Max Planck
April 23, 1858 – October 4, 1947
The kilogram is now defined using the Planck constant.
From the President

Mass Calibration at NIST in the Revised SI
Patrick J. Abbott and Zeina Kubarych

Risk-Based Thinking in the Calibration Laboratory:
Practical Examples
Helga A. Alexander

DEPARTMENTS

From the President
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2019 Workshop & Symposium
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Many years ago, I started collecting posters from the annual NCSLI Conferences. They were colorful and became the perfect wall art for my office. Recently, as I sat in my office contemplating a topic for this edition’s From the President article, it hit me. Looking at 21st Century Innovations in 2010 to Measurements of Tomorrow in 2018, NCSLI has been in motion to address the needs of the metrology community. It is a core value for the organization and part of our mission in providing the best opportunities for the world’s measurement science experts and practitioners. Metrology in Motion is the epitome of what NCSLI is all about.

With summer upon us, it means that final preparations are being made for the annual Workshop & Symposium. Have you made arrangements to attend NCSLI’s premier event? The 2019 Workshop & Symposium will be held at the Cleveland Convention Center in Cleveland, Ohio on August 24-29. This year’s theme, Metrology in Motion, says a lot about measurements and the measurement community as we move into a new era under the redefined International System of Units (Système International d’Unités, with the international abbreviation SI). To use the words of Dr. Bill Phillips, NIST, in his address to the 26th General Conference on Weights and Measures (Conférence Générale des Poids et Mesures, CGPM), we are experiencing “the greatest revolution in measurement since the French revolution.” With the redefinition of the base units of the SI, improvement and innovation in measurements are likely only limited by imagination. I hope you make plans...
to attend our Workshop & Symposium to network with leading experts and organizations in metrology and to hear about the exciting things going on in the metrology community. Up-to-date information about the event can be found on the NCSLI website at www.ncsli.org.

In my last article, I noted that the Board of Directors was placing a concerted effort this year to increase and improve the NCSLI member activities in the regions and sections. At our recent spring meeting, we held a workshop with the board members to identify goals and key performance indicators to facilitate these improvements. Some key concerns were identified: open region/section coordinator positions, hosts for region/section meetings, and key content for meetings. As an outcome of the workshop, goals were established for 2019 and 2020 to improve recruitment and training of region/section coordinators, as well as review and redesign of the divisional regions/sections. If you are not involved as a volunteer in NCSLI or you would like to host a local event, contact your local NCSLI representative or the NCSLI Business office to learn how you can get involved or how we might work together on an event in your area. And if you are looking for a listing of upcoming events in your area, check out the NCSLI events page on the website, www.ncsli.org.

NCSLI offers a great way for you to get connected in the field of metrology and work with other metrology and measurement science professionals. Get connected! I hope to see you at the upcoming 2019 NCSLI Workshop & Symposium. Cheers!
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To provide the best opportunities for the world’s measurement science experts and practitioners:
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TRACK:

Metrology Management

SATURDAY, AUGUST 24
8:00 AM - 5:00 PM | 1-DAY (8 HOURS)

Active Asset Management
INSTRUCTOR: James Smith, The Boeing Company
COURSE DESCRIPTION NUMBER: TMM-1
ABSTRACT: Are you getting bang for the buck? Are your assets making you money, lowering your cost of business, utilized efficiently or are they idle, underused, are you emotionally attached to them, are they costing you in non-recuperated expenses? This course will focus on the increased value a company can realize by taking proactive life cycle management approaches in the ownership and utilization of laboratory assets and facilities. By striving to focus on value orientated uses of capital and expense items, related utilization and visibility of equipment life-cycles, your business will see significant increases on "Return on Investment" (ROI). New lab, new management, merged or acquired? Do you want to avoid creating the culture that has driven so many others to poor performance, failure, bankruptcy and loss of business? Stop managing your assets at arms-length using decades old mental models. Instill forward thinking processes based on proven methods and results, stop sub-optimizing your operational budgets, attend and gather lessons learned from others who battled these challenges and came out better for it.

SUNDAY, AUGUST 25
8:00 AM - 5:00 PM | 1-DAY (8 HOURS)

Understanding Instrument Specifics
INSTRUCTOR: Michael Johnston, Fluke Calibration
COURSE DESCRIPTION NUMBER: TMM-2
ABSTRACT: An entry-level exploration of instrument specifications with a focus on their application to the calibration process, including calculation of test tolerances, identification of specification types, and discussions on the practice of specmanship in the test and measurement industry. This tutorial is intended to help technicians understand the "why" behind the test tolerances.

MONDAY, AUGUST 26
8:00 AM - 5:00 PM | 1-DAY (8 HOURS)

Effective Calibration Interval Analysis
INSTRUCTOR: Mark Kuster, Pantex Metrology
COURSE DESCRIPTION NUMBER: TMM-3
ABSTRACT: Don't know where to start with calibration interval analysis or where to go next? This tutorial lays the foundation for establishing a cost-effective, quality interval analysis system or improving an existing system. Via lecture and hands-on exercises, the course covers all the required program elements for a successful system and directs practitioners toward the most suitable methodology for their situation. The lack of interval analysis negatively impacts a test and measurement program, driving up both support and consequence costs due to overly short and long calibration intervals. A poorly
conceived or implemented interval analysis system will not fare well either. This tutorial targets the fundamental concepts and practices upon which to establish, evaluate, or modify systems and procedures to start or revive an effective manual or automated interval analysis system. The tutorial will break down the interval analysis implementation process and examine it phase by phase to make recommendations. Topics covered include basic interval analysis theory and background, method selection and effectiveness, available software and other resources, data requirements for calibration management systems, instrument grouping, dogs & gems, reliability targets, initial intervals, data quality, configuration management, interval adjustments, due date extensions, delay dating, offset reliability analysis and program evaluation. Hands-on exercises will reinforce the material covered. Attendees will receive spreadsheet tools for computing calibration intervals suitable for use on Linux, Mac OS or Windows. To participate in all exercises, attendees should bring a device capable of running spreadsheet software such as LibreOffice Calc or Microsoft Excel.

**ABSTRACT:** The NIST Uncertainty Machine (NUM) and the NIST Consensus Builder (NICOB) are web-based applications accessible worldwide via any internet browser. The NUM provides a user-friendly interface to uncertainty analysis for measurement models of the type described in the GUM ("Guide to the Expression of Uncertainty in Measurement"), using the GUM approach and also the Monte Carlo method of the GUM Supplement 1. The NICOB provides a user-friendly interface for the analysis and reduction of measurement results obtained in interlaboratory studies, including key comparisons: computation of consensus values, characterization of associated uncertainty, evaluations of reproducibility, and degrees of equivalence. This course will provide a hands-on familiarization with the NUM and with the NICOB, using concrete examples and real data from a wide range of fields of measurement science, and will also give the participants sufficient background and guidelines to empower them to make the particular choices needed to apply these tools thoughtfully and appropriately. The participants will have the opportunity to apply these tools also to their own data during the course, and to share their experiences while doing so. The participants are expected to have general familiarity with the basic notions and methods of uncertainty analysis as are explained in the GUM (or in NIST Technical Notes 1297 and 1900), but do not need to possess specialized knowledge of probabilistic or statistical methods.

**TUTORIAL PROGRAM**

**SATURDAY, AUGUST 24**
8:00 AM - 5:00 PM | 1-DAY (8 HOURS)

**Measurement Uncertainty: Fundamental Applications**

**INSTRUCTOR:** Dilip Shah, E=mc3 Solutions

**COURSE DESCRIPTION NUMBER:** TME-2

**ABSTRACT:** The requirement for measurement uncertainty has been around for quite a few years when it comes to laboratory accreditation. Yet, there is a lot of uncertainty about evaluating uncertainty. This workshop provides the attendee with fundamental tools to evaluate measurement uncertainty. It simplifies the GUM approach, so it is easier to understand and implement. Tools and techniques are discussed using Microsoft Excel spreadsheet to simplify calculations while developing an uncertainty budget.

**SUNDAY, AUGUST 25**
8:00 AM - 5:00 PM | 2-DAY (16 HOURS)

**The NIST Uncertainty Machine and the NIST Consensus Builder**

**INSTRUCTOR:** Antonio Possolo PhD, National Institute of Standards and Technology (NIST)

**COURSE DESCRIPTION NUMBER:** TME-1

**ABSTRACT:** The NIST Uncertainty Machine (NUM) and the NIST Consensus Builder (NICOB) are web-based applications accessible worldwide via any internet browser. The NUM provides a user-friendly interface to uncertainty analysis for measurement models of the type described in the GUM ("Guide to the Expression of Uncertainty in Measurement"), using the GUM approach and also the Monte Carlo method of the GUM Supplement 1. The NICOB provides a user-friendly interface for the analysis and reduction of measurement results obtained in interlaboratory studies, including key comparisons: computation of consensus values, characterization of associated uncertainty, evaluations of reproducibility, and degrees of equivalence. This course will provide a hands-on familiarization with the NUM and with the NICOB, using concrete examples and real data from a wide range of fields of measurement science, and will also give the participants sufficient background and guidelines to empower them to make the particular choices needed to apply these tools thoughtfully and appropriately. The participants will have the opportunity to apply these tools also to their own data during the course, and to share their experiences while doing so. The participants are expected to have general familiarity with the basic notions and methods of uncertainty analysis as are explained in the GUM (or in NIST Technical Notes 1297 and 1900), but do not need to possess specialized knowledge of probabilistic or statistical methods.

**Metrology Engineers**

**SUNDAY, AUGUST 25**
8:00 AM - 5:00 PM | 1-DAY (8 HOURS)

**Sample Size Calculations: Practical Methods for Engineers and Scientists**

**INSTRUCTOR:** Paul Mathews, Mathews Malnar and Bailey Inc.

**COURSE DESCRIPTION NUMBER:** TME-3

**ABSTRACT:** Most situations that require the collection and analysis of sample data present the problem of determining an appropriate sample size. Small samples are more likely to lead to incorrect conclusions but large samples consume more resources. Formal methods of sample size determination are intended to minimize the combined costs associated with incorrect conclusions and resource consumption. Paul Mathews will present methods for calculating sample size for confidence intervals and sample size and power for hypothesis tests for: means, standard deviations, proportions, counts, regression, correlation and agreement, ANOVA for fixed and random effects, reliability, process capability, and gage error studies. Practical methods using large sample approximations, variable transformations, and the delta method will be emphasized but exact methods will be noted where the approximate methods fail. Paul will demonstrate software solutions using Russ Lenth’s free Piface program (www.stat.uiowa.edu/~rlenth/Power/). This workshop is intended for engineers, scientists, statisticians, and quality professionals who are responsible for recommending sample sizes in their organizations. Attendees should have a general understanding of the calculation and interpretation of confidence intervals and hypothesis tests. Knowledge of advanced statistical methods is not required.

**Exhibitor Welcome • RECEPTION •**

**Monday, August 26**
6:00 PM - 8:00 PM

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TUTORIAL PROGRAM AUGUST 24–26 | EXPOSITION HALL AUGUST 26–28 | TECHNICAL PROGRAM AUGUST 27–29
**TRACK:**  
**Risk Management**

**SATURDAY, AUGUST 24**  
8:00 AM - 5:00 PM | 1-DAY (8 HOURS)  
**Decision Rules and Making Statements of Compliance with Confidence**  
**INSTRUCTOR:** Jeff Gust, Fluke Calibration  
**COURSE DESCRIPTION NUMBER:** TRM-1  
**ABSTRACT:** ISO/IEC 17025:2017 requires that when a statement of compliance is made for a customer, that decision rule for making the statement is defined, communicated, and agreed with the customer. When selecting a decision rule, the level of risk should also be considered. This class introduces the attendee to decision rules, provides the underlying assumptions about risk, and discusses the pros and cons of many different decision rules such as guard banding and control of risk through Test Uncertainty Ratios (TURs).

**SUNDAY, AUGUST 25**  
8:00 AM - 5:00 PM | 1-DAY (8 HOURS)  
**Risk Based Thinking in Metrology**  
**INSTRUCTOR:** Andrew Oldershaw, National Research Council Canada (NRC)  
**COURSE DESCRIPTION NUMBER:** TRM-2  
**ABSTRACT:** Risk based thinking has been a growing trend spreading to all aspects of the economy and society for many years. It will become more prominent for laboratories with the revision of ISO/IEC 17025. This module will help those involved planning, managing, implementing and reviewing any aspect of laboratory management systems to apply risk-based thinking to determine what these statements mean to their particular situation. Tools and techniques to identify, analyze, respond to, monitor and review risks will be introduced. Participants will have the opportunity to put them into practice during class room exercises. Intended audience: Anyone with responsibilities for decision making, quality, measurement assurance, auditing or an interest in managing risks in the laboratory.

**TRACK:**  
**Accreditation**

**SATURDAY, AUGUST 24**  
8:00 AM - 5:00 PM | 1-DAY (8 HOURS)  
**An Introduction to the ILAC Policy (P Series) and Guidance (G Series) Documents: A Peek Behind the Accreditation Body Curtain**  
**INSTRUCTOR:** Tim Osborne, American Association for Laboratory Accreditation (A2LA)  
**COURSE DESCRIPTION NUMBER:** TAC-1  
**ABSTRACT:** This course introduces the participants to many of the International Laboratory Accreditation Cooperation (ILAC) Policy Documents (P Series) that Accreditation Bodies apply to Accredited Calibration and Testing Laboratories as part of the ILAC Mutual Recognition Arrangement (MRA). The participants will review a variety of policies including ILAC P8 Guidelines for the Use of Accreditation Symbols and for Claims of Accredited Status by Accredited Laboratories, P9 for Participation in Proficiency Testing Activities, P10 for Traceability of Measurement Results, and P14 for Uncertainty in Calibration. In addition, learners will briefly review some
of the ILAC Guidance Documents (G Series) such as ILAC G8 Guidelines on the Reporting of Compliance with Specification, G17 Introducing the Concept of Uncertainty of Measurement in Testing in Association with the Application of the Standard ISO/IEC 17025 and G18 Guidelines for the Formulation of Scopes of Accreditation in Laboratories.

MONDAY, AUGUST 26
8:00 AM - 5:00 PM | 1-DAY (8 HOURS)
Auditing, Traceability, and Auditing of Traceability to ISO/IEC 17025:2017
INSTRUCTORS: Kari Harper, National Institute of Standards and Technology (NIST); Isabelle Amen, National Research Council Canada (NRC)
COURSE DESCRIPTION NUMBER: TAC-2
ABSTRACT: This tutorial examines the principles of auditing, the concepts of metrological traceability and tools to apply auditing principles in demonstrating the chain of traceability for measurement results. Auditing concepts such as objective evidence, the internal audit process, and interpersonal skills for auditors will be presented. The auditing module will also incorporate guidance from the newly revised ISO 19011 regarding a risk-based approach to auditing. In the traceability section, emphasis will be placed on the importance of appropriate records for all aspects of the management system and their interdependency with metrological traceability and reporting of results. Using the described auditing principles, both companies with new or mature quality systems will be able to transition to the new standard.

MONDAY, AUGUST 26
8:00 AM - 12:00 PM | 1/2-DAY (4 HOURS)
Approaches to Nonconforming Work and Corrective Actions for ISO/IEC 17025:2017
INSTRUCTOR: Helga Alexander, International Accreditation Service (IAS)
COURSE DESCRIPTION NUMBER: TAC-3
ABSTRACT: This tutorial will discuss the requirements of ISO/IEC 17025:2017 with respect to nonconforming work (Clause 7.10) and corrective actions (Clause 8.7). The tutorial aims to illustrate some techniques for dealing with nonconformities and corrective actions in a calibration laboratory by providing the audience with practical examples that include risk assessment, cause analysis and implementation of effective corrective actions for different kinds of non-conforming work. The tutorial will stress the effects of the nonconforming work on laboratory operations when choosing the appropriate corrective actions. Some examples will be worked as group activities to provide the audience with hands-on experience in dealing with these types of issues. Proper documentation of nonconforming work and corrective actions will also be discussed.

MONDAY, AUGUST 26
8:00 AM - 5:00 PM | 1-DAY (8 HOURS)
Dimensional Uncertainties Hands-on Course
INSTRUCTORS: Dr. Ted Doiron and Eric Stanfield, National Institute of Standards and Technology (NIST)
COURSE DESCRIPTION NUMBER: TDM-1
ABSTRACT: The basic principles of dimensional metrology are the same for nearly every calibration made in typical labs. This course teaches these principles through guided hands-on characterization of the most typical dimensional measurement instrument; the Universal Length Measuring Machine (ULM). Topics covered in the course will include uncertainty budgets, thermal effects, scale calibration with gage blocks, cylinders, and rings, elastic deformation and calibration of contact forces, gage and contact geometry effects, measurements of sub-pitch interpolation errors in the encoder system, R&R on end standards, cylinders and ring gages. Participants are encouraged to bring uncertainty budget details for dimensional measurements they make in their lab that they would like to discuss.

MONDAY, AUGUST 26
8:00 AM - 5:00 PM | 1-DAY (8 HOURS)
Introduction to Dimensional Calibration
INSTRUCTORS: Jim Salsbury PhD and Amosh Kumar, Mitutoyo America Corporation
COURSE DESCRIPTION NUMBER: TDM-2
ABSTRACT: This tutorial introduces common dimensional calibrations and will include a variety of hands-on exercises. Towards the end of the tutorial, attendees will have an opportunity to participate in proficiency testing to demonstrate their skills and to potentially earn certified credentials in calibration. The focus of the tutorial will be on the calibration of small dimensional measuring instruments, such as micrometers, calipers, and indicators, and will include procedures, worksheets, and example certificates. The hands-on use of important measurement standards, such as gage blocks, ring gages, and optical flats will also be covered, as well as what to look for in the calibration of reference standards. This tutorial will also briefly discuss the field calibration of major instruments such as optical comparators and coordinate measuring machines.

Metrology Mixers
Enjoy food and drinks as you meet fellow conference attendees from around the world!

VISIT NCSLI.ORG FOR THE COMPLETE WORKSHOP & SYMPOSIUM PROGRAM
TUTORIAL PROGRAM AUGUST 24–26 | EXPOSITION HALL AUGUST 26–28 | TECHNICAL PROGRAM AUGUST 27–29
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TUTORIAL PROGRAM

TRACK:
Pressure Measurements

SUNDAY, AUGUST 25
8:00 AM - 5:00 PM | 1-DAY (8 HOURS)
Pressure Calibration and Expanded Uncertainty
INSTRUCTOR: Michael Bair, Fluke Calibration
COURSE DESCRIPTION NUMBER: TPM-1
ABSTRACT: This tutorial covers the basics of pressure calibration to the conclusion of performing an expanded uncertainty analysis for the points taken during the tutorial. Included is a review of the physics that have an influence on pressure calibrations, pressure modes, units of measurement, types of pressure measuring instruments, connecting hardware including safety precautions, best practices and expanded uncertainty.

MONDAY, AUGUST 26
8:00 AM - 12:00 PM | 1/2-DAY AM (4 HOURS)
Industrial Pressure Calibration and Measurements
INSTRUCTOR: Jon Sanders, Additel Corporation
COURSE DESCRIPTION NUMBER: TPM-2
ABSTRACT: This course will introduce basic pressure calibration and measurement. We will cover considerations when making pressure measurements and calibrations. Some of these considerations include a discussion on different pressure types such as gauge, absolute, compound, differential, negative gauge, and vacuum. We will also cover requirements for field calibration, uncertainties associated with field calibration, errors relating to temperature effects and different methods of calibration. In addition to pressure calibration and measurement theory, this course will also include a hands-on workshop where various methods of pressure calibration are tried and experienced.

TRACK:
Mass Measurements

SUNDAY, AUGUST 25
1:00 PM - 5:00 PM | 1/2-DAY PM (4 HOURS)
Automatic and Robot Efficiency Gains for the Modern Mass Metrology Lab
INSTRUCTORS: Mark Kliebenschaedel and Christian Mueller-Schoell, Mettler Toledo
COURSE DESCRIPTION NUMBER: TMA-1
ABSTRACT: The question arises: how should mass comparators be tested, qualified and calibrated, when used in different missions? Join us as we cover the essential components of a Comparator Qualification and Service. Whether used as a comparison device, or as a high performance, direct-reading balance or scale. We will cover the requirements for both schema. We will also spend some time looking into productivity gains and efficiencies, achieved by the careful and strategic investment in advanced instrumentation for weight calibration. Employing robotic and automatic comparators in the modern Calibration Lab will not only greatly improve achieved uncertainties but will free-up personnel to complete other tasks, whilst the comparators are running their own calibration routines. Hence allowing multi-layer efficiency gains and performance improvements.

MONDAY, AUGUST 26
8:00 AM - 12:00 PM | 1/2-DAY AM (4 HOURS)
Your Weigh to Best Weighing Practices
INSTRUCTOR: Tony Kowalski, Sartorius Lab Instruments GmbH & Co. Kg
COURSE DESCRIPTION NUMBER: TMA-2
ABSTRACT: Balance calibration should also include consideration and an estimation of measurement uncertainty. In addition, one will become aware that balance measurement uncertainty is not attributed to the balance but is instead belonging to the weighing process. Approximately 95 % of analytical balance weighing inaccuracies occur outside of the balance and are
attributed to a variety of influences within the control of the user. This course is designed to make the user aware of how measurement uncertainty occurs and influences measurement across the weighing range of an electronic balance. Material covered includes how to check the calibration of your balances correctly, assess and assign a weighing tolerance and establish the smallest sample size appropriate to each balance having least effect on the intended accuracy of weighing. Additionally, there will be practical examples of efficient use of integrated software and processes to assist in the tasks encountered in lab weighing today. Micropipettes and dispensers are widely used in laboratories and as “Test and Measuring” devices also require in-use calibration checks. Hardware and software solutions for in-house pipette calibration will also be covered with practical demonstrations.

Thermodynamic Measurements

SATURDAY, AUGUST 24
8:00 AM - 12:00 PM | 1/2-DAY AM (4 HOURS)
Thermometry Sensors, Instruments and Calibration
INSTRUCTORS: Adam Fleder and Richard Steiner, Tegam Inc.
COURSE DESCRIPTION NUMBER: TTM-1
ABSTRACT: We will review the types of sensors and their relative strengths in thermometry applications. How probe design affects measurements and how applications drive selection. The considerations and challenges encountered when calibrating thermometers and temperature indicators will also be discussed along with practical means of verify measurement system accuracy. Finally, a discussion of topics affecting IR thermometry will be held.

SUNDAY, AUGUST 25
8:00 AM - 12:00 PM | 1/2-DAY AM (4 HOURS)
Infrared and Radiation Thermometry Fundamentals
INSTRUCTOR: Frank Liebmann, Fluke Calibration
COURSE DESCRIPTION NUMBER: TTM-2
ABSTRACT: This course is geared to those who are new to radiation thermometry metrology, need a refresher on the subject, and to those who would like to make better measurements. This course will cover the basics of radiation temperature measurements, uncertainty budgets, radiation thermometry standards, and infrared thermometry calibration.

SUNDAY, AUGUST 25
8:00 AM - 12:00 PM | 1/2-DAY AM (4 HOURS)
Fundamentals of Humidity Measurement
INSTRUCTOR: Mike Boetzkes, Kinetic Technologies, Inc.
COURSE DESCRIPTION NUMBER: TTM-5 | PAIRS WITH TTM-6
ABSTRACT: The science behind humidity measurement will be covered including key terms, formulas and parameters. The effect of pressure and temperature on relative humidity will be explored using the psychrometric chart as a tool as well as available calculators. Selecting the appropriate measurement technology for various applications will be covered, looking at the key advantages, disadvantages and principles of operation of some of the more common measuring technologies. A closer look at instrument specifications will highlight the different components of the instrument specification and how they relate to the overall instrument performance which can be significantly different than the accuracy specification.
MONDAY, AUGUST 26
1:00 PM - 5:00 PM | 1/2-DAY PM (4 HOURS)
Advanced Topics of Temperature Measurement and Calibration
INSTRUCTOR: Mike Coleman, Fluke Calibration
COURSE DESCRIPTION NUMBER: TTM-4 | PAIRS WITH TTM-3
ABSTRACT: This course is designed for someone who has experience in temperature calibration and is looking to take their knowledge to the next level. It can also provide a refresher to align your knowledge with current best practice and updates in international temperature metrology and calibration especially when considering new and exciting events affecting temperature calibration such as the redefinition of the kelvin, changes with ISO/IEC 17025:2017, and exciting new future technologies. Other topics covered in this course are the latest recommendations for PRT and SPRT management, in-depth analysis and understanding of thermocouple theory and calibration methodology, fixed-point cell operational theory including a review of important fixed-point cell calculations and uncertainty control methods.

TRACK: Electrical Measurements

SATURDAY, AUGUST 24
8:00 AM - 5:00 PM | 1-DAY (8 HOURS)
Time and Frequency Measurements Using GPS
INSTRUCTOR: Michael Lombardi, National Institute of Standards and Technology (NIST)
COURSE DESCRIPTION NUMBER: TEM-1
ABSTRACT: Global Positioning System (GPS) disciplined oscillators and clocks serve as standards of frequency and time in numerous calibration and metrology laboratories. These devices are inherently accurate sources of both frequency and time because they are adjusted via the GPS satellites to agree with the Coordinated Universal Time (UTC) time scale maintained by the United States Naval Observatory (USNO). Despite their excellent performance, it can be difficult to evaluate their uncertainty, and even more difficult for metrologists to prove their claims of uncertainty and traceability to skeptical laboratory assessors. This tutorial is for metrologists and laboratory assessors who work with GPS disciplined oscillators (GPSDOs) or GPS disciplined clocks (GPSDCs). It describes the relationship between GPS time and Coordinated Universal Time (UTC), explains why GPS time is traceable to the International System (SI), and provides methods for evaluating the frequency and time uncertainty of signals produced by a GPSDO or GPSDC.

SATURDAY, AUGUST 24
1:00 PM - 5:00 PM | 1/2-DAY PM (4 HOURS)
RF Power Sensor Linearity Calibration
INSTRUCTOR: Greg Tolentino, Tegam Inc.
COURSE DESCRIPTION NUMBER: TEM-2
ABSTRACT: RF power sensor linearity is a commonly misunderstood topic. However, to obtain the most accurate power measurements, it’s important that technicians understand what linearity is, sources of nonlinearity, and how to measure RF power linearity. This course introduces metrologists and technicians to linearity calibration for low-power (-70 to +20 dBm), high-frequency (9 kHz to > 50 GHz) RF power sensors and explains why it is important for their customers. The material then dives deeper with a discussion of commonly encountered challenges in linearity calibration. Finally, detailed descriptions and examples of commonly used linearity measurement techniques are presented, with a discussion of the advantages of each.
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**AC Current and Resistance Measurements and Principles**

INSTRUCTOR: Mark Evans, Guildline Instruments Ltd.
COURSE DESCRIPTION NUMBER: TEM-3

ABSTRACT: This course will cover AC current and resistance shunt measurements from 20 mA to 100 A; at frequency ranges from 20 Hz to 100 kHz. Topics to be covered relate to AC measurements, both sourcing and measuring including the use of AC current shunts, AC current transformers, calibrators and transconductance amplifiers. The focus will be on generating and measurement AC currents with frequencies from 20 Hz to 100 kHz. Design considerations for AC shunts and transconductance amplifiers will be discussed as well as connectors, cables, grounding, and complete measurement setups. Uncertainty contributions will be examined including power and temperature coefficients as well as AC noise, EMI and frequency effects. In addition to the theory, hands-on measurements will be made to reinforce concepts and best practices. AC sources provided for the training will include a calibrator and a transconductance amplifier. AC measurements will be made with various AC shunts, with frequencies from 20 Hz to 100 kHz. The use of various connectors, adaptors and cables will be discussed and demonstrated. AC current measurements will be examined along with the effects of environment factors such as temperature, power, EMI and other noise sources, and frequency induced parasites. Best practices, including those related to safety, will be demonstrated. Example of Uncertainty budgets will be discussed and developed for the hands-on measurements.

**Josephson Voltage Standard for Primary SI Realization**

INSTRUCTOR: Dr. Alain Rüfenacht, National Institute of Standards and Technology (NIST)
COURSE DESCRIPTION NUMBER: TEM-4

ABSTRACT: An introduction to the operation and theory of the Programmable Josephson Voltage Standard system (PJVS). A prototype system will be running for training purposes. We will discuss the basics of Josephson Voltage Standards and the particulars of implementation in the PJVS system to realize the unit volt within the new SI. Examples of calibration measurements performed with the PJVS system will be covered, as well as best measurement practices in order to eliminate systematic errors.
TUTORIAL PROGRAM

TRACK: Force Measurements

SUNDAY, AUGUST 25
8:00 AM - 12:00 PM | 1/2-DAY AM (4 HOURS)
Improving the Accuracy of Dynamic Force Measurements
INSTRUCTORS: Dr. Akobuije Chijioke and Dr. Nicholas Vlajic, National Institute of Standards and Technology (NIST)
COURSE DESCRIPTION NUMBER: TMF-1
ABSTRACT: This course will consider factors that contribute to uncertainty in measurements of dynamic forces, and methods for reducing the uncertainty, so as to achieve reliable estimates of the force. Different measurement scenarios will be considered, as well as the limitations of some available options, and ongoing developments for reducing measurement uncertainty.

SUNDAY, AUGUST 25
1:00 PM - 5:00 PM | 1/2-DAY PM (4 HOURS)
Force Calibration Short Course
INSTRUCTOR: Mike Tovey, Tovey Engineering
COURSE DESCRIPTION NUMBER: TMF-2
ABSTRACT: Force measurement is a special discipline with many considerations not common to other areas of measurement. Often measurement uncertainties are underestimated due to the omission of significant error sources. Measurement engineers must grapple with the problem of taking a result from their metrology lab and manufacturer’s specifications, and somehow determining the measurement uncertainty of their test. Factors such as second order material responses, interaction of undesired parasitic loading due to fixture characteristics, misalignment of components, magnetic and electro-static fields, temperature effects etc. can have significant influence on the measurement result. This tutorial will briefly cover the characteristics of force transducers, force calibration methods, force calibration standards (E74 and ISO 376), and the effect of influence factors on the test measurement result.

MONDAY, AUGUST 26
1:00 PM - 5:00 PM | 1/2-DAY PM (4 HOURS)
Force Calibration for Everyone with a Focus on Measurement Errors and Risk
INSTRUCTOR: Henry Zumbrun, Morehouse Instrument Company, Inc.
COURSE DESCRIPTION NUMBER: TMF-3
ABSTRACT: Not familiar with all the sources of measurement error in relation to force measurements? These errors include proper calibration adapters. Did you know, using a top block for compression loading can produce up to a 0.5 % error if the end user is using something with a different hardness and/or flatness. Using the wrong pin size on a tension link can cause a 2 % error on a device with an accuracy of 0.1 % of full scale. The measurement errors demonstrated and discussed will include errors associated with improper alignment and use of different and/or incorrect adapter types, thread depth and thread loading as well as some load cell troubleshooting techniques. We will also discuss over 20 common major error sources and how to avoid them. We will then focus on ISO/IEC 17025:2017 section 6.4.5 “The equipment used for measurement shall be capable of achieving the measurement accuracy and or measurement uncertainty required to provide a valid result.” Taking this section into account, we will discuss measurement decision risk with a focus on ANSI/NCSL Z540.3 Method 5 and Method 6 and how the Test Uncertainty Ration (TUR) impacts the laboratories ability to make statements of conformity to a specification per section 7.1.3 of the ISO/IEC 17025:2017 standard. All participants will receive a USB drive with several helpful documents and excel sheets. Included will be a risk calculator and an uncertainty template which will simply calculating calibration and measurement capability (CMC) for both force and torque scopes of accreditation.

NCSL INTERNATIONAL COMMITTEE MEETINGS
Open to All!
Imagine Your Torque Calibrations Are Not as Accurate as You Think They Are: Chances are they’re not!

INSTRUCTOR: Henry Zumbrun, Morehouse Instrument Company, Inc.
COURSE DESCRIPTION NUMBER: TTQ-1

ABSTRACT: There are three essential components to making better torque measurements: The technicians must be competent and realize torque is more than force times length; The right equipment must be selected and with torque, it rarely is; The calibration provider must have low enough uncertainties to meet your needs. The course will cover the problems with torque measurements, torque traceability, and the calibration hierarchy, types of torque standards, the sources of measurement error, and torque wrenches and the proper handling techniques. We will have “hands-on” demonstrations of how to use a torque wrench. Anyone participating will have enough information to correct problems and start making better torque measurements.

Dynamic Sensors and Calibration
INSTRUCTOR: Patrick Timmons, The Modal Shop
COURSE DESCRIPTION NUMBER: TSM-1

ABSTRACT: Vibration calibration class will dive into calibration theory, standards, and methodology for dynamic sensors as well as detailed construction of different sensor types and the operational theories behind them. Target audience is beginner to intermediate level.

Hands-on Training Offers Big Benefits
Learn from industry experts in our Tutorial Program!

Hands-on training can help increase your critical thinking skills as you gain experience with new techniques and equipment. You’ll leave our Tutorial Program with the confidence to use your skills in real-world situations.
Whether this is your first time at an NCSLI Workshop & Symposium, or you're a seasoned attendee of many conferences, the investment of your time and your organization’s resources can be enhanced by following these helpful suggestions before the Conference.

- Review the preliminary program or the NCSLI Workshop & Symposium website for this year’s theme, keynote speakers, and other useful information.
- Start with an end in mind. Review the Conference content and outline your objectives that you will accomplish as a result of attending the Conference. Get support from your management and determine if they have any specific objectives for your attendance as well.
- Prepare a list of the most important questions that you would like answered by the presenters, exhibitors, and other contacts to be made at the Conference.
- Consider which tutorials will help you meet your personal, corporate, and professional development objectives.
- If more than one person from your organization plans to attend the Conference, meet and develop a plan on who will attend which sessions, who will contact which key exhibitors, and how to best organize the Conference experience. That way you can share information and resources with each other and with others in your organization to optimize your time.
- If you are a member of an NCSLI committee, be sure to complete your homework prior to attending the Conference (review draft documents in advance, ask for a copy of the agenda if you haven’t received one, be prepared to actively participate). If you are not currently serving on a committee, review the Committee charters at ncsli.org/committees, and identify the Committees that you would like to contribute to. All NCSLI committee meetings are “open” and welcome guest participation and new members.
- Bring along a stack of business cards for sharing and networking.
- During the registration process you’ll receive the Conference program and other pertinent Conference information.
- If you have extra time, you can find a link to “Things to Do in Cleveland” on ncsli.org.
- Plan to take some time after the Conference to review your notes and the information you collected, to connect with the people and companies you met, and to talk about your experience with your colleagues and management.
## Conference Schedule

The NCSL International Workshop & Symposium offers a full schedule of presentations and tutorials, along with plenty of opportunities for networking.

### Saturday, Sunday, Monday
**August 24, 25, 26**

**Tutorial Program**  
(Additional Paid Workshops)

<table>
<thead>
<tr>
<th>Event</th>
<th>Time</th>
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<tbody>
<tr>
<td>Tutorial &amp; Conference Registration</td>
<td>7:00 AM – 6:00 PM</td>
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<tr>
<td>Monday until 8:00 PM</td>
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<tr>
<td>Continental Breakfast</td>
<td>7:00 AM – 8:00 AM</td>
</tr>
<tr>
<td>Tutorial Program</td>
<td>8:00 AM – 5:00 PM</td>
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<tr>
<td>Morning Break</td>
<td>10:00 AM – 10:30 AM</td>
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<tr>
<td>(Refreshments provided)</td>
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<tr>
<td>Lunch</td>
<td>12:00 PM – 1:00 PM</td>
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<tr>
<td>(Lunch is not included. Onsite choices are available.)</td>
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<tr>
<td>Afternoon Break</td>
<td>3:00 PM – 3:30 PM</td>
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<tr>
<td>(Refreshments provided)</td>
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<tr>
<td>Committee Meetings</td>
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<tr>
<td><strong>TUESDAY, AUGUST 27</strong></td>
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<tr>
<td>Conference Registration</td>
<td>7:00 AM – 6:00 PM</td>
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<tr>
<td>Continental Breakfast</td>
<td>7:30 AM – 9:00 AM</td>
</tr>
<tr>
<td>Exhibit Hall Hours</td>
<td>7:30 AM – 5:30 PM</td>
</tr>
<tr>
<td>Tuesday Keynote Presentation &amp; Wildhack Award</td>
<td>Atrium Ballroom AB (Global Center)</td>
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<tr>
<td>8:30 AM – 10:00 AM</td>
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<tr>
<td>Technical Program</td>
<td>10:30 AM – 4:00 PM</td>
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<tr>
<td>Learning Labs</td>
<td>10:30 AM – 12:00 PM</td>
</tr>
<tr>
<td>Luncheon Buffet in Exhibit Hall A</td>
<td>11:30 AM – 1:30 PM</td>
</tr>
<tr>
<td>Poster Presentations in Exhibit Hall A</td>
<td>12:15 PM – 1:00 PM</td>
</tr>
<tr>
<td>Afternoon Break — Dessert with Exhibitors in Exhibit Hall A</td>
<td>2:00 PM – 2:30 PM</td>
</tr>
<tr>
<td>Metrology Mixer &amp; Sponsor Raffle in Exhibit Hall A</td>
<td>4:00 PM – 5:30 PM</td>
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<tr>
<td>Committee Meetings</td>
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### Monday, August 26

**Conference Open**

<table>
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<tr>
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<tbody>
<tr>
<td>Conference Registration</td>
<td>7:00 AM – 8:00 PM</td>
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<tr>
<td>Exhibitor Move-in Exhibit Hall A</td>
<td>8:00 AM – 5:00 PM</td>
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<tr>
<td>Awards Reception</td>
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<tr>
<td>Atrium Ballroom AB (Global Center)</td>
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<tr>
<td>3:30 PM – 5:00 PM</td>
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<tr>
<td>Conference Welcome Reception</td>
<td>Exhibit Hall A</td>
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<tr>
<td>6:00 PM – 8:00 PM</td>
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<tr>
<td>Exhibit Hall Hours</td>
<td>7:30 AM – 5:30 PM</td>
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<tr>
<td>(Exhibit close and tear-down after mixer)</td>
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<tr>
<td>Wednesday Keynote Presentation</td>
<td>Atrium Ballroom AB (Global Center)</td>
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<td>8:30 AM – 10:00 AM</td>
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<tr>
<td>Technical Program</td>
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<td>Learning Labs</td>
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<tr>
<td>Luncheon Buffet in Exhibit Hall A</td>
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<tr>
<td>Poster Presentations in Exhibit Hall A</td>
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### Tuesday, August 27

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<tr>
<td>Poster Presentations in Exhibit Hall A</td>
<td>12:15 PM – 1:00 PM</td>
</tr>
<tr>
<td>Afternoon Break — Dessert with Exhibitors in Exhibit Hall A</td>
<td>2:00 PM – 2:30 PM</td>
</tr>
<tr>
<td>Metrology Mixer in Exhibit Hall A</td>
<td>4:00 PM – 5:30 PM</td>
</tr>
<tr>
<td>Committee Meetings</td>
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### Thursday, August 29

**Conference Open**

<table>
<thead>
<tr>
<th>Event</th>
<th>Time</th>
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<tbody>
<tr>
<td>Conference Registration</td>
<td>7:00 AM – 8:30 AM</td>
</tr>
<tr>
<td>Closing Keynote, Business Meeting, Overall Best Paper Award</td>
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<tr>
<td>Atrium Ballroom AB (Global Center)</td>
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<tr>
<td>8:30 AM – 10:00 AM</td>
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</tr>
<tr>
<td>Technical Program</td>
<td>10:30 AM – 12:00 PM</td>
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<tr>
<td>Conference Close</td>
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<td>Committee Meetings</td>
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### Wednesday, August 28

<table>
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<tr>
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<td>Continental Breakfast</td>
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<tr>
<td>Exhibit Hall Hours</td>
<td>7:30 AM – 5:30 PM</td>
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<tr>
<td>(Exhibit close and tear-down after mixer)</td>
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<tr>
<td>Wednesday Keynote Presentation</td>
<td>Atrium Ballroom AB (Global Center)</td>
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<tr>
<td>8:30 AM – 10:00 AM</td>
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<tr>
<td>Technical Program</td>
<td>10:30 AM – 4:00 PM</td>
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<tr>
<td>Learning Labs</td>
<td>10:30 AM – 12:00 PM</td>
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<tr>
<td>Luncheon Buffet in Exhibit Hall A</td>
<td>11:30 AM – 1:30 PM</td>
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<tr>
<td>Poster Presentations in Exhibit Hall A</td>
<td>12:15 PM – 1:00 PM</td>
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<tr>
<td>Afternoon Break — Dessert with Exhibitors in Exhibit Hall A</td>
<td>2:00 PM – 2:30 PM</td>
</tr>
<tr>
<td>Metrology Mixer &amp; Sponsor Raffle in Exhibit Hall A</td>
<td>4:00 PM – 5:30 PM</td>
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<td>Committee Meetings</td>
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### Keynote Presentations

**Tuesday, Wednesday & Thursday**

Visit NCSLI.org for the complete Workshop & Symposium program.

<table>
<thead>
<tr>
<th>Date</th>
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<tbody>
<tr>
<td>Tuesday</td>
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<tr>
<td>Wednesday</td>
<td>Keynote Presentation</td>
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<td>8:30 AM – 10:00 AM</td>
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<tr>
<td>Thursday</td>
<td>Keynote Breakfast</td>
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<td>7:30 AM – 8:30 AM</td>
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Mass Calibration at NIST in the Revised SI

Max Planck
The kilogram is now defined using the Planck constant.

Patrick J. Abbott and Zeina Kubarych
Quantum Measurement Division
Physical Measurements Laboratory
National Institute of Standards and Technology
patrick.abbott@nist.gov
ABSTRACT
The unit of mass was realized by the International Prototype Kilogram (IPK) for over 130 years. On May 20, 2019, all fundamental quantities of the International System of Units (SI) were tied to natural constants. In this revision of the SI, mass is tied to the Planck constant. For several years, the world has been engaged in measuring the Planck constant to very high precision, and with the recent Committee for Data on Science and Technology (CODATA) adjustment in 2017, the value of the Planck constant has been fixed with no uncertainty. For the first few years after redefinition, the world will use a consensus value for the kilogram realization rather than individual realizations from the Planck constant. This paper will describe the planned transition from consensus value to individual realizations that will take place during the next decade, and specifically discuss how the National Institute of Standards and Technology (NIST) plans to disseminate mass during this period.

1. INTRODUCTION
On World Metrology Day, May 20, 2019, The International System of Units (SI) underwent a fundament revision that realizes the SI base quantities (time, length, mass, electric current, thermodynamic temperature, amount of substance, and luminous intensity) using seven exact values of a set of defining constants: the ground-state hyperfine splitting of the cesium-133 atom $\Delta \nu(^{133}\text{Cs})_{\text{hfs}}$, the speed of light in vacuum $c$, the Planck constant $h$, the electron charge $e$, the Boltzmann constant $k$, the Avogadro constant $N_A$, and the luminous efficacy $K_{\text{cd}}$ [1]. See Fig. 1.

The unit of mass is now tied to the Planck constant, which has been measured to high precision in the past several years and recently fixed by a special CODATA [2] adjustment [3]. The new SI definition of mass is:

- The kilogram, symbol kg, is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant $h$ to be $6.626\,070\,15 \times 10^{-34}$ when expressed in the unit J s, which is equal to kg m$^2$ s$^{-1}$, where the metre and the second are defined in terms of $c$ and $\Delta \nu(^{133}\text{Cs})_{\text{hfs}}$ [4].

Fig. 1. On May 20, 2019, the International System of Units (SI) was revised so that all the units of measure (outer ring) are derived from fixed natural constants (inner ring).
For the first time in the history of the SI, realization of the unit of mass carries an uncertainty based on experiments that relate mass to the Planck constant. Relating mass to the Planck constant “frees the mass scale” to be realized at values other than one kilogram with non-zero uncertainty [5] according to Dr. Stephan Schlamminger [6], a physicist in NIST’s Fundamental Electrical Measurements Group and co-developer of the NIST-4 Kibble balance. Given a fixed value for the Planck constant and the revision of mass in the SI, it is now possible to realize the unit of mass in any laboratory that has an appropriate experiment, which revokes the geographical limitation of the IPK mass realization, which is only available at the Bureau International des Poids et Mesures (BIPM) in Sèvres, France (near Paris) [7]. Mass artifacts will no longer have to travel to the BIPM for calibration. See Fig. 2. Two major experiments were used to measure the Planck constant using an IPK-traceable mass artifact as input: The Kibble balance [8] and the X-Ray Crystal Diffraction (XRCD) [9] experiments. Now that the Planck constant is fixed, these experiments can be “run in reverse” using the Planck constant as input to determine an unknown mass. This process is shown in Fig. 3. Recent determinations of the Planck constant have shown more variation than expected by the criteria that was used to determine the consistency of the world’s Planck constant measurements [10], [11]. For this reason, the kilogram will not be realized independently by appropriate experiments throughout the world beginning on May 20, 2019; instead mass will be realized by a consensus value that will be implemented gradually over the next few years. This consensus value will be used until the dispersion in the world’s mass realization experiments is reduced to a level below the uncertainties of the individual experiments. This paper will describe this process and the implications for dissemination of mass at the National Institute of Standards and Technology (NIST).
2. THE 2017 CCM MEETING
The concept for changing the realization of the kilogram from a platinum-iridium artifact to a Planck constant-based measurement was first seriously proposed in 2005 [12]. Eventually, the Consultative Committee for Mass and Related Quantities (CCM) set forth four main conditions to be met before redefinition could occur; these are described in reference [9] and consist of the following [13]:

1. CONSISTENCY:
At least three independent experiments, including work from Watt (Kibble) balance and XRCD experiments, yield consistent values of the Planck constant with relative standard uncertainties not larger than 5 parts in $10^8$.

2. UNCERTAINTY:
At least one of these results should have a relative standard uncertainty not larger than 2 parts in $10^8$.

3. TRACEABILITY:
The BIPM prototypes, the BIPM ensemble of reference mass standards, and the mass standards used in the watt balance and XRCD (x-ray crystal density) experiments have been compared as directly as possible with the international prototype of the kilogram.

4. VALIDATION:
The procedures for the future realization and dissemination of the kilogram, as described in the mise en pratique, have been validated in accordance with the principles of the CIPM MRA (International Committee of Weights and Measures Mutual Recognition Arrangement).

All conditions for redefinition were met by the time of the 16th meeting of the CCM in May 2017, and this is reflected in the resulting recommendation submitted to the CIPM (reference [9]). However, the recommendation further notes:

“that the most recent measurement with relative standard uncertainty below $5 \times 10^{-8}$ do not pass the standard chi-squared test of consistency, but it is expected that the CODATA value and uncertainty for the Planck constant will be suitable for even the most demanding applications”

This situation is shown in Fig. 4, which corresponds to Figure 1 of reference [3]. Clearly the IAC [14] -15, NRC [15] -17, and NMIJ [16] -17 measurements fulfill the CCM criteria for redefinition.

Fig. 4 also shows that the values of the Planck constant obtained from the IAC-17 and the NIST-17 measurements differ by about 70 parts in $10^9$ and do not agree within their respective standard uncertainties. These are the
measurements that led to the failure of the chi-squared consistency test. Because of the poor consistency of these recent results for the Planck constant, there were some who felt that the redefinition should be delayed until more consistent results were obtained from the world’s realization experiments. Even so, it was believed by most attendees that the ensuing CODATA value and uncertainty would be sufficient for the most demanding mass metrology applications. As shown in Fig. 4, the CODATA value has a relative uncertainty of $1 \times 10^{-8}$, which translates to ten micrograms on a mass of one kilogram. To deal with the systematic differences between the world’s realization experiments, it was proposed that the world’s National Measurement Institutes (NMI) disseminate the unit of mass from a consensus value derived from an ongoing key comparison of primary realizations of the kilogram [17]. This key comparison “will capture and maintain a table of the experimental degrees of equivalence, which can be used to create a formal procedure for applying corrections relative to the consensus value.” It was further agreed that dissemination from the consensus value would continue until the dispersion in the world’s realization experiments becomes compatible with the individual realization uncertainties.

Practically, this decision by the CCM postpones the ability of laboratories having Planck-constant-based primary realizations of the kilogram to disseminate from these experiments. Instead, the world will use an ongoing pool of measurements to calculate a weighted average of these realizations, which is similar to what was done for fixing the Planck constant. In the subsequent months after the 16th CCM meeting, further guidance emerged detailing how this consensus value will be implemented. By the time of the 17th CCM meeting in May of 2019, a tentative schedule for the ongoing key comparison had been agreed to.

**Fig. 5.** Diagram of the ongoing key comparison to determine the consensus value of the kilogram. Each participating NMI will realize the kilogram and send it to the BIPM for mass measurement. The BIPM will calculate the consensus value based on a weighted algorithm. The consensus value will be used by each NMI to adjust their mass scale until the dispersion between individual realizations has been reduced to an acceptable level.
3. THE CONSENSUS VALUE AND NIST

It has been decided by a CCM Task group [18] that the dissemination of the kilogram will take place in three phases following the revision of the SI. These phases are meant to ensure the world-wide consistency of the unit of mass during the transition from the current IPK definition to the eventual dissemination of mass based on the Planck constant from the world’s realization experiments [19]. These phases are summarized below.

Phase 1 went into effect on May 20, 2019, and maintains traceability to the IPK, but adds an uncertainty to the mass of the IPK for the first time in its history. Practically this means that the IPK will still realize mass for the world, but it will have an uncertainty of ±10 μg derived from the 1 x 10^-8 relative uncertainty determined by the CODATA Planck constant adjustment. Traceability is to the Planck constant via the IPK, with additional uncertainty from the new definition. NIST is currently traceable to the IPK through BIPM calibrations of its national prototype kilograms K20, K4, K79, K92, and K102. These national prototypes will continue to serve as the foundation of NIST’s mass scale during Phase 1, but an additional uncertainty of ±10 μg is now added in quadrature to the uncertainty stated on the BIPM certificates. For example, the most recent calibration certificate for K102 states a combined standard uncertainty of 3.5 μg. At the start of Phase 1, this uncertainty, \( u \), increased to:

\[
u(K102) = \sqrt{(0.0035 \text{ mg})^2 + (0.010 \text{ mg})^2} = 0.0106 \text{ mg}
\]

This increased uncertainty will be propagated to the one-kilogram stainless-steel working standards and will increase their total uncertainty to about 12 μg. The final combined standard uncertainty on one-kilogram customer calibrations at NIST will be approximately 22 μg. This is about 2 μg larger than it was under the previous definition of mass by the IPK. The increase in uncertainty on NIST’s national prototype kilograms propagates throughout the mass scale and is most prominent for multiples of 1 kg (2 kg, 5 kg, 10 kg, etc.). NIST customers who use calibration reports from NIST with dates prior to May 20, 2019, while still traceable to the SI, will have to add in quadrature the additional 10 μg per kilogram.

For example, if the total uncertainty on a 5 kg mass calibration was 0.250 mg before May 20, 2019, the uncertainty after May 20, 2019 will be:

\[
(0.250 \text{ mg})^2 + (0.050 \text{ mg})^2 = 0.255 \text{ mg}
\]

Phase 1 will continue until a true world consensus value of the kilogram is determined from the ongoing international key comparison of primary standards. The key comparison will begin in September of 2019, at which time realizations and measurements of transfer standards at participating laboratories will take place. See Fig. 5. The transfer standards will be sent to the BIPM for measurements in the December 2019 – January 2020 timeframe. After the BIPM measurements, the transfer standards will be sent back to their respective NMIs for a final measurement to determine their stability. Analysis of all data will be performed at the BIPM and will produce an initial consensus value in the second quarter of 2020.

Phase 2 of the dissemination process of the new definition of the kilogram will use the Key Comparison Reference Value (KCRV) of the ongoing international key comparison of primary realizations of the kilogram as the consensus value. In either case, participation in the key comparison will be limited to NMIs having published results having a relative standard uncertainty less than or equal to 2.0 x 10^-7. NIST will participate in the key comparison with its Kibble balance, NIST-4, whose performance has been well documented in the lead-up to the CODATA Planck constant adjustment [20]. The KCRV will be calculated using an established methodology, e.g., the mean value of participants’ data weighed to reflect their reported uncertainties. The consensus value will be revised considering new values from the Key Comparison, with appropriate statistical weighting. New rounds of the Key Comparison will be implemented approximately every two years, until such time that the CCM decides that dissemination from the consensus value is no longer necessary because dispersion of calibration results from the primary realization experiments is compatible with their individual uncertainties. The consensus value should be stable to within the same 10 μg uncertainty that is attached to Phase 1, since this uncertainty is derived...
from the CODATA Planck constant adjustment. The Pilot Laboratory (BIPM) of the Key Comparison will be responsible for disseminating the consensus value to all NMIs.

During Phase 2, NIST will maintain an ensemble of mass standards containing both platinum-iridium and stainless-steel kilograms that are traceable to the KCRV as transmitted by the Pilot Laboratory. This ensemble will be used to create working standards that will be used for disseminating the mass scale to the US measurement system. The ensemble will be maintained in atmospheric pressure air and the masses composing the ensemble will be intercompared frequently to monitor and compensate for any mass drifts in the artifacts.

Phase 3 will begin when the dispersion of the results from individual realization experiments is compatible with the uncertainties of the individual realizations. This eliminates all systematic differences that may exist between the realization experiments so that the natural statistical variation of measurements is the dominant uncertainty. The scientific choice to start Phase 3 will be reviewed and approved by the CCM. In Phase 3 it will be statistically appropriate for the world to disseminate mass from individual realization experiments and to abandon the consensus value. This is the objective of the SI revision, and the implementation of Phase 3 will truly leverage the Planck constant-based kilogram. Figure 6 illustrates a possible timeline for the phase-in of the new definition.

The BIPM will maintain their own pool of artifacts that are tied to the KCRV and used to calibrate their working standards. These working standards, or the BIPM’s own Kibble balance will be used to provide calibrations to NMIs that do not possess their own realization experiment. NIST will realize the kilogram using its Kibble balance. Two ensembles of artifacts in platinum-iridium and stainless steel will be developed, one containing both platinum-iridium and stainless steel kilograms that will be traceable to the KCRV as transmitted by the Pilot Laboratory. This ensemble will be used to create working standards that will be used for disseminating the mass scale to the US measurement system. The ensemble will be maintained in atmospheric pressure air and the masses composing the ensemble will be intercompared frequently to monitor and compensate for any mass drifts in the artifacts.

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<td>new definition</td>
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**Fig. 6.** Phase-in to freedom: Possible timeline for the phase-in of the new definition of the kilogram. Traceability will go through the IPK plus uncertainty to the Planck constant (Phase 1 far left) to traceability to the Planck constant through individual realization experiments (Phase 3 far right).
stainless-steel, traceable to the NIST-4 Kibble balance, will be maintained at NIST. One of these ensembles will be stored in a vacuum environment and the other in atmospheric pressure air. These ensembles will be the basis of the NIST mass scale, and like the NIST ensemble described in Phase 2 above, the composing masses will be intercompared frequently to monitor drift and to determine the frequency of performing a mass realization in the NIST Kibble balance.

4. OUTLOOK AND CONCLUSIONS

It is impossible to predict how long Phase 2 will last, but it is not unreasonable to expect a period of five years before the world is disseminating mass from individual experiments. The world is working to criteria that will ensure the equivalence of realizations. Meanwhile, more NMIs will develop primary experiments for mass dissemination and will have to tie in to the ongoing key comparison to establish equivalence with the KCRV. This will be done via the standard processes set up by the CIPM MRA for evaluating degrees of equivalence between independent realizations.

NIST will be a full participant in all three phases of the implementation of the kilogram redefinition. During Phase 1, NIST will realize mass with its Pt-Ir National Prototype kilograms. The uncertainty of each prototype will contain an additional 10 μg (added in quadrature) derived from the uncertainty of the 2017 CODATA adjustment of the Planck constant. During Phase 2, NIST will contribute to the KCRV of the ongoing key comparison of primary realizations through its NIST-4 Kibble balance. An ensemble of 1 kg mass artifacts will be established at NIST for dissemination of the unit of mass during Phase 2. The artifacts in this ensemble will be traceable to the KCRV that is disseminated by the pilot lab. When Phase 3 is implemented NIST will realize mass using the NIST-4 Kibble balance. It will disseminate through two ensembles of artifacts that are traceable to NIST-4. One of the ensembles will be maintained in atmospheric pressure air; these artifacts will be used for creating working standards for dissemination to the U.S. Measurement System. The second ensemble will be kept in a vacuum environment; these will serve as the starting point for the ensemble that is maintained in air. Both ensembles will be carefully monitored for any drift in the component masses. This information will be used to establish the frequency of primary realizations using the NIST-4 Kibble balance.

REFERENCES

[5] The relative uncertainty of the Planck constant from the 2017 CODATA adjustment is 10 x 10-9; in mass units this translates to 0.010 mg for a 1 kg artifact.
[6] Personal communication
[7] Pavillon de Breteuil, F-92312 Sèvres Cedex
[14] International Avogadro Coordination project
[16] National Metrology Institute of Japan
[17] See Ref. 9
[18] CCM TGPfd-kg, Task group on the phases for the dissemination of the kilogram following redefinition
The NCSL International Albuquerque Section held its winter meeting on March 4, 2019 at the Compa Industries/TEVET Albuquerque Corporate Office. The meeting lasted for approximately three hours and had 23 attendees. The meeting was split between two individuals, Justus Brevik of the National Institute of Standards and Technology (NIST) and Elbara Ziade of the Primary Standards Laboratory at Sandia National Laboratories. The meeting host was Keysight Technologies, which provided both the meeting location and lunch for all attendees. Snacks and refreshments were provided throughout the meeting, provided by the NCSL International Albuquerque Section Leads.

The meeting began with an announcement of the upcoming NCSL International Workshop & Symposium being held August 24-29, 2019 in Cleveland, Ohio. Attendees were urged to become an NCSLI member and register for the conference if they were not already.

After the introduction, the first presenter, Justus Brevik PhD, NIST Boulder, was introduced. His topic addressed the development of quantum-based voltage metrology at NIST Boulder. One of the goals within voltage metrology is to replace artifact standards with quantum standards, whose outputs are derived from fundamental physical constants. Justus began with the history of the representation of the derived unit of the volt from the International System of Units (SI). He discussed an electrochemical battery called the Weston cell, which was the international representation for the volt until it was replaced by the Josephson voltage standard.

The discussion then led into the Programmable Josephson Voltage Standard (PJVS). The PJVS system uses Josephson junction (JJ) arrays operating at 4 Kelvin to generate quantized DC voltages, as well as low-frequency stepwise voltages. From the PJVS, Justus went on to discuss the Josephson Arbitrary Waveform Synthesizer...
a factor for photonic thermometry. With the increase of additive manufacturing across multiple industries, material properties should be analyzed before these parts are utilized in applications where they may present a risk to the operation of the system.

One of the material properties that can be analyzed with Raman spectroscopy is residual stress. After providing the motivation for the work, Elbara went on to describe the physics of the Raman measurement. An analogy to an audio frequency doppler effect was provided to give the audience an idea of the inelastic scattering that is occurring during the Raman effect. For total energy conservation, the scattered photon might gain energy from the lattice which will result in a lower frequency photon, a Stokes shift.

Alternatively, for an anti-Stokes shift the scattered photon will gain energy from the lattice and will result in a higher frequency photon. Elbara then went into the traceability to the SI and the contributions to the expanded measurement uncertainty for the measured spectra including the relative and absolute peak positions.

The expanded measurement uncertainty for the spectrometer comes from three sources including: process uncertainty, the uncertainty due to implementation of ASTM E1840 (Standard Guide for Raman Shift Standards for Spectrometer Calibration), and environmental controls. The process uncertainty is further broken down into three components including Signal to Noise Ratio, resolution, and variability of the sample. After providing uncertainty analysis results for relative and absolute temperature and stress measurements, Elbara concluded that higher accuracy standards are needed for Raman spectrometer calibrations.

The next Albuquerque section meeting will be scheduled for September 2019. We are hoping to have multiple technical presentations that relate to metrology. The meeting announcement is to follow on the NCSL International website.
The NCSL International Twin Cities Region held its spring meeting on a rainy day at the Productivity Quality, Inc. facility in Plymouth, Minnesota. The May 22, 2019 meeting was hosted and sponsored by Productivity Quality, Inc.

The day started with Keith Summers from PQI providing attendees with a history of the company and an overview of their capabilities.

The first speaker of the day was Jack Gaughan from Edmunds Gages. Jack started out by asking attendees, “What is measurement?” Jack then explained that measurement is a part of process control and that it is critical to pick the correct measurement method (e.g. in process, post process, final inspection, classification, etc.) for your application. Jack walked attendees through an example of developing a measurement budget for each component of an internal combustion engine and then wrapped up his presentation with a question and answer session.

After a break for refreshments and networking, Drew Schiltz from Zeiss Industrial Metrology Group explained the challenges and limitations associated with the human visual inspection process. Drew then introduced Zeiss’ SurfMax technology (a technology he helped invent) as an alternative to the human visual inspection process.

Before lunch, we had our Minnesota Twins trivia (make that first place Minnesota Twins trivia!), took a group picture, and were treated to a tour of PQI’s calibration laboratory. Our gracious hosts even provided a delicious lunch!

Our third presenter for the day was Randy Long from ANAB. Randy provided a brief history of ISO/IEC 17025, summarized the major changes with the 2017 revision, and then compared and contrasted the 2005 and 2017 requirements. Attendees had a number of questions for Randy as they prepare for their upcoming re-accreditations.

Our final presenter of the day, Scott Holland from Hexagon Metrology, discussed the impact of coordinate measurement machine geometry issues (e.g. linear, squareness, roll, pitch, yaw, and straightness) on the measurement process. Scott included visual examples of each issue which really helped bring the concepts to life.

The successful and informative meeting wrapped up with a round of door prizes donated by the steering committee members. The Twin Cities section would like to offer a sincere thanks to PQI for sponsoring this meeting and NCSLI for their continued support.
The NCSL International Washington/Oregon Spring Section meeting was held on March 7, 2019 at the Mitutoyo America Showroom in Renton, Washington. The meeting was well attended with measurement scientists, instrumentation vendors and technicians from various industries across the Northwest.

Our section meeting focused on two mini-workshops for our attendees. The morning session was presented by Dr. James Salsbury, General Manager, Corporate Metrology, Mitutoyo America Corporation. Jim begun with a presentation on problem areas in dimensional calibration practices, with a focus on utilizing the latest standards to develop the most efficient calibration methods.

Dr. Salsbury then continued with his second presentation on measurement uncertainty in conformance calibrations, understanding proper sources of measurement uncertainty and key concepts with regards to decision rules in ISO/IEC 17025:2017.

This was a great segue into our afternoon session presented by Helga Alexander from International Accreditation Service (IAS). This session gave an overview of the history of ISO/IEC 17025 and the changes in requirements as labs prepare for accreditation to the newest update. Ms. Alexander presented the changes in the new standard and then asked example questions to our attendees to begin dialogue around these topics. Many of our attendees are directly involved with their organizations accreditation process and Ms. Alexander was able to give direct insight to the new standard and provide guidance to performing a gap analysis between the two documents.

This section meeting was well received by all and offered quite a lot for our members to take back. Many thanks to Mitutoyo America for their fantastic sponsorship of our section meeting. They were a wonderful host and the showroom provided ample room for our exhibitor tables and speaker presentations.

The NCSLI section member team that organized this event included: Tony Reed, NCSLI Division VP, The Boeing Company; Todd Meek, Mitutoyo America Corporation and Wes Thompson, The Boeing Company. A great many thanks go out to our sponsors and exhibitors; Mitutoyo America, Additel, Fluke Calibration, Interface, Mahr and Renishaw — without whom we could not have these meetings.
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<td>1-Day Course (8 hours)</td>
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<td>2-Day Course (16 hours)</td>
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The NCSL International Gulf Coast Section convened for a meeting at the JM Test Systems facilities in Baton Rouge, Louisiana. The event was held on May 30, 2019 and hosted by JM Test Systems, Inc. 22 people were in attendance.

The meeting kicked off with a continental breakfast and welcome from Ben Jack, JM Test System's Alexandria Louisiana Division and Business Development Manager and NCSLI Gulf Coast Section Coordinator. This was followed by introductions of attendees and presenters. A review of the day’s agenda ensued.

The meeting attendees were Ms. Beverly Garcia, JM Test Systems Representative, NCSLI Southeastern Region VP and; Mr. Scott Morrison, CEO JM Test Systems, along with representatives from NASA, Fluke Calibration, FLIR Systems, RKI Instruments, Ametek, Central Louisiana Economic Development Alliance (CLEDA), and JM Test Systems.

The first presentation was delivered by Mr. Scott Crone of Ametek. Scott discussed Deadweight Testers and Digital Pressure Calibrators. After a short break the next presenter was Brent Condie of FLIR Systems. Brent discussed thermography, uses of and interpretations of thermographic imagery. This was followed by Mr. Scott Morrison, JM Test Systems CEO. Mr. Morrison gave a welcome address to the group of attendees and thanked them for their participation. We then went to lunch which was provided by Jason's Deli of Baton Rouge Louisiana. After lunch, Mr. Mark Price, JM Test Systems, gave a presentation on fiber optics, what it is and how it is used. The final presentation was given by Mr. Wayne Denley, CLEDA VP of Knowledge Platforms. Mr. Denley discussed the Advanced Manufacturing Technician (AMT) Program. This is a work/study program partnered by manufacturers and higher learning institutions to offer work and degree opportunities for eligible high school graduates. After Mr. Denley's presentation, we had a short break and then a tour of the JM Test Systems facilities.

Overall, the meeting was a successful event that shared relevant technical information to the attendees. Thanks to NCSL International for their support and, to our host, JM Test Systems, Inc., and all of the attendees and presenters.

Note: Mr. Darrell Pinckard, RKI Instruments was scheduled to give a morning presentation on The Theory of Gas Detection. Unfortunately, he was not able to be present until later in the afternoon. He did however share a copy of his presentation and it is available to attendees.
Regional News

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Ben Jack, JM Test and NCSLI Section Coordinator with attendees.

Scott Crone, Ametek.

Brent Conde, FLIR Systems.

Scott Morrison, President of JM Test Systems, Inc.

Marty Kid, Fluke Calibration.

Mark Price, JM Test Systems, Inc.

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Risk-Based Thinking in the Calibration Laboratory: Practical Examples

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ABSTRACT

Many calibration laboratory managers, who plan to get their laboratories accredited or re-accredited to the new ISO/IEC 17025:2017 standard, worry about how to address a new requirement of the standard: considering the risks and opportunities associated with laboratory activities. They may not realize that a well-run calibration laboratory practices risk-based-thinking routinely. The purpose of this presentation is to remind laboratories that good laboratory management practices already incorporate the consideration of risk and opportunities in their laboratory activities. Practical examples of consideration of risks and opportunities in routine laboratory activities such as calibration interval determination, out-of-tolerance investigations, root cause analysis of nonconformity incidences, etc., will be discussed, and suggestions on how to enhance, monitor and document such activities are addressed. Laboratory personnel will find that they do not have to start from scratch in order to comply with this new aspect of ISO/IEC 17025, but they can leverage and improve upon best practices.

LEARNING OBJECTIVES

• Familiarization with the new ISO/IEC 17025:2017 requirement to consider risks and opportunities.
• Understanding of calibration laboratory practices which already consider risks and opportunities.
• Understanding of how to provide objective evidence to assessors to show that risks and opportunities are being considered in laboratory activities.

1. INTRODUCTION

The latest version of ISO/IEC 17025:2017, General requirements for testing and calibration laboratories [1], was released on November 30, 2017. Similar to ISO 9001:2015, Quality management systems—requirements [2], and other standards in the ISO/IEC 17000 and ISO 14000 series of standards, the new version introduces the concept of risk-based thinking. The standard now requires that risks associated with laboratory activities be identified and addressed. But the standard does not require that formal methods of risk management be employed, such as those outlined in ISO 31000, Risk Management—Principles and guidelines [3]. But naturally, a laboratory can consult ISO 31000 in order to learn more about the principles of risk management.

The consideration of risks and opportunities is not a new concept to a well-run calibration laboratory. In the following sections, we will explore how most laboratory managers already practice risk-based thinking, although they may not be explicitly aware of it.
2. THE NEW REQUIREMENTS
While risk is mentioned in almost every section of the newly structured standard, Clause 8.5 in the management system requirements section is dedicated to actions addressing risks and opportunities. This clause requires the laboratory to consider the risks and opportunities associated with their activities. These activities are described throughout the standard and include risks related to
• impartiality (4.1.4),
• statements of conformity (7.8.6),
• nonconforming work (7.10.1) and
• corrective actions (8.7.1).

3. EXAMPLES OF RISK-BASED THINKING IN THE CALIBRATION LABORATORY
Let us explore typical calibration laboratory activities where we should or already do employ risk-based thinking. While risk-based thinking applies to opportunities as well as risks, this paper concentrates on the latter.

3.1 RISKS WITH RESPECT TO IMPARTIALITY
What do we mean by “impartiality” in the laboratory context? In clause 3.1, ISO/IEC 17025:2017 defines impartiality as “presence of objectivity.” The notes to this clause provide us with examples of what the authors of the standard meant to convey, such as “freedom from conflict of interest,” “freedom from bias,” “lack of prejudice,” “neutrality,” “fairness,” “open-mindedness,” “even-handedness,” “detachment,” “balance.” Let us try to think of some real-world examples where impartiality could be a concern.

For example, let us say you are a calibration laboratory associated with a manufacturing facility, and you serve both internal and external customers. It is important that you have policies in place that ensure that both the interests of your external and internal customers are considered fairly. Your policies, which need to be communicated and enforced by laboratory staff, need to ensure that your external customers’ equipment does not languish indefinitely on your shelves waiting to be calibrated, while you have an influx of internal work. Your policy may be “first in, first out,” regardless of whose equipment it is, or you may be working toward a particular turnaround time (TAT) which you declare to your customers during the contract review process. For example, your policy may promise a TAT of 5 days to external customers for routine calibrations, and 2 days to internal customers. This is perfectly acceptable, but it would not be acceptable for one of your technicians to decide to delay an external customer’s calibration because his friend on the production floor promised to buy him a drink for putting his piece of equipment first on bench.

Another way to help ensure impartiality of laboratory activities is the organizational structure itself. In the case of an internal calibration laboratory, it may be useful if laboratory management did not report directly to the Director of Manufacturing, if their mission is to provide calibration support to that section of the organization. Otherwise the laboratory manager may feel pressure, real or imaginary, to consider product shipment targets rather than calibration history and technical information when making calibration interval extension decisions, or when considering what actions to take when a piece of equipment used on the production floor is found out of tolerance.

Most important when considering risks to impartiality is to require periodic training of your laboratory staff, both technical and administrative, on your policies on impartiality. To make the concept less abstract, you should use real-world, relevant examples of how everyday actions of staff could pose a risk to the laboratory’s impartiality. Do not assume that employees will automatically make the connection between the clauses of the standard and their daily work encounters.

3.2 RISKS WITH RESPECT TO STATEMENTS OF CONFORMITY
The new version of the standard requires laboratories to document their decision rule if they make statements of conformity, and to take into account the level of risk associated with the rule. Section 3.7 of the standard defines “decision rule” as the “rule that describes how measurement uncertainty is accounted for when stating conformity with a specified requirement.” This means that when a laboratory states that an instrument is in...
or out of tolerance, it has to consider how their chosen decision rule affects the likelihood of calling a calibration results a “pass” when it is really a “fail” (false accept), or calling something a “fail” when it is really a “pass” (false reject). While both can have undesirable consequences for the end user of the instrument, this discussion focuses mainly on the false accept risk.

While statements of conformity on calibration reports are not necessarily made routinely in every part of the world, most calibration laboratories in the US provide such statements. When their customers pay good money for a calibration, they expect to be able to see at a glance whether their freshly calibrated instrument met all manufacturer’s specifications, or some other type of specification laid out by an industry standard. However, in the past, the decision rule applied by the laboratory may have been chosen for convenience to the laboratory, without any consideration of the level of risk associated with the rule. The new version of the standard requires laboratories to declare their decision rule to the customer up front. The reason for this is that different decision rules have different false accept and false reject probabilities associated with them, and customers need to be able to decide prior to purchasing a calibration service whether the level of risk this presents is acceptable to their needs.

False accept risk levels associated with different kinds of decision rules are discussed in detail in various publications; see, for example, references [4-11]. Decision rules oftentimes involve guard banding based on measurement uncertainty as a means to limit the risk of making false accept decisions. Guard banding is a method whereby acceptance limits for the calibration result are more restrictive than the actual tolerance limit of the calibration item, thus changing the in- or out-of-tolerance decision point. Different guard banding methods result in different levels of false accept risks, which is why the standard requires that customers be made aware of which method is employed. To illustrate this, we review a few guard-banding techniques.

### 3.2.1 NO GUARD BANDING APPLIED

False accept probabilities without guard banding have been published by previous authors, for example [4-7]. The graphs published in these papers show that the false accept probability may still be at an acceptably low level depending on the ratio of the instrument tolerance to the expanded measurement uncertainty at 95 % confidence level, commonly known as the test uncertainty ratio (TUR) [12]. For example, assuming an in-tolerance probability of 80 % for the calibration item, a TUR of 4:1 provides a probability of false accept (PFA) of approximately 2 %, but for a TUR of 1.5:1, the PFA more than doubles.

### 3.2.2 MANAGED RISK GUARD BAND [4]

This method applies a guard band that is smaller than the expanded measurement uncertainty. The author of this method derived an empirical equation to determine a measurement risk multiplier for guard banding purposes for a given TUR and a desired PFA. A higher TUR leads to a decrease in guard band for a particular PFA. In general, the false accept risk can be kept between 1 % and 2 % for most in-tolerance probabilities and TURs. This guard banding method is similar in nature to a method published in 1993 by Deaver [5].

### 3.2.1 GUARD BAND EQUALS EXPANDED MEASUREMENT UNCERTAINTY

In this method, the acceptance limit is determined by reducing the tolerance by the full amount of the expanded measurement uncertainty. While this reduces the PFA to practically zero, it increases the probability of false reject (PFR) to more than 10 % [4]. While the calibration laboratory employing this method protects the customer from assuming an instrument is good when it actually is bad, making an incorrect out-of-tolerance call may also have undesirable consequences for the customer.

There are numerous other published methods for guard banding that a calibration laboratory can consider when deciding on a decision rule, and all are associated with various levels of risk. Unlike the standard ANSI/NCSL Z540.3 [12], which many US laboratories have to meet, ISO/IEC 17025:2017 does not prescribe that the probability of false accept be kept below a certain level,
nor that a specific decision rule be adopted. However, it does require that the calibration laboratory and the customer agree on a decision rule that is acceptable to them, after considering the risk levels involved. ISO/IEC 17025:2017 thus allows for greater flexibility while ensuring that both parties, laboratory and customer, can agree on a level of risk that is acceptable for their needs.

3.3 RISKS WITH RESPECT TO NONCONFORMING WORK AND CORRECTIVE ACTIONS

Finding a reference standard out-of-tolerance (OOT), a calibration performed incorrectly, an incorrect calibration report issued to a customer—all are examples of nonconforming work in the calibration laboratory. When dealing with these occurrences and deciding what action to take, we consider the following risks: what is the likelihood of a calibration item having been miscalibrated, what is the likelihood of recurrence if we do not take some kind of preventive action, what is the likelihood of a similar issue having occurred elsewhere in the laboratory? These are questions asked routinely in any well-run calibration laboratory addressing nonconforming work. The actions taken depend on the root cause of a nonconformance, and the actions need to fix the immediate problem as well as prevent the problem from recurring.

When a calibration laboratory finds any piece of its measuring and test equipment (MTE) pool out-of-tolerance (OOT) during one of its periodic calibrations, the laboratory must perform an immediate investigation to determine whether the instrument was used as a reference standard in a calibration event. The next question to be addressed is to determine whether the OOT condition could have affected the results of previously calibrated items. It is every calibration laboratory manager’s worst nightmare to have to recall calibrated items, and it is not in the customers’ nor the laboratory’s interests to do so without a thorough analysis of the likelihood and extent of a miscalibration. If a recall is deemed necessary, the more information the laboratory can provide to the customer regarding the nature of the problem, the easier it is for the customer to assess the risks as to whether their own processes were negatively affected.

Offering customers a free re-calibration is oftentimes less important to a customer than a detailed analysis of the nature of the miscalibration of their item.

Next, the laboratory has to determine what actions, if any, need to be taken to prevent the recurrence of the out-of-tolerance condition. For example, the laboratory may decide to reduce the calibration interval of the instrument found OOT. In doing so, it practices risk mitigation by aiming to reduce the likelihood of the reference standard being found out-of-tolerance again in the future. Presumably, the laboratory will have evidence that the instrument’s OOT condition was likely caused by instrument drift, not by some other catastrophic event. The shorter the time period until the next calibration, the smaller the risk of the OOT condition recurring. This is because the “before” or “as found” results of the calibration should alert the laboratory to the fact that an adjustment back to nominal is necessary. If such an adjustment is not possible, the reference standard’s performance specification may have to be downgraded, and its suitability for use in the calibrations has to be re-examined. However, mitigating actions are associated with costs, so the laboratory has to weigh carefully the cost of more frequent calibrations of the reference standard against the risk of potentially having to recall miscalibrated items.

A laboratory may want to mitigate its risks of finding a reference standard out-of-tolerance by performing additional intermediate checks in between calibrations. In this case, a decision rule similar to what we discussed earlier will have to be deployed to determine whether a full calibration is necessary before the end of its assigned calibration interval. The risk here is that if these intermediate checks are performed with equipment that is not sufficiently accurate, resulting in large measurement uncertainties, many false alarms may occur due to the increased likelihood of “false rejects” due to large measurement uncertainties. Or the laboratory may get a false sense of confidence in the equipment’s performance due to the intermediate checks providing “false accept” results. So the effectiveness of intermediate checks has associated risks, which the laboratory should be monitoring to assure that resources spent on intermediate checks have the desired effect.
Depending on the root cause of a nonconforming work issue, other ways of preventing recurrence may be to add more detail to calibration procedures, to improve technician training or to re-train staff at more frequent intervals. In doing so, laboratories can mitigate the risk of different technicians using different techniques or parameters that may produce differences in calibration results significant enough to effect the performance of the instrument.

Whatever the nonconforming work issue, evaluation of both the likelihood of recurrence and the severity of the consequences will determine the level of effort and resources expended to mitigate the risk of recurrence.

### 3.4 OTHER LABORATORY ACTIVITIES INVOLVING RISK-BASED THINKING

#### 3.4.1 SETTING CALIBRATION INTERVALS

We have discussed shortening calibration intervals as a preventive action after an OOT condition of a piece of laboratory measurement and test equipment (MTE). However, the setting of periodic calibration intervals for all of the laboratory’s MTE is another activity where risk-based thinking must be applied. The main purpose of periodic calibration is to ensure the reliability of the instrument, i.e. that the MTE, when employed, performs as designed. Thus, most laboratories’ quality objectives include a set of performance or measurement reliability goals for their pool of MTE. For example, a laboratory may want a minimum of, say, 95% of MTE to be found in-tolerance during their periodic calibrations. Measurement reliability goals may be set to a higher or lower level for certain categories of equipment, depending on the consequences associated with an OOT event.

The setting of optimal calibration intervals strikes a balance between the risk of finding a piece of MTE out-of-tolerance and the cost pressures. If a laboratory is too conservative in setting its calibration intervals in order to maintain extremely high measurement reliability goals, it may calibrate itself right out of business. Hence, setting optimal calibration intervals is not only a means of mitigating OOT risk, but also an opportunity to control calibration costs. Guidance on setting calibration intervals can be found in NCSLI’s RP-1, *Establishment and Adjustment of Calibration Intervals* [8].

#### 3.4.2 ADJUSTMENT BACK TO NOMINAL

Guard banding was discussed earlier in this paper in conjunction with the decision rule at the time of calibration in order to mitigate the risk of a false accept or false reject decision. Setting an adjustment threshold that is lower than the tolerance limits could also be considered a form of guard banding to mitigate a future OOT risk by adjusting an instrument back to nominal prior to its drifting out-of-tolerance.

If the calibration result shows that a measured value is very close to its specification limit, but the calibration laboratory’s adjustment threshold is equal to the specification limit and adjustment to nominal does not take place, the instrument is likely to be out-of-tolerance before the end of its calibration interval. On the other hand, running an adjustment procedure on every instrument every time it comes in for calibration, without regard to how far it has drifted off nominal, is very costly and oftentimes does not help improve the overall performance of a piece of equipment. For example, the adjustment process for a complex electronic measurement instrument may bring most measurement attributes closer to nominal, but it may move others further away. As a result, a calibration laboratory may have a policy to run an adjustment procedure only when the calibration results fall outside a certain adjustment threshold limit, and this limit may vary from laboratory to laboratory.

It is important for the MTE owner performing calibration interval analysis in pursuit of optimal calibration intervals to take this kind of information into consideration. Whether an instrument is routinely adjusted back to nominal by the calibration provider or whether it is already close to its specification limits at the beginning of its calibration interval will influence the laboratory’s measurement reliability performance and the risk of finding MTE out-of-tolerance.
4. PROVIDING EVIDENCE OF RISK-BASED THINKING
This paper has listed many examples of calibration laboratory activities where risk is identified and mitigating action is taken. It is important for the laboratory to document these risks and individual actions, monitor whether the objective of mitigating the risk is met, and take further actions if it is not. Keeping good records of the identified risks, associated mitigating actions and associated trends is not only necessary for good laboratory management, it is also a requirement of the ISO/IEC 17025:2017 standard. It may be helpful to review any existing templates to support laboratory activities, and to explicitly build risk consideration requirements into them. The standard also requires the laboratory to review identified risks during the management review. If careful records are kept on the type of activities discussed in this paper, the information can easily be summarized and provided as management review input for review and discussion.

5. CONCLUSION
The purpose of this paper was to provide examples of risk-based thinking being performed routinely by laboratory management. The examples provided are not new, rather they are activities carried out in today’s laboratories, accredited and non-accredited, on a regular basis. Laboratories that monitor and review the risks involved in these activities on a regular basis should have little difficulty in meeting this aspect of ISO/IEC 17025:2017 requirements.

REFERENCES
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