

material performed satisfactorily, while the enclosed lens and bonded materials did not. The microprismatic material had a much higher initial SIA value than the other two materials and was found to be ten times brighter than the material tested in 1982. In addition, after one year of service, the microprismatic retroreflective material maintained an SIA value that was 87% of the original measurement, which was well above the established minimum conspicuity threshold. The enclosed lens material lost approximately the same percentage of reflectivity as the microprismatic material, but due to its lower original SIA value, this loss was sufficient for it to fall below the minimum reflectivity required. The red microprismatic material degraded approximately the same as the white. However, none of the all red markings evaluated in the study met the minimum reflectivity requirements after one year. In addition, all of the materials placed on the wheels degraded very quickly and became ineffective in only a few months. Of the markings that were comprised of both red and white materials, only the performance of the vertical 4x96 inch strips of microprismatic material (applied to the corner posts of one car) was reported. The reflectivity of these markings decreased to about 67% of their initial value after one year. Because of the relatively large size of the markings, however, this amount of reflectivity was well above the conspicuity threshold level.

Based on the preliminary results of the demonstration test, larger scale trials, spanning approximately two years, were initiated in collaboration with Norfolk Southern Corporation and the Alaska Railroad Corporation. This in-service test allowed data collection of the retroreflective material's durability, performance, and accident reduction potential under in-service conditions. For these trials, two color combinations of microprismatic retroreflective material were selected based on the demonstration test and input from the railroads: A pattern of all white material and a pattern of alternating red and white material. The marking configuration selected consisted of three 4x8 inch white rectangular markings applied horizontally every nine feet just above the side sill (at approximately 42 inches TOR in most instances), and a 4x36 inch strip of red/white material applied vertically at the side sill on both ends of the cars. In 1991, the markings were applied to 29 tank cars carrying various petroleum products on the Alaska Railroad. Because of the

curvature of the tank body, the markings were placed at 72 inches TOR. In January 1992, the markings were applied to 149 Norfolk Southern double-stack intermodal flat cars. Because of the limited surface area of these flat cars, the 4x8 inch markings were placed at 42 inches TOR, while the 4x36 inch markings were placed at 30 inches TOR. This was followed in March and April 1992 with 336 captive Norfolk Southern open top hopper cars and 74 boxcars in clay service, respectively, receiving the marking system.

Although the results of the in-service test showed that the harsh railroad operating environment could have a severe effect on the performance of the retroreflectors, Volpe identified a general correlation between reflector performance and height above TOR. Specifically, reflectors mounted highest on test cars performed the best, while reflectors mounted lower, and particularly below the side sill, did not perform as well. Finding little change in reflector performance due to dirt and grime accumulation above the side sill level (approximately 42 inches TOR), Volpe identified a minimum placement height as 42 inches TOR to allow maximum efficiency of reflector performance. The average performance of the vertical 4x36 inch reflective strips at the ends of the cars remained above the minimum threshold level for all car types for the entire testing period. The average performance of all 4x8 inch reflectors degraded more quickly, especially when mounted under the side sill or in mid-car locations where loading operations occur. Accordingly, Volpe concluded that any reflectorization pattern should minimize reflectors' location under the side sill and at loading points, and should utilize larger reflectors. Larger-size reflectors would lower the acceptable SIA level and would also degrade at a slower rate than the 4x8 inch reflectors.

Although the in-service test did not provide statistically valid results regarding the reflectors' accident reduction potential, the test did show a reduction in RIT accidents. During the three year period before the installation of the reflectors on the captive Norfolk Southern hopper cars, there were six accidents in which the motorist hit the side of the train after the first unit had passed through the crossing (*i.e.*, referred to as Category 1 RIT accidents). These accidents occurred during the hours of dawn, dusk, and darkness. During the three year period after the cars were reflectorized, no RIT accidents occurred.

The primary concern of the fourth phase of the research program, the

human factors evaluation, was to develop a retroreflective pattern that is detectable in time for the motorist to recognize a train in the grade crossing and respond in time to avoid an accident. Specifically, the test was designed to determine the detection characteristics of the new microprismatic retroreflective material in various color and mounting configurations. Several potential placement patterns and color combinations were developed and analyzed to determine the most effective reflectorization configuration. Based on the outcome of both subjective and objective evaluation techniques, reflectorized freight cars were found to be significantly more detectable than non-reflectorized cars. Even the worst performing pattern and color configuration tested was several orders of magnitude better than an unreflectorized car. Generally, the results indicated that a uniform pattern of reflectorized material would facilitate motorists' detection of a hazard in his or her path and recognition of that hazard as a freight car. The results specifically indicated that a uniform vertical reflector pattern yielded the highest levels of detection and recognition and that a red/white color combination was preferable in order to facilitate motorists' recognition of a train as a hazard in the motorists' path and convey a sense of danger. In addition, distribution patterns that outlined the shape or that spaced the retroreflective material over a relatively large area of the rail car side were found to be superior to a distribution that concentrated the material along the bottom of the car. Accordingly, Volpe recommended the development of a standard pattern that: (1) Either outlined the shape of the freight car, or otherwise spaced the material over a large area of the rail car side; (2) could fit on all types of rail cars; and (3) would not likely be confused with other roadway hazards, particularly reflectorized trucks and trailers.

FRA addressed the issue of motorist confusion with the issuance of the 2001 Volpe Report. This study recognized that the previous study did not provide a realistic environment in which to evaluate the detectability and recognition of freight cars reflectorized with microprismatic retroreflective material. For example, in the 1999 study, observers did not see anything else in the scene that might be encountered in an actual driving environment (*e.g.*, signs, other vehicles, lights, foliage, buildings, *etc.*). In the real world, foliage, buildings, or other