applications can be satisfied only by products making use of strontium aluminate pigments.

5. Limitations of Electrically-Powered Systems

Photoluminescence is important because electrically-powered safety way guidance systems have been found lacking in several situations. On some cruise ships and aircraft, they were found to be difficult to maintain. The structure of ships and aircraft flex with the vessel's movement and with changes in temperature. This can stress the integrity of electrical connections. On a ship, the length of the marking and wiring for these systems measures in the kilometers. Also, safety way guidance systems are mounted on the floor or low on the walls and are subject to abuse from foot traffic, rolling carts, cleaning liquids, vacuum cleaners and the like. Frequent electrical failures in a safety way guidance system increase the likelihood of failure during an emergency. Failures during testing can also result in delays in the sailing of a cruise ship or the departure of an aircraft, inconveniencing passengers. Photoluminescent systems cannot fail to operate as long as minimum ambient lighting is maintained. On ships, aircraft, and trains, a great level of emphasis is already placed on maintaining overhead lights. Satisfying the needs of the photoluminescent system is a byproduct of that maintenance.

Even if properly maintained, an electrically-powered system may still fail during an emergency. For example, during the fire on the cruise ship *Ecstasy* in 1999, the fire burned through insulation on the Low-Location Lighting system, generating a trouble alarm on the ship's bridge. The design of the control panel was such that the alarm could not be silenced and, as it was very disruptive to the officers trying to gain control of the fire, an order was issued to the Chief Electrician to do what he must to silence the alarm. With no other alternative, he shut down the system entirely. Fortunately no one died as a result of this action although two crew members were trapped for 30 minutes as they could not find their way to an exit in the complete darkness caused by the thick, black smoke. They eventually got the attention of a rescue party trying to find them.

Thus, only a safety way guidance system that does not rely upon electricity in emergencies can provide the desired redundancy to the overhead lighting and exit signage because it cannot fail to operate. An electrically-powered system is always capable of failure and should not be allowed.

6. Discussion

6.1 Recent Code Developments

The National Fire Protection Association (NFPA), in their "Building Construction and Safety Code" (NFPA 5000) issued in 2002, inserted a new requirement for the illumination of special signs that are used in the course of egress and will need to be legible during an emergency. Previously, posting of signs such as "Area of Refuge" and "No Exit" signs was required but no mention was made, as there is with exit signs, that they be legible during an emergency. NFPA subsequently decided to propose similar modifications to the Life Safety Code (NFPA 101) and other standards. Unfortunately, no mention is made in the new requirement of the intensity of illumination nor the source of power (electrical or photoluminescent). However, these signs are one of the four components of the egress information system and it is important that the need for them to be illuminated has been recognized.

In New York City, code changes have been proposed to the New York City Building Code to require photoluminescent safety way guidance systems in the stairways of all new and existing high rises. This proposal is still under discussion but, if adopted, would create the redundancy sought above, at least in stairways. The proposed change also specifies photoluminescent materials. The luminance levels of such a system have yet to be set but, ideally, luminance levels on the scale of photoluminescent exit signs would result in the highest likelihood for enhancing egress. Additionally, requiring safety way guidance systems in the corridors and in other types of structures beside just high-rise buildings should also be considered. Many accounts from survivors on September 11th reported being unable to easily egress through darkened corridors.

6.2 Demand for Technology Growing

Separately, in New York City, there have been several installations of safety way guidance systems installed in response to tenant demand. These include the stairways in several high-rise office buildings and throughout much of the United Nations complex in stairways and corridors. Tenants and occupants have a higher level of concern about being able to egress since September 11th highlighted that conditions during egress may not be optimal and complete evacuation of a building or complex may be necessary. The response of tenants/occupants to the safety way guidance systems has been positive. Once they see the system in operation, typically demonstrated by extinguishing overhead and emergency lights, occupants gain an appreciation for the fail-safe nature of the photoluminescent materials and report that their level of concern has decreased. Exposing occupants to a safety way guidance system also improves the chances that they will make use of it during an emergency.

A related application of photoluminescent technology, for the marking of steps in large assembly spaces such as stadiums, theaters, and lecture halls reflects a need for alternatives to electrically powered systems from the ease of installation and maintenance perspectives. For the 2000 Olympics in Sydney, Australia, the 5,000-seat Superdome arena was constructed. Requirements for lighting of the steps in the stadium were difficult to meet because electrically powered lighting for the steps was very expensive to install in the concrete steps and, over time, expensive to maintain and power. However, as designers knew of no alternative method, electrically powered lighting on the steps was installed. Much of that lighting installed early on during construction was, by the time the Olympics arrived, reportedly either inoperative or unserviceable. The senior venue attendant for the arena, while searching for an appropriate lighting solution, discovered a company that produced stair nosing with an integrated photoluminescent strip. It was installed.

Building on the Olympic arena installation, subsequent installations in the U.S., Australia and New Zealand, have been performed in stadiums, theaters, and lecture halls. In locations that had no prior lighting to highlight steps during performances (where it may not have been required), instances of slips and falls decreased dramatically after the installation. Such installations were typically owner or tenant driven as the slip and fall issue was a constant source of injury to patrons and a frequent source of litigation against the owners. Although the photoluminescent strip is of interest for the purpose of this paper, a slip resistant strip integrated into the stair nosing has, no doubt, also played a role in the decrease in slips and falls. Ease of installation and maintenance were main reasons cited for installing a

photoluminescent system but owners indicate that they often receive positive comments from occupants regarding the system performance.

6.3 Modifying Standards and Codes

In order to meet requirements for emergency lighting in the U.S. installations, the manufacturer of the photoluminescent stair markings appealed to the International Conference of Building Officials (ICBO) to develop criteria in order for the photoluminescent egress system to be deemed equivalent to electrically powered systems. To ensure equivalence, the duration and intensity of the glow from the system was specified and means of testing the system, with weathering included for exterior installations, was developed. This was a very similar process to those measures taken to have photoluminescent exit signs tested by Underwriters Laboratories (UL) and accepted by the NFPA as equivalent to electrically-powered exit signs. As a result of that effort, there is now a growing demand for photoluminescent exit signs.

7. Conclusions

Safety way guidance systems would satisfy the need for redundancy that is presently lacking in the egress information system that is presently provided for occupants. Power failure, component failure, or smoke in a corridor or stair can compromise the overhead/emergency lighting, exit signage and informational signage. Furthermore, safety way guidance systems are best suited to photoluminescent products as electrically-powered systems can and have failed to operate during an emergency, whether by failure of a battery, electrical component or through some human action that disabled the system. Photoluminescent signs and exit path marking can be very bright for the duration of the emergency and cannot fail to operate.

There are currently proposals to change the New York City Building Code to require safety way guidance systems in the stairways of high-rise buildings. Such proposals are a step in the right direction but additional benefits may be realized from requiring safety way guidance in corridors of high-rise buildings and in other types of structures, as well. Even without regulatory changes for buildings, safety way guidance systems are gaining a following through demand from tenants and occupants and adoption in ships, aircraft, and trains.

Acknowledgements

The support of Rolf Jensen & Associates in encouraging the completion of this paper is greatly appreciated. Cooperation of the staff of the United Nations also warrants mention.

References

- American Society for Testing and Materials (1999), Guide for Recommended Uses of Photoluminescent Safety Markings (E2030-99), West Conshohocken, PA, USA.
- Fahy, R. and Proulx, G. (1995), Collective Common Sense: A Study of Human Behavior During the World Trade Center Evacuation, NFPA Fire Journal, 89(2), pp.59 - 67.
- Federal Emergency Management Agency (2002), World Trade Center Building Performance Study: Data Collection, Preliminary Observations, and Recommendations, Washington, DC, USA, pp.2-24.
- Fern, Richard, "Accounts from the South Tower" New York Times, May 26, 2002.
- Fruin, J. (1971), *Pedestrian Planning and Design*, Metropolitan Association of Urban Designers and Environmental Planners, Inc., New York, USA.
- National Fire Protection Association (2002), Building Construction and Safety Code (NFPA 5000), Batterymark Park, MA, USA.
- National Fire Protection Association (2000), Life Safety Code (NFPA 101), Batterymark Park, MA, USA.

Proulx, G., Creak, J., and Kyle, B. (1999), A Field Study on Photoluminescent Signage Used to Guide Building Occupants to Exit in Complete Darkness, National Research Council of Canada, Ottawa, Canada.

Bibliography

- Amy, Jr., J. (2002), Pathway Marking Can Speed Evacuation, *Building Operating Management*, 49(10), pp.53 - 55.
- Arthur, P. and Passini, R. (1992), *Wayfinding, People, Signs, and Architecture*, McGraw-Hill, New York, USA.
- Ashdown, I. (1999), *Glow-in-the-Dark*, West Vancouver, Canada.
- Frantzich, H. (2001), Occupant behavior and response time results from evacuation experiments, *Proceedings of the 2nd Symposium on Human Behavior in Fire*, InterScience Communication, London, UK, pp.159 - 165.
- National Transportation Safety Board (2001), *Marine Accident Report – Fire on Liberian Passenger Ship Ecstasy PB2001-916401*, Washington, DC, USA.
- Passini, R. (1984), *Wayfinding in Architecture*, Van-Nostrand Reinhold, New York, USA.