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THE INTERNATIONAL JOURNAL OF METROLOGY

2025
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An All-In-One Automatic Multiple Standard for Artifact Calibration of High End Electrical Instruments

Deadweight Primary Standards: Best Practices and Their Associated Risks for Stability Determination in Compliance with ISO/IEC 17025

New Accreditation Tool for Auditors and Laboratory Personnel

PRECISION CURRENT INSTRUMENTATION AND CURRENT CALIBRATION

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Transducers manufacturers calibrated by GMW include, but not limited to, Danisense, LEM, GE, ABB, Danfysik, Hitec, AEMC, VAC, PEM, Yokogawa.

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ON THE COVER: ISO 17025 Calibration of EMC E-Field Probes up to 45 GHz at ATEC Calibration Lab in San Diego, CA. Advanced Test Equipment Corporation has been a trusted provider of test equipment rentals, sales, and service since 1981. ATEC became A2LA ISO 17025 accredited in 2013 and now offers calibration services across multiple disciplines including Electrical, RF, and EMC. Headquartered in San Diego, CA, ATEC serves customers worldwide.

CALENDAR

UPCOMING CONFERENCES & MEETINGS

The following event dates are subject to change. Visit the event URL provided for the latest information.

Jun 18-20, 2025 IEEE 12th International Workshop on Metrology for AeroSpace. Naples, Italy. MetroAerospace aims to gather people who work in developing instrumentation and measurement methods for aerospace. Attention is paid, but not limited to, new technology for metrology-assisted production in aerospace industry, aircraft component measurement, sensors and associated signal conditioning for aerospace, and calibration methods for electronic test and measurement for aerospace. https://www.metroaerospace.org/

Jun 20, 2025 ARFTG Microwave Measurement Symposium. San Francisco, California. The 105th ARFTG Microwave Measurement Symposium will be co-located with IMS-2025. https://arftg.org/

Jun 23-25, 2025 International Conference on Measurements of Energy. Orleans, France. https://icme2025.sciencesconf.org/

Jul 18-24, 2025 NCSLI Workshop & Symposium. Cleveland, OH. This year marks 150 years of the SI, therefore this event will be based around the past, present and future of the SI. https://ncsli.org/mpage/WS_2025

Jul 21-25, 2025 Coordinate Metrology Society Conference. Reno, NV. The Coordinate Metrology Society Conference (CMSC) is the world's premier event for Measurement Technology Professionals sponsored by the Coordinate Metrology Society. https://www.cmsc.org/

Aug 25-28, 2025 MSA Conference. Sydney, Australia. Rapid-Tech MSA2025 will be the place to be to connect with the metrology community, hear about the latest trends, meet experts from National Metrology Institutes and regulatory bodies, find your next instrument investment and enjoy the company of many likeminded professionals. https://metrology.asn.au/events/

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EDITOR'S DESK

Important Work

Each quarter, I repost interesting industry and research news from other websites by posting a short quote with the source URL to redirect readers to the story. While I was looking for any relevant news to repost on our website, I came across a story on NPR[1] about government cuts at NIST. Wired Magazine also covered the same story[2] about a group at NIST that just celebrated its 120th anniversary. The NIST Atomic Spectroscopy Group was reported to have been given notice of their cut, with an April deadline. A petition to save the group was circulated online, signed by 5,000+, but the story itself remained quiet.

I had to know what eventually came of the group, so I reached out to Dr. Yuri Ralchenko (former Leader of the Atomic Spectroscopy Group at NIST), who kindly provided me with not only an update, but patiently responded to my growing number of questions. Refer to the Industry and Research News section for the update. And for those interested, a colloquium of the history and work of this group can be found at: https://www.nist.gov/video/colloquium-120-years-atomic-spectroscopy-nist. The work this group does is exceedingly important for emerging technologies and scientific research all over the globe.

This issue is particularly packed with exceptional papers! Drumroll please…

Flavio Galliana with the Istituto Nazionale di Ricerca Metrologica (INRiM) of Italy and Alessio Pollarolo with Measurements International (MI) in Ontario, Canada sent us their paper explaining the development of "An All-In-One Automatic Multiple Standard for Artifact Calibration of High End Electrical Instruments." This collaboration resulted in the commercially available MI 1330A Artifact Transfer Standard.

Moving from electrical to force, Henry Zumbrun of Morehouse Instrument Company in York, Pennsylvania focuses in on deadweight force standards in his paper, "Deadweight Primary Standards: Best Practices and Their Associated Risks for Stability Determination in Compliance with ISO/IEC 17025." And finally, Christopher Grachanen shares with us a "New Accreditation Tool for Auditors and Laboratory Personnel."

All three papers reflect the valuable work of metrologists and their priority on a job not just well done, but meticulous as well. Thank you for the important work you do!

Happy Measuring,

Sita Schwartz
Editor

1 https://www.npr.org/2025/03/26/nx-s1-5340687/trump-cuts-nist-atomic-spectra-lab-advanced-chips-medical-devices
2 https://www.wired.com/story/nist-doge-layoffs-atomic-spectroscopy/

Sep 1-3, 2025 IMEKO TC2 The International Symposium on Modern Photonic Metrology. Modena, Italy. In alignment with its prestigious setting, PhotoMet 2025 will showcase how photonic technologies are driving sustainability, digital transformation, and industrial innovation. https://www.photomet.org/

Sep 2-5, 2025 IMEKO TC14 13th International Symposium on Measurement and Quality Control. Cluj-Napoca, Romania. Held in the historic city of Cluj-Napoca, Romania, ISMQC 2025 provides a unique opportunity to exchange ideas, share research findings, and build collaborations that drive innovation in metrology, measurement technology, and quality control. https://ismqc.utcluj.ro/

Sep 3-5, 2025 IMEKO TC6 International Conference on Metrology and Digital Transformation. Benevento, ITALY. The 2nd edition of M4DConf represents an international meeting place in the world of research in the field of metrology for digital transformation involving national and international institutions and academia in a discussion on the state-of-the-art concerning issues that require a joint approach by experts of metrology, measurement and instrumentation and industrial testing, typically professional engineers, and experts in innovation metrology. https://www.m4dconf.org/

Sep 14-17, 2025 IMEKO TC8, TC11, TC24 Joint Conference. Torino, Italy. This international conference aims to gather experts both from industry and academia, covering different topics from the fields of 'Traceability in Metrology' (IMEKO TC8), 'Measurement in Testing, Inspection and Certification' (IMEKO TC11), and 'Chemical Measurements' (IMEKO TC24). https://www.imekotorino2025.org/

Sep 15-17, 2025 IMEKO TC4 International Symposium. Zagreb, Croatia. The theme for this event is "Electrical Measurements in the Quantum, Digital and Energy storage world." https://imeko-tc4-2025.org/

Sep 15-17, 2025 IMEKO TC7 & TC13 Joint Symposium. Pretoria, South Africa. Celebrating 45 years of solving measurement challenges in South Africa and the region. https://www.nla.org.za/tm-2025-conference-workshop/

Sep 15-18, 2025 AUTOTESTCON. National Harbor, MD. AUTOTESTCON is the world's premier conference that brings together the military/aerospace automatic test industry and government/military acquirers and users to share new technologies, discuss innovative applications, and exhibit products and services. It is sponsored annually by the Institute of Electrical and Electronic Engineers (IEEE). https://2025.autotestcon.com/

Sep 21-26, 2025 European Microwave Week. Utrecht, Netherlands. EuMW 2025 comprises three co-located conferences: The European Microwave Conference (EuMC), The European Microwave Integrated Circuits Conference (EuMIC), and The European Radar Conference (EuRAD). https://www.eumweek.com/

Sep 22-24, 2025. TC23 8th IMEKOFOODS Conference. Ljubljana, SLOVENIA. The theme for this event is "Food Safety and Metrology for a Sustainable Future." The 8th IMEKOFOODS Conference aims to bring together leading scientists working in food-related fields, such as authenticity, traceability, nutrition, food safety, quality, and risk assessment, where metrology plays a crucial role. https://conferences.imeko.org/event/12/

Oct 7-8, 2025 26th International Symposium on Measurement and Control in Robotics. Sambreville, BELGIUM (Hybrid). ISMCR 2025 serves as a forum for the exchange of recent research results and novel ideas in robotic technologies and applications; this time with specific reference to smart mobility. https://ismcr.org/2025-ismcr/

SEMINARS & WEBINARS: Dimensional

Jun 26-27, 2025 Hands-On Precision Gage Calibration and Repair Training. Bloomington, MN. IICT Enterprises. Enhance your career knowledge in Metrology with this in-depth Gage use, Calibration, and Repair course. Recommended for people interested in pursuing the ASQ CCT Exam. https://calibrationtraining.com/

Jul 29-30, 2025 Virtual Hands-On Precision Gage Calibration and Repair Training. IICT Enterprises. Enhance your career knowledge in Metrology with this in-depth Gage use, Calibration, and Repair course. Recommended for people interested in pursuing the ASQ CCT Exam. https://calibrationtraining.com/

Aug 12-13, 2025 Hands-On Precision Gage Calibration and Repair Training. Portland, OR. IICT Enterprises. Enhance your career knowledge in Metrology with this in-depth Gage use, Calibration, and Repair course. Recommended for people interested in pursuing the ASQ CCT Exam. https://calibrationtraining.com/

Aug 12-14, 2025 EDU-114 Dimensional Gage Calibration and Repair. Aurora, IL. Mitutoyo America's Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. https://www.mitutoyo.com/training-education/

Aug 18-19, 2025 Hands-On Precision Gage Calibration and Repair Training. Santa Clarita, CA. IICT Enterprises. Enhance your career knowledge in Metrology with this in-depth Gage use, Calibration, and Repair course. Recommended for people interested in pursuing the ASQ CCT Exam. https://calibrationtraining.com/

Aug 21-22, 2025 Hands-On Precision Gage Calibration and Repair Training. Las Vegas, NV. IICT Enterprises. Enhance your career knowledge in Metrology with this in-depth Gage use, Calibration, and Repair course. Recommended for people interested in pursuing the ASQ CCT Exam. https://calibrationtraining.com/

CALENDAR

Sep 10-11, 2025 Hands-On Precision Gage Calibration and Repair Training. Schaumburg, IL. IICT Enterprises. Enhance your career knowledge in Metrology with this in-depth Gage use, Calibration, and Repair course. Recommended for people interested in pursuing the ASQ CCT Exam. https://calibrationtraining.com/

Sep 11-12, 2025 Dimensional Measurement Tools Basics Class. Greer, SC. QC Training. This program provides a fundamental and practical review of Basic Dimensional Measurement Tools and Methods, including variable gages such as steel rules, depth and dial gages, micrometers, and calipers. In addition, attribute gages such as plug, ring and screw thread gages are covered. https://qctraininginc.com/courses/

Sep 16, 2025 EDU-101 Introduction to Dimensional Metrology Hand Tools (Fundamental Tools). Aurora, IL. Mitutoyo. EDU-101 is a one-day class for entry-level team members who need to learn the fundamentals of the steel rule, caliper, micrometer, pin gage, and gage block. https://www.mitutoyo.com/training-education/

Sep 17-18, 2025 Hands-On Precision Gage Calibration and Repair Training. Omaha, NE. IICT Enterprises. Enhance your career knowledge in Metrology with this in-depth Gage use, Calibration, and Repair course. Recommended for people interested in pursuing the ASQ CCT Exam. https://calibrationtraining.com/

Sep 17-18, 2025 EDU-113 Dimensional Gage Calibration. Aurora, IL. Mitutoyo America's Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. This course is a condensed version of Seminar #114 (3-day version) focusing on small, hand-held gages. https://www.mitutoyo.com/training-education/

Sep 29-30, 2025 Virtual Hands-On Precision Gage Calibration and Repair Training. IICT Enterprises. Enhance your career knowledge in Metrology with this in-depth Gage use, Calibration, and Repair course. Recommended for people interested in pursuing the ASQ CCT Exam. https://calibrationtraining.com/

Sep 29-30, 2025 Dimensional Measurement Tools Basics Class. Mason, OH. QC Training. This program provides a fundamental and practical review of Basic Dimensional Measurement Tools and Methods, including variable gages such as steel rules, depth and dial gages, micrometers, and calipers. In addition, attribute gages such as plug, ring and screw thread gages are covered. https://qctraininginc.com/courses/

Oct 9, 2025 EDU-V111 Introduction to Dimensional Gage Calibration (1/2 day, Virtual). Mitutoyo America's Gage Calibration courses are unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. This course is taught in the Mitutoyo Institute of Metrology's Training Lab in Aurora, IL and broadcast live in a virtual session. https://www.mitutoyo.com/training-education/

Oct 9-10, 2025 Hands-On Precision Gage Calibration and Repair Training. Bloomington, MN. IICT Enterprises. Enhance your career knowledge in Metrology with this in-depth Gage use, Calibration, and Repair course. Recommended for people interested in pursuing the ASQ CCT Exam. https://calibrationtraining.com/

Oct 23-24, 2025 Virtual Hands-On Precision Gage Calibration and Repair Training. IICT Enterprises. Enhance your career knowledge in Metrology with this in-depth Gage use, Calibration, and Repair course. Recommended for people interested in pursuing the ASQ CCT Exam. https://calibrationtraining.com/

Nov 10, 2025 EDU-101 Introduction to Dimensional Metrology Hand Tools (Fundamental Tools). Aurora, IL. Mitutoyo. EDU-101 is a one-day class for entry-level team members who need to learn the fundamentals of the steel rule, caliper, micrometer, pin gage, and gage block.https://www.mitutoyo.com/training-education/

Nov 11-12, 2025 EDU-113 Dimensional Gage Calibration. Aurora, IL. Mitutoyo America's Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. https://www.mitutoyo.com/training-education/

Nov 13-14, 2025 Hands-On Precision Gage Calibration and Repair Training. Bloomington, MN. IICT Enterprises. Enhance your career knowledge in Metrology with this in-depth Gage use, Calibration, and Repair course. Recommended for people interested in pursuing the ASQ CCT Exam. https://calibrationtraining.com/

Nov 13-14, 2025 EDU-302 Small Tool Repair Course. Aurora, IL. Mitutoyo America is offering a two-day small tool gage maintenance and repair training. Hosted at the Mitutoyo America Headquarters in Aurora, Illinois, the course will be taught be Mitutoyo's very own repair specialists. https://www.mitutoyo.com/training-education/

Nov 20-21, 2025 Virtual Hands-On Precision Gage Calibration and Repair Training. IICT Enterprises. Enhance your career knowledge in Metrology with

Mastering High Voltage: The Importance of Accurate Test Equipment

Introduction

Accurate measurement of electrical performance parameters is crucial for the reliability and safety of high-voltage equipment and cabling.

For applications involving tens of thousands of volts, safety risks and demands on test equipment are high. Proper calibration of test instruments is essential to meet strict performance needs and standards, often conducted by certified laboratories with traceability to national standards like NIST.

This article is a synopsis of the full whitepaper available online at Vitrek.com and discusses the importance of high-voltage test equipment calibration and considerations for ensuring measurement accuracy.

HV Measurement Techniques

Various high-voltage measurement techniques have unique advantages and calibration needs:

- Step-Down Transformers: Reduce high voltage to manageable levels.
- Capacitive and Resistive Voltage Dividers: Divide voltage proportionally.
- Series Resistance (Microampere Measurement): Measure current through high resistance in series with voltage source.
- Analog Style Measurement Devices:
  - Sphere Gaps: Measure breakdown voltage between two spheres.
  - Electrostatic Measurement: Quantify electrostatic force between two plates

Why Measure High Voltage?

Measuring high voltage is increasingly important as technology advances. High-voltage systems reduce current carrying requirements and minimize energy loss. Also, in many cases, voltage values determine system performance. This means the voltage sources must be accurate and reliable in order to meet systems specifications. Also, monitoring systems need to be in place to ensure that the systems perform reliably from end-to-end and year-to-year.

Many types of equipment are used for high-voltage measurement.

High-Voltage Applications by Industry

High voltage is used in various fields including:

- Defense/Aerospace
- Manufacturing
- Research
- Power Products
- Inspection
- Medical
- Semiconductor
- And More

Conclusion

As technology advances, the importance of accurate high-voltage measurements will only grow, making it essential for industries to invest in proper calibration practices. Ultimately, mastering high-voltage measurement is about safeguarding both the equipment and the people who rely on it, ensuring a safer and more efficient future for all.

This article is a synopsis of a free whitepaper that provides additional materials including Calibration of High-Voltage Test Equipment and Choosing the right HV Test Equipment for the Application.

View the full article at: https://bit.ly/4kCQW1J

this in-depth Gage use, Calibration, and Repair course. Recommended for people interested in pursuing the ASQ CCT Exam. https://calibrationtraining.com/

SEMINARS & WEBINARS: Electrical

Sep 29-Oct 2, 2025 MET-301 Advanced Hands-On Metrology. Everett, WA. Fluke Calibration. This course introduces the student to advanced measurement concepts and math used in standards laboratories. https://www.fluke.com/

Nov 3-6, 2025 MET-101 Basic Hands-On Metrology. Everett, WA. Fluke Calibration. This Metrology 101 basic metrology training course introduces the student to basic measurement concepts, basic electronics related to measurement instruments and math used in calibration. https://www.fluke.com/

SEMINARS & WEBINARS: Flow

Sep 23-26, 2025 Gas Flow Calibration Using molbloc/molbox. Phoenix, AZ. Fluke Calibration. This is a four day training course in the operation and maintenance of a Fluke Calibration molbloc/molbox system. https://www.fluke.com

SEMINARS & WEBINARS: Force & Torque

Sep 8-12, 2025 Fundamentals of Force Metrology: Practical Approach. Pretoria, South Africa. NMISA. At the end of the course, attendees should have a good understanding of the fundamentals of force metrology principles and force measurements. https://www.nmisa.org/applied-metrology/Pages/Metrology-Training-Centre.aspx

Sep 10-12, 2025 Force Fundamentals Training Course. York, PA. Morehouse. Whether you're new to force calibration or looking to sharpen your expertise, this course will help you improve accuracy and confidence in your measurements. https://mhforce.com/

Sep 15-19, 2025 Fundamentals of Torque Metrology: Practical Approach. Pretoria, South Africa. NMISA. At the end of the course, attendees should have a good understanding of the fundamentals of torque metrology principles and torque measurements. https://www.nmisa.org/applied-metrology/Pages/Metrology-Training-Centre.aspx

SEMINARS & WEBINARS: General

Sep 15-17, 2025 C-101 Calibration. Mobile, AL. TriNova Technical Education. This instructor led calibration course is delivered by our experienced technical education specialists who deliver a high-quality course covering calibration fundamentals, detailed documentation procedures, temperature, and pressure basics, and basics of DP flow calibration. In-depth demonstrations and hands-on exercises will follow each lecture. https://trinova.arlo.co/w/

Sep 15-19, 2025 Fundamentals of Metrology. Gaithersburg, MD. NIST. The 5-day Fundamentals of Metrology seminar is an intensive course that introduces participants to the concepts of measurement systems, units, good laboratory practices, data integrity, measurement uncertainty, measurement assurance, traceability, basic statistics and how they fit into a laboratory Quality Management System. https://www.nist.gov/pml/owm/owm-training-and-events

Oct 20-22, 2025 C-101 Calibration. Memphis, TN. TriNova Technical Education. This instructor led calibration course is delivered by our experienced technical education specialists who deliver a high-quality course covering calibration fundamentals, detailed documentation procedures, temperature, and pressure basics, and basics of DP flow calibration. In-depth demonstrations and hands-on exercises will follow each lecture. https://trinova.arlo.co/w/

SEMINARS & WEBINARS: Industry Standards

Jun 24-25, 2025 Understanding ISO/IEC 17025 for Testing and Calibration Labs. Online training for the Americas. IAS. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/training/ias-training-schedule/

Jul 8-9, 2025 Understanding ISO/IEC 17025 for Testing and Calibration Labs. Online training for the Middle East and South Asia. IAS. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/training/ias-training-schedule/

Aug 5-6, 2025 Understanding ISO/IEC 17025 for Testing and Calibration Labs. Online training for the Americas. IAS. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/training/ias-training-schedule/

Aug 11-14, 2025 Understanding ISO/IEC 17025:2017 for Testing & Calibration Labs. Virtual. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. https://a2lawpt.org/

Aug 11-14, 2025 Auditing Your Laboratory to ISO/IEC 17025:2017. Virtual. A2LA WorkPlace Training. This ISO/IEC 17025 auditor training course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. https://a2lawpt.org/

Sep 9-10, 2025 Understanding ISO/IEC 17025 for Testing and Calibration Labs. Online training for the Middle East and South Asia. IAS. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/training/ias-training-schedule/

Sep 16-17, 2025 Understanding ISO/IEC 17025:2017 for Testing & Calibration Labs. Virtual. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. https://a2lawpt.org/

Sep 16-17, 2025 Auditing Your Laboratory to ISO/IEC 17025:2017. Virtual. A2LA WorkPlace Training. This ISO/IEC 17025 auditor training course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. https://a2lawpt.org/

Sep 16-17, 2025 ISO/IEC 17043:2023 and Statistical Analysis for Proficiency Testing. Virtual. A2LA WorkPlace Training. This course provides the participant with a comprehensive look at Proficiency Testing (PT), including the design and operation of PT schemes, statistical methods, reporting, and interpretation. https://a2lawpt.org/

Oct 7-8, 2025 Understanding ISO/IEC 17025 for Testing and Calibration Labs. Online Training for the Americas. IAS. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/training/ias-training-schedule/

Oct 13-16, 2025 Understanding ISO/IEC 17025:2017 for Testing & Calibration Labs. Virtual. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. https://a2lawpt.org/

Oct 13-16, 2025 Auditing Your Laboratory to ISO/IEC 17025:2017. Virtual. A2LA WorkPlace Training. This ISO/IEC 17025 auditor training course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. https://a2lawpt.org/

SEMINARS & WEBINARS: Mass

Oct 6-10, 2025 Mass Metrology Course for High Accuracy: OIML class F to E. Pretoria, South Africa. NMISA. The course provides fundamentals of mass measurements, looking at what affects reliability and accuracy of mass measurements, and how to ensure traceability in weighing. It also covers the evaluation of different weighing techniques used to calibrate mass pieces, the requirements for and calibration of weighing instruments and how to evaluate measurement uncertainty in weighing. https://www.nmisa.org/applied-metrology/Pages/Metrology-Training-Centre.aspx

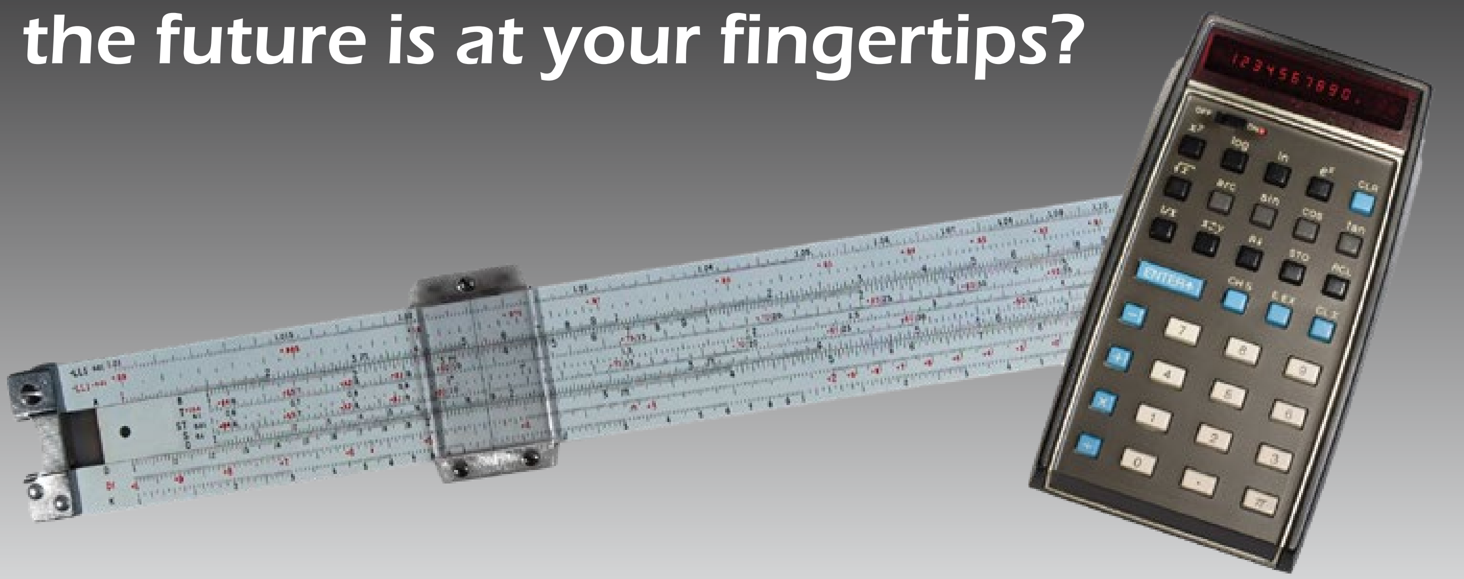
Oct 27-Nov 7, 2025 Mass Metrology Seminar. Gaithersburg, MD. NIST. The Mass Metrology Seminar is a two-week, "hands-on" seminar. It incorporates approximately 30 percent lectures and 70 percent demonstrations and laboratory work in which the trainee performs measurements by applying procedures and equations discussed in the classroom. https://www.nist.gov/pml/owm/owm-training-and-events

SEMINARS & WEBINARS: Measurement Uncertainty

Jul 22-23, 2025 Uncertainty of Measurement for Labs. Online training for the Americas. IAS. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/uncertainty-of-measurement/

METROLOGY.NET®

Why struggle with the past when the future is at your fingertips?



DISRUPTIVE INNOVATION

The **1972 introduction of the HP-35 scientific calculator** by Hewlett-Packard was a **classic example of disruptive innovation** that also triggered a **paradigm shift** in engineering and scientific calculations. The HP-35 effectively rendered the **slide rule**, the dominant tool for engineers and scientists for decades, **obsolete almost overnight**.

Similarly, **Metrology.NET** is positioned to revolutionize the calibration industry by replacing outdated legacy software with a modern, integrated, and automated solution.

Aspect	Slide Rule (Legacy Software)	HP-35 Calculator (Metrology.NET)
Ease of Use	Complex, requires expertise and training	Simple, intuitive, minimal learning curve
Speed & Efficiency	Slow, manual calculations	Fast, automated processing
Accuracy	Prone to human error	Highly precise with minimal error
Portability/Scalability	Bulky, single-user	Compact, multi-user, and scalable
Technological Advancement	Mechanical, limited in functions	Digital, continuously evolving
Market Disruption	Decades of dominance ended overnight	Established software is now outdated
Cost & ROI	Initially cheaper, but labor-intensive	Higher upfront, but massive long-term savings

METROLOGY.NET®
Better software. Better metrology.

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sales@callabsolutions.com

CALENDAR

Aug 18-19, 2025 Uncertainty of Measurement for Labs. Online training for the Middle East and South Asia. IAS. https://www.iasonline.org/training/ias-training-schedule/

Sep 9-10, 2025 Introduction to Measurement Uncertainty. Virtual. A2LA WorkPlace Training. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://a2lawpt.org/

Oct 21-22, 2025 Uncertainty of Measurement for Labs. Online training for the Americas. IAS. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/uncertainty-of-measurement/

Nov 17-18, 2025 Uncertainty of Measurement for Labs. Online training for the Middle East and South Asia. IAS. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/uncertainty-of-measurement/

SEMINARS & WEBINARS: Pressure

Oct 20-24, 2025 Advanced Piston Gauge Metrology. Phoenix, AZ. Fluke Calibration. Focus is on the theory, use and calibration of piston gauges and dead weight testers. https://www.fluke.com

Nov 10-14, 2025 TWB 1061 Principles of Pressure Calibration Web-Based Training (Online). Fluke Calibration. This is a short form of the regular five-day in-person Principles of Pressure Calibration class. https://www.fluke.com

SEMINARS & WEBINARS: RF & Microwave

Sep 1-5, 2025 RF & Microwave Metrology Fundamentals. Pretoria, South Africa. NMISA Training Center. This course is aimed at teaching theoretical and practical principles of measurements and calibrations in RF and Microwave Metrology. Overviews of various instrumentation used for the measurements and calibrations will also be discussed. https://www.nmisa.org/applied-metrology/Pages/Metrology-Training-Centre.aspx

SEMINARS & WEBINARS: Software

Jun 23-27, 2025 TWB 1031 MET/CAL® Procedure Development Web-Based. Online. Fluke Calibration. Learn to create procedures with the latest version of MET/CAL, without leaving your office. https://www.fluke.com

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Jul 8-10, 2025 MC-203 Crystal Report Writing. Everett, WA. Fluke Calibration. This course is designed for those who are involved with modifying or writing custom reports for use with MET/TEAM. https://www.fluke.com

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SEMINARS & WEBINARS:
Temperature & Humidity

Aug 18-22, 2025 Non-Contact Thermometry Metrology. Pretoria, South Africa. NMISA Training Center. https://

www.nmisa.org/applied-metrology/Pages/Metrology-Training-Centre.aspx

Sep 3, 2025 Testing Temperature Controlled Enclosures. Lindfield, NSW. NMI of Australia. This one day course is for people involved in routine performance testing of temperature-controlled enclosures (oven, furnace, refrigerator and fluid bath). It incorporates an extensive overview and comparison of AS2853 and IEC 60068-3-5 requirements, and it also includes an overview of the medical refrigeration equipment temperature mapping requirement to AS3864.2 https://shop.measurement.gov.au/

SEMINARS & WEBINARS: Volume

Sep 22-26, 2025 Volume Metrology Seminar. Gaithersburg, MD. NIST. The 5-day OWM Volume Metrology Seminar is designed to enable metrologists to apply fundamental measurement concepts to volume calibrations. A large percentage of time is spent on hands-on measurements, applying procedures and equations discussed in the classroom. https://www.nist.gov/pml/owm/owm-training-and-events

SEMINARS & WEBINARS: Weight

Nov 4-7, 2024 5853 Balance and Scale Calibration and Uncertainties. NIST. Gaithersburg, MD. This 4-day seminar will cover the calibration and use of analytical weighing instruments (balances and laboratory/bench-top scales), including sources of weighing errors in analytical environments, methodologies for quantifying the errors, and computation of balance calibration uncertainty and global (user) uncertainty. https://www.nist.gov/pml/owm/training

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NIST Group Finds a New Home

The scientific community was shocked to learn this past March that the NIST Atomic Spectroscopy Group would be subject to the new government efficiency cuts. Providing the global scientific community with a continually updated atomic spectra database, the Atomic Spectroscopy Group celebrated its 120th anniversary in December 2024.[1] Because of the Group's long history and well-referenced research, it received much moral support from the international community. Dr. Yuri Ralchenko, former Leader of the Atomic Spectroscopy Group at NIST, now Principal Research Scientist at the Department of Astronomy at University of Maryland, said in an email "I must say that we received incredible support from the community, from numerous reports in the media (search for "NIST atomic spectroscopy") to hundreds of email of support and encouragement to a petition on change.org."

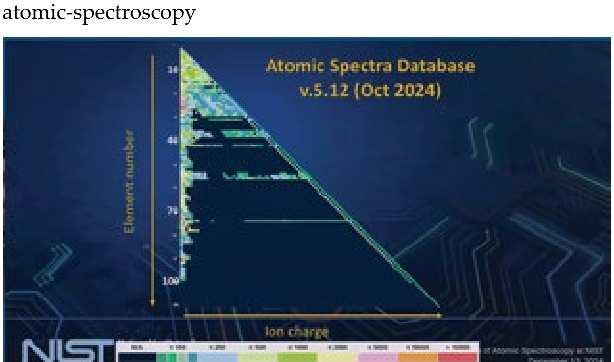
The NIST website still states the mission of the Atomic Spectroscopy Group "is to measure, calculate, critically compile, and disseminate reference data on atomic properties and fundamental constants in support of basic research, commercial development, and national priorities."[2]

Though their mission statement will ultimately change, it turns out the Group will continue much of their work at the NASA Goddard Space Flight Center (GSFC), as employees of University of Maryland College Park, beginning July 1st. The Atomic Spectra Database and online tools will remain static on NIST's website, while the databases and some experiments (and their associated spectrometers) will transfer to Goddard. It was noted that instruments impractical for moving were to remain at NIST.

Once the Group transitions to the GSFC, they will discuss with management where they can best contribute. Hopefully, we can look forward to a press release from NASA GSFC about the availability of new spectra data and continuing experiments of the Group.

1 https://www.nist.gov/video/colloquium-120-years-atomic-spectroscopy-nist

2 https://www.nist.gov/pml/quantum-measurement/atomic-spectroscopy



A slide by Dr. Yuri Ralchenko, presented during the 120th anniversary Colloquium at NIST Gaithersburg, 12/13/2024.

2025 World Metrology Day Marks the 150th Anniversary of the Metric Convention

The 20 May is World Metrology Day, commemorating the anniversary of the signing of the *Metre Convention* in Paris, in 1875. This treaty provides the basis for a worldwide coherent measurement system that underpins scientific discovery and innovation, industrial manufacturing and international trade, as well as the improvement of the quality of life and the protection of the global environment.

The theme for World Metrology Day 2025 is ***Measurements for all times, for all people***, chosen to highlight the importance of measurements in shaping our past, present and future. This theme has added significance in 2025, which marks the 150th Anniversary of the Metre Convention.

As a tribute to this milestone, World Metrology Day 2025 will be at the core of events to celebrate a century and a half of international collaboration in metrology. From ensuring fair trade and advancing scientific discovery to addressing global challenges like climate change and public health, measurements have been fundamental for progress and innovation. The theme also emphasizes inclusivity, recognizing that reliable and traceable measurements are essential for fostering equity and improving the quality of life for all people, everywhere.

Around the world, national metrology laboratories continually advance measurement science by developing and validating new measurement techniques at the necessary level of sophistication. The national metrology institutes participate in measurement comparisons coordinated by the *Bureau International des Poids et Mesures* (BIPM) or by the Regional Metrology Organizations, to ensure the reliability of measurement results worldwide.

The *International Organization of Legal Metrology* (OIML) develops International Recommendations, which aim to align and harmonize requirements worldwide in many fields. The OIML also operates the OIML Certification System (OIML-CS) which facilitates international acceptance and global trade of regulated measuring instruments.

These international metrology systems provide the necessary assurance and confidence that measurements are accurate, providing a sound basis for global trade today and helping us to prepare for the challenges of tomorrow.

World Metrology Day acknowledges and honors the contributions of individuals working in intergovernmental, regional, and national metrology organizations and institutes year-round. In November 2023, a significant milestone was reached as the UNESCO General Conference, during its 42nd Session, officially recognized the celebration on 20 May annually. Underscoring its pivotal role in advancing global scientific cooperation, this endorsement opens up new avenues to promote metrology, aligning with UNESCO's mission to build a better world through science and education.

Source: https://www.worldmetrologyday.org/press_release_en.html

NASA's ER-2 taking off with the air-LUSI moonlight collection equipment on board. Credit: NASA photo/Ken Ulbrich

NIST Moonlight Data Will Help Satellites Get a More Accurate Look at Earth

May 20, 2025, NIST News — Weather forecasting, mineral prospecting and farming all could improve from a trove of data the National Institute of Standards and Technology (NIST) recently gathered about moonlight, late at night and far above the clouds.

NIST's measurements of the Moon's brightness — 10 times more accurate than previously available data — are a valuable commodity for engineers, who can use the data to calibrate the visual sensors aboard Earth-observing satellites. Proper calibration can help ensure that these satellites are accurately recording the actual amounts and colors of light from the ground, water and vegetation far below. NIST obtained its new set of moonlight measurements by deploying its equipment on a high-altitude NASA aircraft[1].

"Our goal with this data release is to help the satellite industry develop better models of lunar irradiance," said Joe Rice, the NIST group leader for the project. "Using the data will help ensure that scientists have a more accurate understanding of what images of Earth from orbit actually mean."

Before a satellite can take reliable visuals of the planet, the satellite's sensors need to be calibrated to make sure they are recording accurate data. Without this vital step, a sensor might indicate that a swath of territory is a different shade or intensity of color than it really is, leading farmers or prospectors to base their decisions on the inaccuracy.

Sometimes engineers calibrate satellites before launch, but it costs time, money and effort, partly because a rocket ride to space puts a lot of stress on a satellite. The acceleration of launch subjects a satellite to forces that are the equivalent of many times Earth's gravity, and powerful vibrations during flight shake and rattle the instruments vigorously, potentially undoing the effects of the calibrations.

Larger satellites might carry devices that allow them to self-calibrate after launch, but such devices add weight and use up valuable real estate. And not all satellites are large enough even to have this option. In cubesats[2], built from a few cubic modules that are 10 centimeters to a side, volume is at a premium.

An easier approach is to use light from the Moon, which has reflectance properties that change very little over time and therefore offers a consistent benchmark. From time to time, a satellite sensor may take an image that includes the Moon, and the sensor can be calibrated to the different wavelengths of light reflecting from its surface.

Land-based telescopes have trouble getting accurate details of the Moon's irradiance because our planet's constantly changing atmosphere introduces too much uncertainty. So NIST physicist John Woodward and his colleagues arranged to mount a special telescope on a NASA ER-2 aircraft that flies at 70,000 feet, or 21 kilometers, which is higher than 95% of the atmosphere. The mission, called the Airborne Lunar Spectral Irradiance Mission (air-LUSI), flew from NASA's Armstrong Flight Research Center[3]. After several years of engineering and test flights[4], the project began gathering data in 2022 and conducted its most recent measurements in early 2025.

The new dataset allows distinct improvements over previous lunar irradiance models, which were good at measurements that could show how a sensor's performance

The air-LUSI telescope during a calibration. The light on the other side of the room is an "artificial moon," a stable source of light that has already been well characterized. Credit: NASA photo/ Ken Ulbrich

1 https://www.nasa.gov/centers-and-facilities/armstrong/nasa-measures-moonlight-to-improve-earth-observations/

2 https://www.nasa.gov/what-are-smallsats-and-cubesats/

3 https://www.nasa.gov/armstrong/

4 https://www.nist.gov/news-events/news/2019/11/fly-me-partway-moon

was changing over time but made it difficult to know if and how the Earth itself was changing. The new data not only reduces the uncertainty inherent in ground-based data, but it is also directly tied to the International System of Units (SI), making it easier to apply.

"This dataset is 10 times more accurate than the data people previously had to use," said Woodward. "It will permit a distinct improvement over the other ways we have calibrated satellites."

The dataset, now available through NIST's data portal[5], is in the netCDF format widely used by the scientific community. It contains irradiance measurements along with the time, location and uncertainty associated with them. It includes information about the instrument NIST used, to help people make useful comparisons with their own sensors' performance. Also available are details of how to read and display the data along with guidance to help users get started working with it.

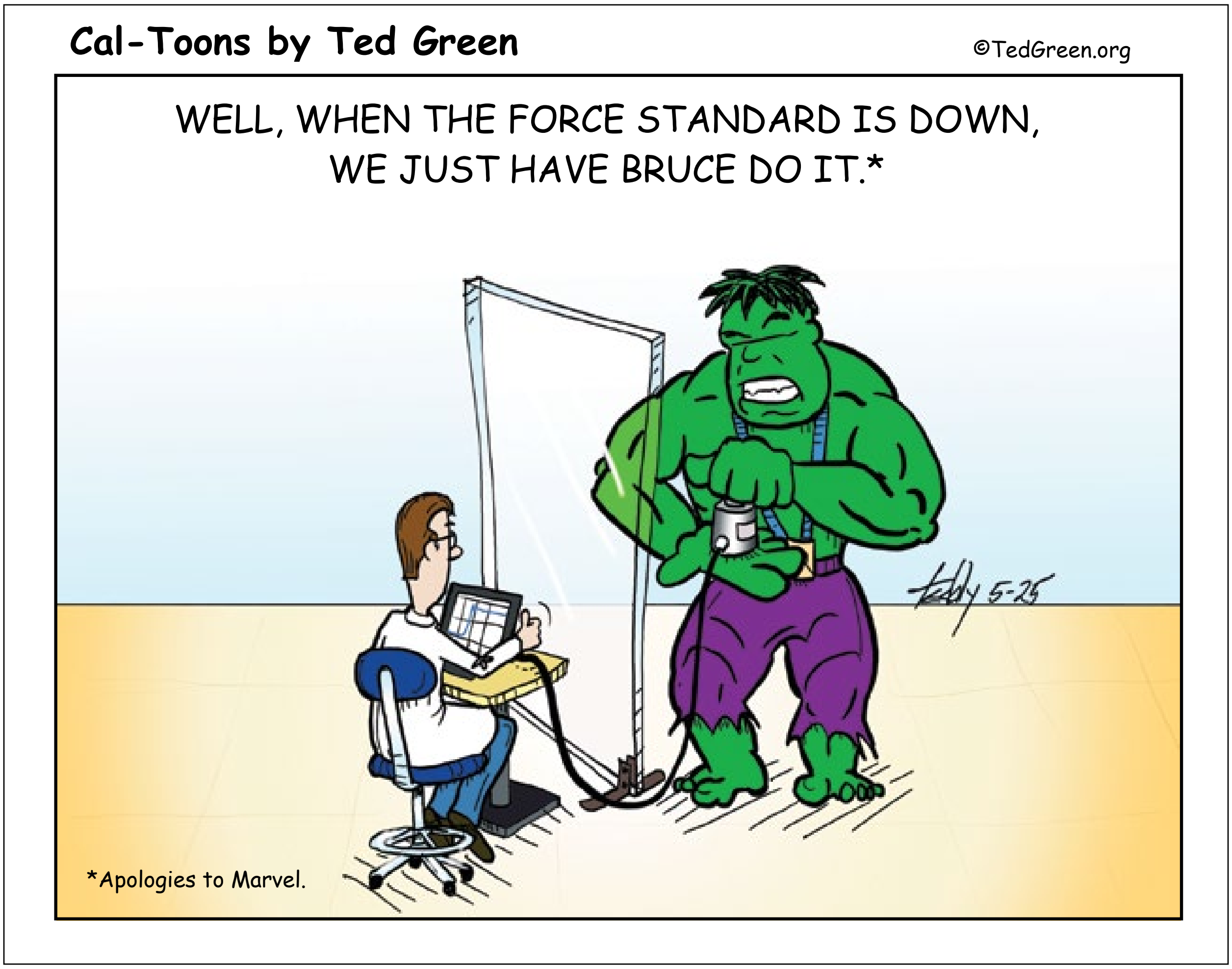
Woodward said he was optimistic about the future use of the dataset. One reason is because accurate, consistent calibration among satellites would enable observers on the ground to spot trends more effectively.

"Satellites are expensive national assets, and you want them to be as useful as possible," he said. "If we calibrate them using the Moon, satellite observations could become more valuable. For example, we'd know whether the color of farmland had changed because rain had improved crop health, rather than because two different satellites took two different images at different times."

The air-LUSI project is a collaboration between scientists and engineers from NASA, NIST, the U.S. Geological Survey, the University of Maryland Baltimore County, and Ontario's McMaster University.

Source: https://www.nist.gov/news-events/news/2025/05/nist-moonlight-data-will-help-satellites-get-more-accurate-look-earth

5 https://github.com/usnistgov/air-lusi



An All-In-One Automatic Multiple Standard for Artifact Calibration of High End Electrical Instruments

Flavio Galliana[1]
Istituto Nazionale di Ricerca Metrologica (INRiM), Turin, Italy

Alessio Pollarolo
Measurements International Ltd. (MI), Ontario, Canada

An automated temperature-controlled DC Voltage-DC Resistance Multiple Standard (VRMS) for artifact calibration of high end calibrators and multimeters was developed by Measurements International (MI) with the support of the Istituto Nazionale di Ricerca Metrologica (INRiM). The VRMS consists of a 10 V, a 1 Ω, and a 10 kΩ standards selectable via a low thermal scanner. The two resistors are high-stability MI standards while the 10 V standard is based on a low-noise circuit developed by INRIM. A smart feature of the VRMS is its internal algorithm providing updated calibration values of the VRMS standards ensuring their reliably use in the whole period between calibrations. The standards are housed in a thermal box shielding them from temperature changes. The use uncertainties of the VRMS standards are consistent with those for artifact calibration of calibrators and multimeters. The VRMS standards can also act as laboratory references or traveling standards for interlaboratory comparisons (ILCs). MI is currently commercializing the VRMS as 1330A Artifact Transfer Standard.

1. Introduction

Electrical calibration laboratories operate in the five electrical quantities in low frequency (DC and AC Voltage, DC and AC current and DC Resistance), typically in the following ranges to calibrate both generators and meters:

- from 0V to 1000 V for DC and AC Voltage (from 10 Hz to 1 MHz for AC voltage);
- from 0 A to 30 A for DC and AC Current (from 10 Hz to 5 kHz for AC current);
- from 1 Ω to 100 MΩ for DC Resistance.

These laboratories are usually equipped with modern electrical digital programmable instruments as digital multimeters (DMMs) and multifunction calibrators (MFCs) that cover wide ranges and replace standards (often manually operating) that in the past were used to cover the same fields. DMMs and MFCs require annual calibration with traceability to the International System of Units (SI) through the national standards maintained by National Metrology Institutes (NMIs). These instruments can be fully calibrated with a wide set of primary standards, as DC voltage and resistors, DC and AC voltage dividers, AC/DC transfer standards, DC and AC current shunts to cover their measurement ranges. This choice, although granting the best calibration uncertainties, is time consuming and very expensive for the calibration costs of all the reference standards at NMIs. At a slightly lower uncertainty level, DMMs and MFCs can be calibrated using, as traceability transfer standard, a DMM or a multifunction transfer standard [1]. Alternatively, DMMs and MFCs can be calibrated (adjusted) with few primary standards by means of the artifact calibration [2, 3]. To fulfil this need, Measurements International (MI) and the Istituto Nazionale di Ricerca Metrologica (INRiM) jointly developed an automated temperature-controlled DC Voltage and DC Resistance Multiple Standard (VRMS) for artifact calibration. The VRMS standards can also function as laboratory references in National Measurement Institutes (NMIs) or travelling standards for interlaboratory comparisons (ILCs) [4].

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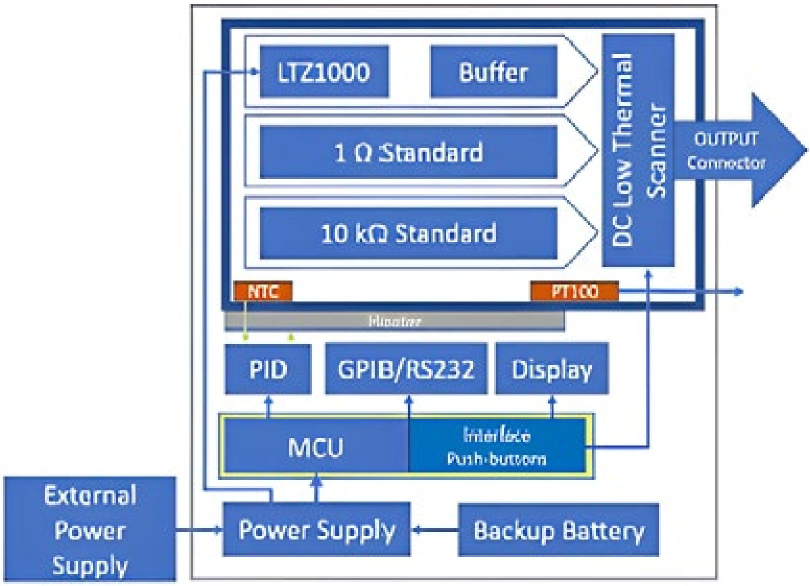

Figure 1. Block diagram of the VRMS. The three standards and the scanner are at constant temperature in an electrostatic shield separated from the electronic control and interfacing system and the power supply. This scheme is reported on the instrument manual [8].

1.1 The Artifact Calibration

The artifact calibration is an in-house calibration (adjustment) method requiring only three standards: 10 V, 1 Ω, and 10 kΩ. This procedure updates the internal references of DMMs and MFCs, which then automatically update the other ranges and functions (self-adjustment). Inside the instruments being calibrated, null detectors compare the measurements and dividers scale the measurement ranges. Artifact calibration makes no physical adjustment, but correction constants are stored. At INRiM, portable temperature-controlled setups for artifact calibration of multifunction instruments were already developed [5-7]. Relying on these experiences, MI, with the scientific support of INRiM, developed an automated temperature-controlled DC Voltage and DC Resistance Multiple Standard (VRMS) for artifact calibration. The VRMS includes a 10 V voltage standard and a 1 Ω and a 10 kΩ resistors. It is also equipped with a low-thermal-output scanner to select the standard minimizing electromotive forces (EMFs) and contact resistances during switching operations. The scanner also allows the polarity reversal of the 10 V standard.

2. The VRMS Setup

Figure 1 shows the block diagram of the VRMS. The standards are placed in a temperature-controlled box where the temperature is monitored by a 100 Ω Platinum Resistance Thermometer (PRT). This aluminium box is internal at the VRMS case (thick blue line in Figure 1). The aluminum box containing the standards is anchored to a thermal mass at 35 °C. This stable temperature minimizes thermal changes, enhancing the stability of the standards. The VRMS has an internal battery and supports remote control via RS-232 or GPIB interfaces. A stabilization period of 12 hours is required after powering on the VRMS to ensure that its standards are ready for accurate measurements [8]. The selected standard is connected to the output via a LEMO- connector and a scanner, either for its calibration or as a reference for artifact calibration.

3. The VRMS Standards

The manufacturer's data sheet reports for the three standards a Temperature coefficient (TCR)[2] of 0.1×10^{-6}/°C and stabilities of 1.5×10^{-6}/year and

2 For ambient temperatures in the range (23 ± 5) C.

Temperature	Deviation from nominal value (×10^{-6})		
(°C)	10 V	1 Ω	10 kΩ
18	1.91		
19			
20	1.84		
21		9.8	-9.49
22	1.85		
23	2.04	10.1	-9.51
24	1.93		
25		10.2	-9.6
26	1.82		
27			
28	1.84		

Table 1. Temperature dependence of the reference standards. The measurements of the 10 V standard were made placing the VRMS inside the INRIM climatic chamber, but the resistors were measured outside the VRMS case.

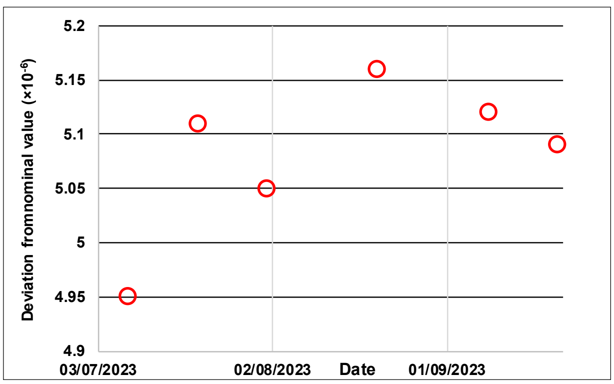

Figure 2. Mean values of the 10 V of a VMRS measured in the INRiM thermal bath.

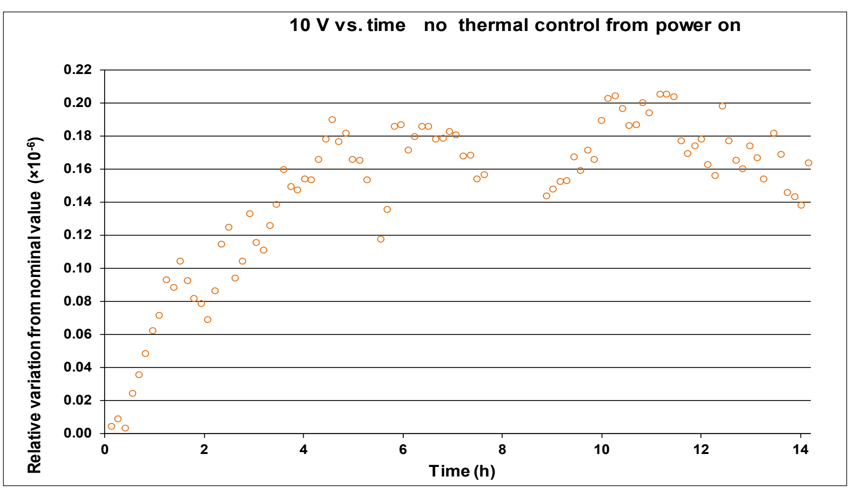

Figure 3. Short-time dependence of the 10 V without thermal control from its power on in laboratory environment.

0.5×10^{-6}/year respectively for the 10 V and for the two resistors respectively. The resistors are manufactured by MI [8]. The 1 Ω is a bifilar non-inductive element with low and negligible temperature and pressure coefficients respectively. Its voltage terminals are welded using Evanohm [9] filler to minimize EMF. An annealing procedure lowers its TCR. The 10 kΩ resistor is instead a metal foil element [10]. The first prototype of the 10 V standard was realized at INRiM with a Zener diode (LTZ1000) maintained at 48 °C. The layout of the 10 V standard minimized thermal effects. The TCR of the standards was evaluated by placing a VRMS in an INRiM thermo-regulated air bath with a stability better than ± 0.01 °C.

The TCR of standards were estimated, assuming linear drifts, 22 nV/V/°C, 0.11 µΩ/Ω/°C and 0.16 µΩ/Ω/°C for the 10 V, 1 Ω and 10 kΩ respectively.

Figure 2 shows the drift of the 10 V in the VRMS in the INRIM climatic chamber at 23 °C. It was evaluated on the order of 2.8 nV/V/day, corresponding to about 1.2 µV/V/year, in line with the manufacturer specification. Figure 3 shows the drift of the 10 V outside the VRMS after power on, in a laboratory thermo-regulated at (23 ± 0.5) °C. This test was made during the assembly of the 10 V prototype.

Figure 3 shows that the drift of the 10 V standard without thermal control is significantly higher in the first seven hours after power-up, approximately 2.2×10^{-8} per hour, and decreases to about 1.4×10^{-9} per hour between the 8th and 14th hour. The thermal control of the VRMS, maintained at ± 0.1 °C, combined with a stabilization period of at least 12 hours prior to measurements, improves the stability of this standard. This time period is also consistent with the stabilization of DMMs and MFCs. Figures 4a–c show the long-term stability of the standards of a VRMS, beginning from its assembly. The measurements were performed in a MI laboratory, at (23 ± 0.5) °C. The standards show a significant drift during the first year and a half presumably due to components stabilization. After this stabilization period, the drift decreases and aligns with the manufacturer's specifications.

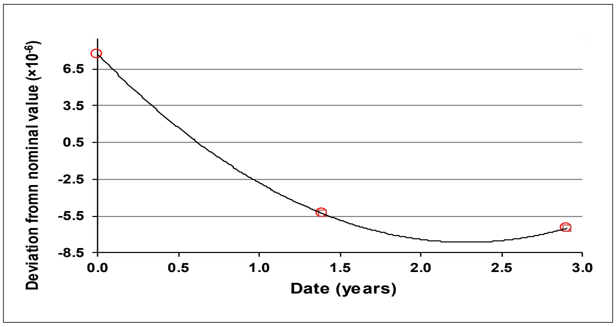

Figure 4a. Long-time stability of the 10 V.

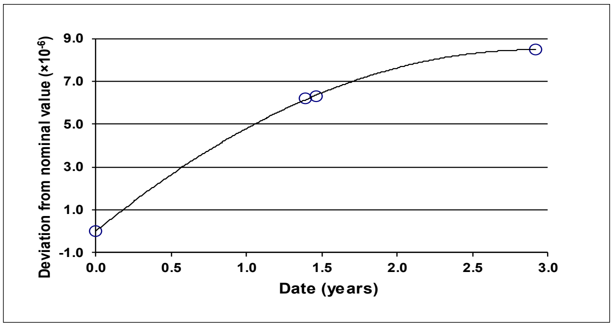

Figure 4b. Long-time stability of the 1 Ω.

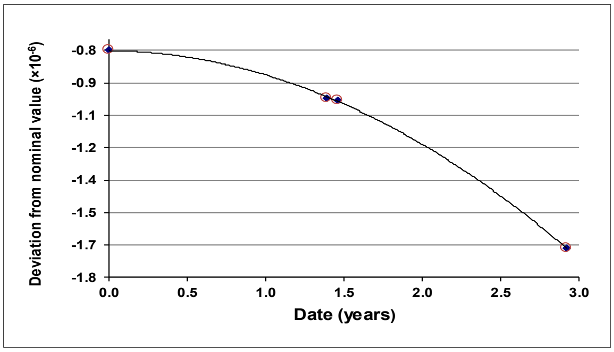

Figure 4c. Long-time stability of the 10 kΩ.

4. Calibration of the VRMS Standards

The 10 V standard can be calibrated either by comparison with a 10 V reference standard or through the Josephson effect [11] via a dedicated connection, using a nanovoltmeter as a null detector. The resistors can be calibrated with current comparator bridges by comparison with reference resistors traceable to the von Klitzing constant [12] or as a direct comparison to the quantum Hall effect with a cryogenic current comparator [13]. Table 2 reports the calibration results of the standards of a VRMS at INRiM.

Nominal values	Calibration values	Measurement current mA	Relative expanded uncertainties (k = 2) (×10^{-6})
10V	10.000051 V		0.5
1 Ω	1.0000101 Ω	100	0.5
10 kΩ	9999.905 Ω	0.1	0.5

Table 2. Calibration results at INRIM of a VRMS standards at 23 °C.

5. Performing Artifact Calibration

Figure 5 shows a measurement setup for the artifact calibration of a MFC using the VRMS standards. The connections and calibration steps are usually reported in the user manuals of the instruments undergoing artifact calibration. For example, the Fluke 5720 MFC [14] shows the changes of its internal references as ± part per million (ppm). Table 3 shows a short report of an artifact calibration carried out at INRiM with the VRMS standards.

Figure 5. Photo of the measurement setup for artifact calibration of a J. Fluke 5720 MFC (below) with the VRMS (above).

Standard	**Reference values**	**J. Fluke 5720 reference changes** (ppm)	
10 V VRMS	10.000051 V	6.5 V 13 V	0.3 -0.3
10 kΩ VRMS	9.999905 kΩ	10 kΩ	0.1
1 Ω VRMS	1.0000101 Ω	1 Ω 1.9 Ω	-2.9 -3.7

Table 3. Short report of an artifact calibration at IRiM of a Fluke 5720 MFC with the VRMS standards.

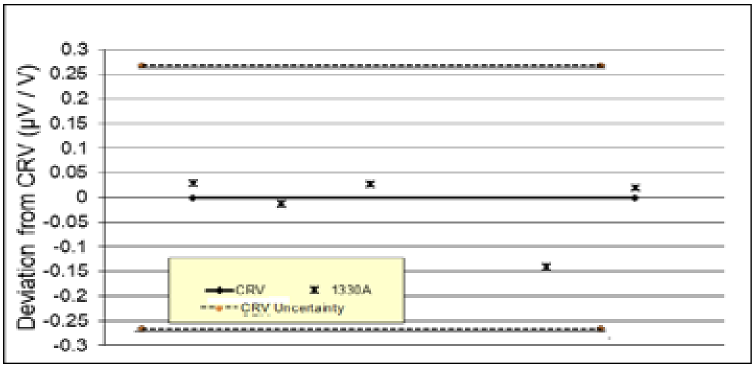

Figure 6. Results of an ILC on DC Voltage at 10 V involving the 10 V standard of a VRMS (1330 A) as one of the traveling standards.

6. Interlaboratory Comparison Involving the 10 V of a VRMS

ILCs [4] are the most important mean for comparing the measurement results of calibration laboratories. They are an effective means to assess the competence of participants and are also important to monitor the quality of calibration results. The 10 V standard of a VRMS was involved as one of the traveling standards in an ILC on DC Voltage. The other traveling standards were two J. Fluke 732B standards. Figure 6 shows the comparison results drift corrected at 10 V regarding only the measurements on the 10 V of the traveling VRMS. The figure shows also the Comparison Reference Value (CRV) and its uncertainty at $k = 2$ [15]. These two parameters are obtained from the measurements and uncertainties of all the participants on all the circulating 10 V standards as weighted mean. The measurements on the VRMS 10 V (MI 1330 A) were satisfactory as falling within the uncertainties of the CRV.

7. How the VRMS Calculates the Real-Time Value of the Standards

Normally, artifact calibration must be performed as soon as possible after the calibration of the 10 V, 1 Ω, and 10 kΩ standards to minimize their drift. Instead, an algorithm of the VRMS providing real-time values of the standards, allows performing the artifact calibration at any time. The user inserts the calibration values of the standards, calibration dates and the evaluated annual drifts. These data are stored in the control EPROM of the VRMS. By means of a real-time clock and the algorithm, the values of the standards are updated with a linear fit.

$$X_d = X_{cal} \quad + \left(d\frac{D}{365}\right) \tag{1}$$

where:
X_d is the value of a selected standard at the day d;
X_{cal} is the last calibration value of the standard;
D is the estimated annual drift of the standard;
d the number of days after the last calibration.

8. Measurement Uncertainties

When a reference standard is used in the period between two calibrations, its in-use uncertainty should be considered[3] [16]. This uncertain is are obtained summing in quadrature the calibration uncertainty and uncertainty components due to drift, temperature variations, power, and transport effects. The VRMS algorithm reduces drastically the uncertainty component due to the drift. Table 4 reports on the in-use typical uncertainties of the standards of the VRMS. The transport effect, evaluated during an ILC, resulted less than 4.0×10^{-8}.

The uncertainty component due to the drift with the values extrapolation is reduced to:

$$u_{\text{drift}} = \frac{\frac{D}{365}}{\sqrt{3}} \tag{2}$$

Considering a rectangular distribution with amplitude $2D/365$ for the drift where D is the annual drift. The manufacturer values were used for D in the uncertainty budget. The uncertainty component due to the temperature effect is also reduced by the thermo-regulation of the standards in the VRMS. The in-use uncertainties of the VRMS standards also apply when they are used as laboratory references during the interval between their calibrations.

3 The use uncertainty has to be considered since the calibration uncertainty of a standard could not be valid after some time after calibration. This is due to the standard drift and to the conditions in which the standard is used that could be different from those in which it was calibrated.

Standard	10 V	1 Ω	10 kΩ	Type
Uncertainty component (*k*=1)	Relative uncertainties (*k* = 1)			
Calibration	2.5×10^{-7}	2.5×10^{-7}	2.5×10^{-7}	Normal B
Drift	2.4×10^{-9}	7.9×10^{-10}	7.9×10^{-10}	Rect. B
Temperature effect	5.810^{-8}	5.8×10^{-8}	5.8×10^{-8}	Rect. B
Emf	1.2×10^{-8}	1.2×10^{-7}	negl.	Rect. B
Power effect	-	1.4×10^{-7}	1.0×10^{-7}	Rect. B
Pressure effect	negl.[4]	negl.	negl.	Rect. B
Transport effect	2.3×10^{-8}	2.3×10^{-8}	2.3×10^{-8}	Rect. B
$\boldsymbol{u_{\text{in-use}}(xi)}$ (k =1)	$\mathbf{2.5\times10^{-7}}$	$\mathbf{3.1\times10^{-7}}$	$\mathbf{2.5\times10^{-7}}$	**Combined uncertainty** (*k*=1)
$\boldsymbol{U_{\text{in-use}}(xi)}$ (k =2)	$\mathbf{0.5\times10^{-6}}$	$\mathbf{0.6\times10^{-6}}$	$\mathbf{0.5\times10^{-6}}$	**Expanded uncertainty** (*k*=2)

Table 4. In-use uncertainty budget according to [15].

Conclusions

The VRMS is a cost-effective and practical choice for artifact calibration of high-end f MFCs and DMMs allowing artifact calibration at any time. Performing this process allows for much better control of the drift and performance of the internal references of DMMs and MFCs compared to traditional instruments, which are only checked during calibration (typically once a year) and can drift out of calibration without the user's knowledge. This lack of awareness may have costly and potentially dangerous consequences. The VRMS specifications meet the uncertainty requirements of MFCs and DMMs for artifact calibration. The VRMS is also suitable for ILCs for DC resistance and DC voltage. Future works aim to improve the data extrapolation algorithm as the number of calibrations increases.

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Deadweight Primary Standards: Best Practices and Their Associated Risks for Stability Determination in Compliance with ISO/IEC 17025

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Morehouse Instrument Company

This paper explores the hierarchy, standards, and long-term stability of deadweight primary standard force machines used in load cell calibration. While many understand the basic principles of load cell calibration, fewer fully grasp the distinctions and implications between force standards, such as ASTM International's E74 Practices for Calibration and Verification for Force-Measuring Instruments (ASTM E74) [1] and the International Standard ISO 376 Metallic materials — Calibration of force-proving instruments used for the verification of uniaxial testing machines (ISO 376) [2]. Despite differing classification and methodology, these standards emphasize the critical role of traceability and uncertainty in force calibration.

Deadweight primary standards represent the highest level of accuracy, achieving expanded uncertainties below 0.002 % of applied force. The paper discusses the construction, materials, and performance characteristics contributing to their exceptional stability. It cites studies by the National Institute of Standards and Technology (NIST) and the United Kingdom's National Physical Laboratory (NPL), demonstrating negligible mass drift over decades. This paper further outlines the best practices for maintenance, interlaboratory comparisons, and statistical process control, arguing against frequent disassembly of deadweight systems due to the associated risks and costs.

Through historical context, technical evolution, and real-world data, this paper concludes that with proper design, environmental control, adequate maintenance, and verification procedures, deadweight primary standards can maintain their accuracy and traceability for intervals of 20–30 years or more, reinforcing their role as the gold standard in force calibration.

Preliminaries

Although many people understand the basic principles of load cell calibration, fewer are familiar with the various standards used to calibrate load cells and their specific requirements and implications. Without a doubt, the two most used and referenced standards for load calibration are ASTM E74 and ISO 376. While they may differ on calculated results, one key thing that they share is an understanding of a hierarchy of load cells and what is required to calibrate them.

The machines used to calibrate load cells also have a hierarchy based on the amount of **measurement uncertainty** they can maintain. The techniques employed to apply load vary by loading capacity and **measurement uncertainty** limitations. This hierarchy of machines, starting with the most accurate and lowest overall uncertainty, begins with deadweights, such as the Morehouse deadweight force standard shown below, followed by standards such as lever deadweights, hydraulic amplification machines, and hydraulic Universal Calibrating Machines, or mechanical machines, with multiple transducers. At the lowest end of the spectrum, some labs may use a Universal Testing Machine or a homemade press to calibrate load cells.

This paper examines deadweight standards' stability, the foundation for achieving the highest classification levels defined by ASTM and ISO. Due to their unmatched precision and long-term reliability, deadweight primary standards represent the ideal starting point in the calibration hierarchy. Subsequently, methods are selected based on each application's specific uncertainty and traceability requirements.

Note: All units and quantities not directly quoted in this paper are presented following the International System of

Figure 1. Morehouse Automated Deadweight Machine.

Units (SI) guidance in NIST Special Publication 811 (2008 Edition). The use of "parts per million" (ppm) appears in this paper to maintain consistency with terminology found in key reference standards and source materials. Where used, "ppm" should be interpreted as 1 × 10⁻⁶, consistent with SI guidance outlined in NIST SP 811, even though "ppm" is not formally an SI unit.

What is a Deadweight Machine?

Deadweight primary standards, also called **deadweight force machines**, represent the pinnacle of accuracy in force measurement calibration, achieving Calibration and Measurement Capabilities Uncertainty Parameters (CMCs) as low as 0.0008–0.0010 % of applied force. These machines apply force through precisely calibrated weights whose mass is traceable to the International System of Units (SI) and adjusted for local gravity, air buoyancy, and material density.

ASTM E74 in section 3.1.2 defines a "deadweight force applied directly without intervening mechanisms such as levers, hydraulic multipliers, or the like, whose mass has been determined by comparison with reference standards traceable to the International System of Units (SI) of mass [1]." The weights are corrected for the effects of local gravity where the machine is used, air buoyancy, and material density.

Deadweight Machine Evolution

The National Bureau of Standards (NBS), which later became the National Institute of Standards and Technology (NIST), performed force calibration work with 3000 kgf **deadweight force machines** in the 1920s. These early machines were limited to weights in 500 kgf increments, with a maximum of 3000 kgf.

Following the war, many early deadweight machines underwent significant upgrades, and in the 1960s, NBS would ultimately build a 4.45 MN machine. This machine is still the world's largest

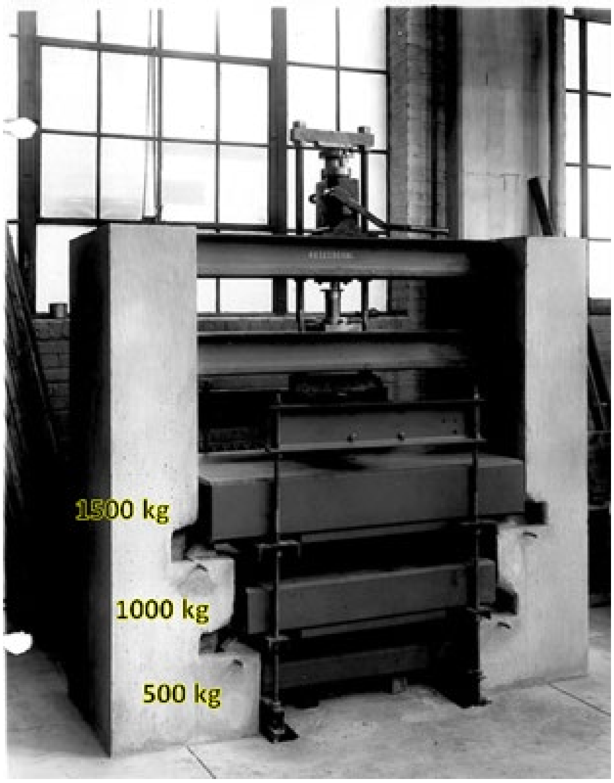

Figure 2. NBS 3000 kgf Deadweight Machine - Image Courtesy of NIST.

deadweight machine today. **Deadweight force machines** can be built in many capacities, from smaller ones with 1 N or less weights to larger machines with 200 kN weights. Common capacity machines are built with weights ranging from 5 kN to 50 kN. It is not uncommon for National Metrology Institutes (NMIs) to have 500 kN or larger machines. Many early **deadweight force machines** after World War II underwent significant upgrades or rebuilds following technological advancements.

Significant technological and methodological advancements have been made over several decades involving primary standards. NIST documentation shows that their **deadweight force machines** have had several enhancements since their installation in the mid-1960s [3]. Initially, the machine's accuracy was fundamentally limited by uncertainties related to gravitational acceleration, mass determination, and air buoyancy effects. However, progressive improvements in sensor technology, computational algorithms, and environmental controls have significantly reduced these uncertainties. Other key milestones include automating weight-changing mechanisms in 1989 and incorporating advanced data acquisition systems that improved measurement precision and reduced human error.

Today, our knowledge of measurements associated with maintaining environmental conditions, calculating material density, air density, and building machines whose frames strictly follow the plumb, level, square, and rigid guidelines has all contributed to an overall decrease in **measurement uncertainty**. Another significant contribution to **measurement uncertainty** is the alignment of the loading axis and having the correct adapters to improve the alignment of the unit under test, which helps minimize measurement uncertainty.

Understanding how weights might wear over time and designing systems with the appropriate lifting mechanisms is paramount in deadweight machine design. Gone are the days of worrying about a more frequent calibration schedule of the deadweight force machine, as our current understanding and collective experience tells us there is more risk in disassembling large weight stacks than there is benefit.

The design of a calibration laboratory should incorporate overhead cranes to facilitate the safe assembly and potential disassembly of **deadweight force machines**. An optimal deadweight primary standards lab often features a multi-level configuration, supported by a robust foundation, carefully planned layout, and strict environmental controls. For example, the photo below shows a two-story setup at the United States Air Force (USAF) facility, where the weight stacks are positioned beneath the main testing floor. This design supports precise force generation

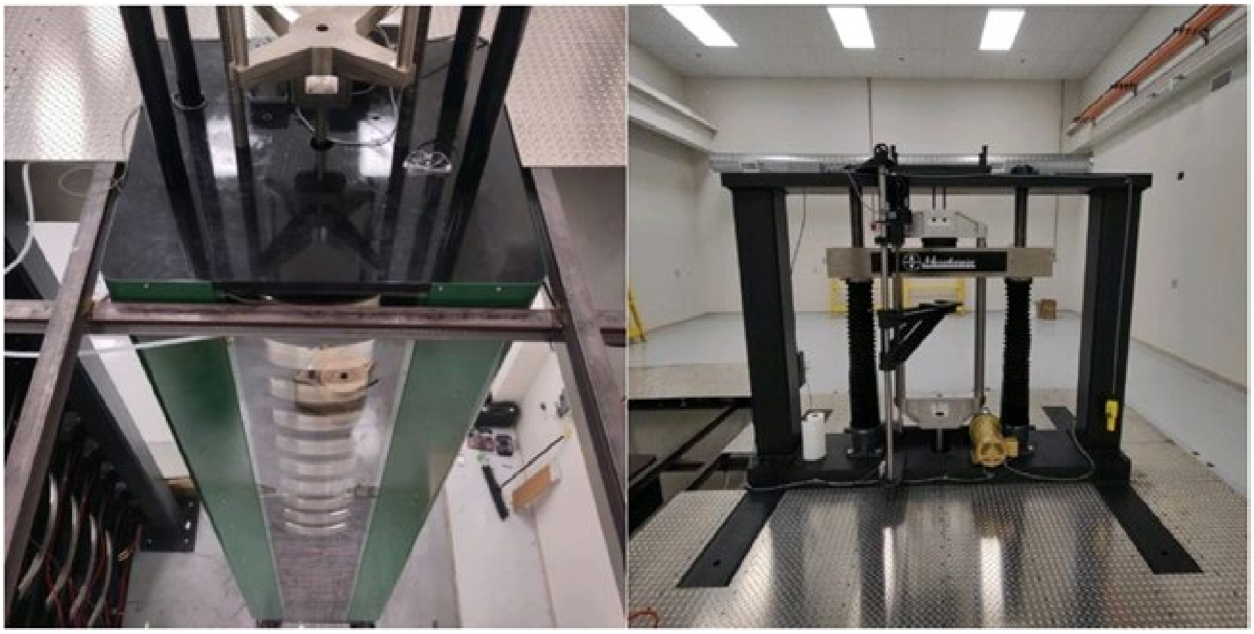

Figure 3. Early Image of the USAF Top Floor Showing Morehouse Machines.

and provides ample clearance and rear access behind the machines, allowing for easier maintenance or disassembly if required.

When multiple **deadweight force machines** are available, a load cell may be used for intra-laboratory comparisons and cross-checks between systems. Additionally, the load cell can function as a high-precision mass comparator in situ and across machines to monitor and verify the long-term stability of the deadweight standards. In this role, the load cell operates by performing substitution weighing, where known weights are applied, removed, and re-applied while monitoring the load cell's electrical output. By comparing the output differences corresponding to known mass changes, any deviation from expected behavior can be detected, allowing subtle shifts in mass or applied force to be identified. This highly sensitive method enables mass differences to be resolved at the parts-per-million (ppm) level, provided environmental and loading conditions are tightly controlled.

Deadweight Force Machines, Measurement Uncertainty, and Stability

Deadweight force machines represent the most accurate method available for calibrating load cells. When overall measurement accuracy is critical, it is strongly recommended that deadweight standards be used. These systems are capable of calibrating force-measuring instruments to the highest classifications, including ISO 376 Class 00 [2], ASTM E74-18 Class AA

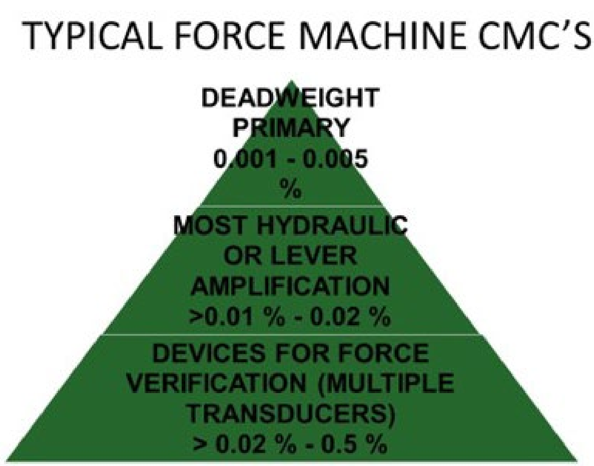

Figure 4. Typical Force CMCs in % of Applied Force.

verified range of forces [1], and Australian Standard AS 2193 Class AA [4], as well as other devices requiring exceptional precision.

Note: If ASTM Class AA is required, a deadweight machine is the only standard suitable to calibrate the ASTM E74 Class AA verified range of forces. Expanded Uncertainty must be better than 50 ppm to assign a Class AA loading. (See ASTM E74 [1].) Deadweight makes classifying a force-proving instrument to Class 00 of ISO 376 easier, though it is not necessarily needed.

All Morehouse automatic **deadweight force machines** have expanded uncertainties better than 0.0025 % of the applied force. Designing these machines requires careful consideration of many factors, including a robust and rigid structure, a weight hanger that minimizes sway, and precisely machined weights to achieve the target mass needed for accurate force generation.

Properly machined weights with enough adjustment cavities to fine-tune their mass are essential for any deadweight machine. If the weights are poorly machined, such as imperfect surface finishes, become even slightly corroded, or are constructed from cast iron, maintaining uncertainties below 0.005 % becomes challenging. These issues and other potential sources of error can alter the actual mass of weights, resulting in higher measurement uncertainties.

The stability of weights can also be an issue, as certain materials may lead to significant measurement errors over time. It has been proven that austenitic stainless-steel masses remain stable to better than 0.2 ppm over ten years, so stability becomes a minimal concern when stainless steel is chosen as the material for manufacturing calibration weights. *Note: When fabricated correctly, plated weights are also stable; the key is to avoid using porous material and magnetization.*

A couple authoritative studies have demonstrated the stability of **deadweight force machines**:

National Institute of Standards and Technology (NIST)

NIST has conducted several internal studies to assess the long-term stability of mass standards. In these efforts, they reweighed various machines after 30 to over 40 years and found minimal changes in the mass values. As reported in Bartel's study on NIST force measurements [3], the average difference

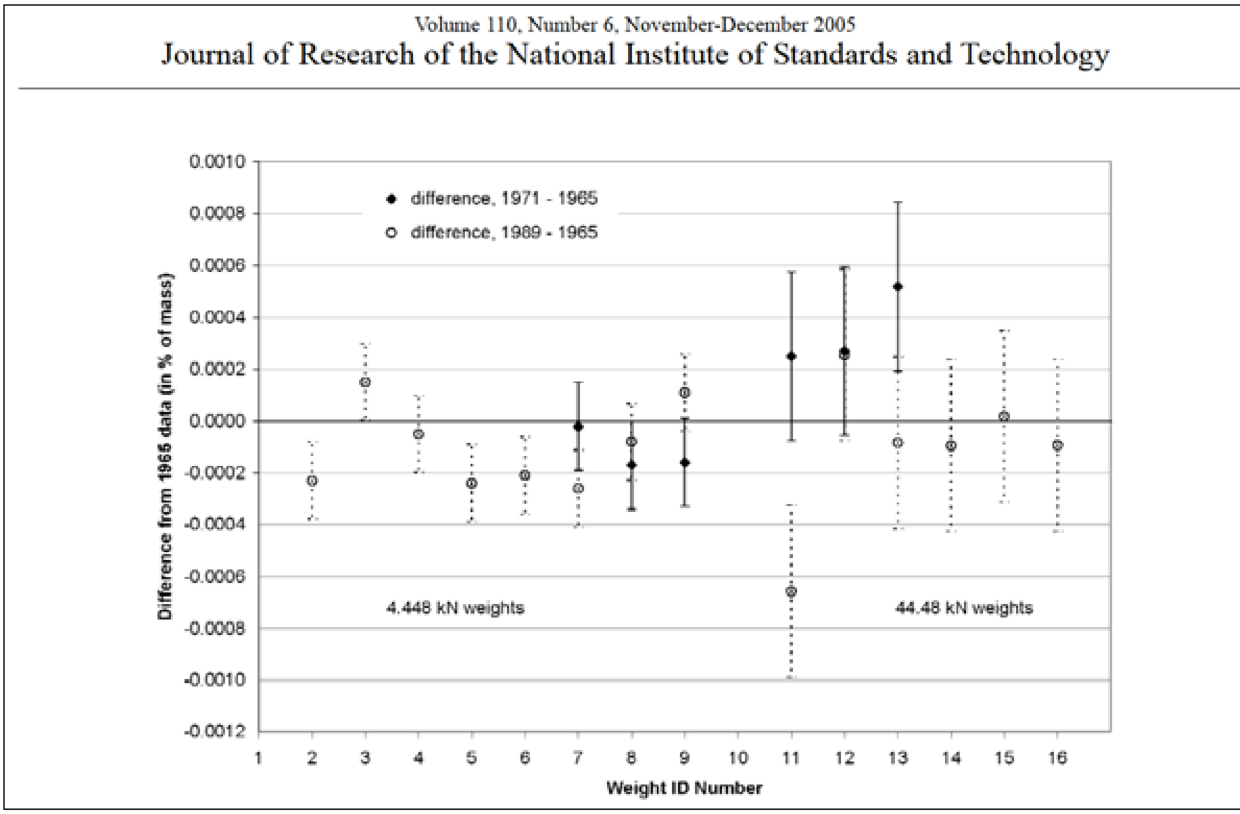

Figure 5. Comparison of mass values determined in 1965, 1971, and 1989 for the NIST 498 kN deadweight machine [3].

across twenty data points was less than 0.0001 % (1 part per million), which is too small to indicate any significant change. The paper also notes that, with only two exceptions, the measured relative mass differences between the 1989 and 1965 data sets fell within the expected uncertainty range of ±0.0003 %, supporting the conclusion that the masses remained stable over time.

A review of weight measurements taken over several decades at NIST showed only slight variations, all generally within the expected measurement uncertainties, highlighting the excellent long-term stability of the masses. More recent mass determinations, when compared with earlier data, revealed minimal increases within the combined uncertainty range, further confirming the consistent stability of these standards over time [3].

The error bars for the 1996 and 1965 mass measurements reflect the combined standard uncertainties, expressed as a percentage of each mass. These uncertainty ranges vary in length because each is explicitly calculated from the data associated with that weight. While one data point falls slightly outside the ±0.0003 % threshold, considered the upper limit for standard uncertainty in mass determination, most values stay within this range. Four out of nine measurements show uncertainty intervals that extend beyond the baseline, and two exceed their expanded uncertainties, assuming a coverage factor of $k = 2$. However, the average difference of +0.0001 % is too small to suggest any meaningful or systematic change in mass. Given that larger **deadweight force machines** are expected to experience even smaller relative mass variations than the 2.2 kN system, the findings support the conclusion that no significant long-term mass changes have occurred within NIST's force laboratory equipment [3].

National Physical Laboratory (NPL) Studies

ASTM E74 quotes an NPL study in Section X1.5, which states, "The National Physical Laboratory in England reports experience with austenitic stainless-steel masses shows the mass is likely to be stable to

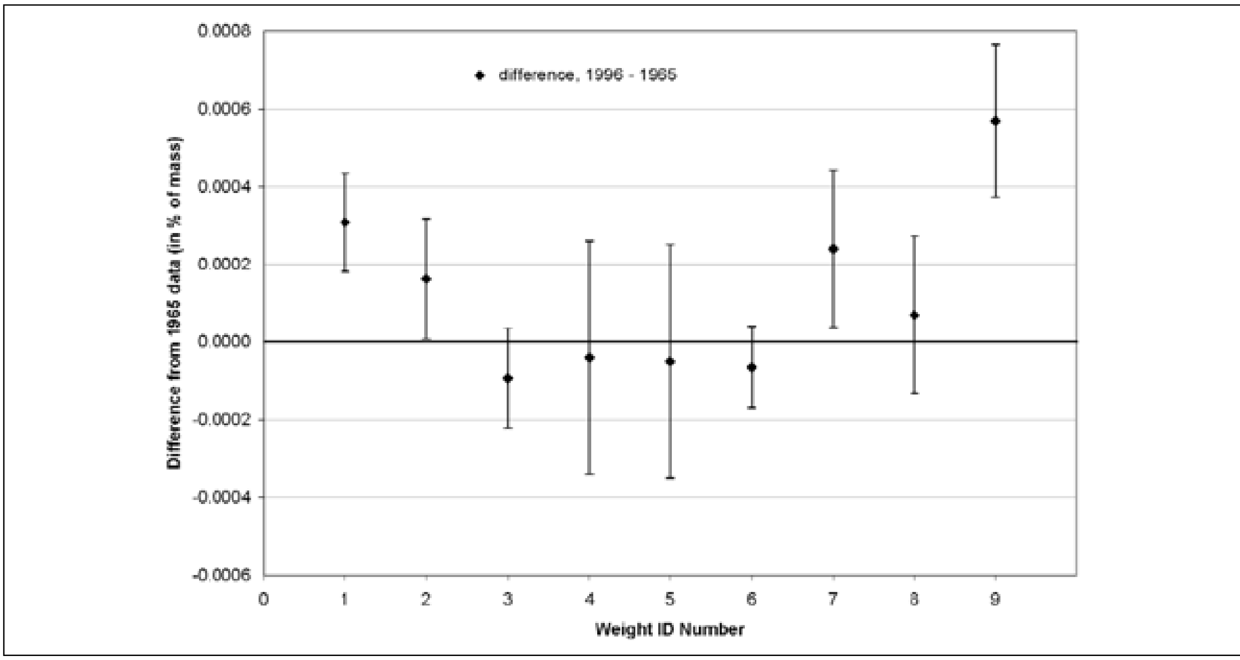

Figure 6. Comparison of mass values determined in 1965 and 1996 for the NIST 2.2 kN deadweight machine [3].

better than 0.2 ppm over a period of ten years. For the purpose of this example, a stability of 0.2 ppm (0.00002 %) for ten years will be used [5]."

These authoritative references consistently affirm the remarkable stability of meticulously maintained and well-engineered deadweight primary standards.

These studies conclude that deadweight force calibration machines are the most accurate means for calibrating other force-measuring devices. They are recognized for their exceptional stability and long calibration intervals.

The below figure is data taken from the NPL Validity Extension Justification internal document, which shows the change in the measured value of weights in 1992 and their recalibration in 2001/2002. Each data point represents the individual weights. Pack 1 weights are designed to generate a nominal force of 10 kN, Pack 2 weights 20 kN, and Packs 3

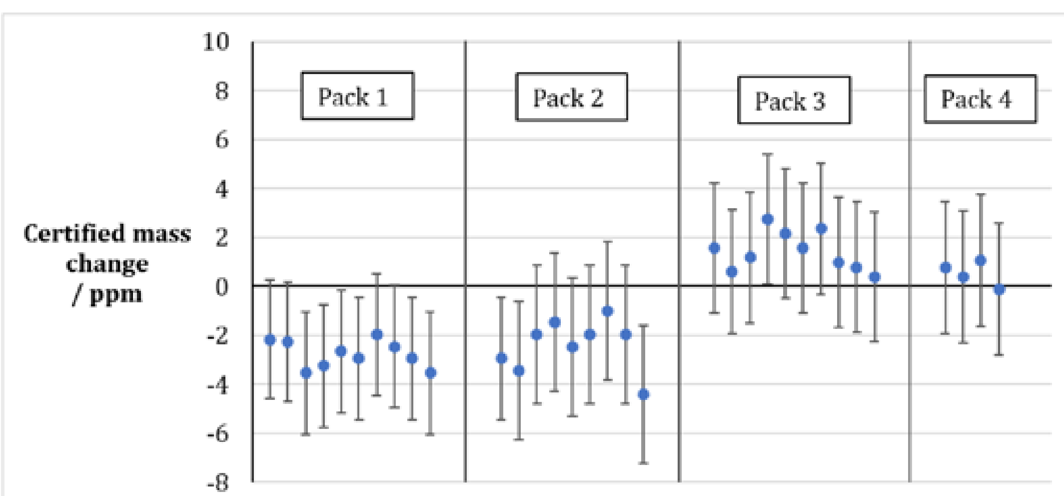

Figure 7. NPL Evidence Supporting the Stability of NPL UK's kN Deadweight masses [6].

and 4 each 25 kN per individual weight. The error bars represent the quadrature sum of the expanded uncertainties from the two calibration events.

This data concludes that "These calibration results demonstrate no significant systematic change in mass value for any of the weights over an extended period of time. It can also be concluded that there is no reason to suspect that there will be any significant systematic change in mass value for any of the weights over future time periods, assuming that they are maintained in the same environmental conditions [6]." It is important to note that deadweight primary standards have consistently demonstrated exceptional stability and reliability over extended periods, substantiating extended calibration intervals. NPL UK conducted a thorough internal analysis, documented in their Validity Extension Justification, highlighting negligible systematic mass changes in precision-calibrated stainless-steel weights across decades. Additionally, regular cross-checks and intercomparisons by respected institutions, such as NPL and NIST, further support these findings, indicating insignificant deviations and maintaining high confidence in the sustained accuracy of **deadweight force machines**. Systematic monitoring of other parameters, including local gravity, air density, and weight density, has also reinforced this long-term stability.

These studies suggest that the risks of dismantling **deadweight force machines** for recalibration, such as potential mechanical damage, contamination, and unnecessary handling errors, significantly outweigh the benefits. Empirical evidence and rigorous verification practices strongly advocate for recalibration intervals of twenty to thirty years or more, minimizing unnecessary disruptions to these high-precision instruments.

Best Practices: Compliance with ILAC G24 and ISO/IEC 17025

Laboratories using **deadweight force machines** should implement robust measures to maintain measurement confidence. **These measures include participation in proficiency tests, intra- and inter-laboratory comparisons, and establishing a comprehensive Statistical Process Control (SPC) system, all aligned with ISO/IEC 17025, International Laboratory Accreditation Cooperation (ILAC) Guidance Document ILAC-G24, and other relevant International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC) standards.** With these practices in place, frequent calibrations at intervals of ten years or less pose more significant risks than advantages.

Figure 8. Multiple Load Cells that Can be Used for Various Checks.

In-situ checks offer significant advantages because the load cell is tested under identical mechanical conditions, preserving critical factors such as machine rigidity, levelness, plumbness, squareness, and torsional characteristics. By contrast, these conditions can vary when comparing results between different machines, potentially introducing additional mechanical errors and affecting measurement consistency. Regular use of one or more load cells in this manner provides an effective means to verify machine stability and detect changes in applied forces without requiring full disassembly or recalibration.

Note*: Intra-laboratory comparisons, cross-checks, and in-situ weight checks are valuable tools for monitoring the performance of* ***deadweight force machines****; however, they are not a substitute for the initial calibration of the weights by National Metrology Institutes (NMIs) or accredited laboratories, which is necessary to achieve low measurement uncertainties and maintain traceability to the International System of Units (SI).*

While in-situ weight checks and cross-machine comparisons provide valuable point-in-time monitoring, broader statistical tools such as control charts offer continuous oversight of machine stability over time.

Control charts are vital tools for ensuring measurement assurance and maintaining metrological traceability. These statistical instruments provide real-time insights into process performance. They allow organizations to monitor measurement variability, identify abnormal patterns or trends, sustain process stability, and build confidence in their measurement systems.

By visualizing process behavior, control charts help distinguish between inherent process variation and significant anomalies that require corrective action. They function as an early warning system, alerting users when measurements exceed established control limits.

Figure 9 illustrates a control chart created using one load cell and multiple **deadweight force machines**, verifying that each machine yields consistent results. This chart represents an intra-laboratory comparison at Morehouse, specifically force intercomparisons between machines. In addition to intra-laboratory checks, cross-checking can be a helpful tool, as a technician may do a quick, undocumented check or verification check to ensure machine agreement.

Cross-checking between machines involves comparing the forces generated by two or more deadweight systems at specific points to ensure consistency within their combined uncertainties. It might occur if a technician questions a load cell's behavior in one machine and then uses another machine at the same force point to see if the results match.

Intra-laboratory comparisons are formal, documented exercises to validate internal consistency and competence; cross-checks are simpler, and routine or sporadic checks between machines confirm agreement and detect problems quickly.

Both tools allow internal consistency monitoring, help ensure measurement integrity, and support compliance with international quality standards.

According to ILAC-G24:2022, laboratories must justify and periodically review equipment recalibration intervals through one or more structured approaches (Section 6). While deadweight primary standards have repeatedly demonstrated exceptional long-term mass stability through studies by NIST, NPL, and other NMIs, reliance solely on historical data is insufficient to meet the complete requirements of ILAC-G24. **Laboratories must supplement this evidence with a documented methodology, such as control charting, in-use time monitoring, or statistical analysis, as outlined in Sections 6.1 through 6.7 of ILAC-G24 [7].**

The selection of this method, per Section 4.8, must be justified and maintained as part of the laboratory's quality documentation. ILAC-G24 also emphasizes the implementation of intermediate checks (Sections 4.9 & 4.10) to ensure equipment remains within performance specifications throughout extended intervals [7].

These checks may include force intercomparisons between machines, as mentioned earlier, replication of measurements with control instruments, and routine monitoring of environmental factors. When correctly implemented, such practices satisfy the intent of ILAC-G24 while preserving the integrity of highly stable systems like **deadweight force machines**.

These practices align directly with ISO/IEC 17025:2017, particularly in equipment control and performance verification. Clause 6.4.7 of ISO/IEC 17025:2017 requires laboratories to establish and maintain a calibration program that maintains

Figure 9. A Control Chart Comparing the mV/V Output of One Load Cell in Three Different Deadweight Force Machines Over Time.

confidence in the calibration status; meanwhile, Clause 6.4.10 mandates intermediate checks when necessary to confirm ongoing performance. Moreover, Clause 7.7.1 requires statistical techniques and routine monitoring to ensure the validity of results, including interlaboratory comparisons and proficiency testing (Clause 7.7.2). Clause 6.5 further mandates metrological traceability of all measurement results, including those produced by in-house calibration systems such as **deadweight force machines** [8].

To fully meet ILAC-G24 and ISO/IEC 17025 requirements, laboratories utilizing deadweight primary standards should **maintain control charts**, **participate in proficiency and/or interlaboratory comparisons**, and **document internal verification processes**. These actions confirm that measurement performance remains within acceptable bounds, reduce the risk of undetected drift, and validate extended calibration intervals without unnecessary and potentially harmful teardown of the system.

To adhere to this ISO/IEC 17025, Section 7.7 requirement, while maintaining the integrity of deadweight primary standards, laboratories likely should follow best practices such as:

1. Implement automated systems to apply and remove weights individually, reducing handling errors and enhancing repeatability.
2. Maintain rigorous environmental control (temperature, humidity, air density) to minimize variability in air buoyancy corrections.
3. Schedule periodic internal verifications and interlaboratory comparisons to ensure ongoing validation of measurement performance.
4. Setup Statistical Process Control Monitoring using various statistical tools.
5. Employ data acquisition systems capable of capturing multiple readings to provide representative average values over a specified and controlled timing profile, enhancing measurement reliability.
6. Ensure transparent documentation and record-keeping of environmental conditions, calibration procedures, and equipment performance checks to demonstrate continuous compliance and traceability.

Note: Morehouse automated ***deadweight force machines*** *are either already capable of implementing all these practices or allowing end-users to implement all these practices by purchasing the appropriate tools. While several manufacturers of environmental logging equipment exist, we use and recommend Vaisala.*

Design Attributes

Some other manufacturers have built all types of machines that may be inadequate or have shortcomings in the overall machine design, so we have compiled a list of recommended attributes necessary for meticulous and robust deadweight force calibration machines:

1. Use corrosion-resistant materials, particularly stainless steel, to prevent deterioration and maintain weight accuracy. Plated weights are also acceptable, as stainless steel can be more costly.
2. Automated individual weight application and removal to prevent shock loading and operator-induced variability.
3. Flat lifting surfaces might be needed for weights if conical lifting surfaces cannot overcome the friction required for self-alignment and can induce swaying. Weights can even see-saw on conical surfaces if the center of gravity is too high and the diameter is large.
4. Air bladder systems are used to gently lower weights and mitigate shock effects. The Morehouse proprietary lift system eliminates all pneumatic/hydraulic cylinders and requires no scheduled maintenance for the machine's life.
5. A robust yoke design, allowing for multiple force-measuring instrument sizes and capacities, engineered to prevent fatigue and mechanical failure.
6. The strategic arrangement of weights, typically with the largest at the top, to maintain stability and accuracy.
7. Eliminate the use of all hydraulics. Any leaks onto the weights will require complete dismantling to clean the machine properly. Even a few drops of oil can significantly impact the **measurement uncertainty**.

8. The machine's frame should not be built based on strength. Instead, it should be overbuilt to reduce deflection throughout. As the weights are added or removed, any machine movement will cause swaying or touching of the weights. High deflection can also cause parts of the machine to act like a spring and bounce up and down.
9. Advanced automated controls enable precise timing profiles and loading sequences, conforming to industry standards like ISO 376, which require uniform intervals between successive loadings. Such automation enhances repeatability, minimizes human error, and provides consistent data acquisition.

When **deadweight force machines** are thoughtfully designed with these attributes and maintained under controlled conditions, they provide unmatched accuracy and long-term stability in force measurement. However, even the most meticulously engineered systems are vulnerable to disruption when subjected to unnecessary handling or disassembly. Despite the precision and durability built into high-end machines like those from Morehouse, removing weights introduces many potential risks that can compromise performance. It is, therefore, essential to understand the implications of weight removal and why minimizing such interventions is necessary.

Risks Associated with Removing Weights

Frequent removal of weights from deadweight force machines for external calibration can introduce unnecessary risks, potentially compromising the machine's accuracy and stability. Mechanical disturbances, damage, or contamination occurring during transport or handling may lead to shifts in mass values or surface damage, affecting the accuracy of subsequent calibrations. The integrity of the deadweight system is best preserved by minimizing weight handling, thereby reducing calibration drift and enhancing long-term stability.

The National Institute of Standards and Technology in the USA (NIST) performed periodic maintenance and teardowns of their **deadweight force machines**, notably their 498 kN machine. These teardowns, conducted in 1971 and again in 1989, provided valuable insights into the system's long-term stability. Upon disassembly, NIST conducted detailed mass determinations of the individual weights removed; comparative analyses of these weights across years revealed minimal mass variations, typically within measurement uncertainties, demonstrating outstanding long-term stability. A Euramet comparison (EURAMET.M.M-S7) for 500 kg Mass Standards showed better stability than 0.000278 % over several years [9].

The precise engineering, robust materials, and careful handling contributed significantly to the observed minimal wear and negligible mass changes. Such findings underscore the importance of maintaining the integrity of these highly precise systems.

Beyond the technical risks of removing and recalibrating weights, a substantial financial and logistical burden is also tied to full-scale teardowns of **deadweight force machines**. Even when performed by highly experienced national laboratories, the process requires significant planning, heavy lifting equipment, specialized refurbishment, and considerable downtime. To illustrate the extent of this undertaking (and why it should be avoided unless necessary), it is helpful to examine a high-profile example from NIST, where one of the world's largest and most precise **deadweight force machines** underwent a restoration.

Expensive Teardown and What Is at Risk

In 2014, NIST initiated a significant teardown and restoration of its 4.45 MN (1 million pounds-force) deadweight machine, the largest in the world. This process was completed in 2016 and marked the first significant overhaul since the machine's construction in 1965. Their key findings and repairs performed can be summarized as follows:

1. **Material Galling**: The primary reason for the teardown was to address material galling in key structural components within the stainless-steel weight stack. Galling is a form of wear caused by friction, leading to the fusion of surfaces, which can cause mechanical failures.
2. **Disassembly and Inspection**: The weight stack, consisting of 19 nearly identical stainless-steel discs, was disassembled, with each disc weighing 50,000 pounds (about 22,696 kg). During the disassembly, previously suspected damage in conical contact joints was confirmed,

particularly on the bottom hub plates and pick-up studs of some weights.

3. **Repair and Refurbishment**: The damaged components were remachined and treated with a solid lubricant to prevent future galling. The weights were recalibrated to ensure precision in force generation.
4. **Reassembly and Testing**: The machine was reassembled and tested after refurbishment. This process involved massive equipment, including 30-ton cranes and large air hammers.
5. **Calibration and Accuracy (No Change in Forces Realized)**: Previous measurements made with the machine were unaffected despite the damage. The restoration ensured that the machine could continue to provide precise force calibrations for load cells used in various industries, such as aerospace and construction.
6. **Validation and Comparisons**: The machine's accuracy was validated through repeated measurements and international comparisons, which demonstrated agreement with other standards and reinforced confidence in the integrity of the forces realized by the machine.

This teardown was a massive effort involving years of planning, heavy machinery, and expert-level work to repair and reassemble the system. In the end, even with signs of wear, the machine's accuracy hadn't changed—a powerful reminder that these systems are built for the long haul. When designed and maintained properly, **deadweight force machines** can stay reliable for decades without needing disruptive or costly overhauls.

Considering the decades of demonstrated stability, the significant risks introduced by unnecessary weight handling, and the substantial cost of dismantling these machines, it is clear that deadweight systems do not require frequent recalibration absent specific evidence of instability.

Common Sense Preventative Maintenance Practices

While the exceptional stability of deadweight primary standards minimizes frequent disassembly or recalibration, it does not eliminate the need for routine maintenance.

Routine preventative maintenance is essential to preserving the accuracy and longevity of these critical systems. ISO/IEC 17025:2017, specifically Clause 6.4.13.g, requires laboratories to maintain equipment to ensure its functionality and integrity [8].

In practice, this means keeping deadweight force machines clean, ensuring they remain level, verifying proper environmental controls, and periodically checking for any signs of corrosion, mechanical wear, or contamination. Surfaces must be kept free of excess dust and debris, which can introduce friction or alter mass distribution.

All structural loading elements should be inspected regularly to confirm that they are level and properly aligned. The air lines should be checked for leaks if the machine is pneumatic. Gears, screws, or drive mechanisms should be lubricated at appropriate intervals according to the manufacturer's recommendations. Visual inspection of loading surfaces and the surrounding area should occur with every calibration. Environmental monitoring devices (**temperature**, humidity, and air density) should be calibrated appropriately to ensure accurate air buoyancy corrections.

*Note: The need to monitor humidity and air density can be eliminated if the **measurement uncertainty** budget includes allowances for variations and provides supporting evidence of these variations.*

It is considered best practice to perform these maintenance checks at defined intervals, to document findings, and to address any anomalies immediately. If anomalies could impact measurement results, additional SPC checks should be performed to confirm continued system performance.

Skipping or overlooking these seemingly simple tasks can lead to cumulative errors over time, undermining the system's exceptional performance and risking nonconformities during audits. Proper maintenance complements long-term stability studies and is vital to any force laboratory's quality assurance system.

Conclusion

Calibration intervals for deadweight force standard machines should be determined by empirical stability data rather than arbitrary timeframes like every four or five years. Leading metrological agencies emphasize that no one-size-fits-all schedule exists;

calibration frequency should reflect each machine's performance history and long-term stability.

Relying on measured data, such as historical drift, control charts, and interlaboratory comparisons, allows laboratories to make informed, evidence-based decisions. This approach meets the intent of ISO/IEC 17025 and ILAC G24. It helps avoid the unnecessary risks, costs, and disruptions associated with frequent recalibration or teardown. By basing recalibration decisions on observed performance over time, laboratories can maintain confidence in results while minimizing avoidable downtime and expenses.

Empirical evidence from multiple NMIs supports the exceptional long-term stability of well-engineered deadweight force machines. Adopting automated systems, ensuring proper handling, and maintaining robust environmental controls further enhance stability, reliability, and compliance. As confirmed by NIST's teardown analysis, these practices also help safeguard against errors introduced by unnecessary manual interventions.

Numerous scientific community references support ongoing internal checks, comparison results, and statistical process control programs in place of repeated disassembly or recalibration of the masses. As one experienced United Kingdom Accreditation Service (UKAS) assessor aptly said, "The worst thing you can do to a working deadweight machine is take it apart." With proper design, maintenance, and monitoring, these machines remain the most accurate and dependable force calibration standards.

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New Accreditation Tool for Auditors and Laboratory Personnel

Christopher L. Grachanen

Calibration and Testing laboratories seeking accreditation status or maintaining their existing accreditation status must comply with the requirements denoted in ISO/IEC 17025 *General requirements for the competence of testing and calibration laboratories*, current edition 2017-11.

ISO/IEC 17025 requirements, identified by clause numbers, give details as to activities, policies, procedures and documentation necessities that laboratories need be able to demonstrate satisfactory fulfillment of. The ISO/IEC 17025 standard is +30 pages, comprised of five main sections that include Section 4 (General Requirements), Section 5 (Structural Requirements), Section 6 (Resource Requirements), Section 7 (Process Requirements), and Section 8 (Management Systems Requirements). The standard has twenty four clause groupings and 147 specific clause requirements. The first three clauses cover scope, normative references, and terms and definitions.

Assessors and laboratory personnel tasked in accreditation compliance must not only be familiar with these clauses but also the interdependencies between clauses which typically requires flipping through paper pages or searching through an electronic edition of the standard.

The vast majority of these clauses do not provide guidance or examples for clause fulfillment often require referencing other publications to determine compliance, which can be both daunting and time consuming. Additionally, example nonconformances related to a clause are also not provided which would otherwise provide valuable insight on things to be avoided. It was during an A2LA[1] assessor class final exam that the author realized the need of a more efficient means to access ISO/IEC 17025 clauses with additional guidance for individuals not intimately familiar with the standard and clauses minutia.

Figure 1. "Error" search word

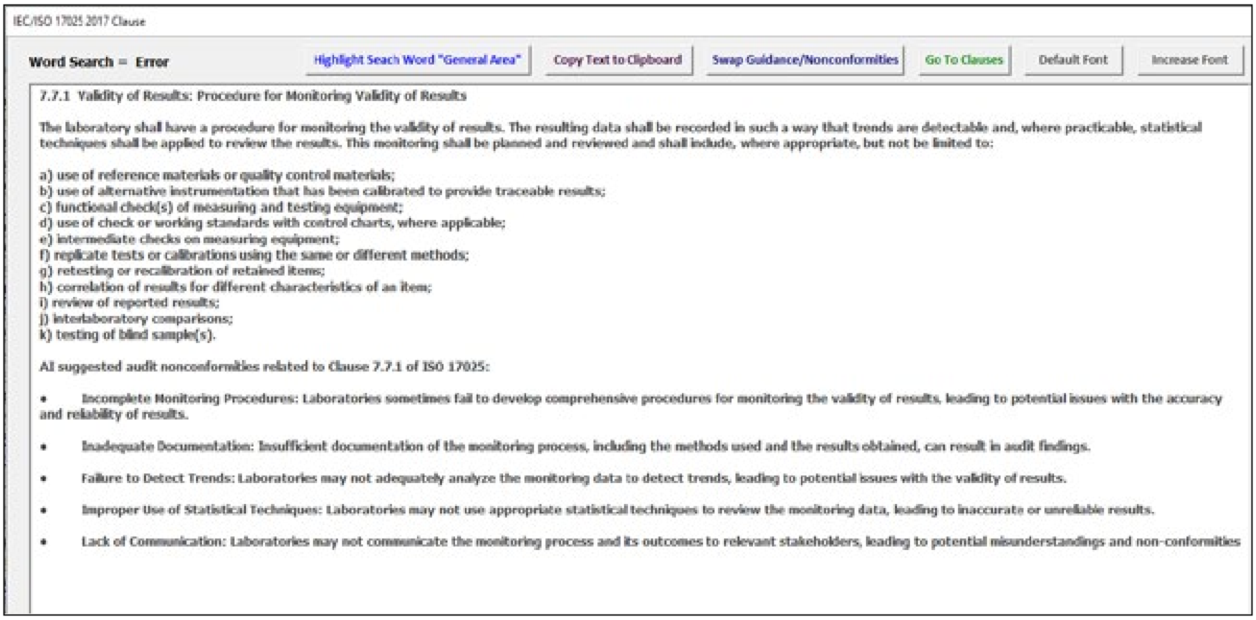

Figure 2. Clause Guidance “Error - Validity of Results”

“17025 Lookup” is a password protected, VBA macro driven Microsoft Excel worksheet incorporating clause snippets[2] from the ISO/IEC 17025 standard with the ability to search for a word from an entered or drop down listing. Initiating a search will highlight any displayed clause header whose related information contains the search word (see Figure 1).

Clicking any clause number, with or without an entered search word, will display the Clause Info screen. The Clause Info screen displays a snippet of the clause[2] and either clause guidance[2] (Figure 2) or clause AI suggested nonconformities[2] (Figure 3), selectable from the Clauses screen or the Clause Info screen.

Clause guidances were obtained via public domain, peer reviewed presentations, published papers and applicable accreditation related websites[2]. Clause AI suggested nonconformities were obtained using AI internet queries after proper AI query training.

If a search word was used, clicking the “Highlight Search Word General Area” command button will highlight the search word vicinity in the displayed information. Displayed info can be selected and copied to the Windows Clipboard. The Clauses screen contains an “Instructions” sheet explaining how to use 17025 Lookup functions.

Example Using 17025 Lookup

Let’s look at a scenario where I found 17025 Lookup most useful. During a laboratory audit it was learned that technicians routinely deviated from a section of a testing procedure. Performing a 17025 Lookup word search on “Deviation” highlighted 20 different clauses. A quick eyeballing of the highlighted clauses yielded the most relevant clause group as “Test Method Selection.” Note: other clause groups such as “Structure Requirements” and “Lab Processes” were also highlighted as they contained the word “Deviation” in their header, snippet or guidance information. Upon scrutinizing “Test Method Selection” clauses, “7.2.1.7 Test Method Selection: Deviations from Methods,” was found to be the most appropriate clause to write the nonconformity to.

So, it would seem that after documenting the nonconformance and instructing technicians not to deviate from the testing procedure as corrective action, one could assume all bases regarding this nonconformance have been covered.

However, upon examining 17025 Lookup guidance for Clause 7.2.1.7, it was apparent other topics such as risk assessment, results review, and customer notification may also need to be addressed for satisfactory closure of the nonconformity.

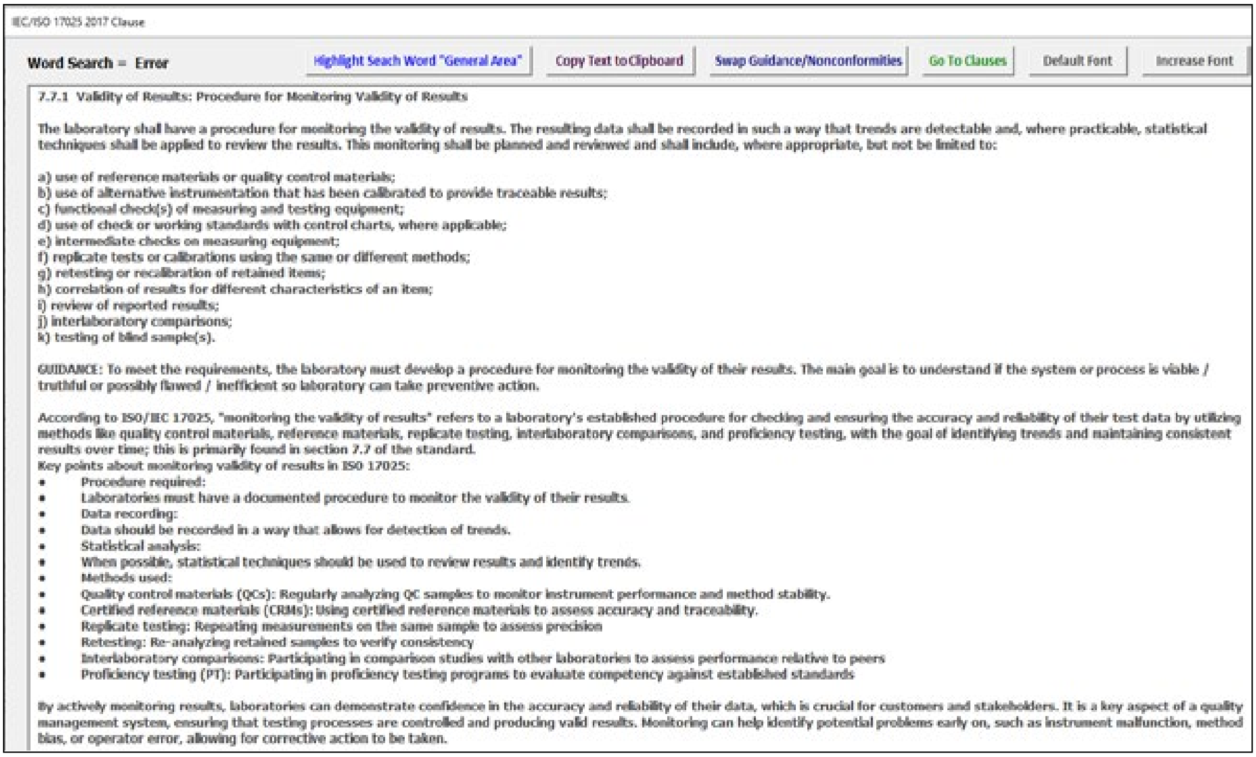

Figure 3. Clause Nonconformities "Error - Validity of Results"

Conclusion

As you can see, 17025 Lookup provides an easy means to look over ISO/IEC 17025 clauses, coupled with clause guidance and AI suggested nonconformities. Additionally, clicking "< >" from the 17025 Lookup Clauses screen (Figure 1) displays a listing of common laboratory audit clauses/ nonconformities (often the quickest way to identify a nonconformity to a clause).

In the tradition of Tolerance Calculator, Uncertainty Calculator and Mismatch Uncertainty Calculator, 17025 Lookup is a freeware software tool. The latest version of 17025 Lookup may be downloaded courtesy of the National Association of Proficiency Testing (NAPT) at: https://proficiency.org/resources/.

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Endnotes

1 American Association for Laboratory Accreditation (A2LA)

2 Snippets and captured information used for instruction purposes, being respectful of copyright and intellectual property guidelines.

Yokogawa Test & Measurement Releases SL2000 High-Speed Data Acquisition Unit

A high-performance DAQ system that meets the latest evaluation and test needs in the automotive, mechatronics, and power electronics fields

Tokyo, Japan - May 28, 2025 – Yokogawa Test & Measurement Corporation announces the release today of the SL2000 High-Speed Data Acquisition Unit, a ScopeCorder series product with a wide range of data logging functionalities for evaluation and test applications, including high-speed sampling and analysis. The SL2000 is a modular platform that combines the functions of a mixed signal oscilloscope and a data acquisition recorder, and is designed to capture fast signal transients and long-term trends. It is suitable for applications such as R&D, validation, and troubleshooting.

The SL2000 can be used separately or in combination with the DL950 ScopeCorder, depending on the application. No other product family on the market offers this level of flexibility in handling multi-channel measurements. With the ScopeCorder product family, Yokogawa provides a multifaceted, total solution for the high-precision mechatronics and electric power markets that is contributing to the advancement and development of new technologies and applications.

Development Background

In the four years since the DL950 ScopeCorder was first brought to the market by Yokogawa Test & Measurement, there have been many technical advances in the electric vehicle (EV), renewable energy, and other industrial fields. Today, there is an ever-greater requirement for the capability to simultaneously measure multiple parameters and for the systemization of mechatronic measurements in product development. For example, in the development of motors for industrial and EV systems, one essential test for checking and improving a product is the durability test. This test takes a long time to complete and requires a highly reliable measuring instrument and high sampling rates.

Main Features

1. Enabling both high-speed sampling and multi-channel measurement. The SL2000 performs long-duration multi-channel measurements while precisely analyzing even the most detailed aspects of waveforms. With its dual capture function, the SL2000 can perform durability tests over long periods of time at speeds of up to 200 MS/s.

   By using the IS8000 integrated software platform, it is easier to perform the long-term measurements required for durability testing, helping to improve the efficiency of product design and evaluation work. In addition, isolation measurement technology ensures the noise resistance required for durability testing in harsh environments.
2. Supporting simultaneous measurement of a wide variety of devices. The SL2000 has eight available slots (with up to 32 channels), for which over 20 types of input modules are available to enable measurements of electrical signals, mechanical performance parameters indicated by sensors, and decoded vehicle serial bus signals. To increase the number of measurement channels, up to five SL2000 and DL950 units can be synchronized.

Major Target Markets

- Transportation (automotive, rail, aviation, etc.)
- Power and energy (renewable energy, smart cities/homes, data centers, etc.)
- Mechatronics, including industrial robots and motors

Applications

- Durability and reliability testing of components and vehicles that requires high sampling rates and multi-channel simultaneous measurement of analog signals and in-vehicle bus signals such as CAN and CAN FD
- Simultaneous measurement and evaluation of temperature, vibration, and other mechanical signals that change relatively slowly as well as mechatronic and other such high-speed control signals
- Electrical analysis and control signal evaluation

For More Information

https://tmi.yokogawa.com/solutions/products/oscilloscopes/scopecorders/sl2000/

About Yokogawa Test & Measurement

Yokogawa has been developing measurement solutions for 100 years, consistently finding new ways to give R&D teams the tools they need to gain the best insights from their measurement strategies. The company has pioneered accurate power measurement throughout its history, and is the market leader in digital power analyzers and optical spectrum analyzers. Yokogawa measuring instruments are renowned worldwide for their high levels of precision, quality, durability, and service support. Meet the precision makers at https://tmi.yokogawa.com/

NEW PRODUCTS AND SERVICES

NAPT Announces Game-Changing Proficiency Testing Risk Analysis Module

Eagan, MN, June 4, 2025 – The National Association for Proficiency Testing (NAPT), the most trusted name in the metrology community for providing administration, development, software tools, and support for interlaboratory comparisons, is excited to announce the new Proficiency Testing Risk Analysis Module, a breakthrough tool designed to streamline the often time-consuming and complex process of conducting a thorough risk analysis for any proficiency testing (PT) program.

Recent updates to accreditation requirements now mandate that laboratories conduct a risk assessment associated with their PT activities. These changes emphasize the need for ongoing evaluation and documentation of potential risks related to PT participation in order to maintain compliance with ISO/IEC 17025 and related standards. NAPT's free online Proficiency Testing Risk Management Tool is the most robust, comprehensive, and user-friendly resource available today to support the metrology and quality community in meeting these evolving requirements.

This new tool not only enables any laboratory to stay in full compliance with accreditation body expectations, but also provides the framework for performing a detailed analysis of PT-related risks. Built with compliance in mind, it aligns with the requirements outlined in ILAC P9, ISO 17025 and supports the expectations of any accreditation body. This sophisticated, detailed, yet remarkably user-friendly tool is included at no extra charge as part of NAPT's ongoing service to the metrology community.

"If you're responsible for managing risk and ensuring the integrity of your proficiency testing participation, you owe it to yourself to look at this powerful application. It will save you hundreds of hours by automating and guiding you through a comprehensive risk analysis process," said Richard Brynteson, Managing Director of NAPT. "Once you start using it, you'll quickly understand why we're so excited—and chances are, you'll be telling all your colleagues about it too."

For more information about NAPT's services or the new Proficiency Testing Risk Analysis Module, please visit https://proficiency.org/, or contact the NAPT team at napt@proficiency.org.

About NAPT

The National Association for Proficiency Testing (NAPT) is a leading organization dedicated to setting the gold standard for metrology proficiency testing. With over twenty-five years of experience, NAPT offers unparalleled expertise and resources to professionals and organizations across various industries. NAPT is proud to be a not-for-profit entity committed to integrity and serving as the only true independent provider of proficiency testing services in the metrology community.

DFB pro 633 – Mode-Hop Free DFB Laser

Single-frequency laser based on a DFB diode, engineered for high-precisionapplications like semiconductor metrology and phase-shifting interferometry

Graefelfing, Germany | June 6, 2025 – TOPTICA (https://www.toptica.com/) introduces the DFB pro 633, the newest member of our family of mode-hop-free tunable lasers for metrology.

"Our DFB pro 633 provides a mode-hop-free tuning range of 200 GHz. Driven by the DLC pro controller, it is ready to be integrated into OEM customers' tools," explains Stéphane Junique, product manager for the DFB pro laser platform at TOPTICA.

The DFB pro 633 offers a mode-hop-free tuning range of 200 GHz. The DFB pro, a single-frequency laser based on a distributed-feedback (DFB) diode, covers wavelengths from 633 nm and 760 nm up to 3500 nm and offers a mode-hop-free tuning range of up to 1400 GHz. It is well-suited for a variety of applications, including semiconductor metrology and spectroscopy.

Distributed feedback (DFB) lasers unite wide tunability and high output power. The frequency-selective element – a Bragg grating – is integrated into the active section of the semiconductor and ensures continuous single-frequency operation. Due to the absence of alignment-sensitive components, DFB lasers exhibit exceptional stability and reliability. The lasers work under the most adverse environmental conditions – even in the Arctic or in airborne experiments.

Learn more at https://www.toptica.com/products/tunable-diode-lasers/ecdl-dfb-lasers/dfb-pro.

About TOPTICA

TOPTICA has been developing, producing, and marketing highend lasers and laser systems for science, research, and industry for over 25 years. The portfolio includes diode lasers, ultrafast fiber lasers, terahertz systems, and optical frequency combs. Worldwide, TOPTICA has 600 employees in seven business units with a consolidated group revenue of €140 million.

Talk About Fast!

Michael L. Schwartz
Cal Lab Solutions, Inc.

I talk to many people about how long it takes to write an automated calibration procedure in various languages. Also, as a manager, I know just how bad developers are at estimating their own time. Unlike Scotty from the Starship Enterprise, software developers are notorious for underestimating the time required to write something. This is why I want to share some real-world numbers.

Last week, while I was onsite training CalRight Instruments on how to create test packages in Metrology.NET®, one of their younger technicians created three new test packages for the Keithley 2700 DMM, 7700 & 7701 Plugin Cards in less than three days. This is truly impressive for a technician, who has never written automation before, to have written and tested three units with an average time of about six hours each.

We started the training with our standard training package based on Keysight 34450A DMM calibrated with a Transmille 4010 Calibrator. Covering this training usually takes about four hours, and that is how we spent the first four hours on day one of the training.

After lunch, we moved on by selecting a DMM currently in for calibration, grabbed the manuals, and then started the training. Vince, the technician, was able to create his first test package in the second half of the first day. Before the end of the day, he successfully tested the Source.Voltage.DC test points on the 2700, ending the day on a high note.

On the morning of the second training day, Vince continued testing the 2700, and around noon, the Test Package's VISAScripts (used to control the UUT) were thoroughly tested. So he asked his boss, "What's Next?" David's reply: "Do the cards too." Before the end of the third day, both cards were finished and fully tested.

Gemini generated image

During the training, there were challenges and rewrites to the test package. The first challenge with all automation is figuring out the commands and how to control the UUT. This step is especially difficult for technicians who have never remotely controlled a device with SCPI commands. But part of the training is showing people how to use the manual(s) and look up, then testing the commands. There is a lot of trial and error, beeps from the instrument, closely looking, and the command for typos.

When starting on the second card, we discovered that the second card's test points were 90% the same as the first card—the test package he just built and tested. This led to a rewrite of the first test package, updating it to support both cards in a single test package using the "AppliesToModel" parameter. Rather than copying all the test points and data into a second test package, Metrology.NET® uses "AppliesToModel" and other filters to sort and filter test points, allowing a single test package to cover several Make, Model, and Option configurations.

This rewrite of the test package took a little more time because the concepts were new to Vince, but well before the end of the third day, all their units were tested and ready for QA.

Manually testing these three units would have consumed approximately five hours of a technician's time. Remarkably, in roughly triple that duration, a technician unfamiliar with automation successfully developed their initial automated calibration procedure, aptly named "Now That's Fast!"

CalRight Instruments has contributed these three test packages to the Starter Pack, making them the fifth company to offer test packages in the Metrology.NET® Test Package Store. This is great news for the calibration community.

Additel 992 / 993 / 997
Handheld Pressure Pumps

Additel
Metrology Made Simple

Handheld Operation Capability

Adjustable Reference Connection

Up To 10,000 PSI Range