



U.S. Department  
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Administration

# Research Results

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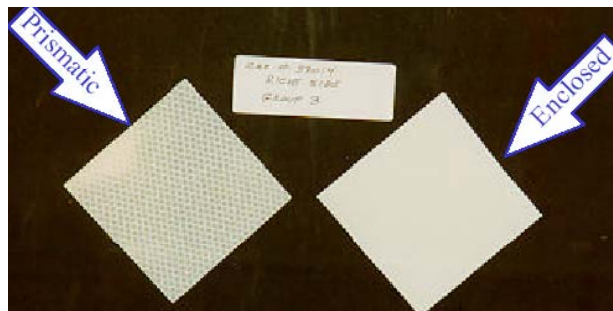
## Retroreflective Markings on Rail Cars

### SUMMARY

For several decades, railroads and researchers have mounted reflective materials on rail cars to enhance their conspicuity at night and in other low visibility environments, such as rain, snow, or fog. Retroreflection has long been the preferred pattern of the transportation industry. As shown in Figure 1, it produces a more concentrated reflection than other patterns used. However, until the development of microprismatic corner cube materials in the late 1980s, none of the materials available (such as enclosed lens, shown with the new material in Figure 2) were sufficiently bright and durable to be considered for Federal requirements. In the early 1990s, the Federal Railroad Administration (FRA) Office of Research and Development sponsored a study of the newly developed materials to assist the FRA Office of Safety in determining their appropriateness for rulemaking action and the nature of any specifications.

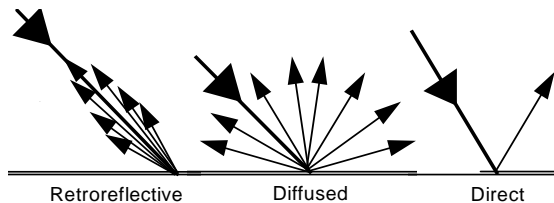


**Figure 1. Mounting of Retroreflective Materials on a Box Car**



**Figure 2. Prismatic Material Compared with an Earlier Material**

The FRA study, conducted by the Volpe Center, consisted of two components: (1) technology assessment and (2) human perception and recognition. The technology assessment addressed the brightness, durability, and adhesiveness of microprismatic retroreflective materials. The materials were mounted on four types of freight cars, each carrying different cargo in revenue service. Reflectivity was measured, and the materials were inspected several times during the next 3 years. The human perception and recognition research addressed the effectiveness of different colors and patterns of materials in alerting motorists to rail cars. Motorists and transportation experts reviewed and ranked several designs according to their detectability. Additionally, a driving simulator was used to measure (1) the degree to which motorists could recognize reflectorized freight cars in a grade crossing when both the motor vehicle and the train were moving and (2) the ability of motorists to differentiate reflectorized freight cars from other traffic objects, such as reflectorized truck trailers.



**Figure 3. Retroreflection Compared with Other Reflection Patterns**

The technology assessment demonstrated that the tested materials were sufficiently durable to survive the harsh environments of freight operations. With only minimal cleaning and maintenance, the materials maintained a high degree of their original intensity. Therefore, rulemaking action was initiated. Findings from the human perception and recognition experiments served to support the regulatory requirements.



## BACKGROUND

Tests conducted by the Volpe Center in the early and mid-1970s showed that use of reflectors or reflective materials made trains more visible at night.

A 1980 Volpe Center literature review of railroad experience showed that use of retroreflective materials on rail cars was an effective means of enhancing nighttime conspicuity. Retroreflectivity was found to be more conspicuous than either the direct or diffused patterns. Retroreflective material reflects light in angles close to the angle of incidence and is maintained over wide variations of the incident (source) radiation angle.

In 1982, the Volpe Center conducted a study, sponsored by FRA, of the feasibility and effectiveness of retroreflective materials available at that time. The study found that, although the enclosed lens materials tested improved conspicuity, they were not sufficiently durable and bright to be cost effective for use in the harsh railroad environment. FRA, therefore, concluded that rulemaking action was not warranted at that time.

In the decade following those tests, technical improvements in the brightness, durability, and adhesive properties of retroreflective materials were achieved. A new material consisting of microscopic prisms (or corner cubes) was introduced to the market. Each corner cube contained three surfaces oriented at 90-degree angles to each other. The incident rays of light were reflected from each of the surfaces and returned to the observer in a more concentrated and focused beam than either enclosed or bonded materials. These developments rekindled FRA interest in retroreflective markings, resulting in initiation of the Volpe Center study in 1990.

## RESEARCH OBJECTIVES

### *Technology Assessment:*

- Determine the ability of microprismatic retroreflective material to retain brightness and intensity under various harsh railroad conditions.
- Determine preliminary capital costs and maintenance costs of the materials.

### *Human Perception and Recognition:*

- Determine the optimal design for retroreflective materials on rail cars.
- Determine the perception characteristics of the new material and its accident reduction potential.
- Examine the ability of observers to discriminate reflectorized freight cars from reflectorized truck trailers in roadway traffic.

## RESEARCH METHODS

### *Technology Assessment:*

In 1990, a literature survey of reflectorization experiences in transportation was conducted to determine colors and patterns used.

A 1-year demonstration test was conducted in 1991–1992. Various colors and patterns of three different retroreflective materials (microprismatic, enclosed lens, and bonded), their selection based on the literature survey, were mounted on a train that traveled 12,941 miles.

In 1991, microprismatic sheeting was mounted on a captive fleet of revenue-service Alaska Railroad (ARR) tank cars carrying various petroleum products. In 1992, the same type of material was mounted on three captive fleets of revenue-service freight cars on the Norfolk Southern Railroad (NS)—intermodal double-stack cars carrying containers, steel open-top hopper cars carrying coal, and box cars carrying clay. The materials were mounted in the preferred design configuration derived from the demonstration test.



Figure 4. Design Used in Revenue-Service Tests

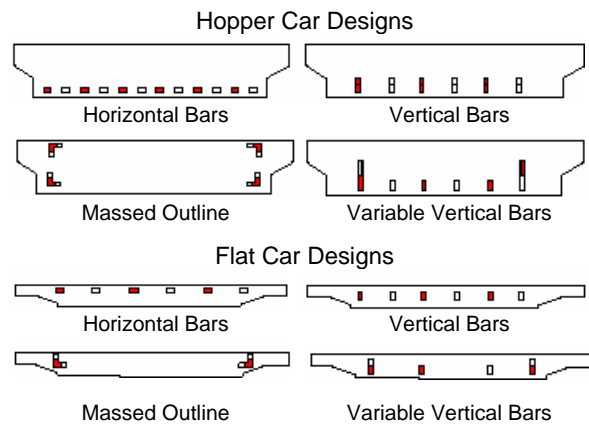
The reflectivity of the materials was measured when they were mounted. During the following 3 years, the reflectorized cars were used continuously in revenue service, and the materials were inspected and measured before and after washing. The subsequent measurements were compared to the initial measurements. The cost of the materials for a car and the labor costs to install them were recorded. The maintenance cycle and labor costs were estimated.



**Human Perception and Recognition:**

Various retroreflective designs were evaluated in 1993 and 1994. Six transportation professionals with experience in traffic engineering, railroad operations, and human factors created 25 designs, reviewing and ranking them based on their alerting effectiveness. The eight designs with the highest rankings and three other designs (including the one used in the technology assessments conducted on the ARR and NS) were selected for further testing by a larger group of transportation experts and licensed motorists. The subjects ranked the 11 designs based on subjective criteria of personal preferences. The same group then performed an objective test of detectability distance based on a static image of a freight car. Each design was projected individually on a slide, which was progressively enlarged until detected by the subject.

In 1997 and 1998, two laboratory experiments were performed using a human-in-the-loop driving simulator. Four patterns of red and white reflectors were evaluated on both hopper cars and flat cars, as shown in Figure 5.



**Figure 5. Designs Used in Simulator Tests**

The four patterns for both car types were tested in rural and urban environments.

In the first experiment, the subjects, located at a fixed position from a simulated grade crossing and parallel roadway, viewed more than 1,000 scenes showing one of three items: a moving train, a moving motor vehicle, or nothing. The subjects' recognition of different reflector patterns was recorded and analyzed.

In the second experiment, subjects drove the simulated motor vehicle and reported all objects on the roadway. The course included a series of roadway intersections, grade crossings, traffic

signs, traffic lights, trains, and motor vehicles. The recognition distance from the participants' position to the train was recorded and analyzed.

**FINDINGS AND CONCLUSIONS**

The technology assessment showed that the microprismatic corner cube material was sufficiently bright, durable, adhesive, and cost effective to warrant rulemaking activity by FRA. The results of the human perception and recognition research served as the basis for the design specifications in 49 CFR Part 224, *Reflectorization of Rail Freight Rolling Stock*, effective March 4, 2005.

**Technology Assessment:**

The microprismatic material evaluated in the demonstration test was far brighter than the other two types of retroreflective materials (enclosed lens and bonded) and was therefore selected for the revenue-service testing.

The average specific intensity per unit area (SIA) levels of the unwashed microprismatic materials measured on the ARR and NS freight cars generally exceeded the minimum intensity thresholds and far exceeded the levels measured for the enclosed materials in 1982. After washing, the SIA levels returned close to their original values. Natural environmental factors had no significant impact on the luminous intensity of the materials, and they generally maintained adhesiveness. Most of the significant degradation in luminous intensity and adhesiveness occurred at mid-car locations on tank cars and box cars, due to loading operations.

The cost to purchase, install, and maintain the tested materials for 10 years was estimated at \$220 per car in 1996. The tests showed that the only maintenance required would be heavy washing every 12 to 18 months.

**Human Perception and Recognition:**

The design evaluations conducted in 1993–1994 at the University of Tennessee suggested that (1) a standardized pattern should be used for all types of rail cars to facilitate recognition and (2) the design should be sufficiently distinctive so that it is not confused with the retroreflective markings used on truck trailers and warnings for other roadway hazards.

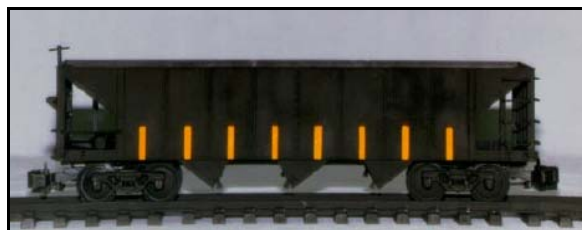


In addition, fluorescent yellow rectangular reflectors were found to be the most effective for both detection and recognition. The most effective marking systems used simple rectangular shapes in a pattern that indicated the profile (i.e., size and shape) of the rail car.

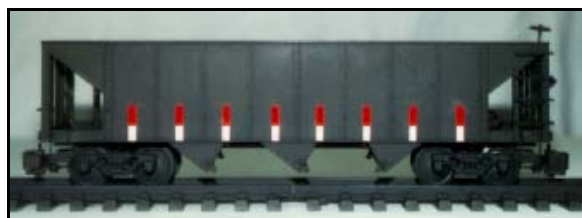


**Figure 6. Outline of Cars with Fluorescent Yellow Rectangles**

In 1997–1998, driving simulator experiments were conducted at the Massachusetts Institute of Technology (MIT) to research driver reaction in real-life situations. The simulation results subsequently showed that vertically oriented patterns were recommended over outline and horizontally oriented patterns because they were less likely to be confused with the horizontally oriented truck trailer patterns.



**Figure 7. Vertical Fluorescent Yellow Rectangles**



**Figure 8. Vertical Fluorescent Red/White Rectangles**

FRA used the results of the research conducted at the University of Tennessee and MIT as input in the rulemaking process. The final rule requires the application of yellow or white retroreflective material to the sides of freight rolling stock, freight cars, and locomotives, in a vertically oriented pattern.

## REFERENCES

- [1] *Freight Car Reflectorization*. Carroll, A.; Multer, J.; Williams, D.; Yaffee, M. Final Report. January 1999. DOT/FRA/ORD-98/11, DOT-VNTSC-FRA-97-2.
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- [3] *Evaluation of Retroreflective Markings To Increase Rail Car Conspicuity—Safety of Highway-Railroad Grade Crossings*. Ford, R.; Richards, S.; Hungerford, J. Final Report. October 1998. DOT-VNTSC-RR897-PM-98-22

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