COUNCIL FOR OPTICAL RADIATION MEASUREMENTS

CORM EIGHTH REPORT

Pressing Problems and Projected National Needs in Optical Radiation Measurements

May 2016

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PREFACE

The Council for Optical Radiation Measurements (CORM) is a non-profit organization composed of individual members interested in optical radiation measurements. CORM's aim is to establish a consensus among interested parties on scientific, industrial, and academic requirements for physical standards, calibration services, and inter-laboratory collaboration programs in the field of optical radiation measurements. This includes setting priorities, liaison with the National Institute of Standards and Technology (NIST), National Research Council of Canada (NRC), Centro Nacional de Metrologia (CENAM) of Mexico, dissemination of information, response to inquiries, and cooperation with other organizations for the benefit of the public at large.

CORM was organized on February 10, 1972 at a conference of industrial and governmental representatives. This meeting was held at the former National Bureau of Standards (NBS) under the title "Second Conference on the Definition of Pressing Problems and Projected National Needs in Radiometry and Photometry". The formation of CORM resulted from the recognition than an action program must follow the definition of measurement problems, and for this purpose a permanent organization was necessary. In 1978, CORM objectives were broadened to encompass needs relative to organizations and parties other than NIST.

This report is the eighth in a series of CORM reports dating back to the CORM FIRST REPORT issued in May of 1973. Because of the time since the publication of the CORM SEVENTH REPORT in 2001, as well as the rapid evolution since that time in light source, display and measurement technologies, this CORM REPORT differs in format and structure from previous reports. It is intended to provide background behind prior CORM REPORTS and serve as a foundation for the CORM NINTH REPORT to be published shortly after the present CORM REPORT.

1. INTRODUCTION

It could be argued that the reason for CORM's existence as a technical organization is to provide guidance to national metrology institutes (NMIs) such as the National Institute of Standards and Technology, the National Research Council of Canada (NRC), and the Centro Nacional de Metrologia (CENAM) of Mexico, in the form of CORM REPORTS. In 1971 and 1972, the first two conferences entitled "Conference on the Definition of Pressing Problems and Projected National Needs in Radiometry and Photometry" were held. Recognizing that NMIs needed input from industry and academia to help set priorities for standardization activities, the Council for Optical Radiation Measurements (CORM) began, initially as a technical committee of the U.S. National Committee of the Commission Internationale de l'Éclairage (CIE), the International Commission on Illumination. While the initial efforts of CORM were directed mainly to the U.S. National Bureau of Standards (NBS, the forerunner to NIST), collaboration among NMIs was desired and CORM's scope was broadened in 1978 to an international one.

CORM REPORTS presently serve as half of a dialogue between the measurement and instrumentation communities and the NMIs serving North America. To develop the recommendations contained within CORM REPORTS, CORM members and other individuals concerned with measurement of optical radiation are surveyed regarding the type of assistance they require in terms of documenting calibration and accuracy of their measurements. They are also prompted to identify new measurement methodologies in response to new light source or instrumentation technological developments, and to provide recommendations about certification, documentation or educational resources that might be needed.

As such, CORM REPORTS serve in part almost as a wish list on behalf of the industrial and academic photometry and radiometry communities regarding desired priorities of the NMIs, and they also serve as an action plan for industry societies and committees, recognizing that NMIs are severely constrained by limited resources, and that coordination among NMIs and industrial constituents can be powerful catalysts for action.

2. HOW HAVE CORM REPORTS BEEN USED?

Unless CORM REPORTS are read and acted upon, their significance is quite limited. Fortunately there is a history of the impact of CORM REPORTS on the assessment of national radiometry and photometry standards activities, at least in the U.S. In 1983, the National Resource Council evaluated the National Measurement Laboratories, stating in its report, "This year CORM issued its Fourth Report to NBS on Pressing Problems and Projected Needs in Optical Radiation Measurements. In spite of its shortages in personnel and discretionary funds, the Division has been able to initiate an impressive response to filling the high-priority needs in radiometry described in the report." Another example comes from the National Academy of Sciences assessment of NIST programs in 1990, stating "The division's major focus for the 1990s is the achievement of 0.1 percent radiometry. The need for 0.1 percent radiometry transfer standards has been clearly communicated by U.S. industry, as documented in the recent CORM Fifth Report." Both examples demonstrate that CORM REPORTS are used as benchmarks to assess NMI activity.

It is also worth noting that NIST, for example, has responded in writing to previously published CORM REPORTS. In 1994, NIST wrote in its response to the CORM FIFTH REPORT, "The CORM Fifth Report has served as an impetus for significant improvement and change in NIST programs serving the optical radiation measurement community…. At NIST a major and long-lasting result of the Fifth Report will be the efforts put into establishing a much improved and more accurate radiometric measurement service." In 2001, NIST responded to the CORM SIXTH REPORT by stating "…since the CORM 6th report was issued in 1995, the Optical Technology Division has made numerous strides in improving all aspects of optical radiation measurements…. The recent widespread use of LEDs in displays and lighting was foreseen in the CORM 6th report and in its immediate predecessor, the CORM 5th report, and consequently NIST is presently disposed to meet many of the needs of this important area." In 2005, NIST responded to the CORM SEVENTH REPORT by stating "Over the past four years, the Optical Technology Division has successfully addressed many of the high-priority recommendations in the CORM 7th report…. The CORM reports have also aided the Division in ensuring that its programs are current with changing industry needs. Examples include CORM requests for improved measurements and standards for LEDs and for color and appearance. Both of these requests have led to significant NIST efforts in developing new measurement facilities directly addressing needs in these areas." NMI efforts like the responses described here demonstrate that CORM REPORTS can have impact.

3. RECENT CORM REPORTS

In order to develop a projection of CORM's recommendations over the past two decades, the two most recent CORM REPORTS are summarized to describe the data collection efforts underlying them and the types of needs that were identified.

3.1. CORM SIXTH REPORT

Published in 1995, the CORM SIXTH REPORT included a survey of individuals from industry (64%), government (19%) and academia (7%), and identified needs in several areas: accreditation, optical properties of materials, and radiometry.

Regarding accreditation, the CORM SIXTH REPORT called for the establishment and maintenance of an internationally recognized accrediting body for laboratories engaged in photometric, colorimetric and radiometric characteristics such as luminance, illuminance, luminous flux, color temperature, laser power, laser energy, transmittance, specular reflectance, and the coefficient of luminous intensity retroreflectance. Related to optical properties of materials, the CORM SIXTH REPORT called for new standards of regular and diffuse transmittance, for example encompassing 0.05-6 absorbance units in the visible range, and for wavelength ranges between 190-850 nm, and between 850-2500 nm. Colored standard reference materials were also sought, as well as guidance on measurements of fluorescence. In addition, the report requested the development of new standards for bidirectional reflectance distribution functions (BRDFs) and for bidirectional transmittance distribution functions (BTDFs). For work in radiometry, the CORM SIXTH REPORT requested detector standards for radiometry in the ultraviolet (UV, 180-400 nm) and infrared (IR, 750-30,000 nm) regions. Related to sources and standards for radiometry, this report also requested NMIs set target uncertainties for wavelengths between 225-2400 nm. Guides for measurement methodology in radiometry and hands-on workshops were also sought.

3.2. CORM SEVENTH REPORT

A similar breakdown of survey respondents replied to CORM's survey underlying the CORM SEVENTH REPORT, published in 2001, consisting of industry (64%), government (19%) and academia (8%). Respondents identified needs in radiometry, optical properties and measurement uncertainty.

Regarding radiometry, new standards for luminous flux and luminous intensity were desired, partly because of needs brought on by the introduction of solid state light sources such as light emitting diodes (LEDs), with the potential for narrowband wavelength emission and potentially for narrow geometric distribution as well. A need for new standards for reflected color was identified in order to facilitate measurements with less than 0.5 CIELAB color difference units. As variability in round-robin BRDF and

BTDF measurements showed variability, new standards for these requirements were requested. Fluorescence standards were also identified as an area of need, particularly traceability of measurements on items such as fluorescent "hunter orange" materials. A significant need to reduce measurement uncertainty and indeed, to promulgate a better understanding of the concept of measurement uncertainty was identified. For spectral irradiance measurements, an uncertainty of 0.3%, k=2 between 250-1100 nm was identified as a need. For spectral radiance measurements, an uncertainty of 0.5%, k=2 in the same wavelength range was identified.

4. RECENT CORM DATA COLLECTION EFFORTS

In preparation for the CORM EIGHTH REPORT, a survey instrument was developed and administered in 2006-2007. Interested individuals from industry (88%), government (8%) and academia (4%) responded to this survey.

Among the most frequently identified issues among survey respondents were characterizing the properties of LED and other solid state light sources, measuring and characterizing lamps and luminaires, the measurement of reflectance properties of materials, understanding and characterizing the response of solid state detectors for photometry and radiometry, and improving the accuracy of measurements in the UV range. To a large extent, a need for improved repeatability and agreement among measurements conducted by different entities (e.g., vendors and their customers) was judged as very important.

In 2010-2011, an additional survey effort was made. A high degree of interest in LED sources, LED displays and other evolving technologies for light sources and lamps was expressed in the responses to this survey. Characterizing the properties of materials in terms of their reflectance and transmittance was also identified as an extremely important priority within the measurement community. Uncertainty continued to be an area of concern, and a desire for educational materials, workshops and courses devoted to understanding measurement uncertainties was clear. Additionally, survey respondents expressed concerns related to the costs for standards and calibrations related to photometric and radiometric measurement.

The latter survey also expressed a need for whiteness standards of materials, accreditation for laboratory procedures and personnel, calibration standards dealing with light sources differing from CIE Illuminant A, and guidance to measurement personnel in the form of an index of relevant standards and measurements as well as documentation on various measurement instruments and the conditions under which they should be used.

In order to qualitatively ascertain the overall responses to each question of the 2010-2011 CORM survey, word clouds and pie charts summarizing the answers given to each of the five main questions in that survey are shown in Figures 1 through 5. (A pie chart is not shown for responses to Question 2 because there was a wide variety of responses to that question.

Figure 1a: Word cloud summarizing responses to the question "What kind of artifacts/products/hardware do you measure now?"

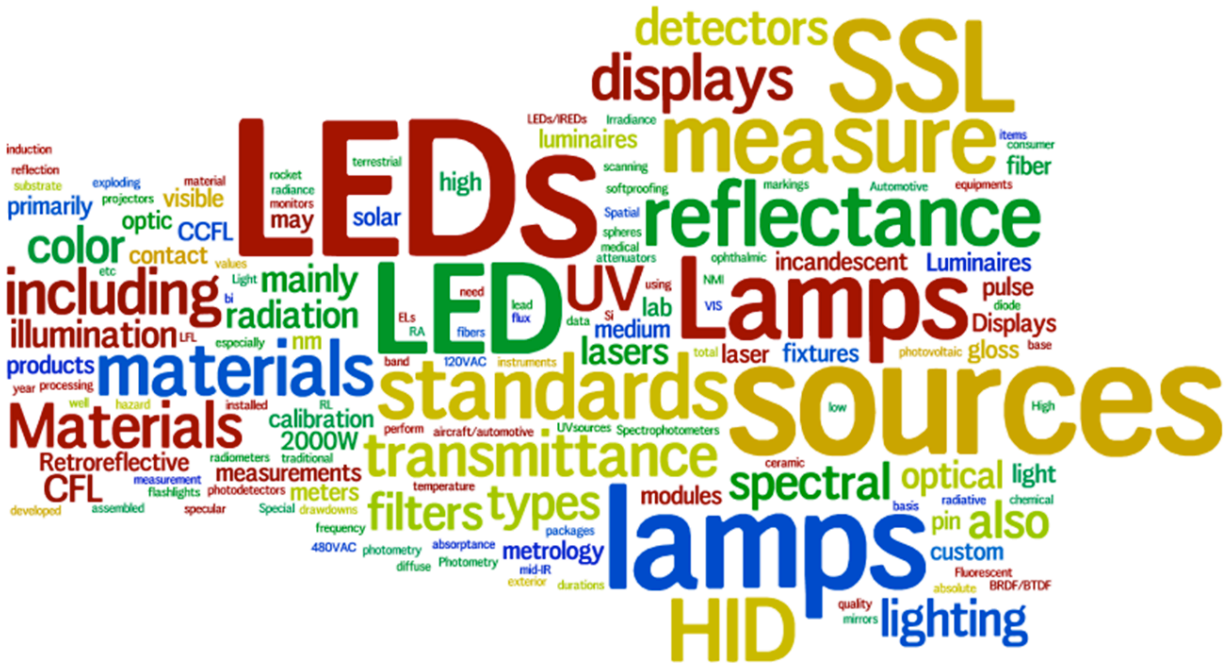


Figure 1b: Numerical categorization of responses to the question "What kind of artifacts/products/hardware do you measure now?"

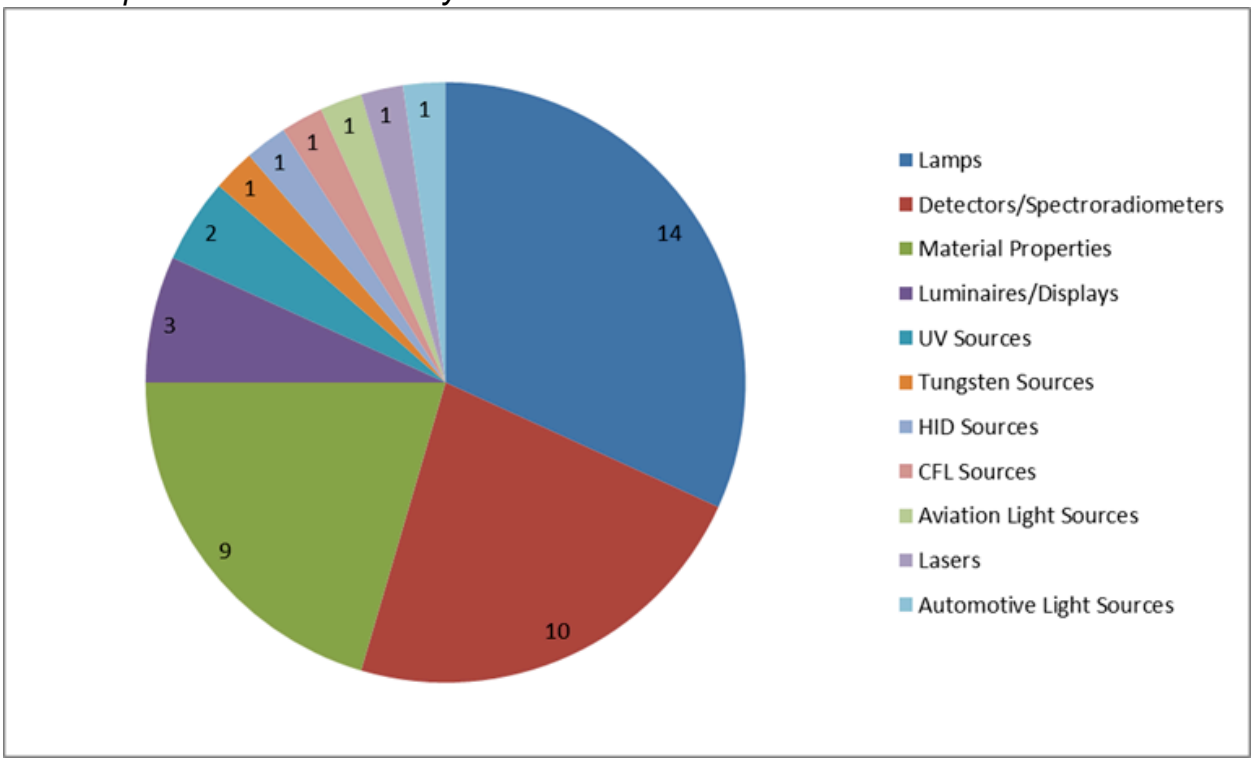


Figure 2: Word cloud summarizing responses to the question "What challenges in optical radiation measurement do you face or anticipate?"

Figure 3a: Word cloud summarizing responses to the question "What new or enhanced services are needed (from NMIs) to address your challenges?"

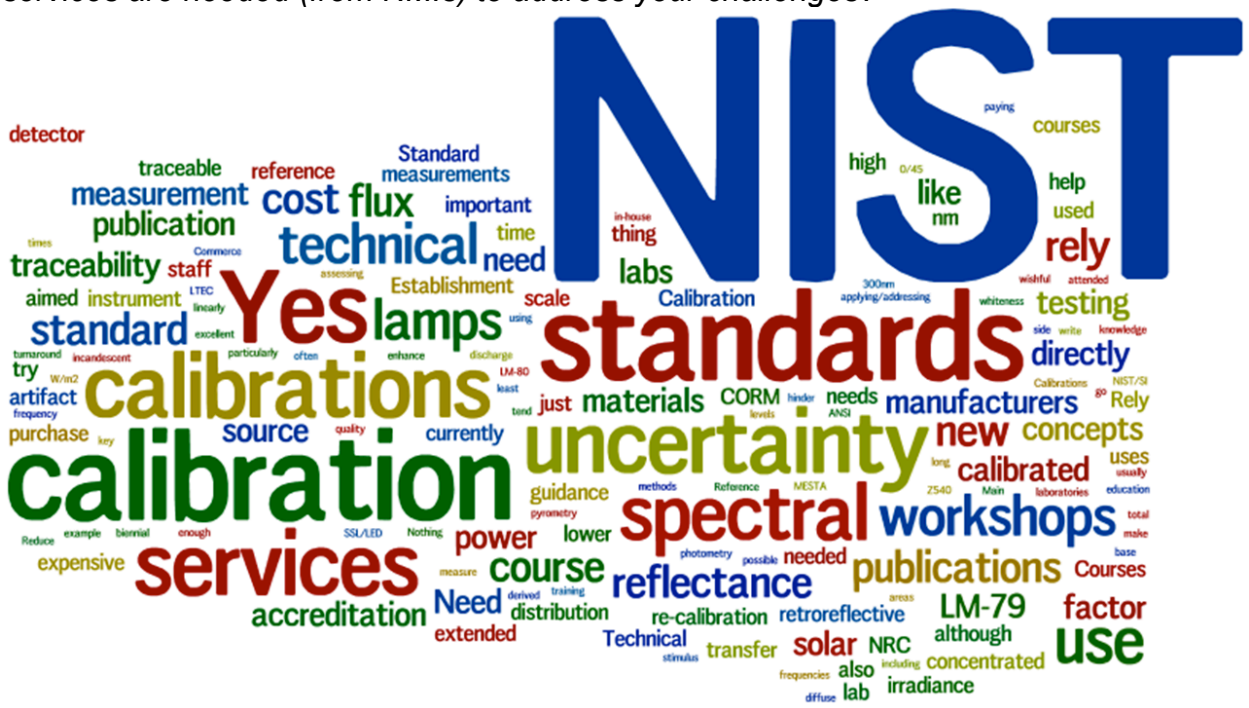


Figure 3b: Numerical categorization of responses to the question "What new or enhanced services are needed (from NMIs) to address your challenges?"

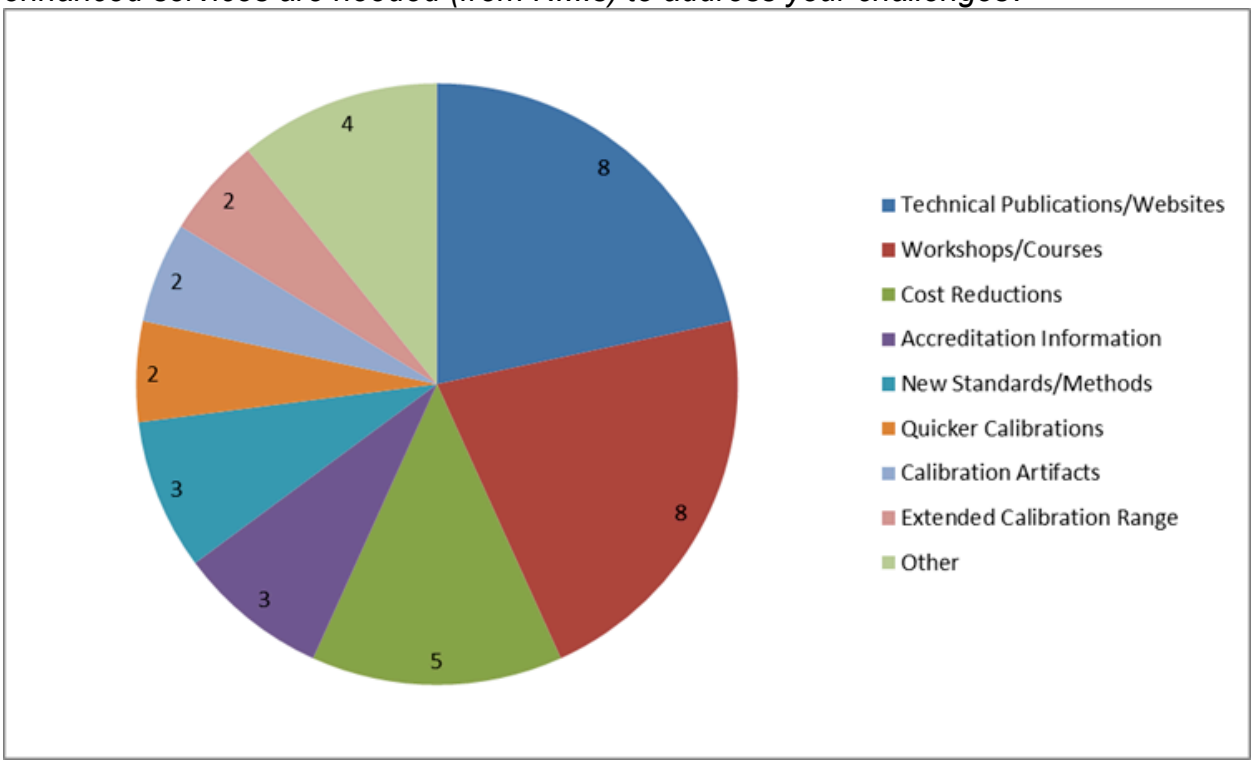


Figure 4a: Word cloud summarizing responses to the question "What are your needs in the areas of accreditation and measurement traceability?"

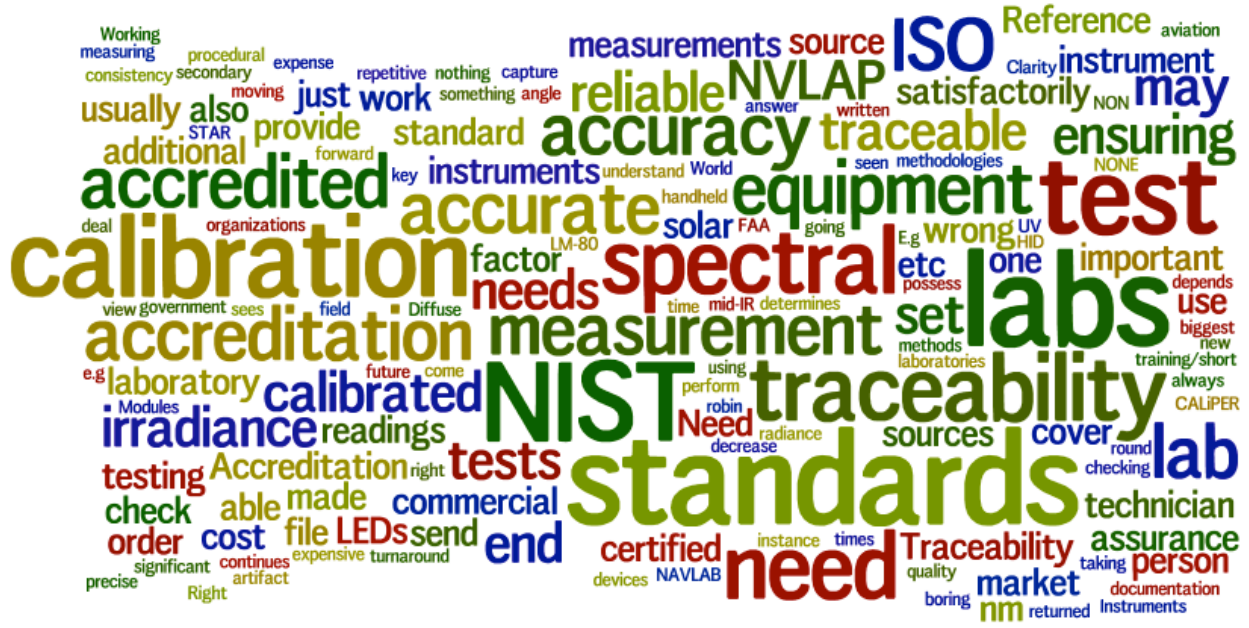


Figure 3b: Numerical categorization of responses to the question "What are your needs in the areas of accreditation and measurement traceability?"

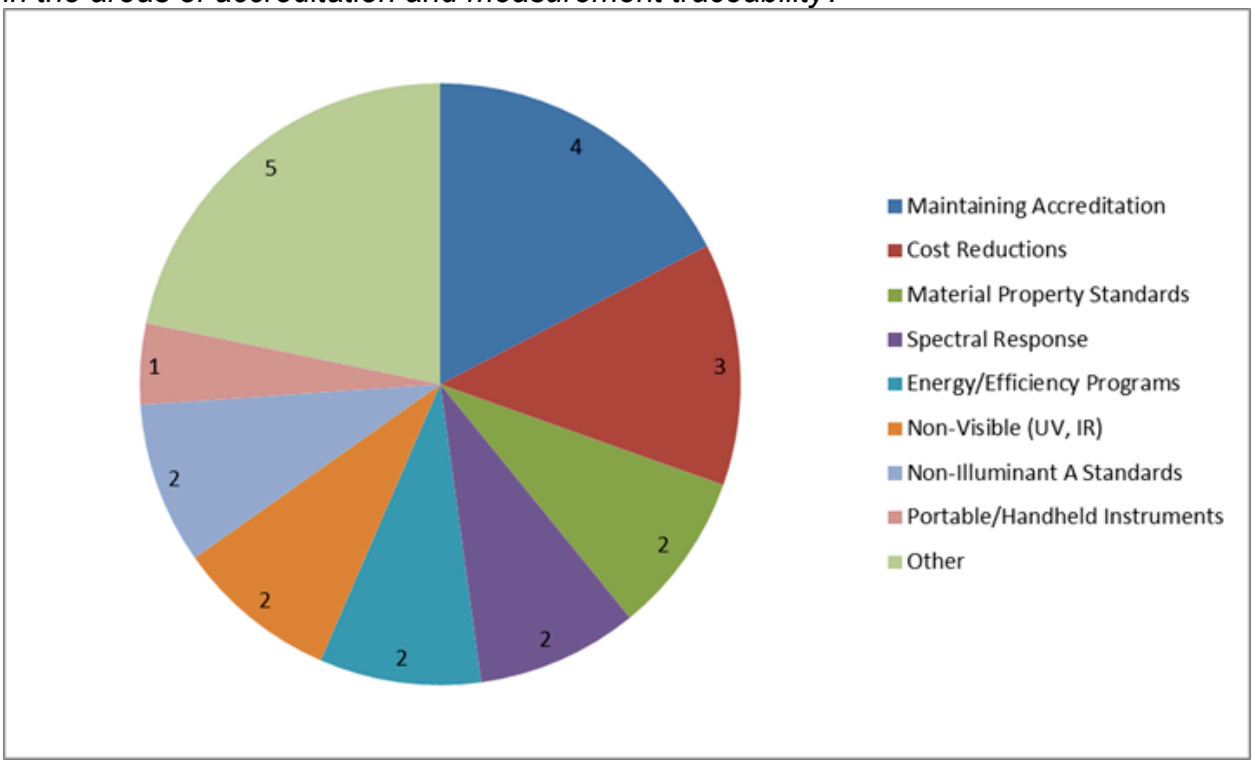


Figure 5a: Word cloud summarizing responses to the question "What are your needs for documentary standards or guidelines?"

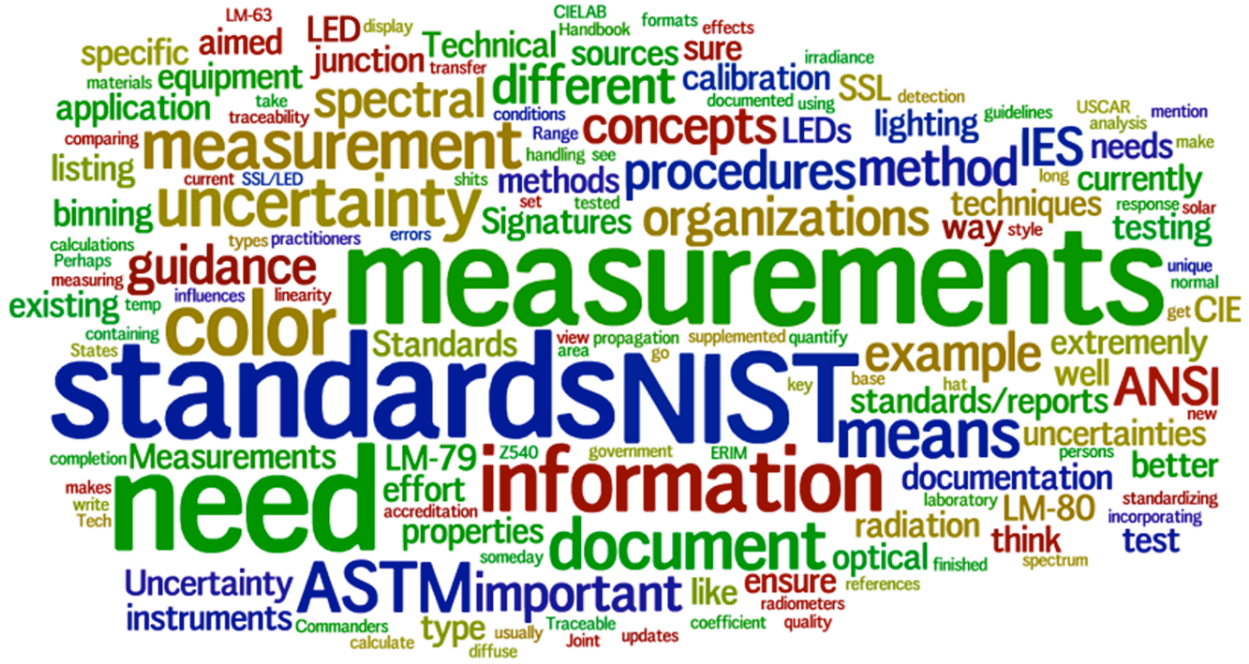
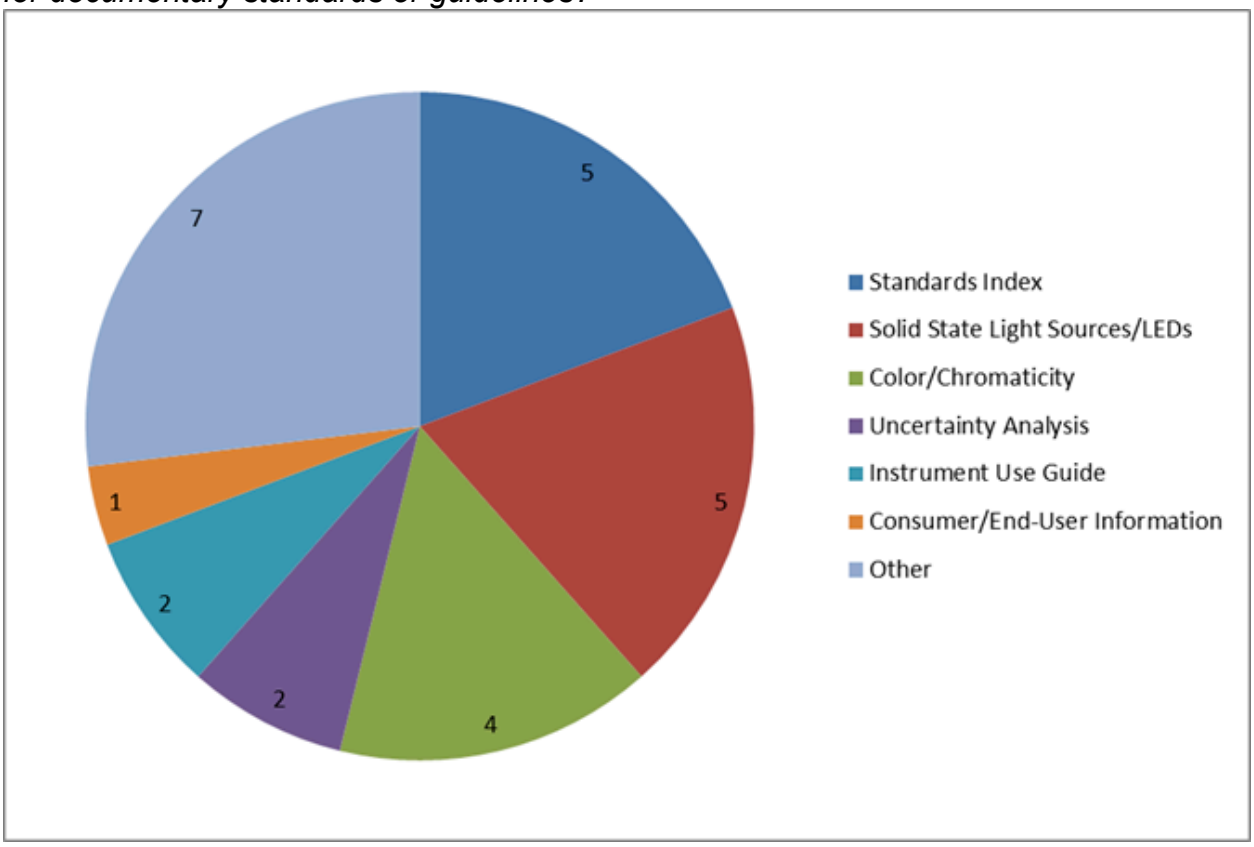


Figure 5b: Numerical categorization of responses to the question "What are your needs for documentary standards or guidelines?"



The information in Figures 1 through 5 reinforces the needs of survey respondents in the areas of characterizing LEDs and other solid state light sources, understanding uncertainty in measurements, and new standards able to deal with spectral measurements for narrowband sources where accuracy of broadband measurements may be lacking.

Because of the relatively long period of time since the publication of the CORM SEVENTH REPORT in 2001 and the NIST response in 2005, a small number of individuals within North American NMIs (NIST, NRC, CENAM) was contacted informally in 2014 to answer several open-ended questions. As a preliminary effort to spur dialogue those responses are summarized here. The initial question related to the main constituents of NMIs. NMI respondents identified the lighting industry as a primary constituent, as well as the instrumentation, pharmaceutical, military, remote sensing, and textile industries, as well as service providers such as testing laboratories. When asked what challenges they faced or anticipated, NMIs responded that decreasing uncertainty and assisting industry with managing measurement uncertainty was a primary challenge, along with the development of new standards and methodologies to deal with narrowband sources and imaging devices. Electrical and color measurements for solid state lighting was anticipated as an area of growing concern, as well as methods to accelerate life testing for new light source technologies. Maintaining and developing standards for absolute radiometry, microspectrophotometric measurements and fluorescence measurements were also described as challenges.

Among the services that NMIs felt they should provide included calibration services, educational resources and workshops (particularly related to characterizing uncertainty in measurement), and research that would provide the basis for new measurement standards. Spectral radiant flux standards were also identified as an important service area. NMI services in providing technical support for companies developing innovative optical technologies were also mentioned. When asked what areas of accreditation, certification and traceability were most critical, among those listed were accreditation and proficiency for testing related to the regulation of solid state lighting products and systems, and traceability of imaging devices, of measurements involving multiple-angle measurements, and of fluorescence measurements. Oversight of UV measurements and solar radiometry was also cited as a rapidly growing area of concern.

5. RECOMMENDATIONS

The latest data collection efforts made by CORM, summarized in the previous section of this report are consistent in pointing to several areas where efforts by NMIs would be beneficial to the measurement, industrial and research communities:

- There are many challenges facing solid state lighting and the growing use of LED sources, specifically related to reference standards and spectral measurements.
- Resources are needed for estimating and characterizing uncertainty in photometric and radiometric measurements accurately and meaningfully.
- Procedures and documentation for ensuring consistent and accurate measurements are necessary.
- Information related to radiometric measurements in the infrared and ultraviolet spectral regions is increasingly essential.

5.1. Solid State Lighting

Reviewing the responses from the most recent CORM REPORT survey, many of the pressing issues deal specifically with solid state lighting technologies and systems, and reviewing recent CORM Conference proceedings, this emphasis has not abated. Among the recent and planned efforts underway among NMIs related to solid state lighting include:

- Development of standards and methodologies for narrow-spectra light sources.
- Refinement of electrical and color measurements for solid state lighting.
- Advancement of accreditation and proficiency recognition for testing related to the regulation of solid state lighting products.

These efforts should continue. Respondents to the most recent CORM REPORT survey also reported growing needs for documentary standards and guidelines for solid state light sources. CORM recommends that NMIs maintain their leadership in addressing these needs.

5.2. Uncertainty

After looking carefully at the consistent themes from the surveys summarized above, it became clear that the photometric and radiometric community could benefit greatly from an industry-wide increase in the understanding of measurement uncertainty. Many of the respondents directly identified the need for education about measurement uncertainty. In addition, there are several areas of need that would also benefit from such programs.

It should be noted that there have been several successful efforts in the past few years that have helped to support this need. Some of the notable efforts include:

- NIST's leadership role in the Illuminating Engineering Society's Testing Procedures Committee development of an informative document for the calculation of calibration uncertainty in the photometric laboratory (including goniometer and integrating sphere measurement systems).
- CORM's latest two annual conferences (2014 and 2015), which each featured a session devoted to papers on measurement uncertainty calculation in the photometric laboratory.
- NIST/National Voluntary Laboratory Accreditation Program sponsored workshop on measurement uncertainty calculation.
- Department of Energy sponsored paper detailing the calculation of measurement uncertainty for an integrating sphere and a goniometer system.

The work that has been done in this area has helped to move the industry forward, and positive progress has been made since the 2010-2011 survey. It is therefore recommended that NMIs continue their support of increased education and guidance in the area of the calculation of measurement uncertainty for photometric and radiometric measurements and calibrations. This continued support will be extremely valuable to the industry for the following reasons:

- This support will help labs to understand their own systems, and to recognize the specific impact that their processes and equipment have on the quality of their service.
- This knowledge will help the labs to have a greater understanding of the impact that calibration uncertainty has on their overall measurement uncertainty, and thus help them to make an intelligent decision regarding the tradeoffs involved with the cost of calibration standards and services.
- The end-users of the data provided by laboratories will also benefit from this increased understanding of measurement uncertainty. They will be able to apply the data to their lighting designs appropriately and with more confidence. Additionally, the specification-writers will be able to appropriately apply measurement uncertainties when determining the acceptable limits for product performance.
- The standards-writers will be able to evaluate the constraints that are built into test methods. This will serve to ensure that the standards do not over-specify the requirements and needlessly drive the cost of testing and calibration up. Additionally, the standards-writers will be able to appropriately constrain certain crucial requirements and reduce the variability in measurement among laboratories.

5.3. Documentation Needs

Respondents to the most recent CORM REPORT survey reported several areas of need for documentation and guidelines, as indicated in Figures 5a and 5b. Among the areas identified by survey respondents, which NMIs should continue to address, include:

- Compiling and categorizing existing standards and documentation about photometric and radiometric measurements.
- As identified in Section 5.1 of this CORM REPORT, the proliferation of LED and other solid state lighting technologies requires revised, or in some cases, new measurement procedures.
- Information about the measurement, definition and specification of color properties of light sources and of materials is needed, as standards and guidelines are rapidly evolving in this area.
- Tutorial information about issues such as uncertainty analysis (see Section 5.2), instrumentation selection and use, and consumer issues such as photobiological safety from authoritative bodies such as NMIs is needed.

It should be pointed out that efforts such as compiling and indexing existing standards and documentation could be carried out jointly among NMIs and organizations such as CORM.

5.4. Radiometric Measurements

Measurements in the nonvisible spectral regions (e.g., UV, IR) are increasing in importance. Radiometry is a growing issue of interest in recent CORM Conferences, with sessions devoted to radiometric measurements being featured in conference programming. CORM REPORT survey respondents identified the following issues as worthy of continued attention by NMIs:

- Measurement of UV sources was identified as a major proportion of measurement effort among CORM REPORT survey respondents.
- Extending calibration ranges outside the visible light region of the electromagnetic spectrum was identified as a new/enhanced service needed to address current challenges (see Figures 3a and 3b).
- Being able to define and support the traceability and reliability of measurements in the IR and UV spectral regions was identified as an important area of need among survey respondents.

NMIs reported that efforts to assist industry, academia and research efforts with absolute radiometry, oversight of UV measurements and data collection efforts

associated with solar radiometry were also seen as areas of need. CORM encourages NMIs to continue in each of these areas.

6. OUTLOOK

The usefulness of CORM REPORTS as mechanisms for facilitating dialogue between NMIs and the radiometry and photometry communities is clear. Since CORM's last report in 2001, challenges facing the measurement of optical radiation have grown, rather than diminished, largely because the development of new light source and measurement technology has been so rapid in the past decade. The findings summarized briefly in this CORM REPORT provide an indication of what issues have emerged in that decade, and how NMIs are continuing to respond to these issues. In future CORM REPORTS, CORM seeks the input and feedback from the members of the optical radiation measurement community to identify the most appropriate and efficient ways to maintain communication between the community and the national bodies that support it. In this way, subsequent CORM REPORTS can continue to have impact.