Attorneys and Scientists in the Courtroom: Bridging the Gap

Attorneys and Scientists in the Courtroom: Bridging the Gap

Metrology: A Knowledge Base for Communication and Understanding

Truth

"The ultimate mission of the system upon which we rely to protect the liberty of the accused as well as the welfare of society is to ascertain the factual truth."

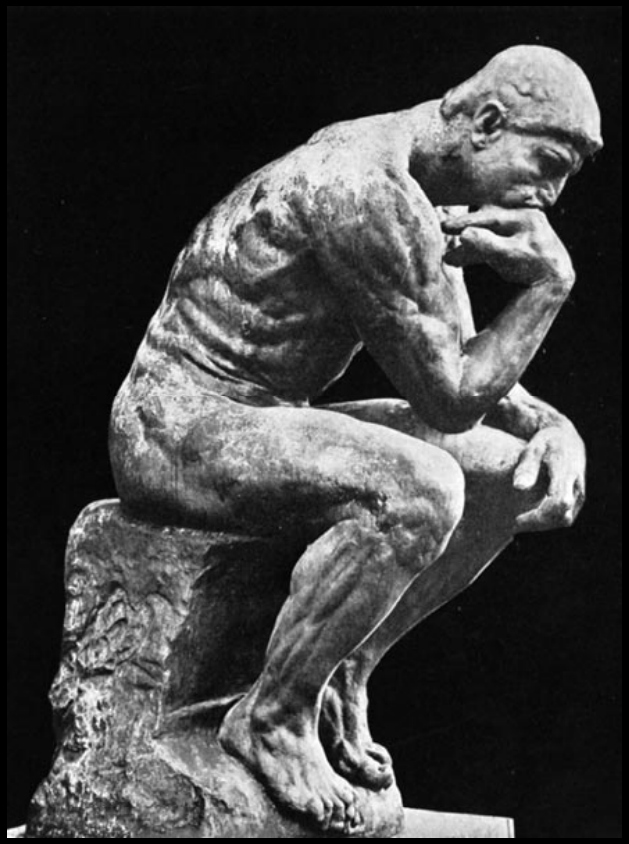
Commonwealth of Northern Mariana Islands v. Bowie, 243 F.3d 1109, 1114 (9th Cir. 2001)

The Goal of Forensic Science: To Facilitate the Discovery of Truth

1. ENLISTING THE METHODS OF SCIENCE IN THE INVESTIGATION OF CRIMES.

2. PROVIDING EVIDENCE FOR USE IN COURT THAT HAS BEEN TESTED BY SCIENTIFIC METHODOLOGY.

Metrology as Knowledge Base and Language:
Enhancing Science, Communication, Understanding and Law



Epistemic Basis

1) Forensic science.

2) Communication and evaluation of forensic science by legal professionals.

3) Jurisprudence governing forensic science evidence.

Why Epistemology?

Forensic Science

"The law's greatest dilemma in its heavy reliance on forensic evidence…concerns the question of whether—and to what extent—there is *science* in any given 'forensic science' discipline." NAS

Forensic Science

"Adherence to scientific principles is important for concrete reasons: they enable the reliable inference of knowledge from uncertain information—exactly the challenge faced by forensic scientists." NAS 217.

Why Epistemology?

Legal Professionals

The "judicial system is encumbered by…judges and lawyers who generally lack the scientific expertise necessary to comprehend and evaluate forensic evidence in an informed manner."

Legal Professionals

Judges and lawyers must become familiar with the basic tenants and language of science. Professional competence requires the ability to actively participate in the analysis, understanding and communication of science in the courtroom. The floor cannot simply be ceded to the claims of experts.

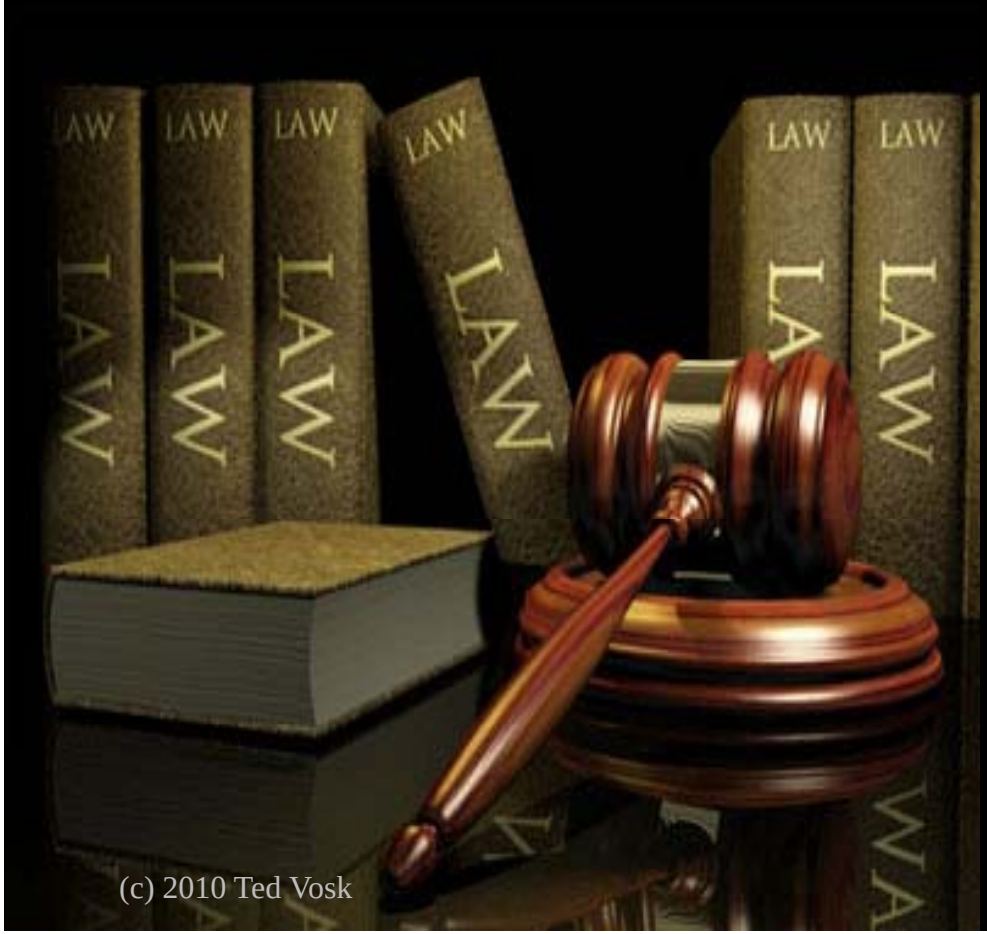
Why Epistemology?

Jurisprudence

If judges have insufficient understanding of science, gatekeeping decisions cannot satisfy ultimate goals of justice system of being non-arbitrary and facilitating discovery of factual truth in subsequent cases.

Jurisprudence

"In this age of science we must build legal foundations that are sound in science as well as in law." Justice Stephen Breyer in, *Reference Manual on Scientific Evidence* 4 – 8 (2nd ed. 2000).

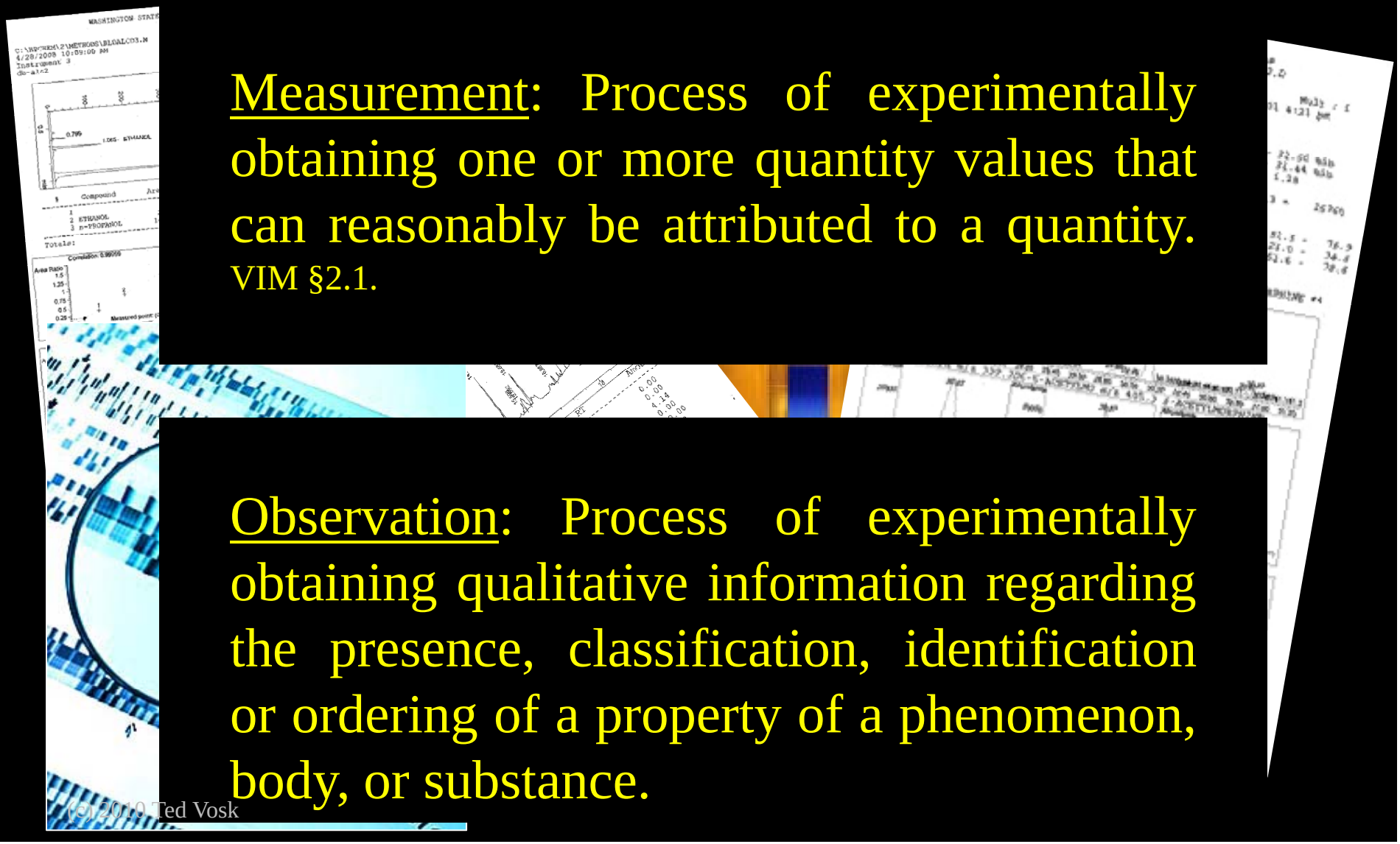


Outcomes consistent with scientific reality require scientific evidence that conforms to the standards and criteria to which scientists themselves adhere. Black, 239 Science 1508, 1512 (1988).

Scientific Knowledge

"Scientific method refers to the body of techniques for investigating phenomena, acquiring new knowledge, or correcting and integrating previous knowledge. It is based on gathering *observable*, *empirical* and *measurable* evidence subject to *specific principles of reasoning*." Sir Isaac Newton, Principia Mathematica.

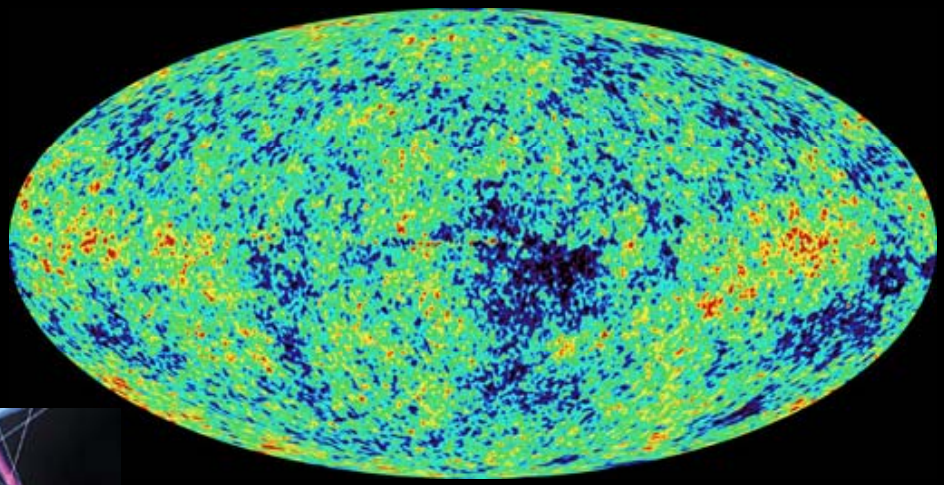
Observable, Empirical and Measurable

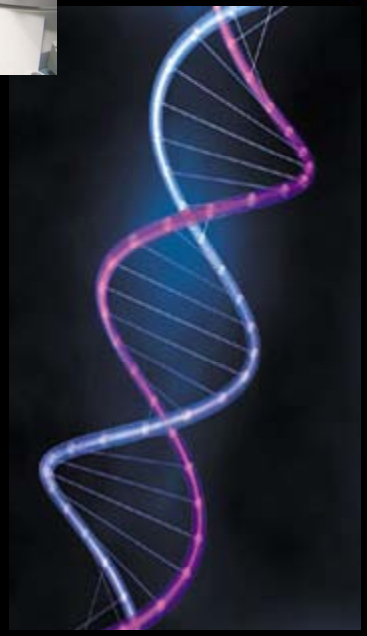


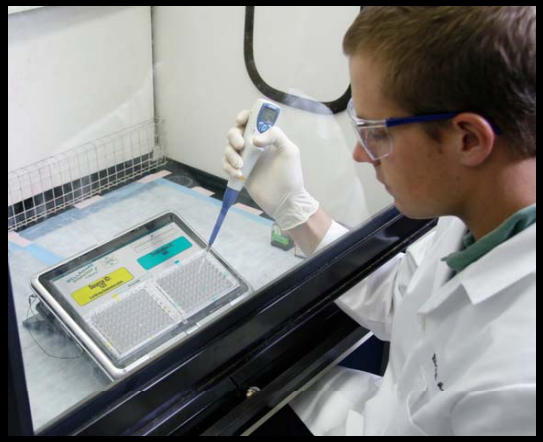
Measurement: Process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity. VIM §2.1.

Observation: Process of experimentally obtaining qualitative information regarding the presence, classification, identification or ordering of a property of a phenomenon, body, or substance.

Fundamental Principles of Reasoning







Metrology
Fundamental Principles of Reasoning

"Science of measurement and its application."

International vocabulary of metrology (VIM) JCGM 200 §2.2 (2008)

"[I]f science is measurement, then without metrology there can be no science." Lord Kelvin, 1886.

Subjects of Metrology

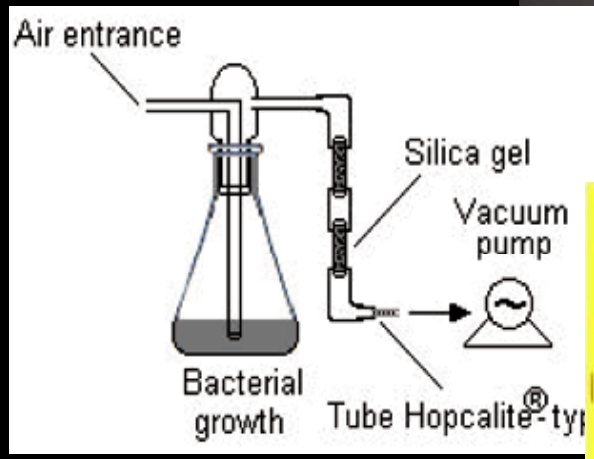
Weights & Measures:
- Reference standards
- Traceability

Validation:
- Methods
- Reliability

Quality Assurance:
- Calibration
- Standard Operating Procedures (SOPs)

Meas./Obs. interpretation:
- Reporting results
- Error & Uncertainty

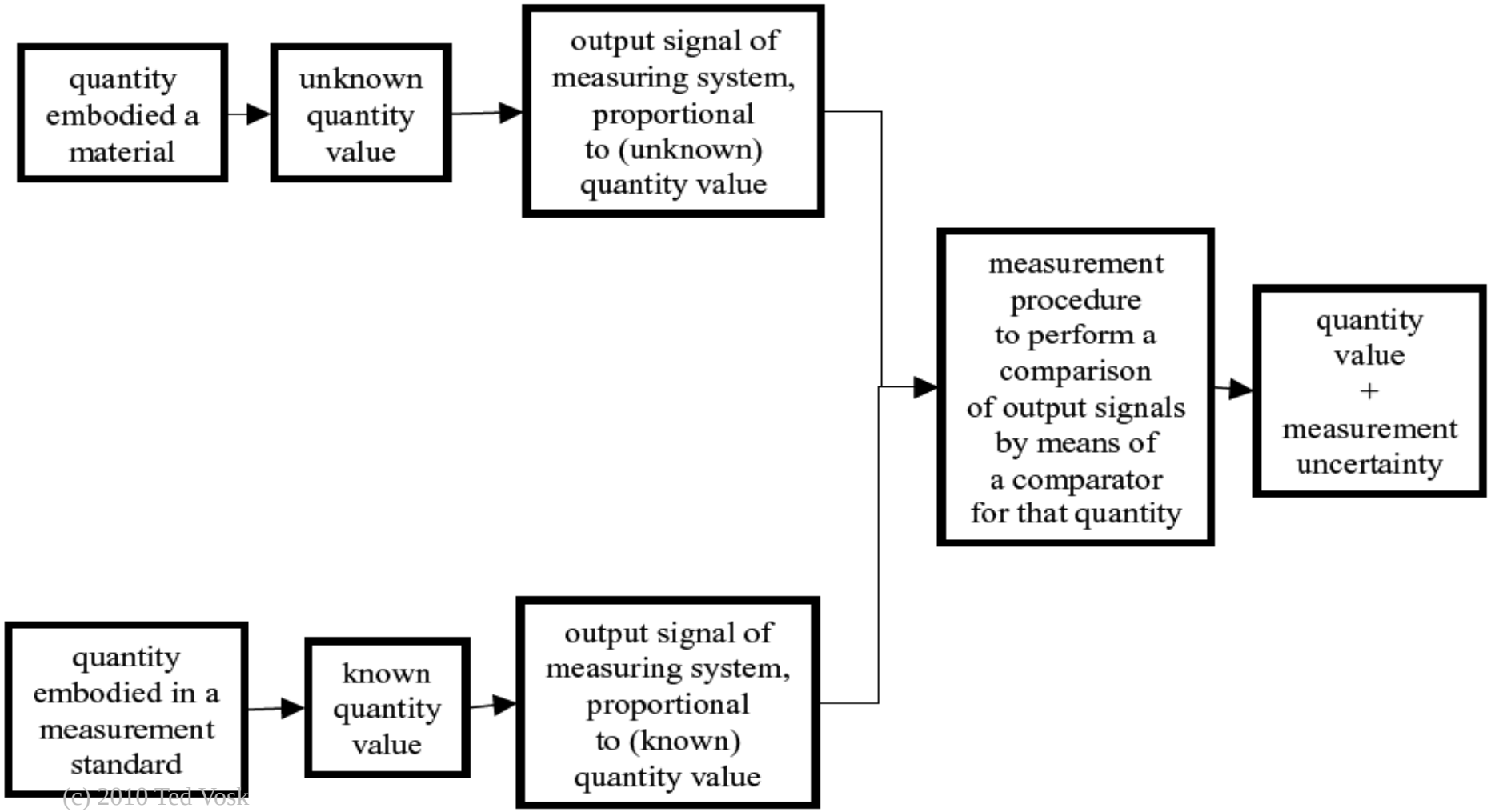
Scientific Standards:
- General & specific
- Accreditation



The Measurement Process

"Measurement implies comparison of quantities."

VIM § 2.1



Reference Standards

Object, material, substance or process one or more of whose properties are well enough established to be used for instrument calibration, assessment of method, assignment of values and/or classification.

MASS

CONCENTRATION/ IDENTITY

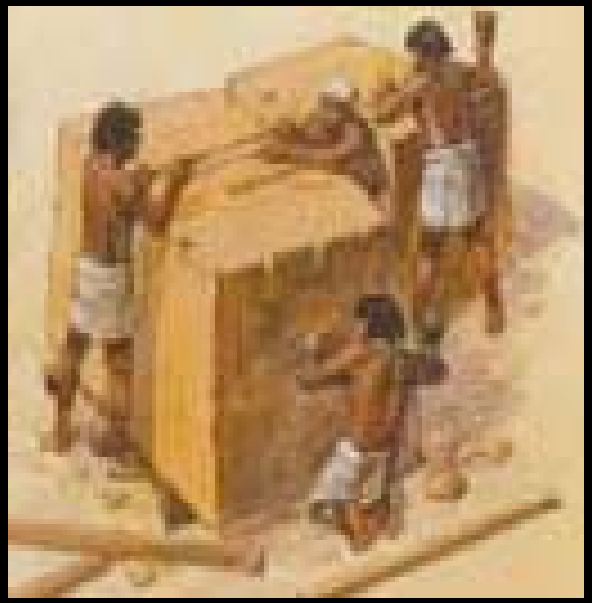
LENGTH

Reference Standards: The Cubit

Cubit: Length from forearm from bent elbow to tip of middle finger.

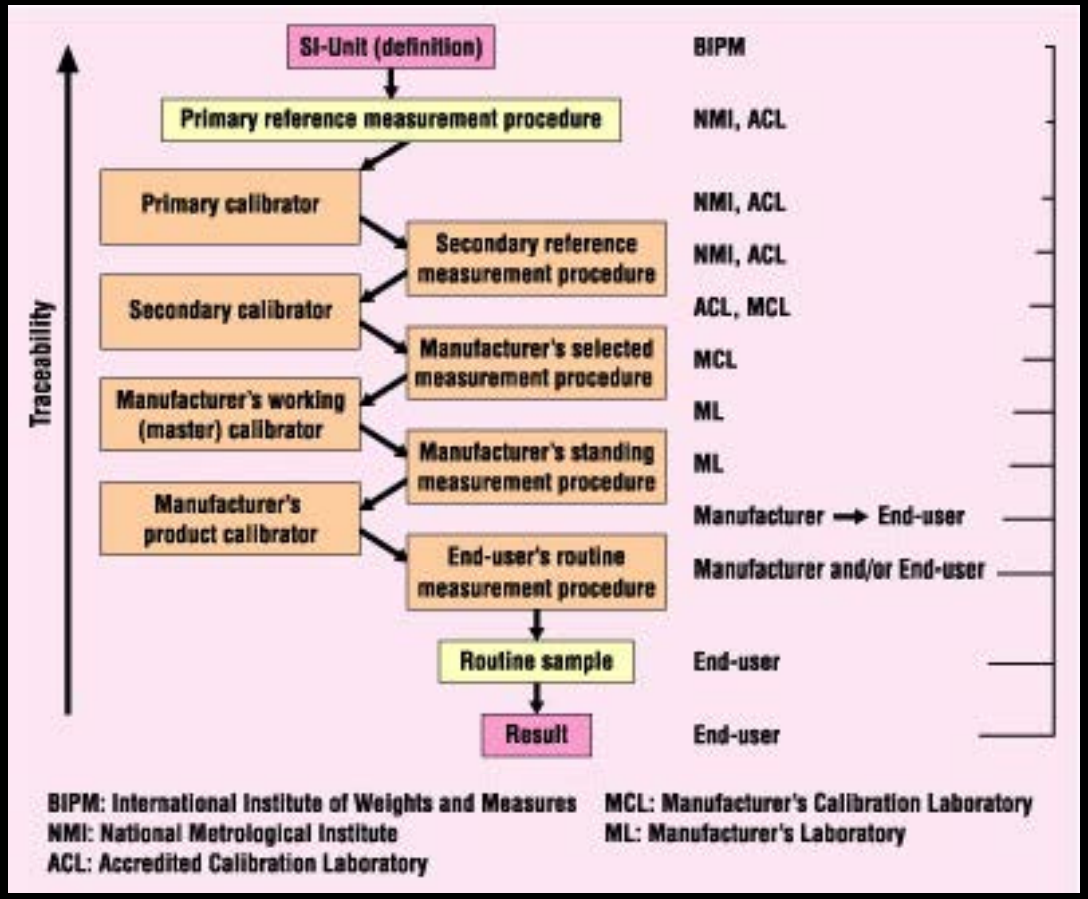
Reference Standards: The Cubit

Egyptians utilized the cubit as the standard measure of length for construction.

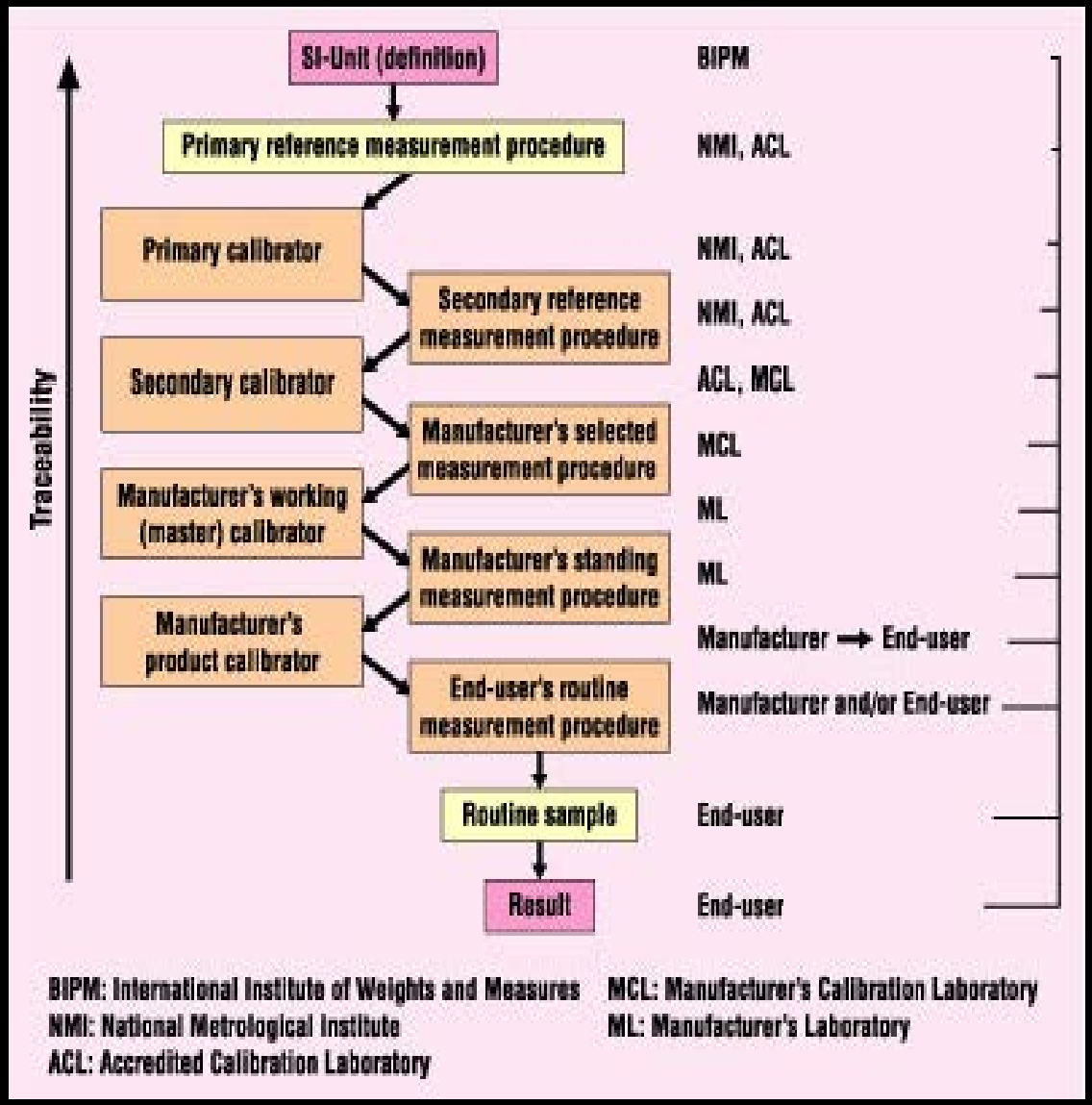


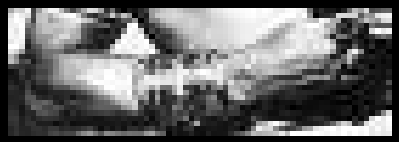
Traceability

Traceability: "Property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty." VIM § 2.41.



Traceability: The Cubit





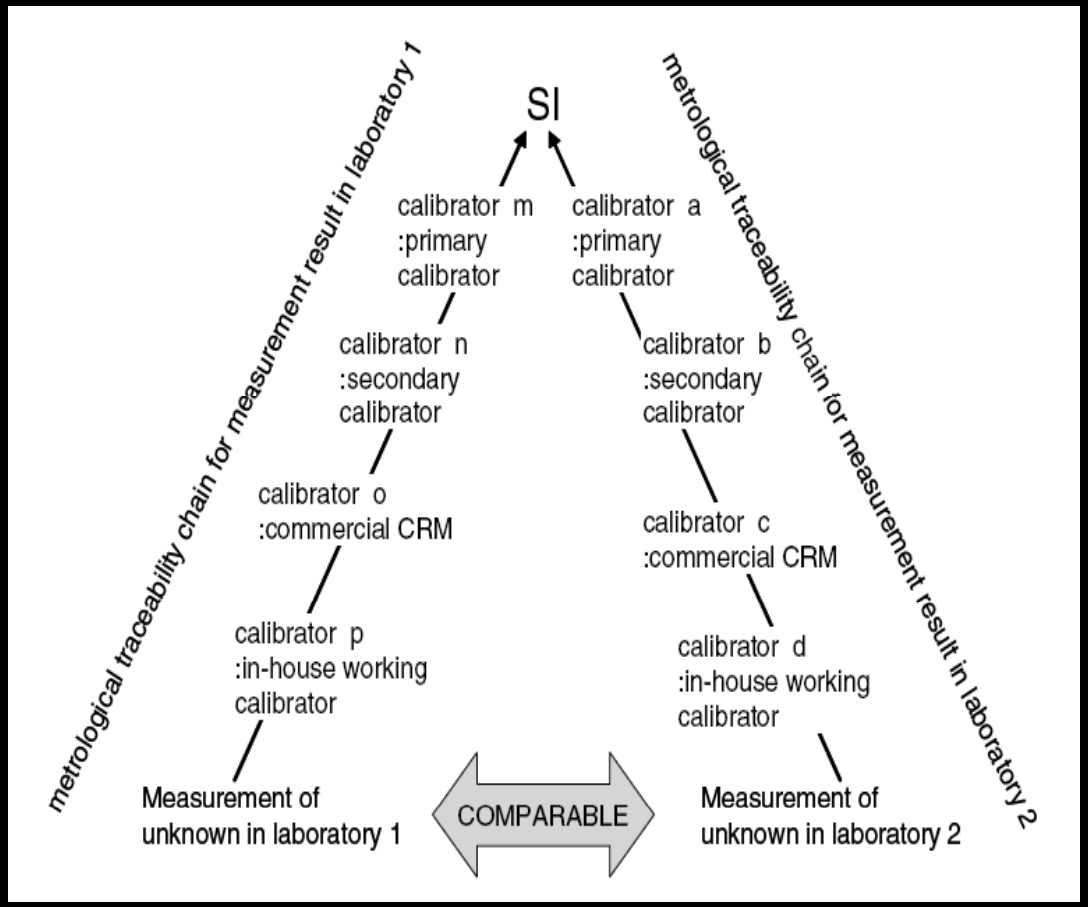
Traceability: The Cubit

Using cubit Egyptians were able to construct massive pyramids accurate to within 4.5 inches!

Comparability: The Cubit

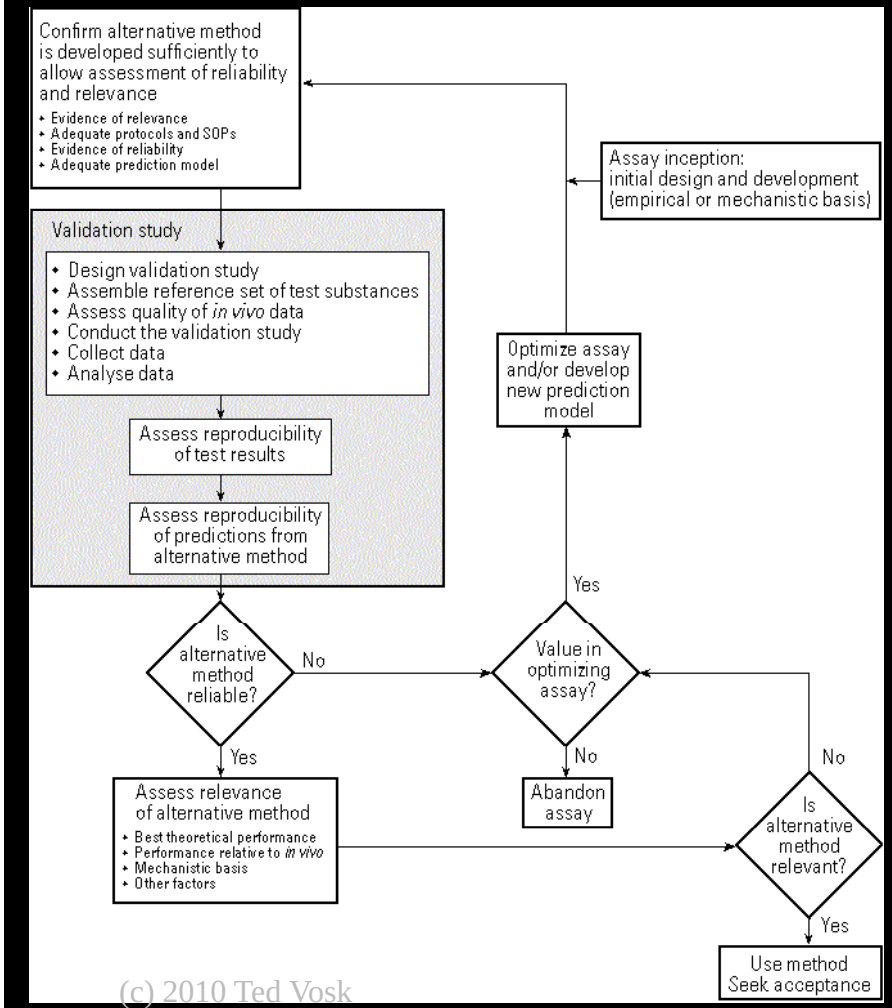
Traceability & Comparability

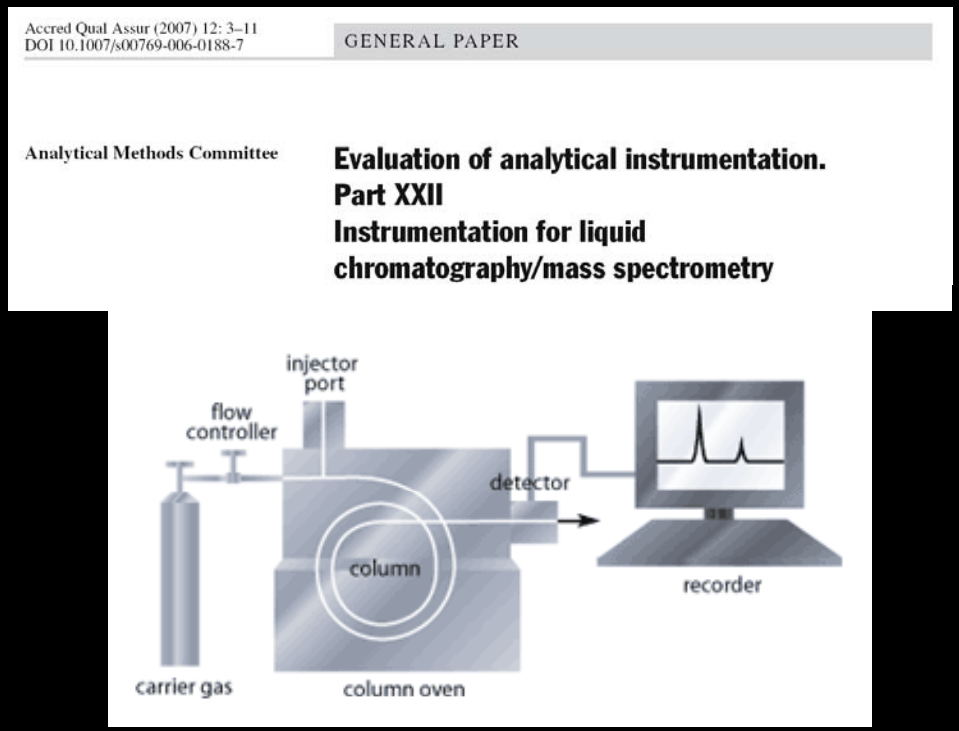
Traceability to documented reference standards is necessary for the comparison of measurement results.



Validation

A central component of science is the validation of methods to determine their ability to answer questions posed and their limitations.




Accred Qual Assur (2007) 12: 3–11
DOI 10.1007/s00769-006-0188-7

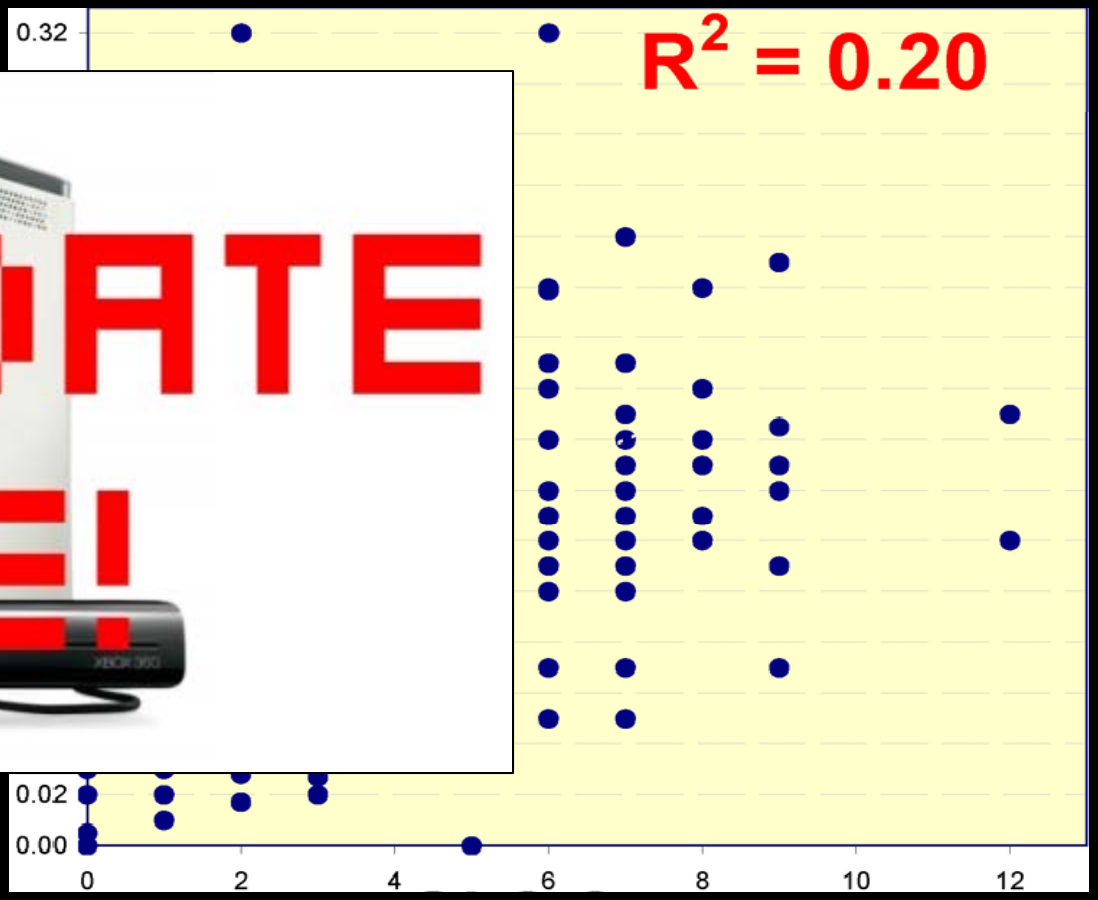
GENERAL PAPER

Analytical Methods Committee

Evaluation of analytical instrumentation. Part XXII Instrumentation for liquid chromatography/mass spectrometry

Validation

"To confirm the validity of a method or process for a particular purpose…validation studies must be performed." NAS 113



Validation

The most important information from a validation study is:

(1) Can a method discriminate a hypothesis from its alternative;
(2) Can a method measure a quantity of interest;
(3) Sources and magnitude of error/uncertainty;
(4) Consequences of error/uncertainty on the decisions relying upon method.

Validation Method Reliability

	Test Result A	**Test Result ¬ A**	
A	True Positive N_{TP}	False Negative N_{FN}	$\mathbf{N_{TP} + N_{FN}}$
¬ A	False Positive N_{FP}	True Negative N_{TN}	$\mathbf{N_{FP} + N_{TN}}$
	$\mathbf{N_{TP} + N_{FP}}$	$\mathbf{N_{FN} + N_{TN}}$	**N**

Validation
Method Reliability

	Test Result A	Test Result ¬A	
A	True Positive N_{TP}	False Negative N_{FN}	$N_{TP}+N_{FN}$
¬A	False Positive N_{FP}	True Negative N_{TN}	$N_{FP}+N_{TN}$
	$N_{TP}+N_{FP}$	$N_{FN}+N_{TN}$	**N**

SENSITIVITY: Percent confirming a true condition.

$$S_e = [N_{TP} /(N_{TP} + N_{FN})]$$

SPECIFICITY: Percent rejecting a false condition.

$$S_p = [N_{TN} /(N_{FP} + N_{TN})]$$

FALSE NEGATIVE (TYPE I ERROR) RATE: Percent rejection of true condition.

$$FNR = [N_{FN} /(N_{TP} + N_{FN})]$$

FALSE POSITIVE (TYPE II ERROR) RATE: Percent failure to reject false condition.

$$FPR = [N_{FP} /(N_{FP} + N_{TN})]$$

POSITIVE PREDICTIVE VALUE: Percent indicating condition true that are correct.

$$P_{pv} = [N_{TP} /(N_{FP} + N_{TP})]$$

NEGATIVE PREDICTIVE VALUE: Percent indicating condition false that are correct.

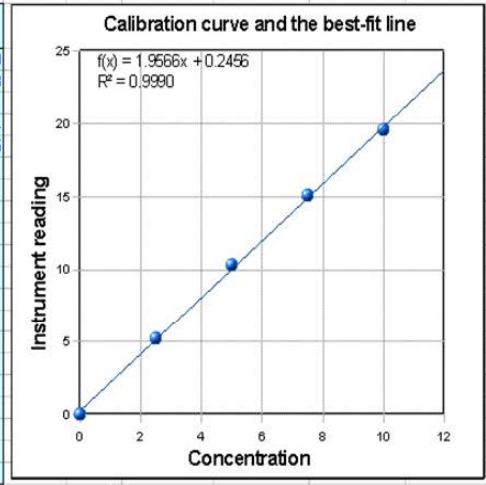
$$N_{pv} = [N_{TN} /(N_{FN} + N_{TN})]$$

Quality Assurance: Calibration

Procedure by which it is ensured that a given instrument can yield a traceable results with known level of uncertainty.

Calibration data

Concentration of standards	Instrument readings
0	0
2.5	5.23
5	10.31
7.5	15.04
10	19.55



Application to unknowns

Readings of the unknowns	Calculated concentration	Estimated error (σ)	Estimated % relative error
5.0000	2.4300	0.12	4.88%
10.0000	4.9855	0.14	2.85%
20.0000	10.0965	0.21	2.10%

Standard deviation of the residuals = 1.217%

	value	Error (σ)
Slope	1.9566	0.0352
Intercept	0.2456	0.2156

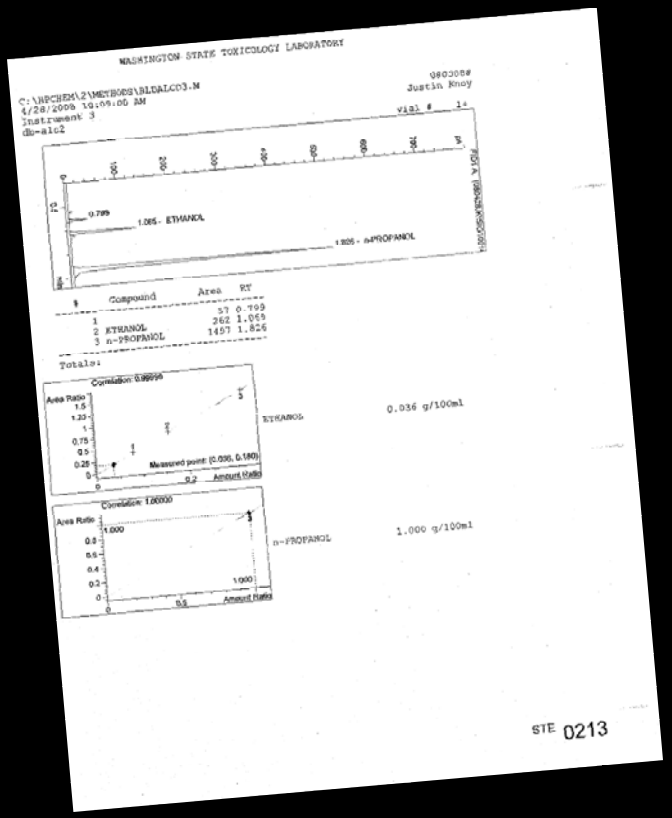
Calibration: Range of Calibration

"Standards should never be used in an extrapolative mode. They should always bracket the measurement range. No measurement should be reported at a value lower or higher than the lowest or highest standard used to calibrate the measurement process." NIST, *Standard Reference Materials: Handbook for SRM Users*, NISTSP 260-100, 6 (1993).

CERTIFICATION RESULTS (g/210L)

	0.04	0.08	0.10	0.15
Reference Value	0.0399	0.0799	0.1003	0.1510
QAP Batch #	09002	09003	09004	09005
Simulator #	DR4542	DR4472	DR4532	DR4473
Sim Thermometer #	DR4542	DR4472	DR4532	DR4473
1	0.041	0.079	0.103	0.150
2	0.039	0.079	0.103	0.151
3	0.040	0.080	0.103	0.152
4	0.039	0.080	0.104	0.153
5	0.039	0.079	0.103	0.153
6	0.040	0.079	0.103	0.153
7	0.038	0.079	0.103	0.153
8	0.039	0.079	0.103	0.153
9	0.040	0.079	0.102	0.153
10	0.040	0.079	0.102	0.154
Mean	0.0395	0.0792	0.1029	0.1525
SD	0.0008	0.0004	0.0006	0.0012
Bias %	-1.00	-0.88	2.59	0.99
CV %	2.03	0.51	0.58	0.79

Result Interpretation
Quantitative & Qualitative



WASHINGTON STATE TOXICOLOGY LABORATORY

C:\HPCHEM\2\METHODS\BLDALCD3.M
4/28/2009 10:55:05 AM
Instrument 3
db-alc2

Justin Knoy

vial # 14

0.799
1.065 - ETHANOL
1.826 - n-PROPANOL

#	Compound	Area	RT
1		57	0.799
2	ETHANOL	262	1.065
3	n-PROPANOL	1457	1.826

Totals:

Correlation: 0.99998
Area Ratio
Measured point: (0.036, 0.180)
Amount Ratio
ETHANOL
0.036 g/100ml

Correlation: 1.00000
Area Ratio
1.000
n-PROPANOL
1.000 g/100ml
Amount Ratio

STE 0213

Interpreting Results

ST

agency case #:
attn:
agency:

date received: 4-2 -2008
date completed: 4-2 -2008

Last name	First name	Middle initial

sample	blood - peri	urine
container	vg	vr
labeled	Y	Y

BLOOD ETHANOL 0.04 g/100mL

BLOOD ANALYSES
not performed

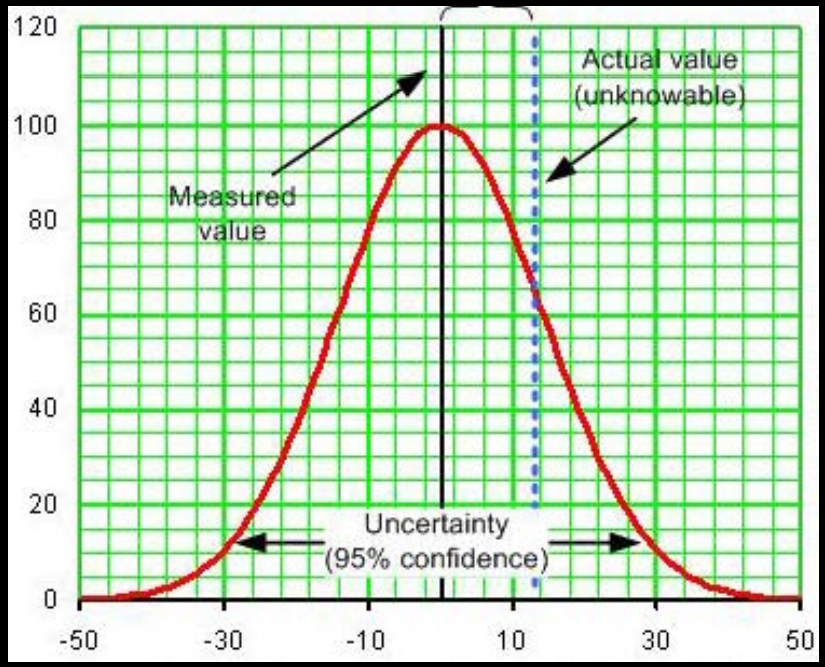
"It is scientific only to say what is more likely and what is less likely." Richard Feynman.

Reporting Results

"Forensic reports, and any courtroom testimony stemming from them, must include clear characterizations of the limitations of the analyses, including measures of uncertainty in reported results and associated estimated probabilities where possible." NAS 186.

Quantitative Results & Uncertainty

UNCERTAINTY: For a given measurement result, there is not one value but an infinite number of values dispersed about the result that are consistent with the observations and data and one's knowledge of the physical world, and that with varying degrees of credibility can be attributed to the measurand. GUM §5.2



Quantitative Results & Uncertainty

UNCERTAINTY: Characterization of the dispersion of values assignable to a measurand based on the information available and taking into account all sources of error associated with the measurement or test process.

Quantitative Results & Uncertainty

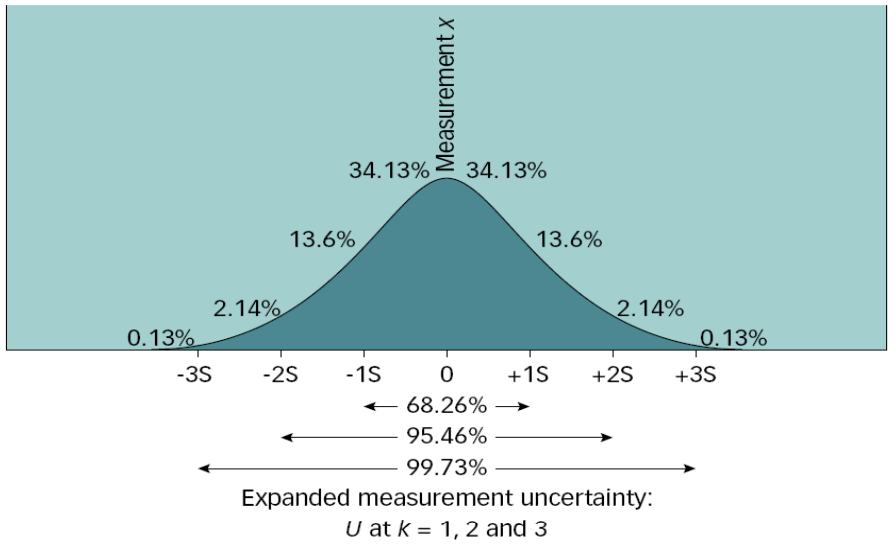
Coverage Interval & Expanded Uncertainty ($U = k\mu_c$)

Define an interval about a measurement result expected to encompass a large fraction of the distribution of values that can reasonably be attributed to the measurand with a given level of confidence.

Coverage factors for reporting expanded measurement uncertainty / TABLE 1

Confidence interval	*k* coverage factor
68.26%	1.000
90%	1.645
95%	1.960
95.45%	2.000
99%	2.576
99.73%	3.000

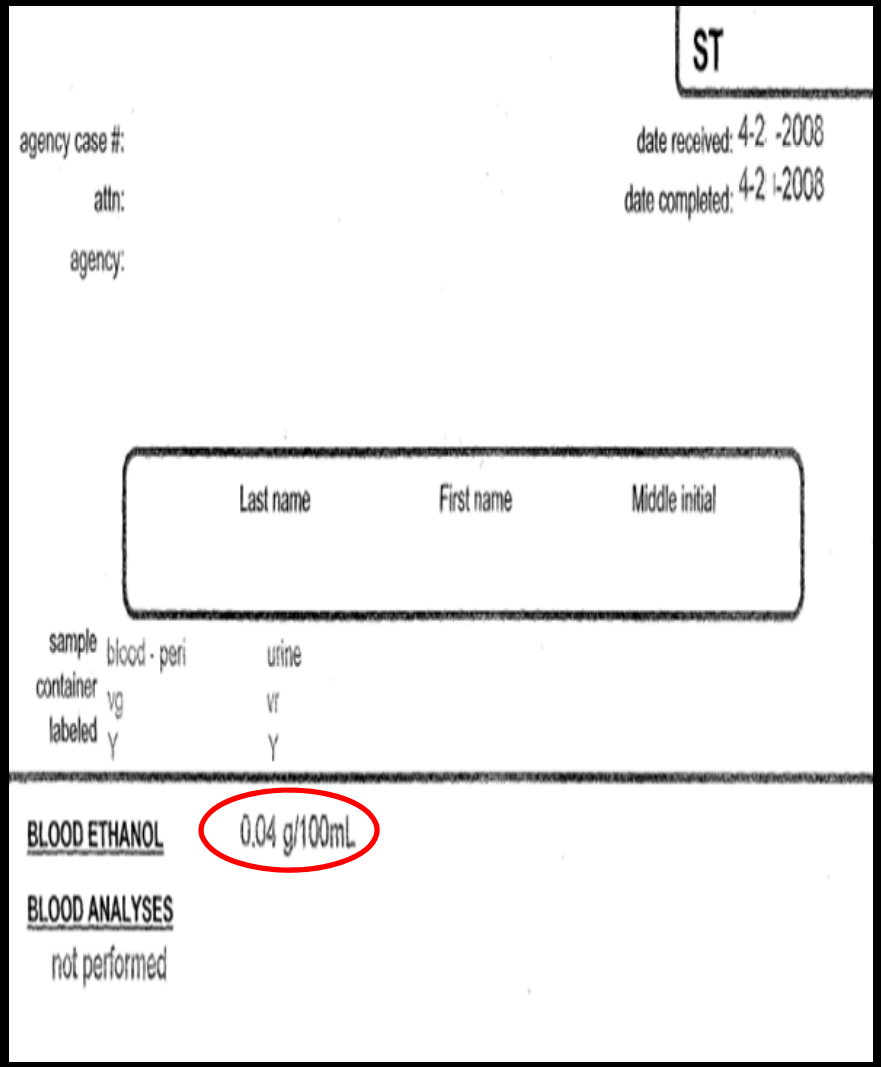
Expanded measurement uncertainty of measurement *x* / FIGURE 1



Quantity value = Y ± U (k = 1.96; 95%)

Quantitative Results & Uncertainty

"In general, the result of a measurement is only an approximation or estimate of the value of the specific quantity subject to measurement…and thus the result is complete only when accompanied by a quantitative statement of its uncertainty." NIST 1297 § 2.1.


ST

agency case #:

attn:

agency:

date received: 4-2 -2008

date completed: 4-2 -2008

Last name | First name | Middle initial

sample	blood - peri	urine
container	vg	vr
labeled	Y	Y

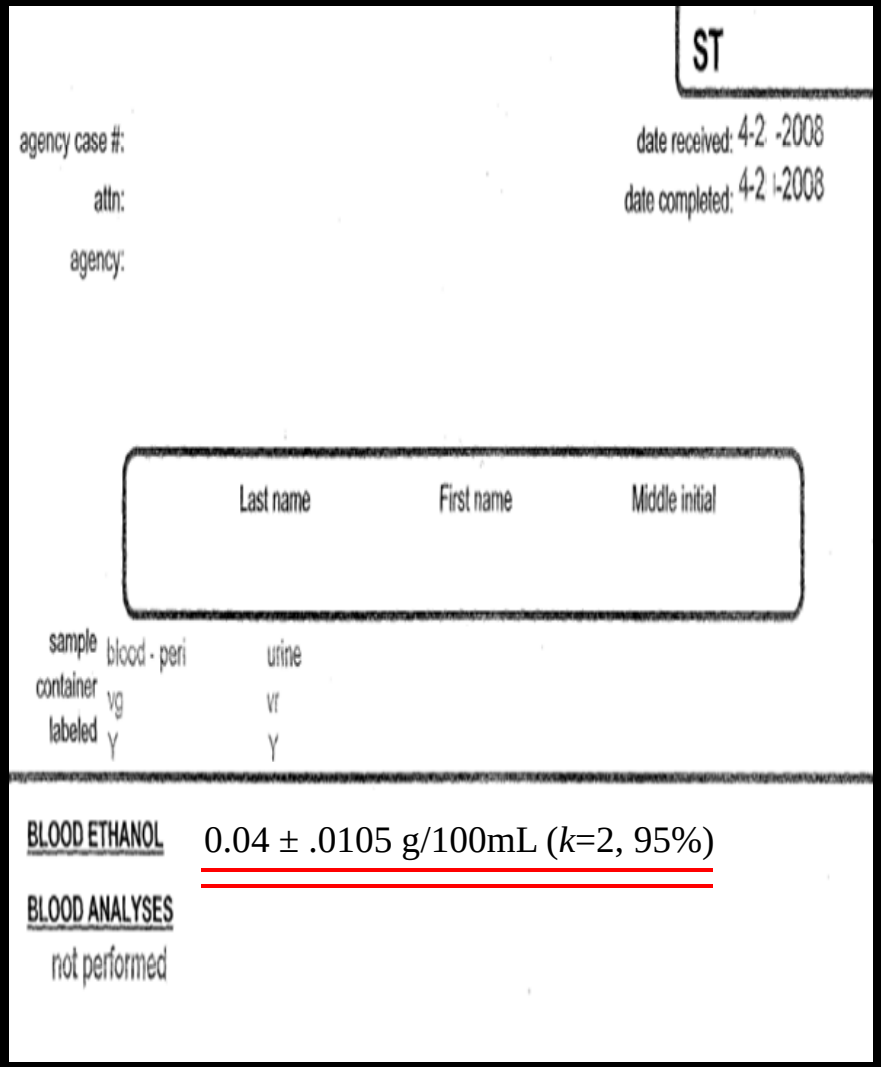
BLOOD ETHANOL 0.04 g/100mL

BLOOD ANALYSES

not performed

Quantitative Results & Uncertainty

"In general, the result of a measurement is only an approximation or estimate of the value of the specific quantity subject to measurement…and thus the result is complete only when accompanied by a quantitative statement of its uncertainty." NIST 1297 § 2.1.


ST

agency case #:

attn:

agency:

date received: 4-2 -2008

date completed: 4-2 -2008

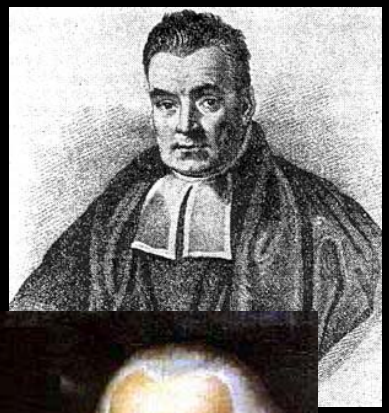
Last name First name Middle initial

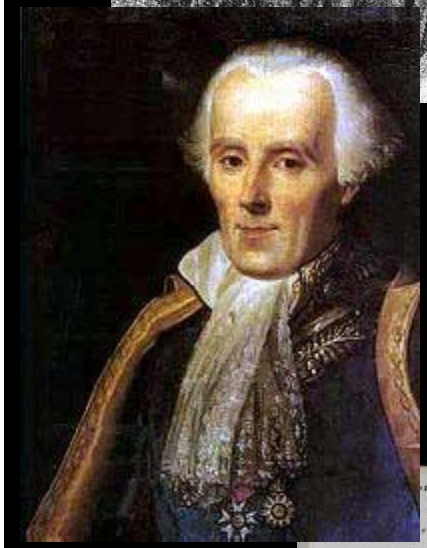
sample container labeled	blood - peri vg Y	urine vr Y

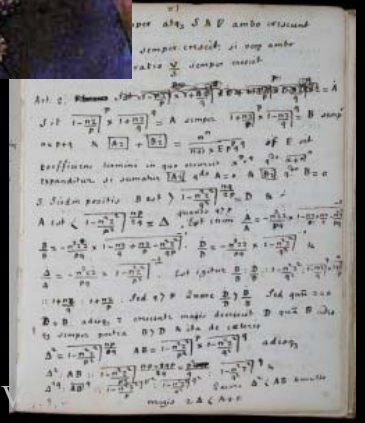
BLOOD ETHANOL 0.04 ± .0105 g/100mL (*k*=2, 95%)

BLOOD ANALYSES not performed

Bayesian Methods







Baye's Theorem

$$p(H \mid I) \alpha p(H)\, p(I \mid H)$$

where

$p(H \mid I)$ = Posterior probability: Probability of H given result I.

$p(H)$ = Prior probability: Probability of (degree of belief in) H prior to result I.

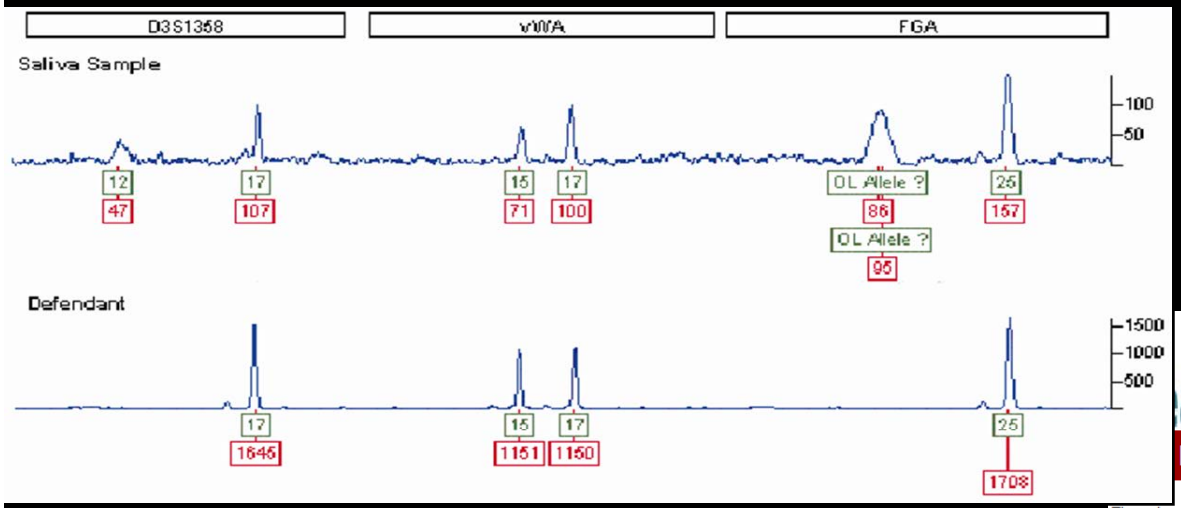
$p(I \mid H)$ = Probability of result I if H true.

Likelihood Ratio

$$LR = p(I \mid H) / p(I \mid \neg H)$$

Interpreting DNA Results

Random Match Probability & False Positives



seattlepi Local

Local | Nation/World | Business | Sports | A&E

Thursday, July 22, 2004

Rare look inside state crime labs reveals recurring DNA test problems

Thursday, July 22, 2004

DNA testing mistakes at the State Patrol crime labs

Local

Thursday, July 22, 200

Produce crime lab error rates, some urge

But defense attorneys would misuse data, scientists counter

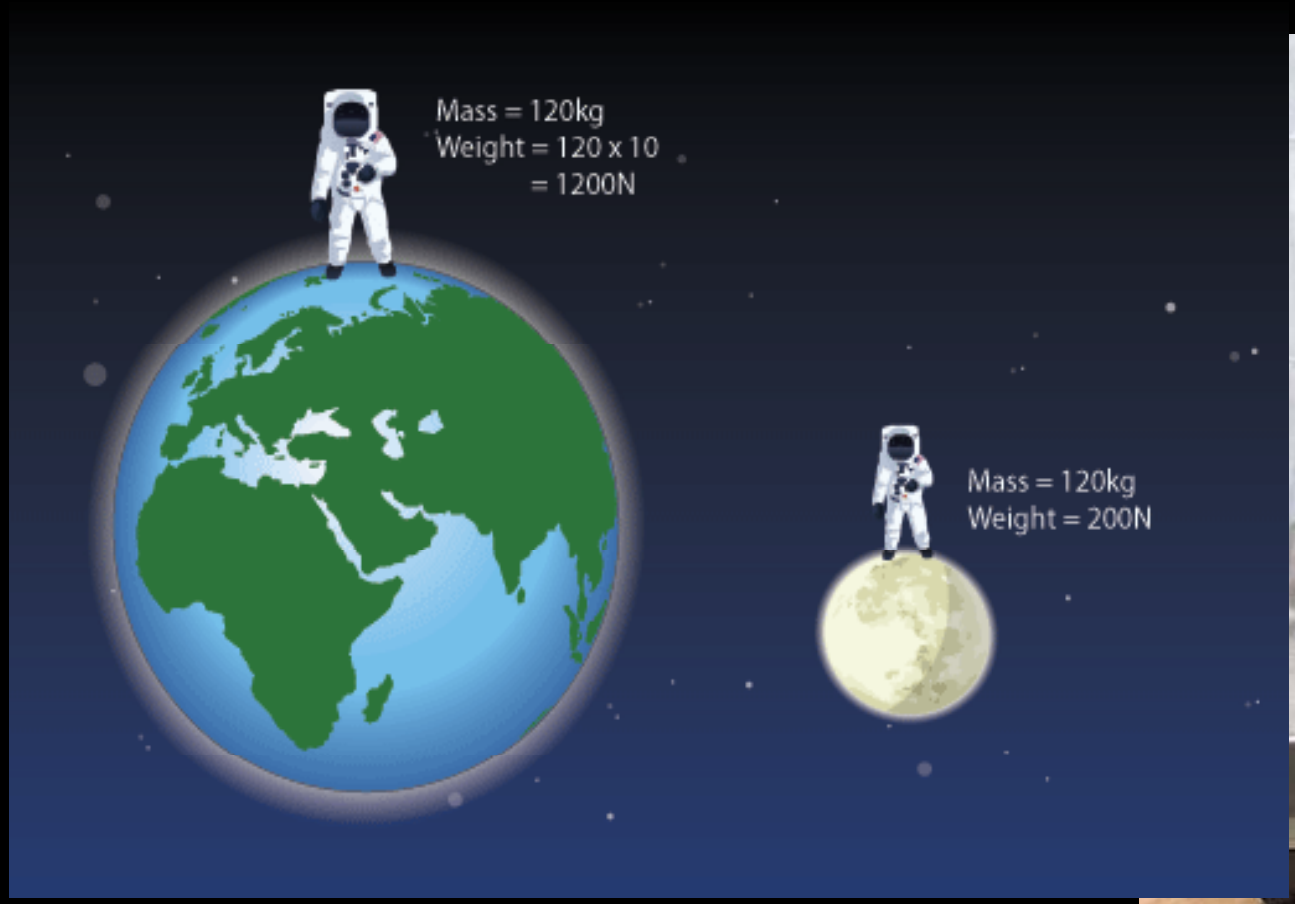
Both random match and false positive probabilities must be taken into account to properly interpret DNA evidence.

Interpreting Results

Meaning of result cannot be determined without estimate of uncertainty or reliability!

Result Interpretation
The Measurand

Measurand: quantity intended to be measured



Scientific Standards

"Standards provide the foundation against which performance, reliability, and validity can be assessed. Adherence to standards reduces bias, improves consistency, and enhances the validity and reliability of results." NAS 201.

Metrology Standards

Metrological standards are established by consensus, based on the consolidated results of science, technology and experience, and approved by a recognized body. ISO Guide 2 § 3.2.

ISO 17025

"This International Standard specifies the general requirements for the competence to carry out tests and/or calibrations…[and] is applicable to all organizations performing tests and/or calibrations." ISO 17025 § 1.1 – 1.2.

Metrology
Fundamental Principles of Reasoning

You

CAN

do

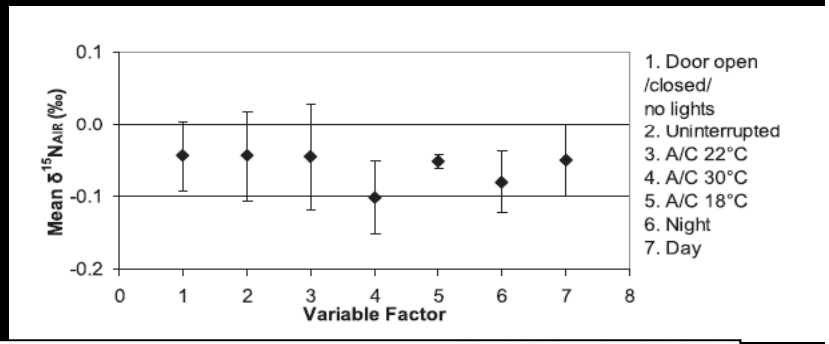
this!

Metrology and the Jurisprudence of Science

"[I]n order to qualify as 'scientific knowledge,' an inference or assertion must be derived by the scientific method." *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 509 U.S. 579, 590 (1993)

Metrology & Legal Principles

A key question is whether a scientific method has been tested. Scientific evidence "must be supported by appropriate validation." Daubert.

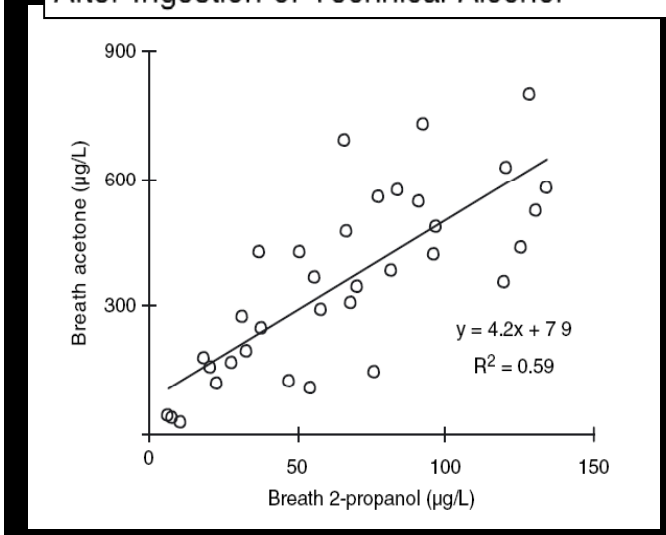


TECHNICAL NOTE

J Forensic Sci, July 2007, Vol. 52, No. 4
doi: 10.1111/j.1556-4029.2007.00454.x
Available online at: www.blackwell-synergy.com

Olli Laakso,[1,2] M.D.; Matti Haapala,[3] M.Sc.; Teemu Pennanen,[4] M.Sc.; Tapio Kuitunen,[5] M.D., Ph.D.; and Jaakko-Juhani Himberg,[6] M.D., Ph.D.

Fourier-Transformed Infrared Breath Testing After Ingestion of Technical Alcohol*



TECHNICAL NOTE
CRIMINALISTICS

J Forensic Sci, January 2010, Vol. 55, No. 1
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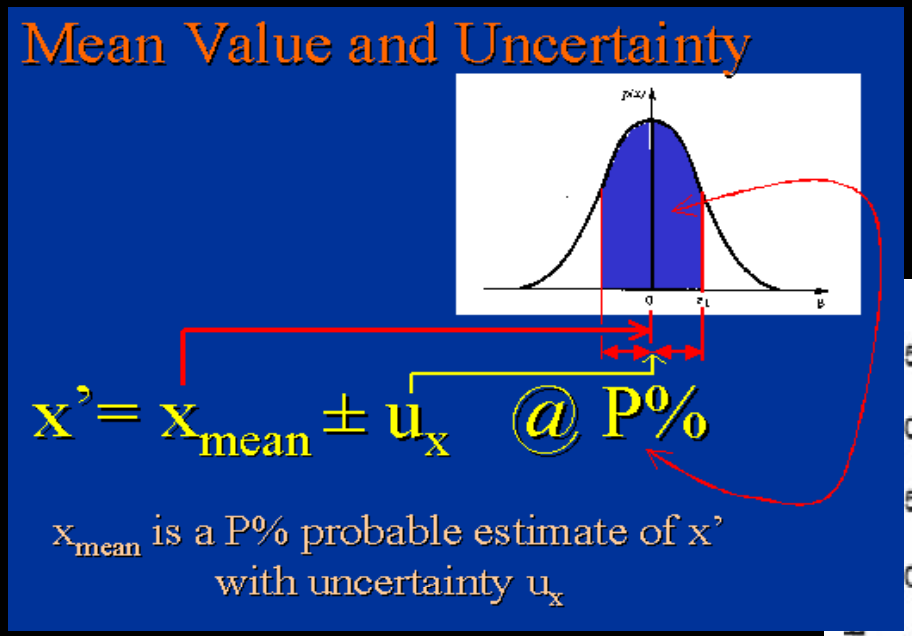
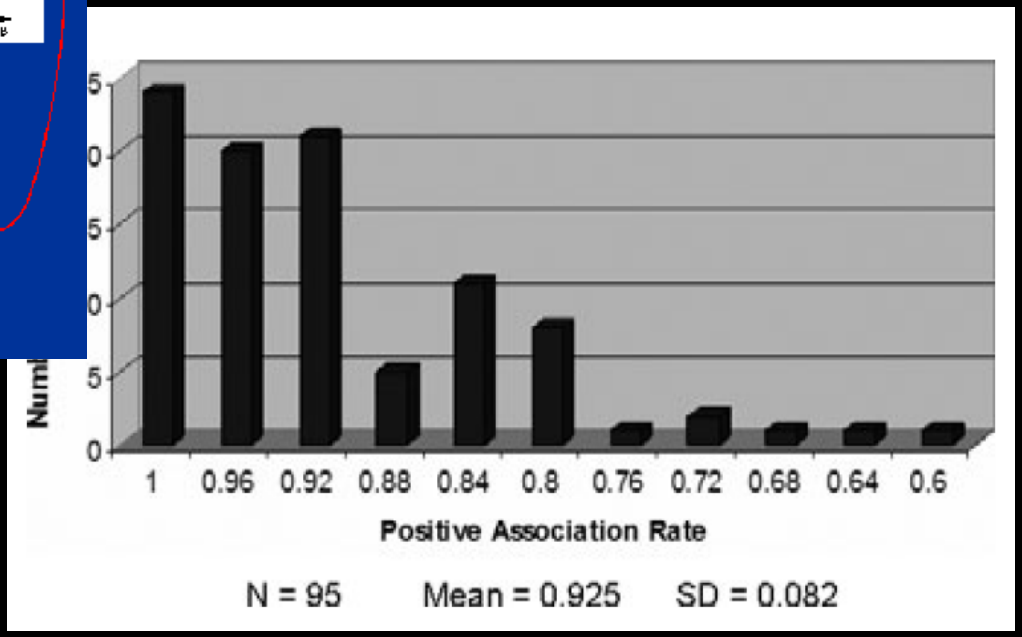
Forensic Analysis of Explosives Using Isotope Ratio Mass Spectrometry (IRMS)—Part 1: Instrument Validation of the DELTA^{plus}XP IRMS for Bulk Nitrogen Isotope Ratio Measurements

Metrology & Legal Principles

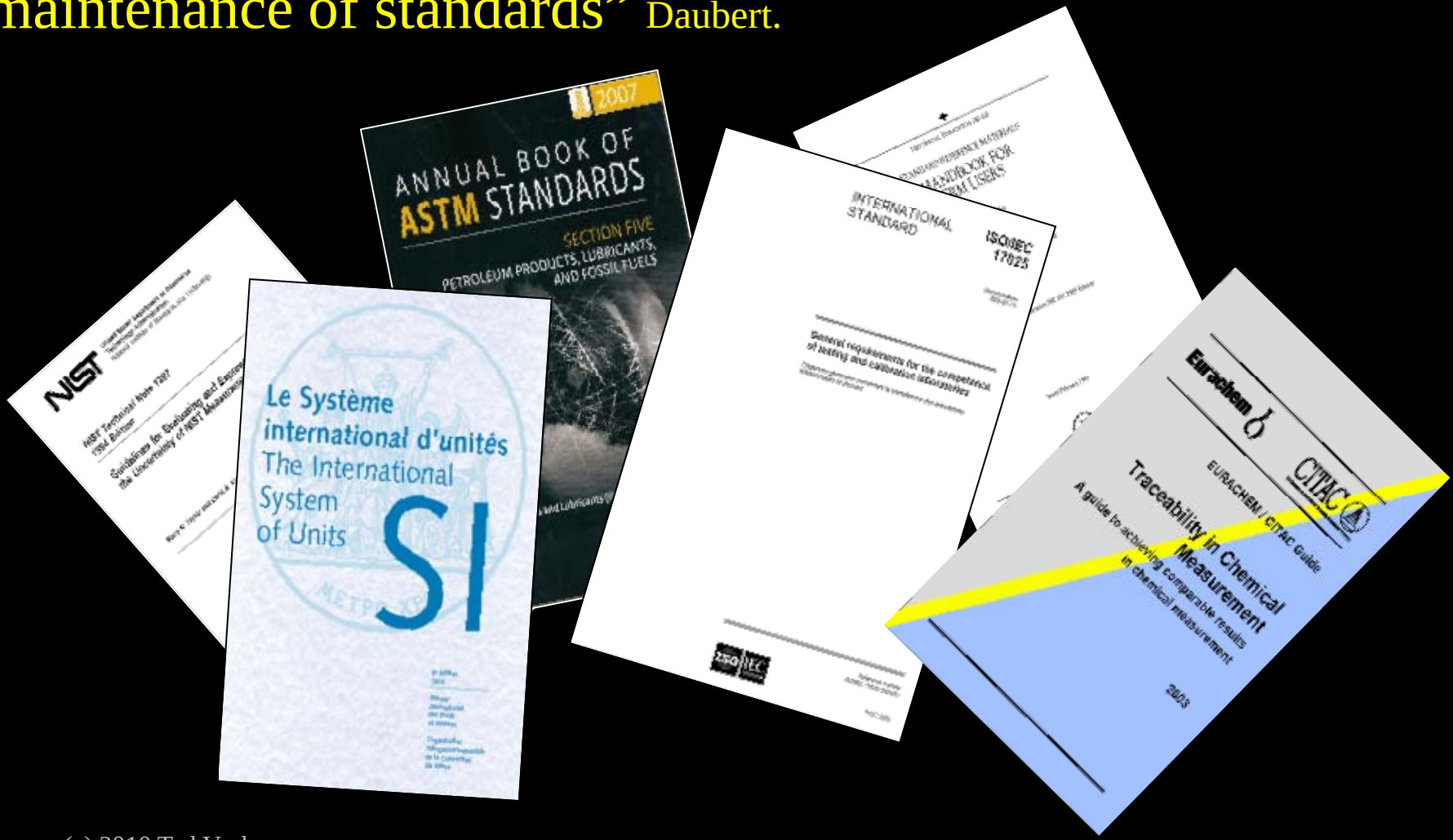
"[T]he court ordinarily should consider the known or potential rate of error…" Daubert.





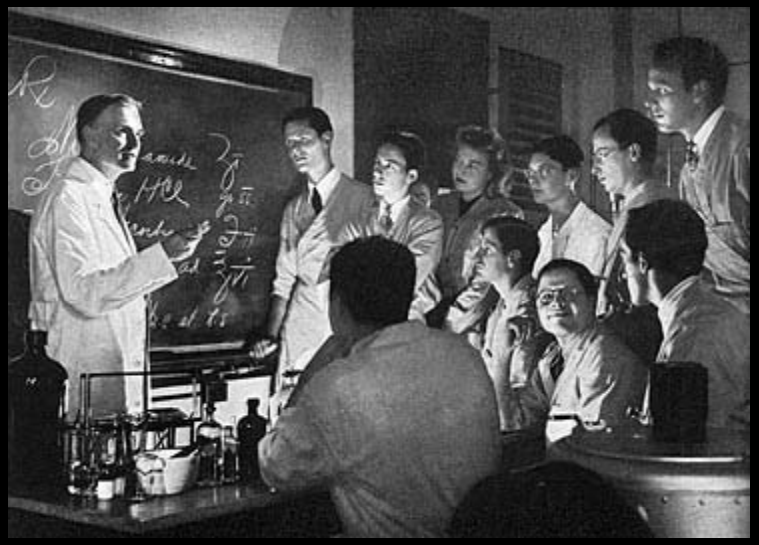
Metrology & Legal Principles

"[T]he court ordinarily should consider…the existence and maintenance of standards" Daubert.



Metrology & Legal Principles

"General acceptance... can be an important factor." Daubert. Frye.



Metrology
Fundamental Principles of Reasoning

"If the citizens of the State of Washington are to have any confidence in the breath testing program, that program has to have some credence in the scientific community as a whole."

Traceability

Uncertainty

"While forensic science is distinct from research science some may believe that a lesser standard is acceptable. Such a conclusion would be erroneous…When evidence of measurement relies on inadequate scientific foundation, the proffered evidence must be classified as untrustworthy and inadmissible. To admit bogus and misleading science under the pretext of legitimate science is irrational and harmful to any notion of justice."

"...the proposition that robust scientific standards are expected in the WSTL still remains."

ISO 17025

So simple even a judge can do!

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American Academy of Forensic Sciences
February 22, 2010

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