reflector lamps. The exit port is imaged by an Abbe projection system similar to the system used in the strip lamp system. The sphere system has similar characteristics to the strip lamp system with more operating complications. The real advantage of the sphere projection system is that any light can be coupled into the sphere without changing any of the projection optics. The high intensity discharge (HID) lamps that are available in cars have a very distinct spectral pattern. The retroreflectance of devices can be calculated if spectral coefficients of retroreflection are measured, but, to experimentally verify the results, the sphere projection system is the better option.

The goniometer of the reference retroreflectometer is mounted on a rail system. The illumination distance is variable from 5 to 35 m and will have an absolute uncertainty of 0.005 m ($k = 2$). The largest retroreflective device the goniometer can accommodate is a device 95 cm in diameter. It has a clear view to allow almost any length of pavement marking. The sample mounting plate uses vacuum cups to hold the retroreflective devices against a precision register. The mounting bracket has an adjustable depth to accommodate different sample thicknesses. The detector package can also be mounted to the sample plate to measure the illuminance at the sample plane. In addition to the three automated rotation axes, the goniometer is able to translate along three axes using stepping motors providing an accuracy of 0.25 mm along the illumination axis and 0.05 mm perpendicular to the illumination axis. These translations are for research purposes, such as studying uniformity of the source and the sample.

The detector is supported by the observation angle positioner, which comprises a 2-m translation stage, a rotation stage and a 0.2-m translation stage. Each of these motions has an optical encoder to ensure accuracy. The observer apertures will range from 3 to 20 arc minutes. With this detector system and source, the detection limit (signal-to-noise of 2:1) for the NIST reference retroreflectometer is 0.17 mcd/m^2/lx. A calibration limit can be defined as the magnitude of the coefficient of retroreflected luminance where the signal-to-noise ratio does not dominate the uncertainty budget (typically 1000:1, in this case 500:1); therefore, the calibration limit for the NIST reference retroreflectometer is 42 mcd/m^2/lx.

The reference retroreflectometer has been analyzed and characterized for over forty different aspects that are components in the overall uncertainty budget for the calibration of retroreflective material, including signage and pavement marking material. The typical calibration of a white encapsulated bead retroreflective sheeting material for coefficient of retroreflected luminous intensity is expected to have a relative expanded uncertainty of 1% ($k = 2$). The uncertainty will be somewhat higher, up to 2% ($k = 2$) for microprismatic and/or colored materials. Typical white or yellow pavement marking material will have a relative expanded uncertainty of 2% ($k = 2$).

CALIBRATION SERVICES AND TRACEABILITY TO NIST

The mission of NIST is to develop and promote measurement, standards, and technology to enhance productivity, facilitate trade, and improve the quality of life. To help meet the measurement and standards needs of retroreflective materials manufacturers and users, NIST provides calibrations, test methods, proficiency evaluation materials, measurement quality assurance programs, and laboratory accreditation services that assist a customer in establishing traceability of results of measurements or values of standards.

Traceability requires the establishment of an unbroken chain of comparisons to stated reference artifacts or materials. NIST assures the traceability of results of measurements or values of standards that NIST itself provides or calibrates. Other organizations are responsible for establishing the traceability of their own results or values to those of NIST or other stated references. The role of this project was to develop a calibration program to provide the stated references.

The specific calibration service procedures at NIST are expanded upon in a series of documents labeled Special Publications. A Special Publication in the NIST 250 series is to be published in the spring of 2005 on the calibration of retroreflective material. The publication provides a general description and then describes the scale realization, appropriate artifacts for calibration, equipment for calibration, calibration procedures, and uncertainty budget of the calibration.

The cost of the calibration service changes with time depending on factors determined by the NIST management. All of these factors are based on the number of hours required to perform the calibration.

A time budget for the calibration of retroreflective samples has been prepared. With the basic automation of the equipment and the complete uncertainty analysis, an estimate of the time required for calibration has been determined:

Number of hours = [n * (m + 0.3) + 2]

where n is the number of test samples and m is the number of angle combinations per sample.

NIST also assists in helping laboratories establish traceability of their measurements through a variety of support mechanisms that include round robin comparisons, workshops, the Measurement Assurance Program (MAP), and the National Voluntary Laboratory Accreditation Program (NVLAP). The MAP and NVLAP programs are described in more detail in the final report for Project 05-16.

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REPORT AVAILABILITY

The complete report for NCHRP Project 05-16 is available on TRB's website as *NCHRP Web-Only Document 72*.

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