History of Traceability

Ted Doiron
Engineering Metrology Group
NIST
Traceability

Traceability is not a scientific term. It is barely a technical term in that it lacks a precise, universally accepted definition. It is a term used by writers of contracts and regulations which have a measurement component. As we shall see, it is meaningless in itself and is redefined explicitly, with more or less precision, every time it is used. It does, however, carry quite a burden of implicit meaning.

John Simpson
Unpublished draft
Traceability is quantifiable

“Nevertheless, measurement uncertainty determines the strength of the links in the traceability chain and as a result it is of enormous importance for the traceability of measurement results.”

Typical Traceability Requirement

- National Association of Securities Dealers (NASD)
  - Order Audit Trail System (OATS)
    - Rule 6953
    - NASD Notice 98-33
    - OATS Reporting Technical Specifications, Chapter 2
  - Clocks traceable to NIST within 3s
Metrological Timelines in Traceability

Classically, traceability provides a way of relating the results of a measurement (or value of a standard) to higher level standards. Such standards are usually national or international standards, and the comparisons used to provide the traceability must have well-understood uncertainties.

An additional complexity arises because all instruments and standards are subject to change, however slight, over time. This paper develops approaches for dealing with the effects of such time dependent changes as a part of traceability statements.

Charles D. Ehrlich1 and Stanley D. Rasberry
Lifetime of the traceability chain in chemical measurement

Since the uncertainty of each link in the traceability chain (measuring analytical instrument, reference material or other measurement standard) changes over the course of time, the chain lifetime is limited.

Ilya Kuselman
Boris Anisimov
Irena Goldfeld
“We had a very short traceability path, less than 4 meters.”
- Measurement Science Conference, Doiron & Doiron, 1992

Longest traceability path I have heard of was 7 laboratories deep. Our method, although eccentric, is probably superior.
The Fluke Corporation is a leading manufacturer of precision multi-function and multi-product calibrators used to maintain traceability of dc and low frequency ac measuring devices. These calibrators are manufactured in a factory annex located 5 km from the corporate headquarters and the standards laboratory. The test consoles used in their manufacture must be maintained on a routine basis, to make them traceable to national standards. In 1988, Fluke implemented a quality method called Process Metrology which provides the traceability for these test consoles at the factory annex.
What is Traceability?

I hear it stated, and I read it in texts, that traceability is important because it reduces uncertainty. Of course not.

The traceability of a measurement result is not about reduction of uncertainty. It has nothing to do with it.

Traceability is about establishing a trace of the quantity value of a measurement result to a stated reference, such as the result obtained by using a reference measurement procedure. It is established, not measured.

Accreditation and Quality Assurance
Journal for Quality, Comparability and Reliability in Chemical Measurement
Editorial
Traceability is not meant to reduce uncertainty
Paul De Bièvre, Editor-in Chief, Geel, Belgium
What is Traceability?

Allow a modest proposal: “Traceability is the ability to demonstrate that measurements are what they are purported to be”.

Because measurements are always expressed and communicated in the form of numerical values (with associated uncertainties or equivalent intervals between numerical values, at stated levels of confidence) multiplied by measurement units, it then follows by ineluctable logic that the end point of any traceability chain is simply the units in which the measurement is expressed.

Accred Qual Assur (2003) 8:475–476

Gary Price

“Traceability to units”
History – Who is Responsible?
4.2 Measuring and Testing Equipment.
The contractor shall provide and maintain gages and, other measuring and testing devices necessary to assure that supplies conform to technical requirements. These devices shall be calibrated against certified measurement standards which have known valid relationships to national standards at established periods to assure continued accuracy. The objective is to assure that inspection and test equipment is adjusted, replaced or repaired before it become inaccurate. The calibration of measuring and testing equipment shall be in conformity with military specification MIL-C-45662. In addition, the contractor shall insure the use of only such subcontractor and vendor sources that depend upon calibration systems which effectively control the accuracy of measuring and testing equipment.
14 CFR § 145.47 Equipment and materials: Ratings other than limited ratings.

(b) The equipment and materials required by this part must be of such type that the work for which they are being used can be done competently and efficiently. The station shall ensure that all inspection and test equipment is tested at regular intervals to ensure correct calibration to a standard derived from the National Bureau of Standards or to a standard provided by the equipment manufacturer. In the case of foreign equipment, the standard of the country of manufacture may be used if approved by the Administrator.

Flight readiness FAA.
Measuring and test equipment shall be calibrated by the contractor or a commercial facility utilizing reference standards (or interim standards) whose calibration is

certified as being traceable to the National Bureau of Standards,

has been derived from accepted values of natural physical constants,

or has been derived by the ratio type of self-calibration techniques.
3.5 Traceability. The ability to relate individual measurement results through an unbroken chain of calibrations to one or more of the following:

3.5.1 U.S. national standards maintained by the U.S. National Bureau of Standards (NBS) and the U.S. Naval Observatory;
3.5.2 Fundamental or natural physical constants with values assigned or accepted by the U.S. NBS;
3.5.3 National standards of other countries which are correlated with U.S. national standards;
3.5.4 Ratio type of calibrations;
3.5.5 Comparison to consensus standards.
6. Reports for the highest level standards of sources other than NBS or a Government laboratory must bear a statement that comparison has been made and is traceable to National Standards at planned intervals. An NBS test number is one means of substantiating comparison.
GGG-G-15

The “one means” eventually became THE MEANS when the individual standards, like the gage block standard GGG-G-15, called for specific items to be in a calibration report.

3.9 Manufacturer’s report of calibration. A report of calibration is required (see 6.2), it shall be furnished with each gage block or set of gage blocks showing the results obtained at the manufacturer’s final inspection of each individual block and containing the following information:

(g) Statement on traceability of calibration to NBS shall include NBS test number and date.

Thus the “Traceability = NBS Number” became the US norm.
5.8 Calibration sources. M&TE and measurement standards shall be calibrated by the contractor or another calibration facility utilizing measurement standards whose calibration is traceable. All measurement standards used in the calibration system shall be supported by certificates, reports, or data sheets attesting to the description or identification of the item; the calibration source; date of calibration; calibration assigned value; statement of uncertainty and environmental or other conditions under which the calibration results were obtained.

3.4 Measurement standard. Those devices used to calibrate M&TE or other measurement standards and provide traceability.
Taking cognizance of the fact that as a quality control technique it is incomplete, for the part of the task traceability does address, traceability has been, and is, a useful mechanism.

1. It does control standards.
2. It does call attention to the role of measurement.
3. It is easy to predict the cost of compliance.
4. It has mandated a high degree of organization in what prior to this was an untidy sector of the National Measurement System.

J Simpson
Why Did It Work?

1. The existence of a valid NBS number on the lab calibration report was reasonable assurance that an NBS calibration was somewhere in the chain.

2. The standards used were better than what was actually needed by some significant ratio.

These two requirements, together, meant that the unit was probably the actual unit and that with reasonable care the final measurements were “good enough” for the intended purpose. Part of the secret was that the manufacturers of standards, both physical standards and instruments, were far more capable than the actual needs of most industrial use.
Standards

- MIL 9808
- MIL 45662A
- ISO Guide 25
- ISO 17025
- ISO 9000-94
- Z540-1

?
6.10 *traceability*  
property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.

Note the change from standards traceability to measurement result traceability!
9. Measurement traceability and calibration

9.1 All measuring and testing equipment having an effect on the accuracy or validity of calibrations shall be calibrated and/or verified before being put into service. The laboratory shall have an established program for the calibration and verification of its measuring and test equipment to ensure the recall or removal from service of any standard or equipment which has exceeded its calibration interval or is otherwise judged to be unreliable.
9.2 The overall program of calibration and/or verification of equipment shall be designed and operated so as to ensure that, wherever applicable, measurements made by the laboratory are traceable to national standards, ... Calibration certificates and/or reports shall, wherever available, state the traceability to national, international, or intrinsic standards of measurement and shall provide the measurement results and associated uncertainty of measurement and/or a statement of compliance with an identified metrological specification.
Problems

1. Calibration intervals don’t exist under Measurement Assurance Programs. NBS was the main advocate of MAP, so they worked to make changes.

2. Many labs were audited by a very large portion of their customers, some over 100 times a year!

3. Simple minded approach of N:1 rules were harder and harder to maintain, particularly when cascaded.

4. No one was actually tracing the chain of comparisons.

5. World focus moved to the actual measurement, away from the measurement standards.
Traceability Chain

SI unit → NMI realization, comparisons, various fuzzy stuff

NMI working standards, uncertainty → Lab Standards, uncertainty

Lab Standards, uncertainty → Lab Standards, uncertainty

Lab Standards, uncertainty → Measurement, uncertainty

Who looks at the rest?

Comparison, uncertainty → Laboratory Audit
US Response

The changes in the definition of traceability, while appropriate, had the consequence of destabilizing traceability. It was now obvious that an NBS number was not adequate proof of traceability. Somehow the lab at the bottom would have to prove that all the links existed and had uncertainty statements.

First Response: the requirement was simply ignored.

The new definition of traceability was only in the International Standards system, and had not been adopted into the US Government or US voluntary standards system. This changed dramatically with the rise of laboratory accreditation in the 1990s.
International Trend

Internationally recognized accreditation bodies began requiring that their accredited testing and calibration laboratories get their calibrations done directly by a national metrology institute or by internationally accredited calibration laboratories, where ever possible.
View From Outside US

• The chains of traceability in the USA were not clearly unbroken

• Measurement uncertainty was not being calculated in accordance with the “Guide to the Expression of Measurement Uncertainty” (GUM) (4:1 rule not used outside US)

• Calibration reports and certificates did not contain appropriate traceability statements (NIST numbers)

• Estimations of Measurement Uncertainty were not expressed as expanded uncertainties with coverage factors \( k=2 \) and confidence levels (95%)

• In general, there was no confidence that the laboratories were technically competent to work with the GUM, calculate budgets, and express measurement uncertainty and traceability claims so that the unbroken chains could be realized.
Relationship between National Standard Provision Scheme and Calibration Laboratory Accreditation Scheme under JCSS

- **National Institute of Advanced Industrial Science & Technology (AIST)**
  - Designated Calibration Laboratories
  - International comparisons
  - Calibration with National Primary/Sub-Primary Standards and issuing JCSS Calibration Certificate

- **Accredited Calibration Laboratories**
  - Accreditation Body
  - Assessment & Accreditation with Guide 25 (ISO/IEC 17025), Proficiency Testing with Guide43
  - Calibration of User's Reference Standards and issuing JCSS Calibration Certificate

- **Users (Laboratories, Factories, etc.)**
  - Accredited Calibration Laboratories
  - Calibration of User's Reference Standards and issuing JCSS Calibration Certificate
Traceability is characterized by a number of essential elements:

1. an unbroken chain of comparisons going back to a standard acceptable to the parties, usually a national or international standard;

2. measurement uncertainty; the measurement uncertainty for each step in the traceability chain must be calculated according to defined methods and must be stated so that an overall uncertainty for the whole chain may be calculated;

3. documentation; each step in the chain must be performed according to documented and generally acknowledged procedures; the results must equally be documented;
ILAC G2:1994 Traceability of Measurements

4. competence; the laboratories or bodies performing one or more steps in the chain must supply evidence for their technical competence (e.g. by demonstrating that they are accredited);

5. reference to SI units; the “appropriate” standards must be primary standards for the realization of the SI units;

6. recalibrations; calibrations must be repeated at appropriate intervals; the length of these intervals depends on a number of variables, (e.g. uncertainty required, frequency of use, way of use, stability of the equipment).
View From Inside US

Far too many audits of laboratories (all paid for by US Gov)

European customers required accredited calibration and US manufacturers were not accredited. They are forced to start labs in Europe.

Guide 25 not adequate because it does not treat equipment separately as in 45662A
## US Accredited Calibration Labs

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<th>Organization</th>
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<th>MRA Signatories</th>
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Goal of International Agreements

ILAC ISO Guide 58

MRA

APLAC

Signatories to APLAC
NATA SCC
CNAL HKAS
NABL KAN
JAB IAJAPAN
KOLAS DSM
IANZ SAC
CNLA DMSc
TLAS A2LA
IAS NVLAP
VILAS-STAMEQ

EA

Signatories to EA MRA
BMWA BELTEST
BKO/OBE BELCERT
CAI EAK
DANAK FINAS
COFRAC DAR
DACH DAP
DASMIN, DATech
DKD TGA
EYSD SINAL
SINCERT SIT
LATAK LA
RVa NA
IPQ SNAS
SA ENAC
SWEDAC SAS
UKAS

MRA

NACLA

Signatories to NACLA
A2LA
NVLAP
AIHA
IAS
PRI-Nadcap

LAB Perry Johnson
...
Current Status, 2004

Signatories to APLAC
- NATA Australia
- SCC Canada
- CNAL P.R. of China
- HKAS Hong Kong
- NABL India
- KAN Indonesia
- JAB Japan
- IAJAPAN Japan
- KOLAS Korea
- DSM Malaysia
- IANZ New Zealand
- SAC Singapore
- CNLA Taipei
- DMSc Thailand
- TLAS Thailand
- A2LA USA
- IAS USA
- NVLAP USA
- VILAS-STAMEQ-Viet Nam

Signatories to EA MRA
- BMWA - Austria
- BELTEST, BKO/OBE, BELCERT - Belgium
- CAI – Czech Rep.
- EAK - Estonia
- DANAK - Denmark
- FINAS - Finland
- COFRAC - France
- DAR, DACH, DAP, DASMIN, DATech, DKD, TGA - Germany
- EYSD - Greece
- SINAL, SINCERT, SIT - Italy
- LATAK – Latvia
- LA – Lithuania
- RvA – Netherlands
- NA – Norway
- IPQ – Portugal
- SNAS – Slovakia
- SA – Slovenia
- ENAC – Spain
- SWEDAC – Sweden
- SAS – Switzerland
- UKAS – United Kingdom
CIPM - MRA

International recognition of national measurement standards and of calibration and measurement certificates issues by national metrology organizations

Based on key- and supplementary comparisons (Appendix B)

Quality assurance (ISO 17025, Guides 35, 35)

(Peer-) assessments (accreditation)

NMI capabilities (Appendix C)
International Traceability

CIPM

Mutual Recognition Arrangement

NIST
NRC
NPL
PTB

NVLAP
SCC
UKAS
Remaining Problems

How many of the subsidiary measurements must have documented traceability?

Dimensional Metrology – temperature, force, air pressure, thermal expansion coefficients …

Mass Metrology – air pressure, air temperature, density of weights, air speed

Force – local value of gravity, density of weights, T, P
Example

I am measuring a 1 meter piece of wood with a tape, and need an uncertainty of 1 mm do I need a traceable temperature measurement.

The worst case (across the grain) CTE wood is about $60 \times 10^{-6/°C}$, and my tolerance means I need to know the temperature to about 20 °C.

I would maintain I can reliably guess the room temperature to much better than that, although I have never been personally calibrated.
The ILAC G16 document of 2001

(a) Laboratories accredited by ILAC Member Bodies shall be able to demonstrate that calibration of *critical equipment*, and hence the calibration or test results generated by that equipment, relevant to their scopes of accreditation, is traceable to the International System of Units (SI units).

Note 3:
“Critical “ equipment used by testing and calibration laboratories is considered by ILAC to be those items of equipment necessary to perform a test or calibration from the scope of accreditation and which have a significant effect on the uncertainty of measurement of test or calibration results. ILAC member bodies have agreed to investigate this issue further and to develop guidelines to differentiate between calibrations that are critical and less critical and to indicate how in the latter case the traceability requirements may be less rigorous.
Remaining Problems

Comparisons:

How much alike should the standard and test piece be?
- Same dimension
- Same shape
- Similar shape and size
- Has similar features
Traceability Chain for Grid SRM

• Multiple measurements on industry owned metrology tool (IOMT).
• Measurements on IOMT in multiple orientations.
  – Translation/rotation comparison and analysis of coordinate mappings of photomask measures repeatability and tool error mapping.
• Measure artifacts on NIST linescale interferometer.
• Investigation of straightness residual errors
• Appropriate combination of uncertainty terms.
• Procurement of multiple mask batches.
• All IOMT measurements include measurements of check standard.
Complications in Chemistry

Traceability of Analytical Results is more than Traceability of Standards

- SAMPLING
- STABILIZATION
  - TRANSPORT
- EXTRACTION
- PRECONCENTRATION
- MEASUREMENT

SI-unit
pure chemical standard
Traceability

More recently, proficiency evaluation programs have produced similar traceability linkages, but with a novel twist. The proficiency test material (transfer standard) is sent without attachment of results. The laboratory under test receives both an independent confirmation of measurement ability and, indirectly, a traceability linkage when the test is concluded and the assigned value of the measurand is disclosed. It is unlikely that proficiency evaluation will supplant traditional forms of providing traceability links. However, the concept does provide metrologists with an additional tool.

Stanley Rasberry
Example

Figure shows the error in a number of complementary small plastic rulers (CSPRs) that were calibrated. These rulers, being free, have no documented traceability. The solid line is the mean of all of the rulers, showing that the “average” CSPR is quite accurate, nearly within the resolution of the ruler. This is an example of the fact that everything is “traceable” in some sense, although undocumented, and the only real issue is uncertainty.
Conclusions

Traceability is basically a legal or contractual issue, and as such, the technical issues, while real, are not the primary problems.

Laboratory accreditation is the major player in traceability. In the end, ILAC will define and interpret traceability, and the ILAC Members will enforce those interpretations.

The graph shows the number of papers in the IE Compendix using various terms in paper titles. Luckily, traceability is seldom used and the trend in the technical literature is toward extinction.