A Needs-based Assessment of Measurements for Nanotechnology / Environmental Health and Safety

C.M. Allocca*, T.A. Campbell**

*United States Measurement System Office, National Institute of Standards and Technology, Gaithersburg, MD, clare.allocca@nist.gov
**ADA Technologies, Inc., Littleton, CO, tomc@adatech.com

ABSTRACT

The National Institute of Standards and Technology (NIST) is engaged in a continuing needs-based assessment of the state of the United States Measurement System (USMS). The USMS assessment addresses innovation-limiting measurement needs in three ways: by allowing potential providers of solutions to specific measurement problems to be engaged and mobilized; by bringing the attention of stakeholders to systemic issues in the functioning of the U.S. measurement system as a whole; and by serving as a catalyst for the identification of other needs and issues of the USMS. An in-depth study of measurement issues in the area of Nanotechnology / Environmental Health and Safety has been undertaken. Preliminary results will be presented, and potential implications will be reviewed. Recommendations will be made to address the most critical of these needs, and future plans for the world of nanomaterials will be explored.

Keywords: measurement, environment, health, safety, assessment

1 ASSESSING US MEASUREMENT NEEDS

The 2005 Council on Competitiveness report, Innovate America, notes that, "Innovation will be the single most important factor in determining America’s success through the 21st century," and further asserts that the acceleration of innovation is critical for the United States to maintain its competitive edge in the world economy. Advanced measurement capabilities are essential to innovation in every major economic area and at every state of the innovation process. Advanced tools and measurements are required to innovate—to design and incorporate new or better features into next-generation products and processes necessary for the United States to compete effectively and stay ahead in the global marketplace.

The United States Measurement System (USMS) encompasses all private and public organizations that develop, supply, use, or ensure the validity of measurement results. Together, these entities provide and apply the tools required by science and industry to accelerate innovation. A NIST assessment of the United States Measurement System (USMS) identified 723 unmet measurement needs that are significant barriers to technological innovation, many in high-impact, priority areas. [1] Given the growing diversity of processes, products, and services it must support, the USMS will be challenged to function as a coherent system that responds effectively to multiplying and ever-more sophisticated measurement needs. As cycles to commercialize products based on technological innovation continue to accelerate, so, too, does the need for measurement solutions to enable these products. The USMS must be able to deliver increasingly timely and complex measurement solutions.

Since these measurements and standards issues represent only a portion of the total body of unmet measurement needs, the USMS is clearly challenged. Difficulties abound: the system is decentralized; and communications links are not broadly available. There exists a growing chasm of unmet critical measurement needs that, if left unchecked, could place the competitiveness of the U.S. innovation economy in jeopardy. NIST has established a permanent USMS Office at NIST to expand upon the work described in the initial assessment report. NIST, in its role as leader of the USMS, is positioned to facilitate the involvement of the larger USMS in addressing the highest priority critical measurement solutions. This partnership includes NIST core laboratory programs, other measurement solution providers / users, and customers / stakeholders.

USMS-developed tools and methods will provide measurement-related knowledge that will enable industry to inform its own strategic decision making processes; prioritize its measurement concerns; and develop and apply measurement solutions. In pursuit of its objective to enhance the effectiveness and efficiency of the USMS in developing and deploying measurement solutions, the USMS Office is developing:

- A Measurement Knowledge Hub that provides accessibility to measurement needs, solutions, and other knowledge;
- The Measurement Knowledge Hub at http://usms.nist.gov will have unique tools/characteristics that provide access to measurement information and position the entire USMS for success. The Hub will serve as a meeting place for measurement solution providers and users, and it will contain a continually evolving Measurement Needs and
Solutions Database which will serve as the foundation for later analyses. Key Hub features include individual discussion corners for specific interests, with opportunities to discuss sets of measurement needs; a Technology Roadmaps database; tools for tailoring analyses of measurement needs; and links to important events and resources.

- Enhanced methodologies to enable the continuing assessment of the USMS
  - In addition to providing measurement information resources, NIST is also developing and implementing enhanced methodologies to use this information to assess the USMS. NIST is currently conducting several analyses in the focus areas of Nanotechnology Environmental, Health and Safety; Biosciences; and Energy. The results of these analyses will be published in a report and used as a basis for the continued communication among measurement solution providers and users.

- A Measurement Needs Toolkit to facilitate action on the part of both measurement solution providers and users.
  - NIST will develop and release a USMS Measurement Needs Toolkit to help our partners identify measurement needs and solutions. This toolkit is intended to assist Measurement Solution Providers and Users in strategic decision making as well as development of critical measurement solutions.

The basis of the information for USMS assessments is the Measurement Need. This input, in conjunction with unique tools/characteristics that provide access to measurement information, positions the entire USMS for success:

- Individual Measurement Needs consider the entire path that must be traversed to transform measurement science into effective, efficient tools (measurement solutions) that can address technical barriers to technological innovation, thus opening the door for associated commercial products. This “begin with the end in mind” approach will most effectively position any new measurement research to anticipate the needs of customers at each step. The Measurement Needs Database is the foundation for later analyses. All are invited to submit measurement needs in any technology area.

- The definition of a set of tags (e.g., sector/technology area; measurement barrier; type of measurement solution…) that are addressed for each measurement need has allowed the development of Analysis and Assessment tools to allow tailored analyses of the measurement needs in the USMS database. In addition, NIST-sponsored analyses will also be made available as they are completed.

- The Authentication procedure, required for both measurement needs and the findings of any associated analyses, demonstrates that each measurement need is representative of a significant portion of the customer/stakeholder base, and that supporting information comes from credible sources; this early involvement by the customer/stakeholder base also ensures delivery in an optimal form to enable technological innovation.

NIST will use this assessment to focus its own work in support of U.S. innovation and competitiveness. The report’s results and findings, along with input gathered in follow-up activities, will inform NIST’s strategic planning decisions. Feedback on this assessment from stakeholders in industry, academia, and government will continually be solicited and used to guide follow-up efforts.

2 NANOTECHNOLOGY ASSESSMENT

One of the eleven industrial sectors initially surveyed by NIST USMS was Nanotechnology. Within the Nanotechnology sector, 54 Measurement Needs were identified from expert input of government, industrial and academic researchers and manufacturing personnel, and 45 Roadmap Measurement Needs were identified from a review of roadmaps, workshop reports and conference session summaries. Major thematic subcategories for which Measurement Needs were submitted are:

- Nanoparticles, including nanotubes (17)
- Nanoelectronics/nanomagnetics (27)
- Reliability (6)
- Imaging/mapping (10)
- Nanomanufacturing (24)
- Nanobiomaterials, including drug delivery (9)

Analysis and Assessment (as described above) yielded the following major observations in the Nanotechnology sector:

- There exists high demand for new, advanced measurement instrumentation for accurate, high resolution characterization of physical, chemical and biological properties of materials at nanometer dimensions
- The absence of regulations is having a serious impact on innovation
- Timely delivery of materials measurement solutions is increasingly challenging
- The principal measurement barrier to innovation is the absence of measurement instruments, techniques and methods capable of accurately characterizing the behavior of complex materials systems and structures
• A key factor driving the need for innovation is anticipation of the production/marketplace needs for the evaluation of Materials Performance, Manufacturability, and Reliability

3 NANO-EHS ASSESSMENT

An important subset of the Nanotechnology sector is Nanotechnology Environmental, Health and Safety (Nano-EHS). Nano-EHS is a cross-cutting discipline encompassing nanomaterials (i.e., nanoscale structures in unprocessed form), nano-intermediates (i.e., intermediate products with nanoscale features) and nano-enabled products (i.e., finished goods incorporating nanotechnology). As such, there exists a strong driver for nanotools (i.e., capital equipment and software to visualize, manipulate and model matter at the nanoscale) to support the fundamental understanding and implementation of nanotechnology. Measurement needs are consequently a critical enabler for Nano-EHS research, documentation and implementation of safety protocols.

3.1 Inferential Analysis of Nano-EHS Measurement Needs

Out of the initial survey within the Nanotechnology sector, 26 Measurement Needs were identified as particularly relevant to Nano-EHS. A preliminary inferential analysis of this subset has identified trends that are for the first time reported here. *It should be kept in mind that this analysis, a subset of the initial USMS survey [1], is only a very small subset of the array of existing measurement needs and that a more comprehensive analysis is needed to further strengthen these preliminary conclusions.* Figure 1 shows several primary analysis results of the Nano-EHS sector.

The first plot in Figure 1 – “Stage of Technological Innovation” – gives us the strong indication that almost all the Nano-EHS Measurement Needs are truly early-stage, falling into the categories of Applied Research Stage of Technological Innovation. Given the preliminary nature of Nano-EHS research, this is not quite unexpected. Scientists and industrial manufacturers are only beginning to investigate the ramifications of nanomaterials in the workplace and environment. Consequently, measurement needs fall primarily in the Applied Research category.

Further insight can be gleaned from the “Measurands” plot in Figure 1. In this sense, a Measurand is defined as a variable characteristic, property, or attribute of a substance, object, or system that is to be measured. The majority of the Measurement Needs identified fall into the Chemical or Physical Measurand categories. This result must, however, be considered in light of the early nature of Nano-EHS research. As the EHS community matures in its identification of measurement needs, it is expected that greater discretization will be found in the Measurand category.

![Figure 1. Preliminary Inferential Analysis of](image-url)
“Measurement Barriers” is also a telling category that again is a strong indicator of the early nature of Nano-EHS research. The top three Measurement Barriers from the Authenticated tags are Accuracy; Lack of Fundamental Knowledge; and Data, Data Collection & Retrieval. As in the Measurand category, we expect further discretization of the Measurement Barriers category as Nano-EHS research progresses.

Lastly, an analysis is presented in Figure 1 of the “Current Public/Private R&D Efforts” to create measurement solutions for the measurement needs. The Authenticated results indicate a bias toward Public Efforts here. Federal laboratories such as NIST are therefore shown to be carrying much of the weight for measurement solution developments. As in the other analyses, we may conclude this is related to the incipient nature of much of Nano-EHS research. It is anticipated that nanometrology tool vendors will eventually become more involved as the measurement technology further develops and the market need becomes more pronounced.

3.2 Conclusions from Preliminary Nano-EHS Analysis

It is recommended by the NIST USMS Office that this preliminary analysis of Nano-EHS be substantially extended to provide further, more accurate insight into the state of the USMS. This work is already underway, and readers are strongly encouraged to contribute their expert opinions by engaging with the USMS by visiting http://usms.nist.gov and/or contacting this article’s authors.

As more Measurement Needs are acquired in both the Nanotechnology and Nano-EHS sectors, such preliminary analysis will be refined further. A key implication of the USMS work will be the unprecedented acquisition and analysis of this information to help NIST itself, offer direction to the National Nanotechnology Initiative (http://www.nano.gov), guide other federal agencies, and provide industry with a database of information to inform its prioritization of research efforts to maximize technological and societal benefits with limited resources.

REFERENCES