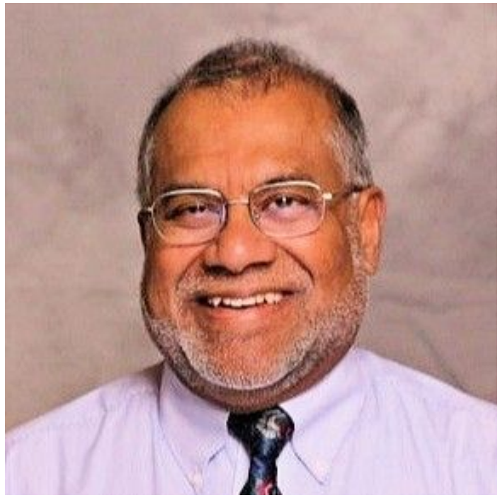
CPR for Confidence in Your Measurements



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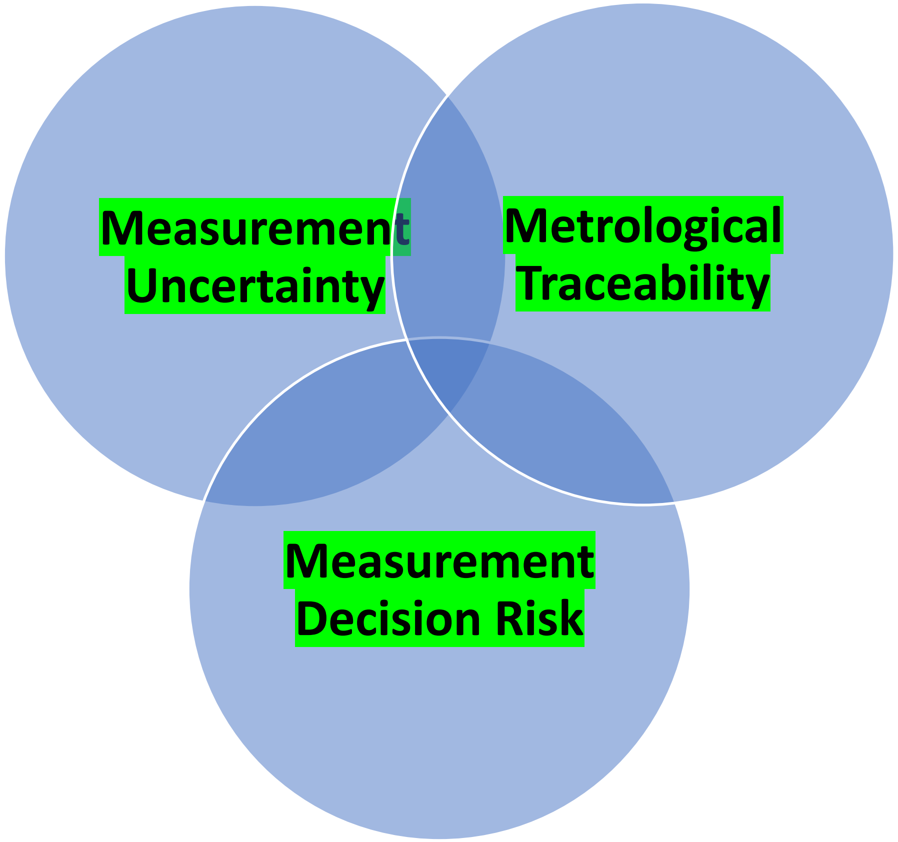
SCAN ME

CPR for Confidence in Your Measurements



Proper Evaluation of Uncertainty

Minimum Contributors to Consider:

- Repeatability (Type A) *(Testing Laboratory)*
- Resolution *(Testing Laboratory)*
- Reproducibility (Type A) *(Testing Laboratory)*
- Reference Standard Uncertainty *(Testing Laboratory)*

- Reference Standard Stability
- Environmental Factors

Calculating Repeatability and Reproducibility

- Take Repeatability data, compile R&R. Sounds simple right?

	Tech 1	Tech 2	Tech 3
Nom. Value ->	100	100	100
1	100.000 309	99.999 849	99.999 929
2	100.000 328	100.000 095	100.000 026
3	100.000 058	99.999 821	100.000 192
4	100.000 149	100.000 102	100.000 001
5	100.000 304	100.000 022	100.000 081
6	99.999 830	100.000 136	99.999 833
7	100.000 139	100.000 506	99.999 744
8	100.000 213	99.999 669	100.000 025
9	100.000 353	99.999 681	100.000 072
10	100.000 271	99.999 820	100.000 227

Group Mean	**100.000 060**		
Mean	100.000 196	99.999 970	100.000 013
StdDev	0.000 160 30	0.000 254 91	0.000 148 48
DOF	9	9	9
Sum of Squares (SS)	2.31273E-07	5.84805E-07	1.98413E-07
	Group (Tech) 1	Group (Tech) 2	Group (Tech) 3

Error of SS	1.01449E-06	
Total DOF	27	(in UOM)
Repeatability	0.000 193 84	1.94
Reproducibility	0.000 119 70	1.20

Calculating Repeatability and Reproducibility

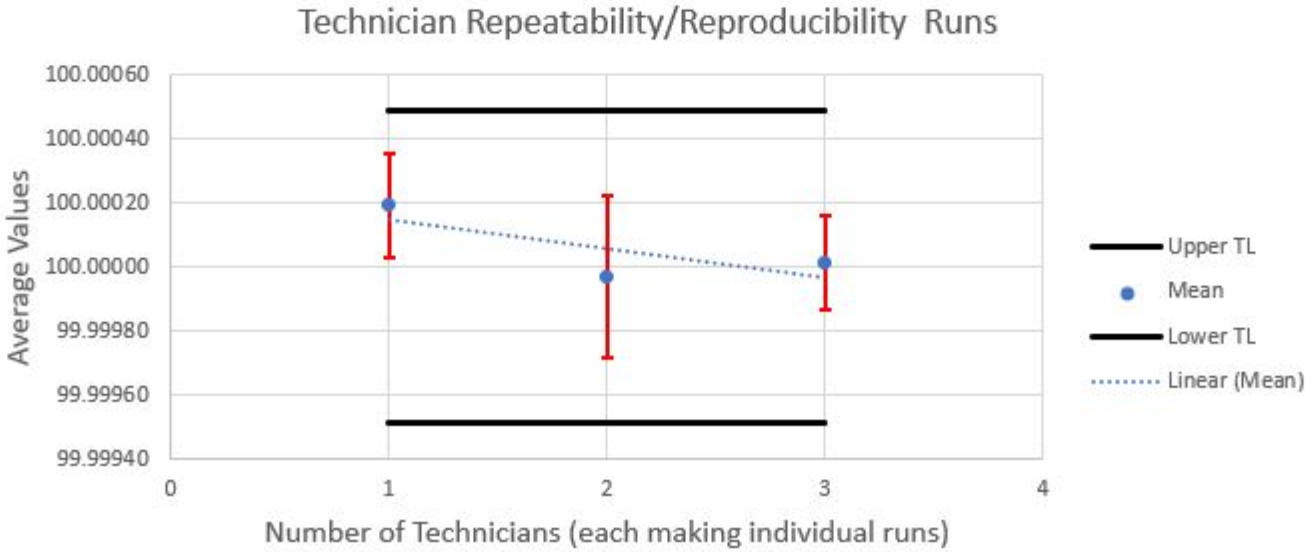
- Anything look out of place?

SUMMARY

Groups	Count	Sum	Average	Variance	% of Total Variance
Tech 1	10	1000.001 955	100.000 196	25.697E-09	22.8%
Tech 2	10	999.999 701	99.999 970	64.978E-09	57.6%
Tech 3	10	1000.000 130	100.000 013	22.046E-09	19.6%

ANOVA - Single Factor

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.86563E-07	2	1.43282E-07	3.813351641	3.478%	3.354130829
Within Groups	1.01449E-06	27	3.75737E-08			
Total	1.30105E-06	29				



Calculating Repeatability and Reproducibility

Sub Groups	1	2	3	4	5
1	0.9956	1.0087	1.0069	0.9927	1.0029
2	1.0092	1.0000	0.9938	1.0047	0.9908
3	1.0073	1.0014	0.9943	0.9913	1.0053
4	1.0049	0.9926	0.9921	0.9919	0.9956
5	0.9940	0.9986	0.9953	1.0070	0.9940
Sum	5.01100	5.00130	4.98240	4.98760	4.98860
Mean	1.00220	1.00026	0.99648	0.99752	0.99772
Range	0.01520	0.01610	0.01480	0.01570	0.01450
Standard Deviation	0.00695	0.00579	0.00594	0.00766	0.00613
Variance	0.000048	0.000034	0.000035	0.000059	0.000038
Repeatability (s_r)	0.006533	=SQRT(AVERAGE(B11:F11))			0.020
Reproducibility (s_R)	0.002338	=STDEV(B8:F8)			
$s_r^2 + s_R^2 =$	0.000048	$SQRT(s_r^2 + s_R^2) =$	0.006939084		
$s_L^2 =$	*-0.000003*	$s_L =$	*0.000000*	$s_R = SQRT(s_r + s_L^2) =$	*0.006533*
$s_L^2 = s_{X\text{-}Bar}^2 - s_r^2/n$					
if s_L^2 is negative, set $s_L^2 = 0$ and $s_L = 0$					

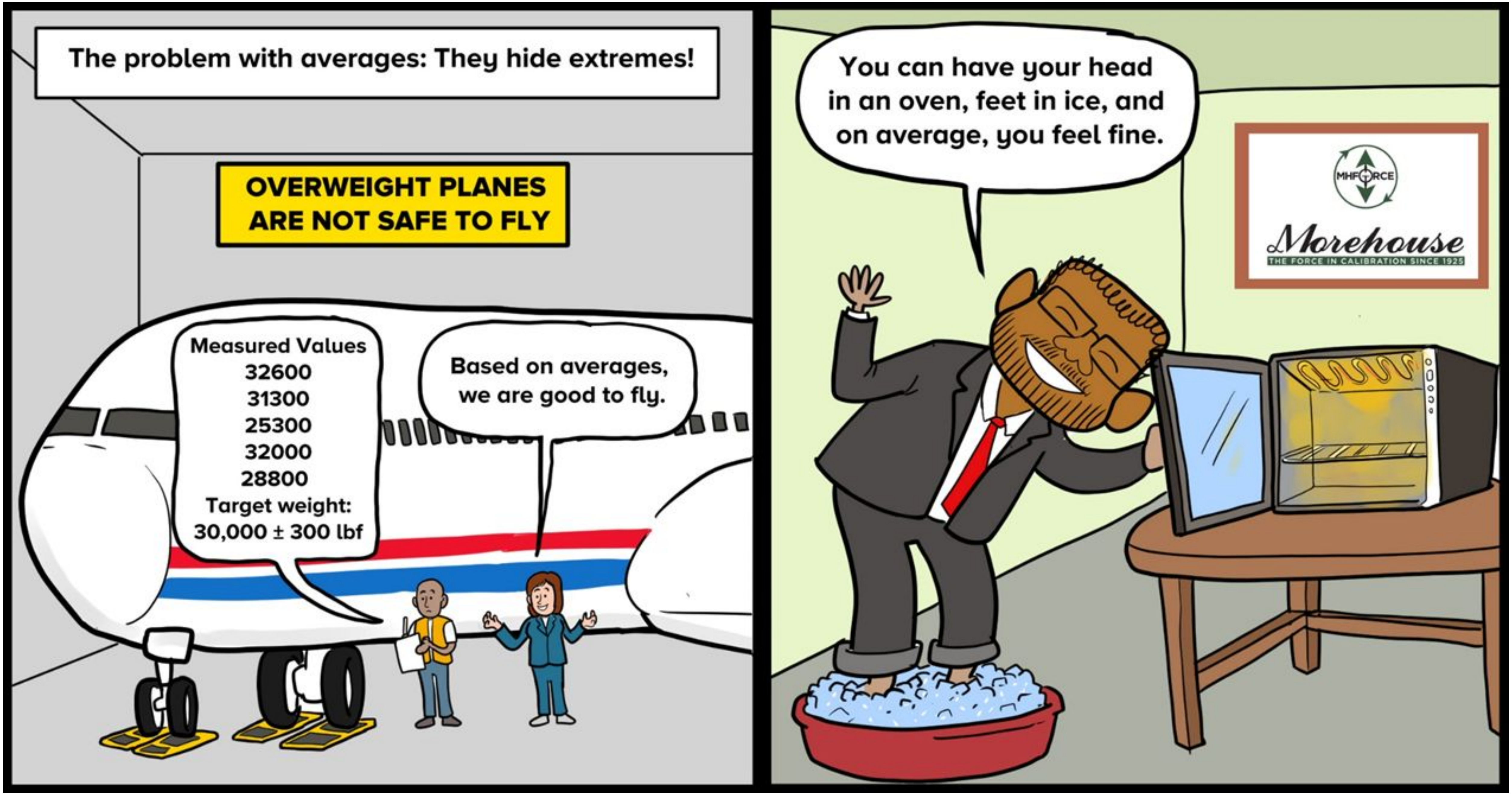
Documented Measurement Uncertainty Budget.

Contributors	Magnitude	Type	Distribution	Divisor	df	Std. Uncert.	Variance	% Contribution	u^4/df
Repeatability	19.950E-6	A	Normal	1	20	19.950E-6	398.000E-12	56.4%	7.920E-21
Reproducibility	16.793E-6	A	Normal	1	4	16.793E-6	282.000E-12	40.0%	19.881E-21
Resolution	10.000E-6	B	Resolution	3.464101615	100	2.887E-6	8.333E-12	1.2%	694.444E-27
Reference Standard Uncertainty	5.00E-06	B	k=2	2	100	2.500E-6	6.250E-12	0.9%	390.625E-27
Reference Standard Stability	3.00E-06	B	Rectangular	1.732050808	100	1.732E-6	3.000E-12	0.4%	90.000E-27
Environmental Factors	4.00E-06	B	U-Shaped	1.414213562	100	2.828E-6	8.000E-12	1.1%	640.000E-27
			Combined Uncertainty			**26.563E-6**	**705.583E-12**	**100.0%**	**27.803E-21**
			Effective Degrees of Freedom			**17**			
			k=			**2.11**			
			Expanded Uncertainty			**56.043E-6**			

	1	2	3	4	5
1	1.00003	0.99997	1.00000	0.99997	0.99997
2	1.00002	0.99999	1.00002	1.00001	1.00002
3	1.00003	0.99998	1.00003	0.99998	1.00003
4	1.00000	1.00001	1.00003	0.99999	1.00003
5	0.99999	0.99998	1.00003	0.99997	0.99997
Sum	5.0001	4.9999	5.0001	4.9999	5.0000
Average	1.0000	1.0000	1.0000	1.0000	1.0000
Std. Dev.	18.166E-6	15.166E-6	13.038E-6	16.733E-6	31.305E-6
Variance	330.000E-12	230.000E-12	170.000E-12	280.000E-12	980.000E-12
Repeatability	19.950E-6				
Reproducibility	16.793E-6				

The Effect of UUT Resolution on Risk & Uncertainty

1 000.0 kgf load cell example with a resolution of 0.01 kgf


The problem with averages: They hide extremes!
OVERWEIGHT PLANES ARE NOT SAFE TO FLY
Measured Values 32600 31300 25300 32000 28800 Target weight: 30,000 ± 300 lbf
Based on averages, we are good to fly.
You can have your head in an oven, feet in ice, and on average, you feel fine.
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Morehouse
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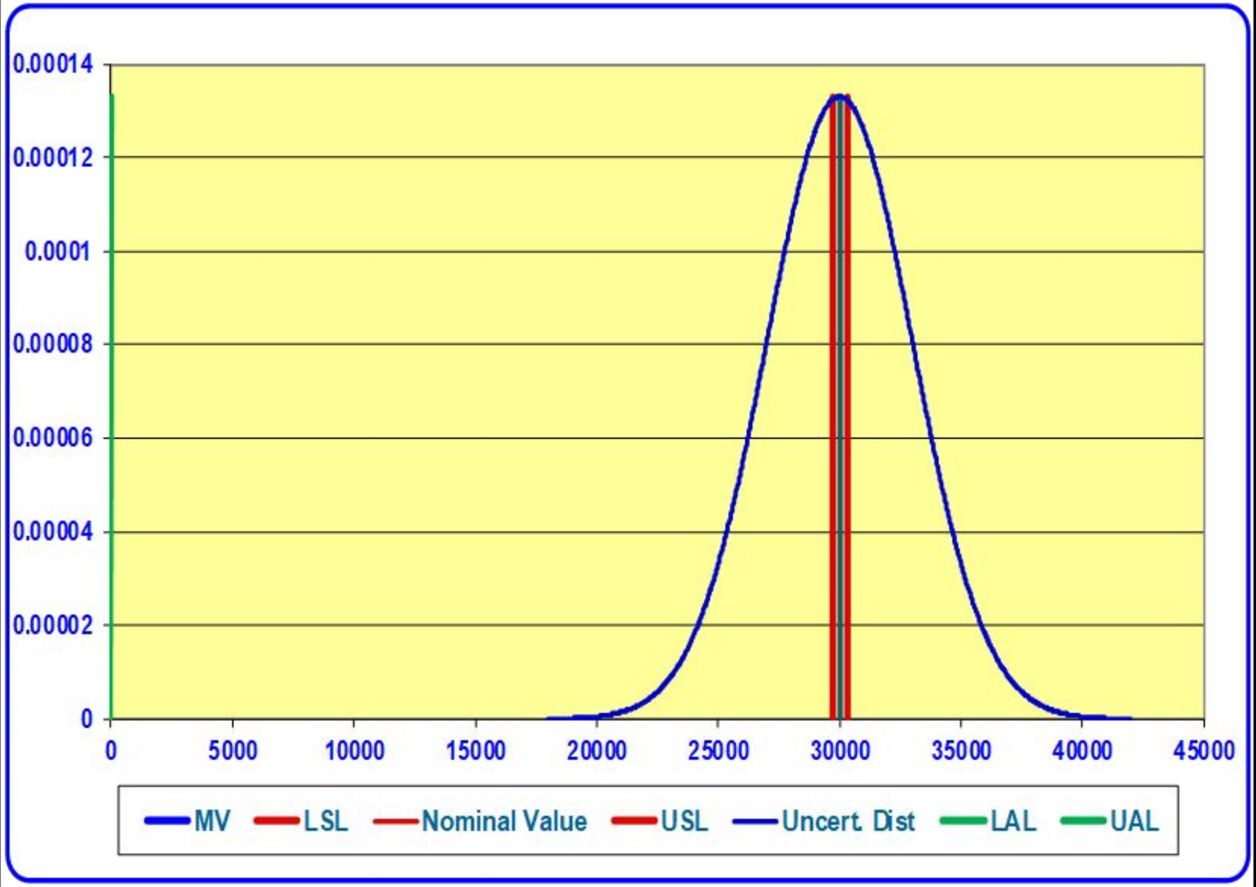
The Problem with Averages

A1	B	C	D
2	E = mc^3 Solutions	Reported Result	Acceptance Limit
3	Nominal Value	30000	
4	Lower Specification Limit	29700	INDETERMINATE
5	Upper Specification Limit	30300	INDETERMINATE
6	Measured Value	30000.0000	30000.00
7	Std. Uncert. (k=1)	3.00E+3	
8	Total Risk	92.032%	
9	Upper Limit Risk	46.016%	
10	Lower Limit Risk	46.016%	
11	Test Uncertainty Ratio (TUR) =	0.05	
12	Process Capability (C_{pk})	0.033	
Area below for calculations			
	Sample	Measurement	
	1	32600.0	
	2	31300.0	
	3	25300.0	
	4	32000.0	
	5	28800.0	
	Sample Mean	30000.00	
	Sample Standard Deviation	2999.17	

SELECTION OF GUARDBAND METHOD				
Choose Decision Rule >>>>>>>	LAC G8:2009 Decision Rule(95%	########	Custom Acceptance Limit	2



Resolution in UNC budget

$E = mc^3$ Solutions

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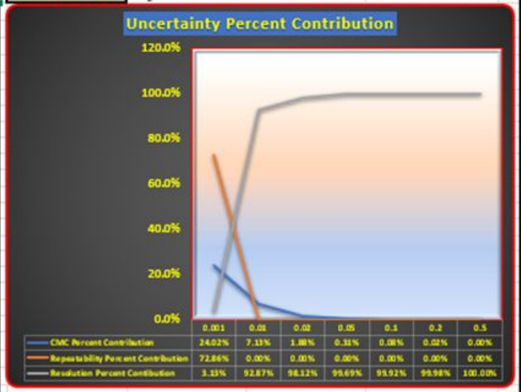
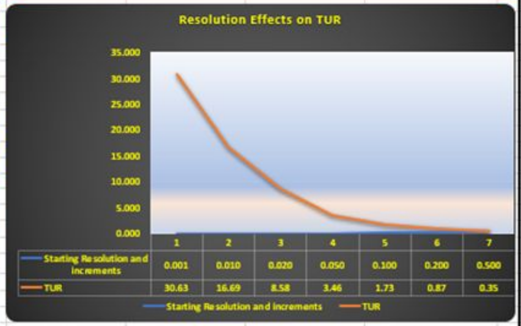
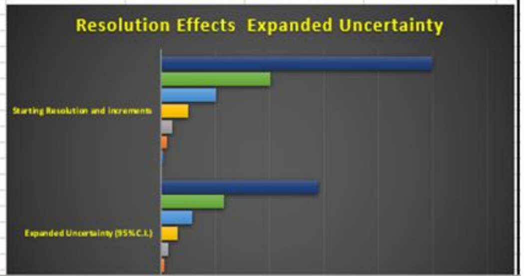
Resolution/Repeatbility/CMC Risk Analyzer

Raw Data | Regenerate Random Raw Data

Inputs (Light Yellow Background Cells with Red	ake Repeatability Better (Tolerance						100
Nominal Value	100	Tolerance (%)		0.100%	+ No of Counts		0
CMC (k=2)	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016
k =	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Sample Size (Maximum 30)	19	Student's t correction inpu			Y	df	18
tarting Resolution and incremen	0.001	0.01	0.02	0.05	0.1	0.2	0.5
sured Value (Average of Sample	100	100	100	100	100	100	100
olerance due to the No. of Coun	0	0	0	0	0	0	0
Tolerance	0.1	0.1	0.1	0.1	0.1	0.1	0.1
ance in Units (including Counts	0.100	0.100	0.10	0.1	0.1	0.1	0.1
Lower specification Limit	99.900	99.900	99.900	99.900	99.900	99.900	99.900
Upper Specification Limit	100.100	100.100	100.100	100.100	100.100	100.100	100.100
CMC (k=1)	#####	#####	#####	#####	#####	#####	#####
Repeatability Uncertainty	1.39E-3	#####	#####	#####	#####	#####	#####
Resolution Uncertainty	#####	2.89E-3	5.77E-3	#####	#####	#####	#####
df - CMC (k=1)	1000	1000	1000	1000	1000	1000	1000
df - Repeatability Uncertainty	1000	1000	1000	1000	1000	1000	1000
df - Resolution Uncertainty	1000	1000	1000	1000	1000	1000	1000
Combined Variance (RSS)	3E-06	9E-06	3E-05	0.0002	0.0008	0.0033	0.0208
Combined Uncertainty (k=1)	0.0016	0.003	0.0058	0.0145	0.0289	0.0577	0.1443
Effective Degrees of Freedom	1696	1152	1038	1006	1001	1000	1000
$k_{95\%}$ =	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Expanded Uncertainty (95% C.I.)	0.00327	0.00600	0.01167	0.02895	0.05783	0.11563	0.28904
TUR	30.63	16.69	8.58	3.46	1.73	0.87	0.35
u^4/df - CMC (k=1)	#####	#####	#####	#####	#####	#####	#####
u^4/df - Repeatability Uncertaint	#####	#####	#####	#####	#####	#####	#####
u^4/df - Resolution Uncertainty	#####	#####	1.11E-12	#####	#####	11.11E-9	#####
CMC Percent Contribution	24.02%	7.13%	1.88%	0.31%	0.08%	0.02%	0.00%
epeatability Percent Contributic	72.86%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Resolution Percent Contibution	3.13%	92.87%	98.12%	99.69%	99.92%	99.98%	100.00%
Total Contribution	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Nominal Value	100	100	100	100	100	100	100
Lower Specification Limit	99.900	99.900	99.900	99.900	99.900	99.900	99.900
Upper Specification Limit	100.100	100.100	100.100	100.100	100.100	100.100	100.100
Measured Value	100	100	100	100	100	100	100
Combined Uncert. (k=1)	0.0016	0.003	0.0058	0.0145	0.0289	0.0577	0.1443
Total Risk	0.00%	0.00%	0.00%	0.00%	0.05%	8.33%	48.84%
Upper Limit Risk	0.00%	0.00%	0.00%	0.00%	0.03%	4.16%	24.42%
Lower Limit Risk	0.00%	0.00%	0.00%	0.00%	0.03%	4.16%	24.42%
TUR	30.63	16.69	8.58	3.46	1.73	0.87	0.35
C_{PK}	20.41	11.13	5.72	2.31	1.15	0.58	0.23
Randomly Generated RAW Data							
Resolution	0.001	0.01	0.02	0.05	0.1	0.2	0.5
100.0020625	100.002	100.00	100.00	100.00	100.0	100.0	100
99.99861804	99.999	100.00	100.00	100.00	100.0	100.0	100
99.99972596	100.000	100.00	100.00	100.00	100.0	100.0	100
100.0018811	100.002	100.00	100.00	100.00	100.0	100.0	100
100.0001556	100.000	100.00	100.00	100.00	100.0	100.0	100
100.0003677	100.000	100.00	100.00	100.00	100.0	100.0	100
99.99869022	99.999	100.00	100.00	100.00	100.0	100.0	100
99.99955564	100.000	100.00	100.00	100.00	100.0	100.0	100
100.0003823	100.000	100.00	100.00	100.00	100.0	100.0	100
100.0001281	100.000	100.00	100.00	100.00	100.0	100.0	100
99.99722099	99.997	100.00	100.00	100.00	100.0	100.0	100
100.000993	100.001	100.00	100.00	100.00	100.0	100.0	100
99.9995032	100.000	100.00	100.00	100.00	100.0	100.0	100
99.99842996	99.998	100.00	100.00	100.00	100.0	100.0	100
100.0003777	100.000	100.00	100.00	100.00	100.0	100.0	100
99.99938112	99.999	100.00	100.00	100.00	100.0	100.0	100
99.99990872	100.000	100.00	100.00	100.00	100.0	100.0	100
100.0027166	100.003	100.00	100.00	100.00	100.0	100.0	100

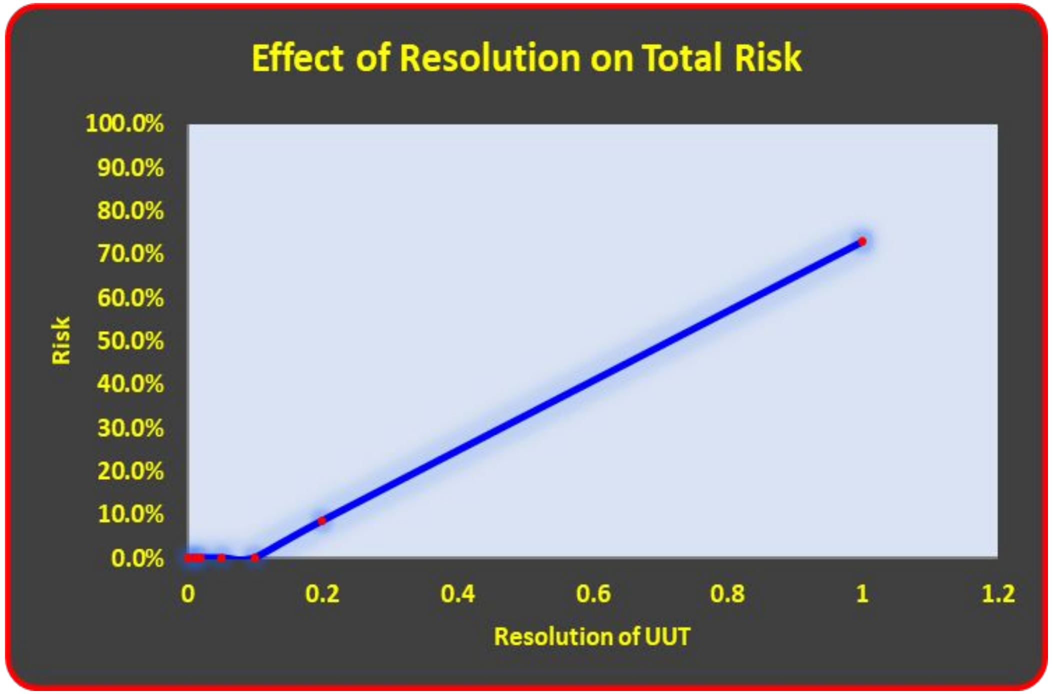




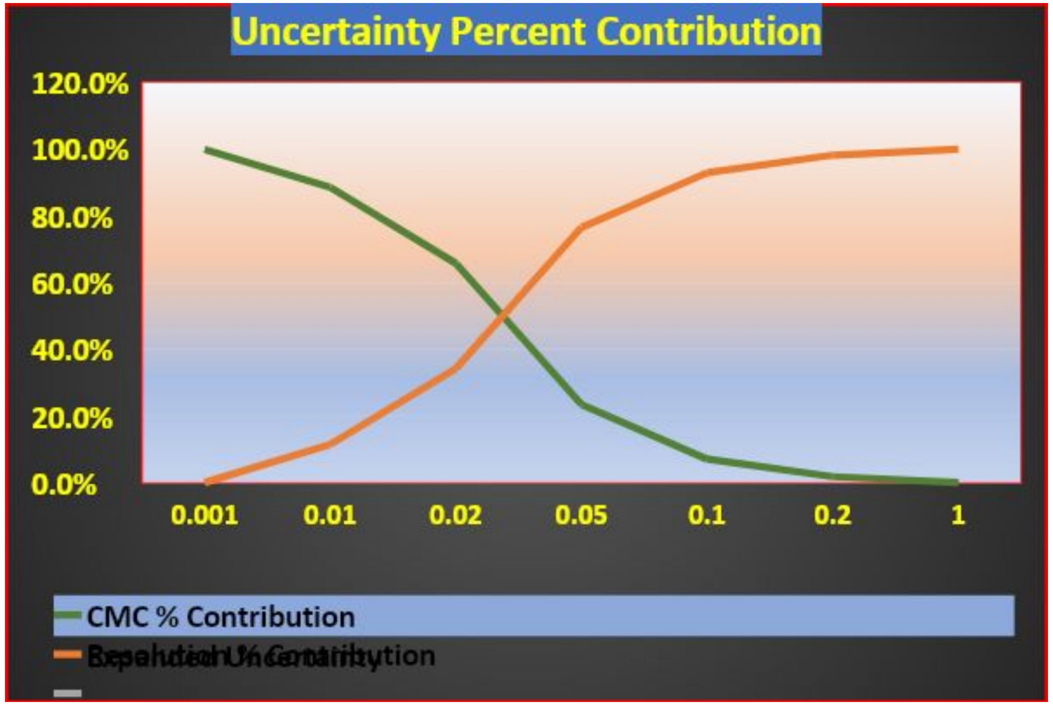


The Effect of UUT Resolution on Risk & Uncertainty

Resolution and the Effect on Total Risk Using a 1 000 kgf Morehouse Load Cell and Varying the Indicator Resolution

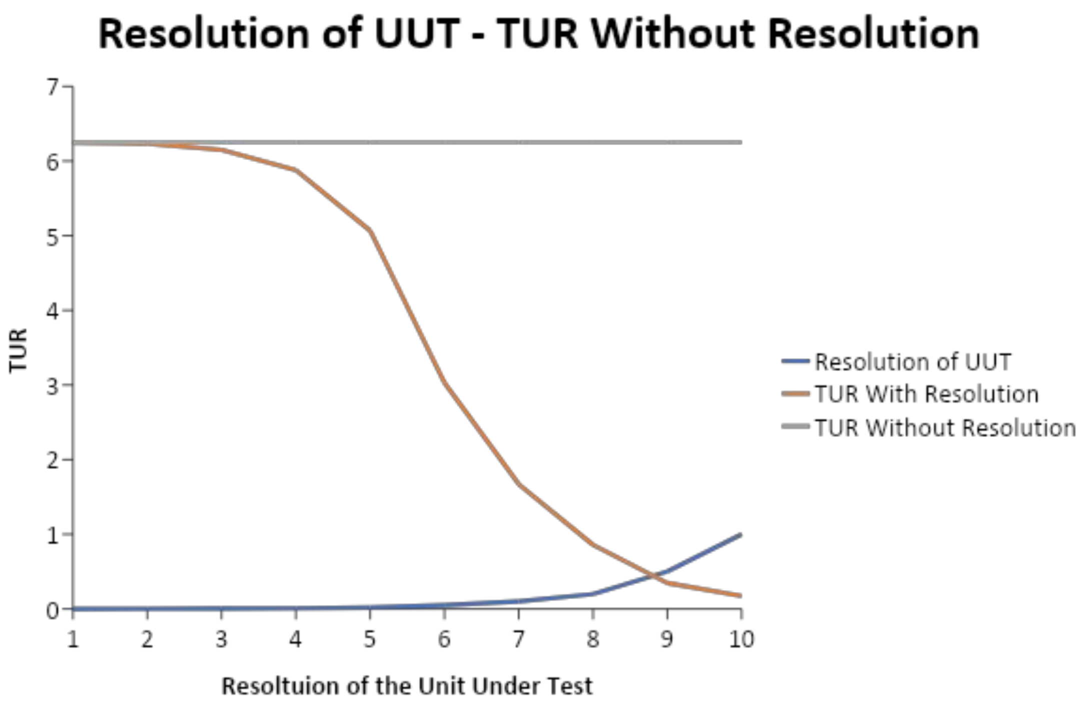


The risk starts to increase quite dramatically as the resolution increases so, does the overall uncertainty

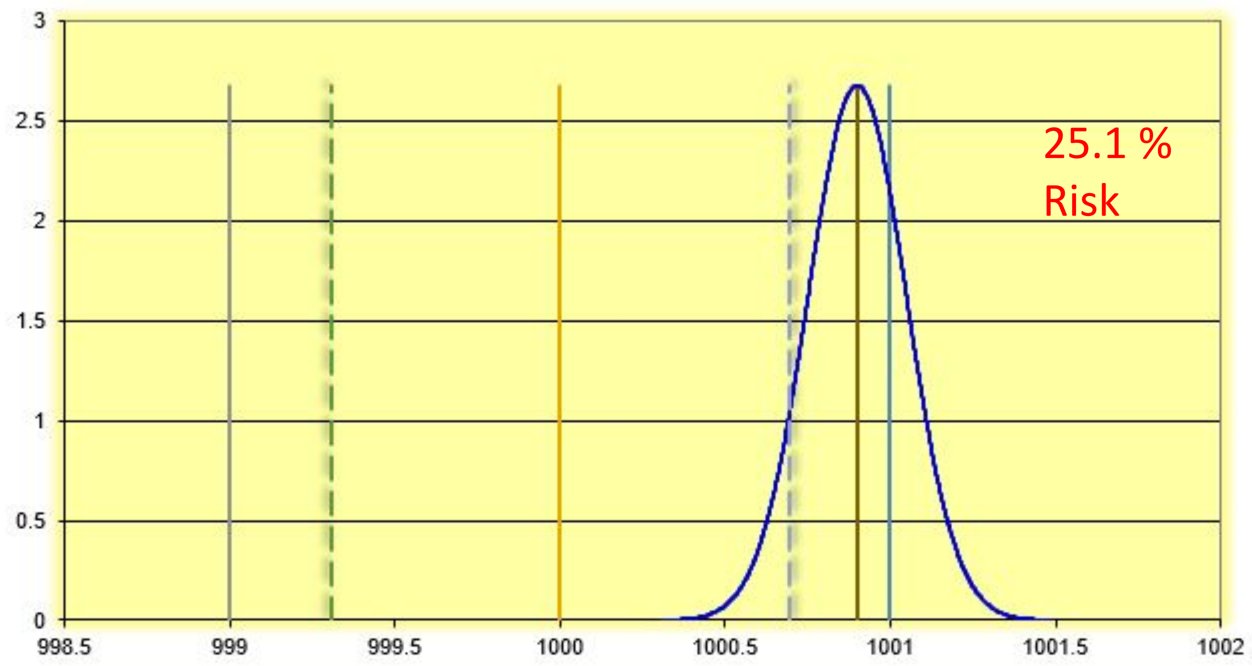


When the resolution is 0.001 kgf, it is insignificant. At 0.01 kgf, it is 11.52 % of the overall budget, and when raised to 0.05 kgf, it becomes dominant.

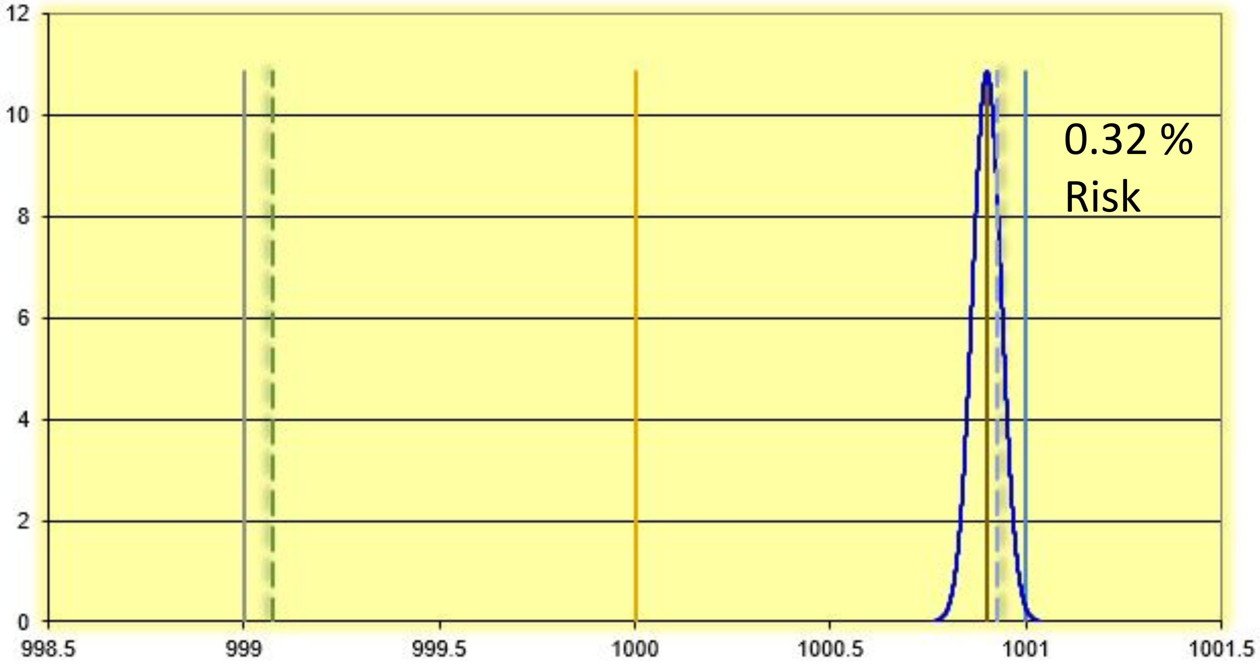
Resolution



Resolution of UUT - TUR Without Resolution
TUR
Resoltuion of the Unit Under Test
Resolution of UUT
TUR With Resolution
TUR Without Resolution



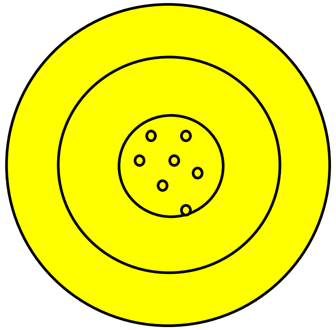
25.1 %
Risk



0.32 %
Risk

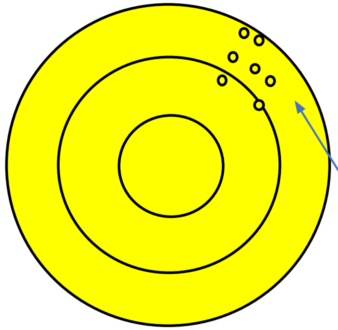
Accuracy and Precision

1



High Precision (Small Random Error)
High Accuracy (Low Bias)

2

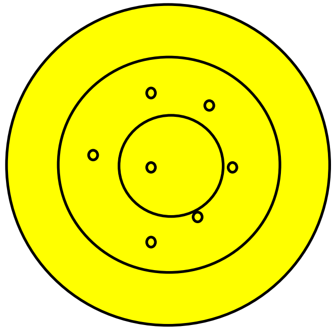


High Precision
Low Accuracy (High Bias)

This is what we see happening a lot and the reason for this discussion.

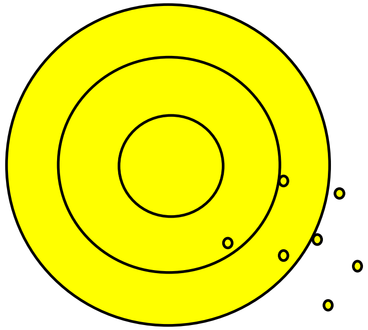
A precise instrument with a known Systematic Error

3



Low Precision (Large Random Error)
High Accuracy (Low Bias)

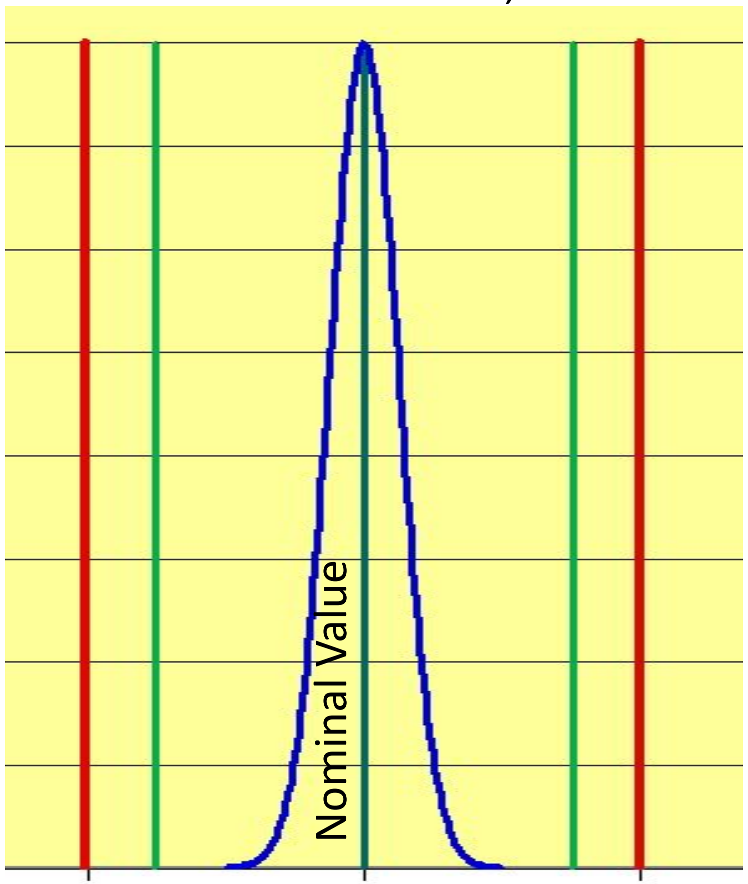
4



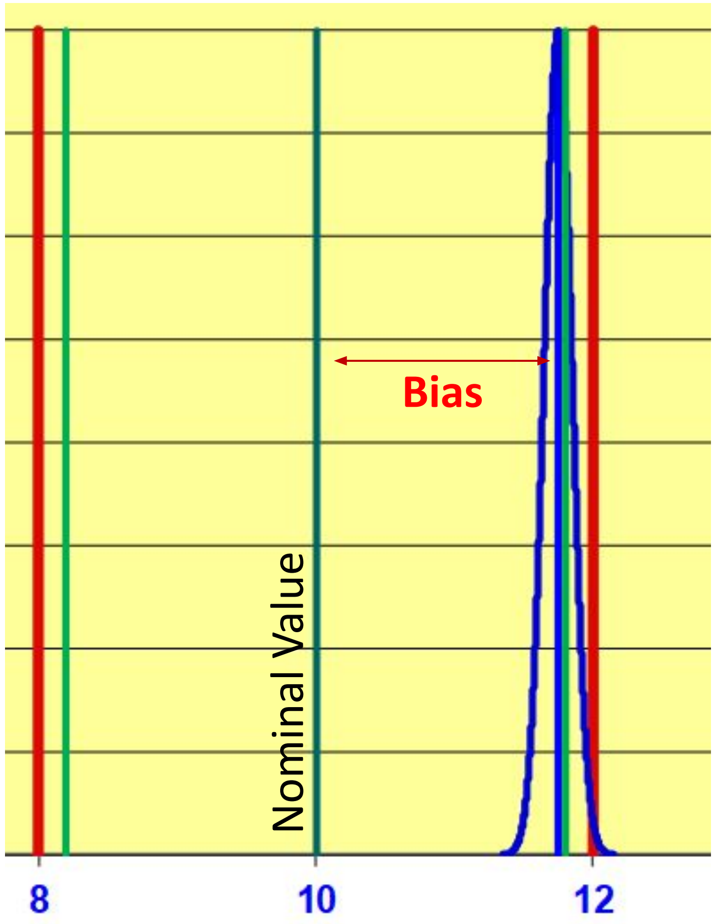
Low Precision
Low Accuracy (High Bias)

Instrument Bias

Nominal Value of **10**
Measured Value of **10**, **No Bias**

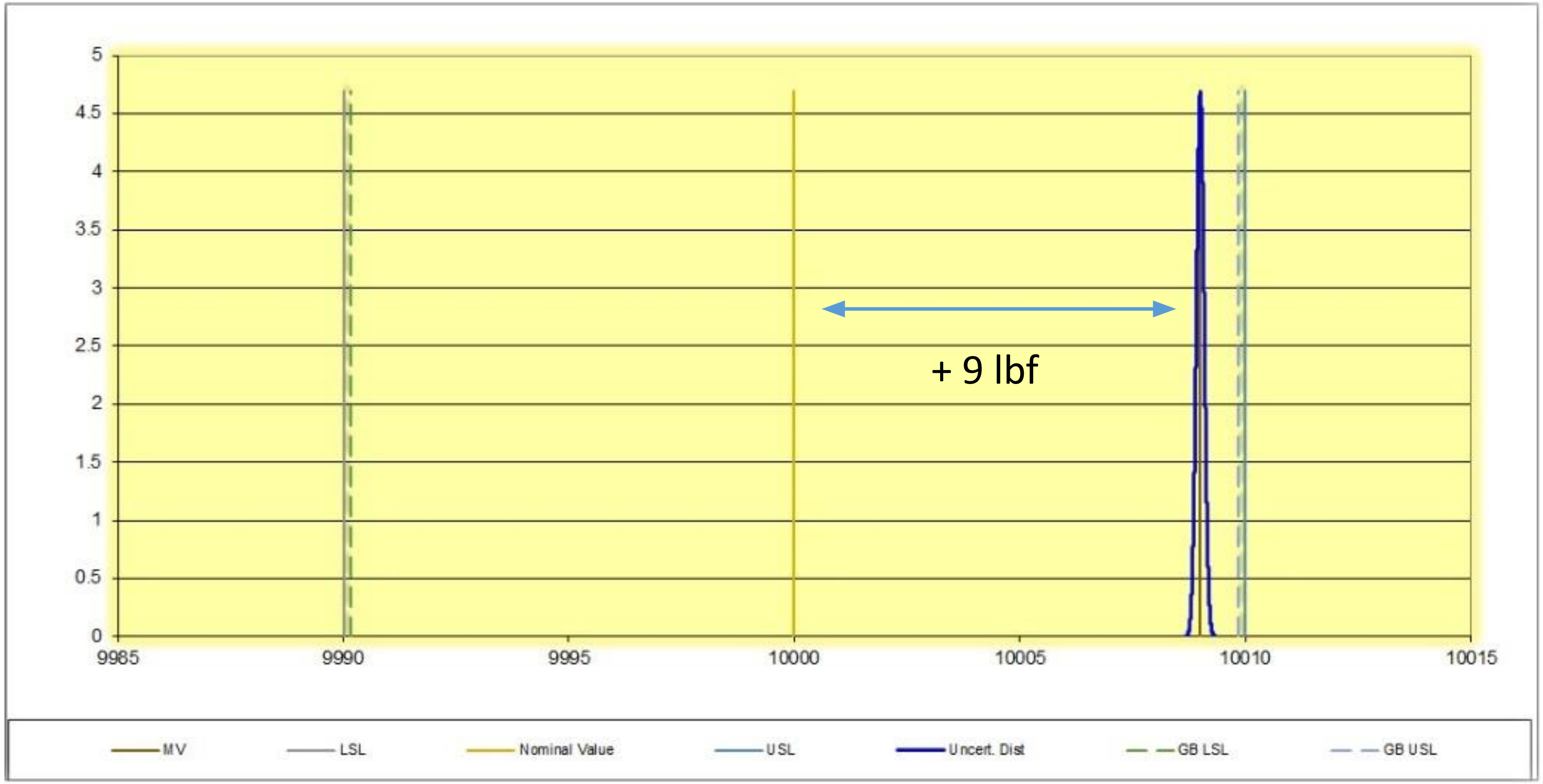


Nominal Value of **10**
Measured Value of **11.75**, **Bias**



Instrument Measurement
+ 9 lbf Bias

Nominal Value	10000.0
Lower specification Limit	9990.0
Upper Specification Limit	10010.0
Measured Value	10009.0
Measurement Error	9.0
Std. Uncert. (k=1)	0.085
Total Risk	0.00%
Upper Limit Risk	0.000%
Lower Limit Risk	0.000%
TUR =	58.78943644
Cpk=	5.999032319
TAR=	62.5
Simple Guard Band (Subtract Uncertainty)	
Guard Band LSL	9990.170
Guard Band USL	10009.8299
Percent of Spec	98.30%
Guard Band Limits for Risk of	2.500%
Guard Band LSL	9990.167
Guard Band USL	10009.833
Percent of Spec	98.33%



Graph Showing 10 009.0 as the measured value with a 58.789:1 TUR, which is achieved by using a lab with low uncertainties (Morehouse actual example) There is a bias of + 9 lbf in this example.

Instrument Measurement
+ 9 Bias

Force Applied	Measurement Value	Offset, Bias ,Systemic Measurement Error
10 000.00	10 009.00	+ 9
10 000.00	10 009.00	+ 9

When we make repeated measurements or have enough history on the device to know that replicate measurements will produce the same result, we have a known systematic error (Bias).

Bias – Centered Measurement

- Page 92 Section 5.2 Introduction to Statistics in Metrology

5.2.1.5 Risk with Biased Measurements

While the 4:1 TUR requirement is commonly used to ensure a measurement is adequate for making an accept/reject determination, this metric assumes that the process distribution is centered between the specification limits, that is $\mu_p = (SL_U + SL_L)/2$. If this is not the case, TUR cannot be reliably used as an indicator of risk, however, the PFA and PFR equations are still valid assuming the correct μ_p is used.

The measurement uncertainty distribution is also assumed to be centered about the actual value t when calculating TUR. The measurement process is said to be biased if it is not centered about t and systematically overstates or understates the true value of the measurement. Properly accounting for measurement bias provides a more accurate risk evaluation. If bias is ignored, the risk might be understated, perhaps significantly.

In the presence of bias, the distribution of the measurement y, given the actual value t, shifts from a $N\left(t, \sigma_m^2\right)$ distribution to a $N\left(t - b_m, \sigma_m^2\right)$ distribution, where b_m is the measurement bias.

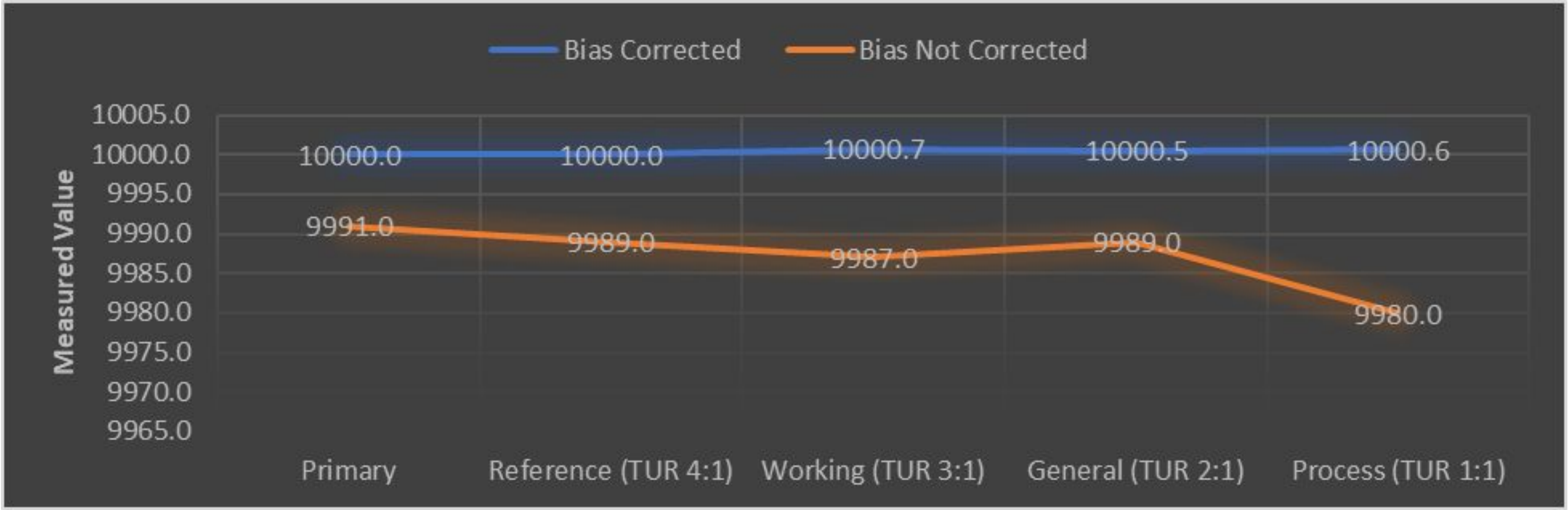
With bias b_m, the expressions for the PFA and PFR (without guardbanding) become

$$\begin{aligned} \text{PFA} = & \int_{-\infty}^{SL_L} \left(\int_{SL_L}^{SL_U} \frac{1}{\sigma_m \sqrt{2\pi}} e^{-\frac{1}{2\sigma_m^2}(y-(t-b_m))^2} dy \right) \frac{1}{\sigma_p \sqrt{2\pi}} e^{-\frac{1}{2\sigma_p^2}\left(t-\mu_p\right)^2} dt \\ & + \int_{SL_U}^{+\infty} \left(\int_{SL_L}^{SL_U} \frac{1}{\sigma_m \sqrt{2\pi}} e^{-\frac{1}{2\sigma_m^2}(y-(t-b_m))^2} dy \right) \frac{1}{\sigma_p \sqrt{2\pi}} e^{-\frac{1}{2\sigma_p^2}\left(t-\mu_p\right)^2} dt. \end{aligned} \quad (5.18)$$

What happens when we do not correct the bias?

	Measurement Uncertainty $k = 2$	BIAS Measured Value With Bias	BIAS CORRECTED Measured Value Bias Removed
Primary	0.17	9991.0	10000.0
Reference (TUR 4:1)	2.5	9989.0	10000.0
Working (TUR 3:1)	3.3	9987.0	10000.7
General (TUR 2:1)	5	9989.0	10000.5
Process (TUR 1:1)	10	9980.0	10000.6

Not correcting for Bias



The Figure above shows what happens when the reference laboratory does not correct for bias and applies 9,991.0 lbf and not 10,000 lbf.

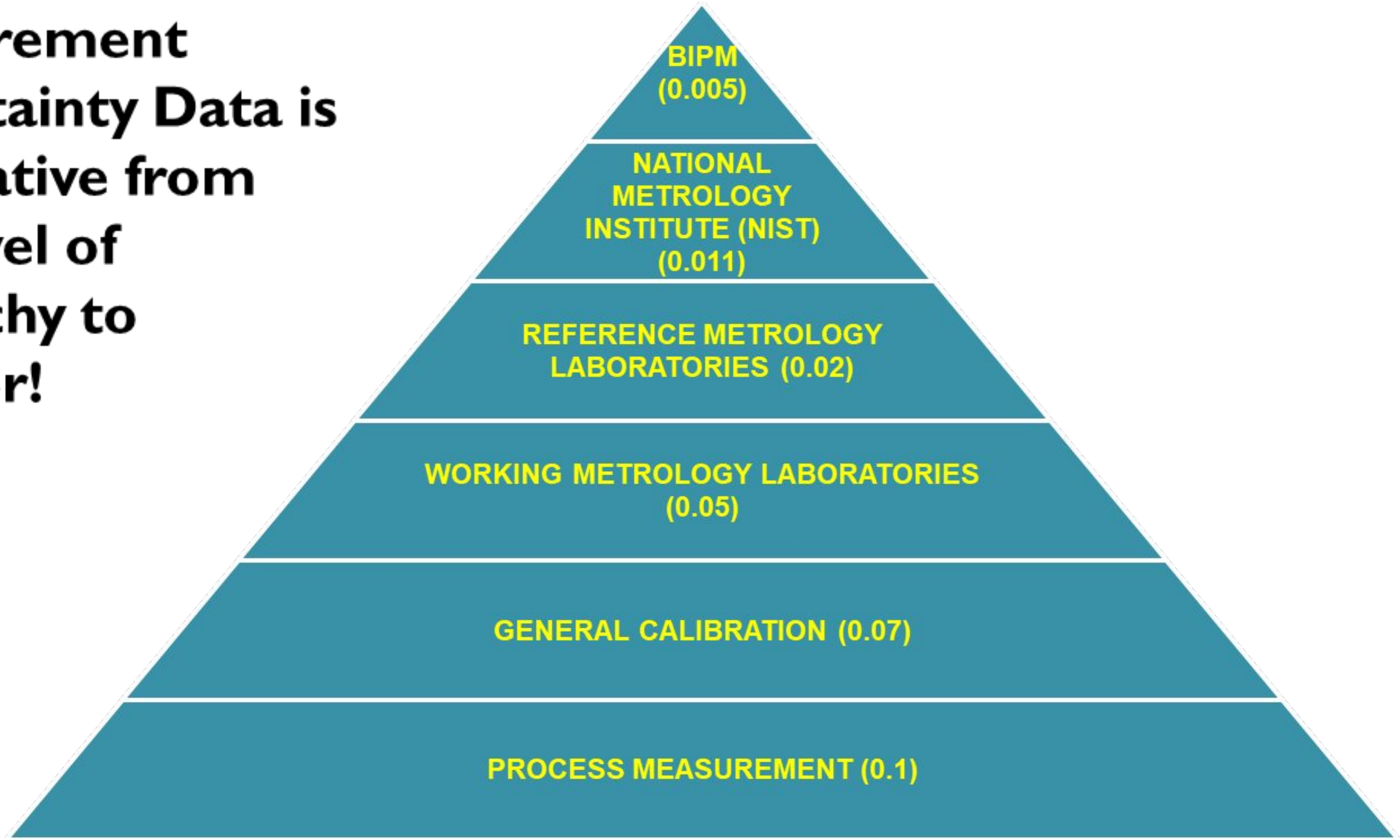
In this scenario, instruments may have failed when they would have passed calibration.

Metrological Traceability

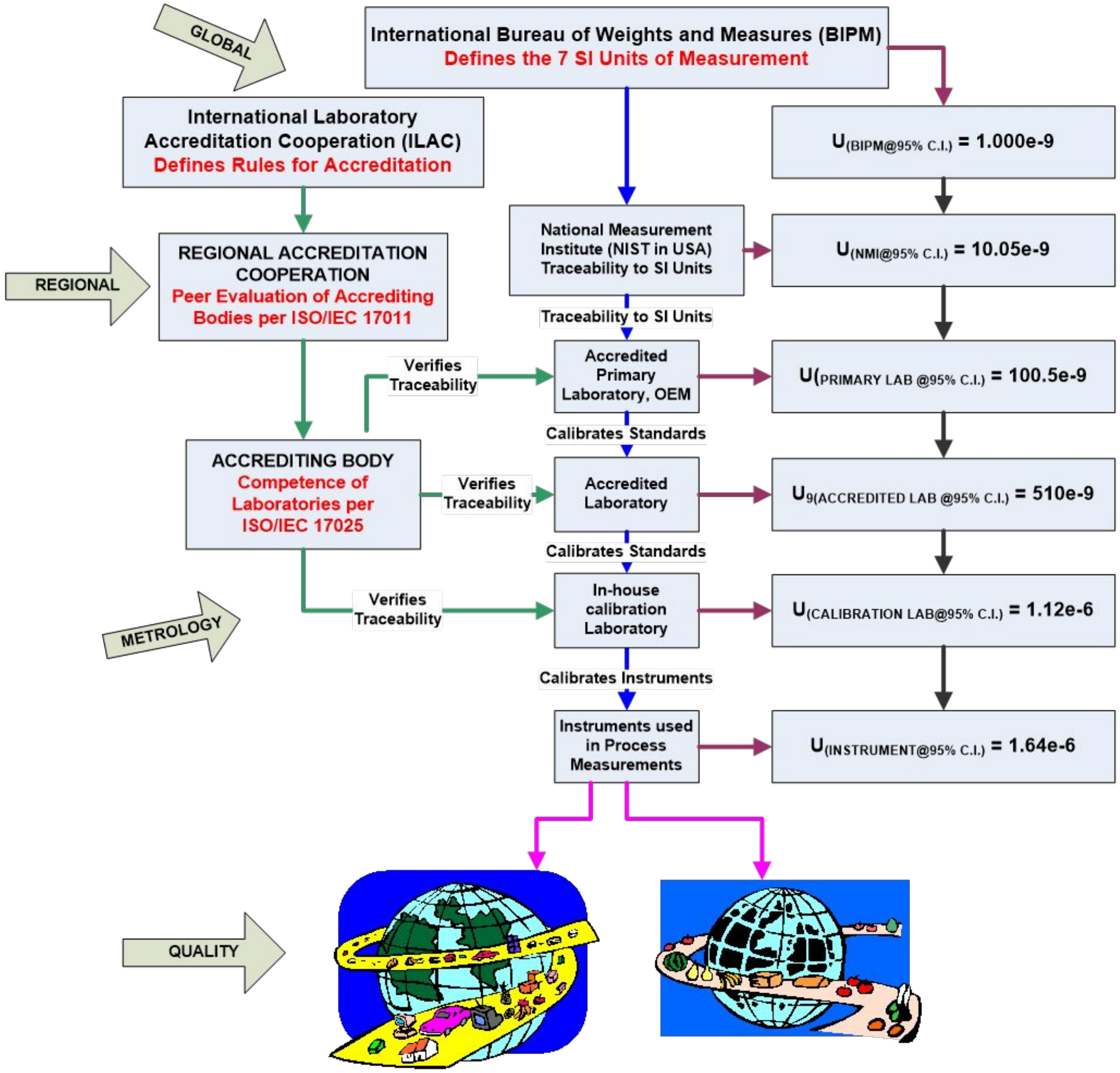
- **Metrological Traceability:** Property of a measurement result whereby the result can be related to a reference through a ***documented unbroken chain of calibrations, each contributing to the measurement uncertainty.***
  - NOTE 1 For this definition, a ‘reference’ can be a definition of a measurement unit through its practical realization, or a measurement procedure including the measurement unit for a non-ordinal quantity, or a measurement standard.
  - NOTE 2 Metrological traceability requires an established calibration hierarchy.
  - NOTE 3 Specification of the reference must include the time at which this reference was used in establishing the calibration hierarchy, along with any other relevant metrological information about the reference, such as when the first calibration in the calibration hierarchy was performed.
  - NOTE 4 For measurements with more than one input quantity in the measurement model, each of the input quantity values should itself be metrologically traceable.

Metrological Traceability

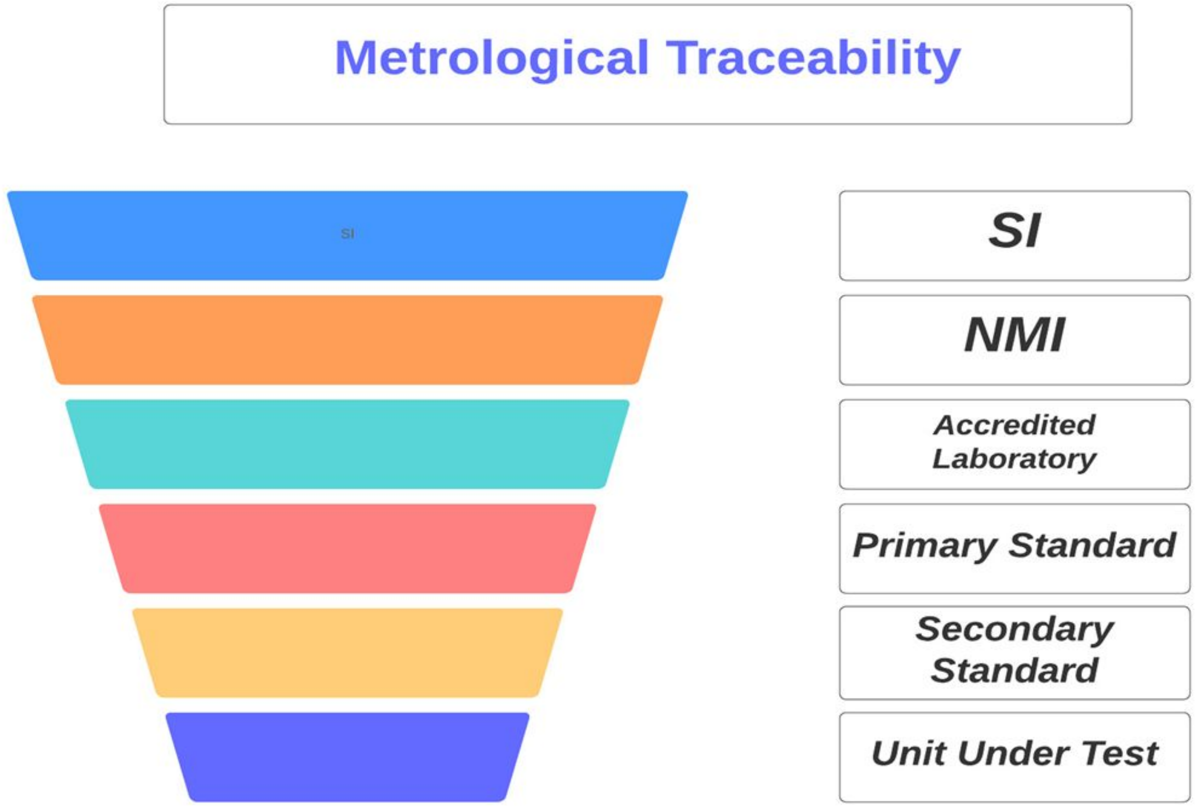
Measurement Uncertainty Data is cumulative from one level of hierarchy to another!



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***



Metrological Traceability



The Correct Definition and Calculation of TUR

$$TUR = \frac{\text{Span of the } \pm \text{ UUT Tolerance}}{2 \text{ x } k_{95\%}(\text{Calibration Process Uncertainty})}$$

TUR Formula found in ANSI/NCSLI Z540.3 Handbook

- **The ratio of the span of the tolerance of a measurement quantity subject to calibration to twice the 95% expanded uncertainty of the measurement process used for calibration.** ANSI/NCSLI Z540.3-2006

- **The ratio of the tolerance, TL, of a measurement quantity, divided by the 95% expanded measurement uncertainty of the measurement process where TUR = TL/U.** ILAC G8:2019

TUR Defined ANSI/NCSL Z540.3 Handbook

$$\text{TUR} = \frac{\text{Span of the } \pm \text{UUT Tolerance}}{2 \text{ x } k_{95\%}(\text{Calibration Process Uncertainty})}$$

TUR Formula found in ANSI/NCSLI Z540.3 Handbook

"For the numerator, the tolerance used for Unit Under Test (UUT) in the calibration procedure should be used in the calculation of the TUR. This tolerance is to reflect the organization's performance requirements for the Measurement & Test Equipment (M&TE), which are, in turn, derived from the intended application of the M&TE. In many cases, these performance requirements may be those described by the Manufacturer's tolerances and specifications for the M&TE and are therefore included in the numerator."

ANSI/NCSL Z540.3 Handbook "Handbook for the Application of ANSI/NCSLI 540.3-2006 - Requirements for the Calibration of Measuring and Test Equipment."

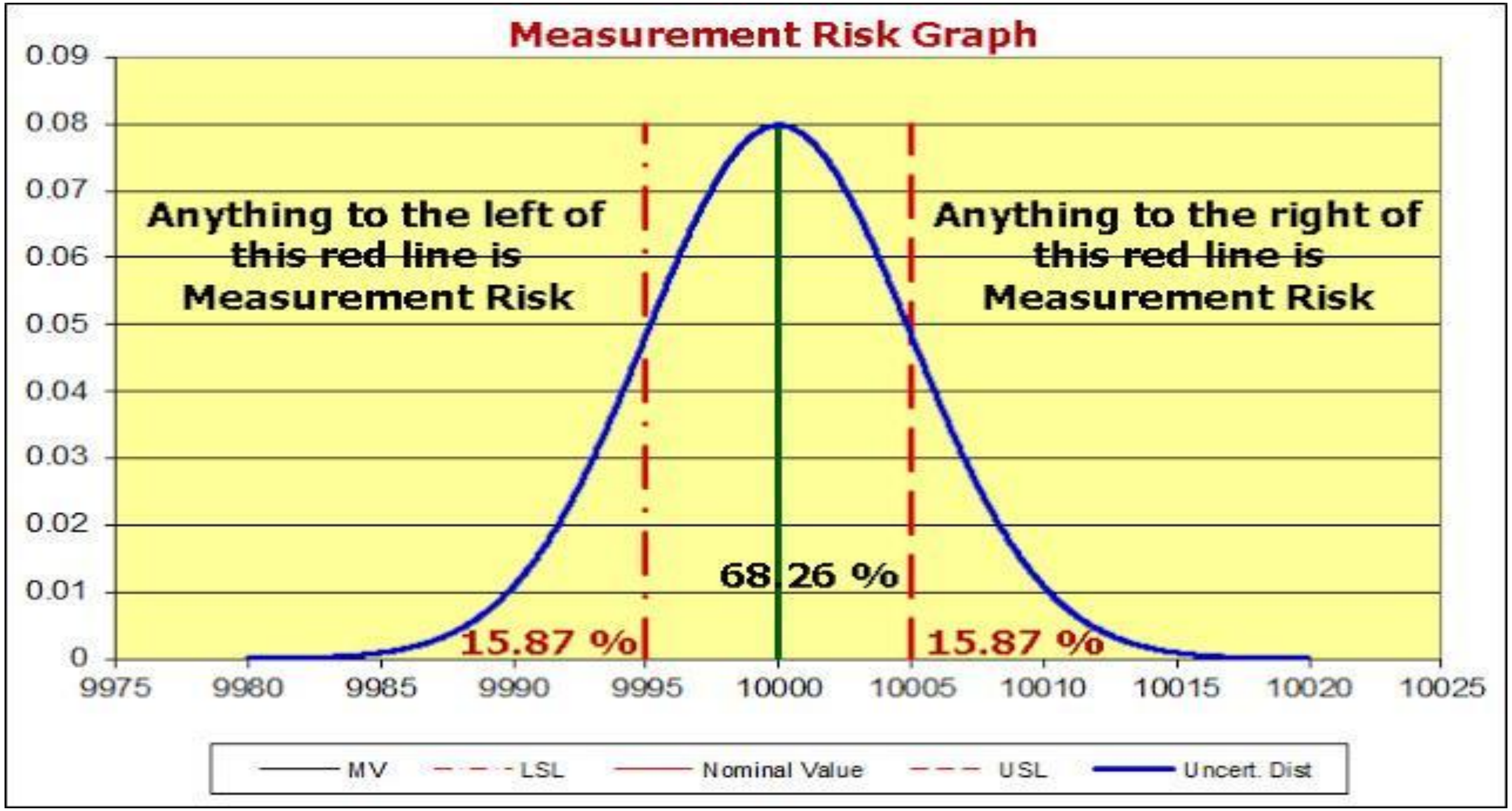
The Correct Definition and Calculation of TUR

$$\text{TUR} = \frac{\text{Span of the } \pm \text{Tolerance}}{2 \text{ x } k_{95\%}\left(\sqrt[2]{\left(\frac{\text{CMC}}{k_{\text{CMC}}}\right)^2 + \left(\frac{\text{Resolution}_{\text{UUT}}}{\sqrt[2]{12}}\right)^2 + \left(\frac{\text{Repeatability}_{\text{UUT}}}{1}\right)^2 + \cdots (u_{Other})^2}\right)}$$

Example of a TUR Formula (Adapted from the ANSI/NCSL Z540.3 Handbook)

In most cases, the numerator is the UUT Accuracy Tolerance. The denominator is slightly more complicated. Per the ANSI/NCSL Z540.3 Handbook, "For the denominator, the 95 % expanded uncertainty of the measurement process used for calibration following the calibration procedure is to be used to calculate TUR. The value of this uncertainty estimate should reflect the results that are reasonably expected from the use of the approved procedure to calibrate the M&TE. Therefore, the estimate includes all components of error that influence the calibration measurement results, which would also include the influences of the item being calibrated except for the bias of the M&TE. The calibration process error, therefore, includes temporary and non-correctable influences incurred during the calibration such as **repeatability**, **resolution**, error in the measurement source, operator error, error in correction factors, environmental influences, etc."

Measurement Decision Risk



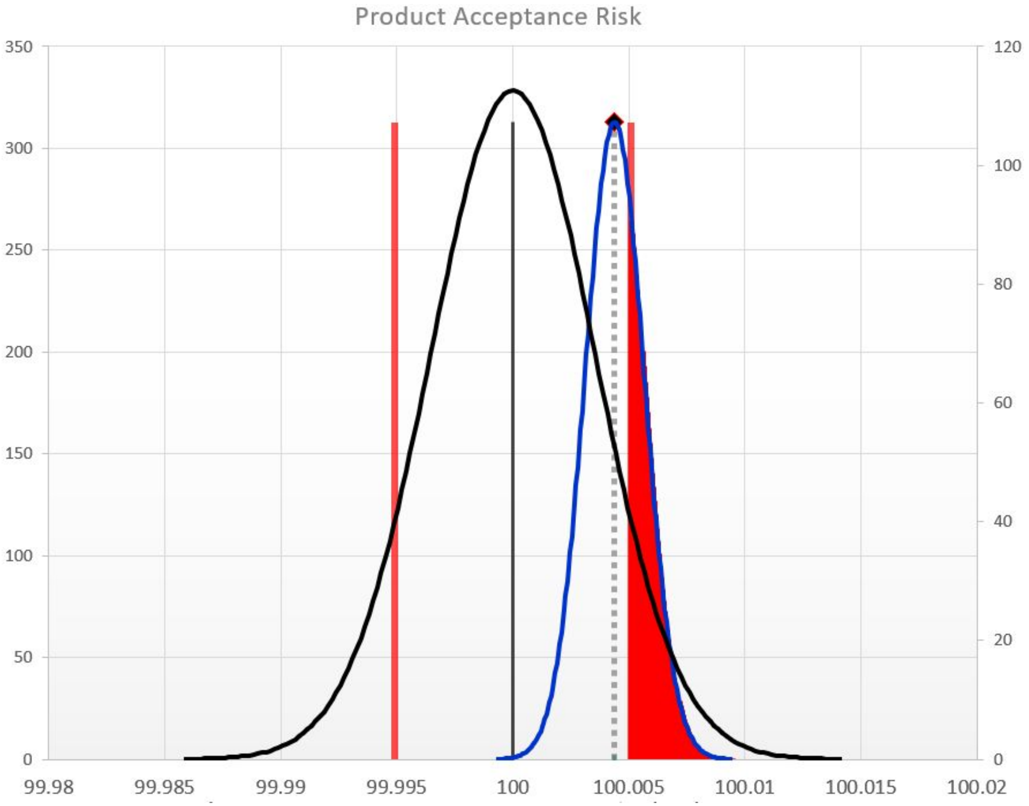
ISO/IEC 17025: 2017 Section 3.7 defines a decision rule as a rule that describes how measurement uncertainty is accounted for when stating conformity with a specified requirement

A calibration laboratory cannot make a statement of conformity or "Pass" an instrument without violating ISO/IEC 17025:2017 as section 3.7 defines a Decision Rule as a rule that describes how measurement uncertainty is accounted for when stating conformity with a specified requirement. Some may argue that you can take it into account by ignoring it.

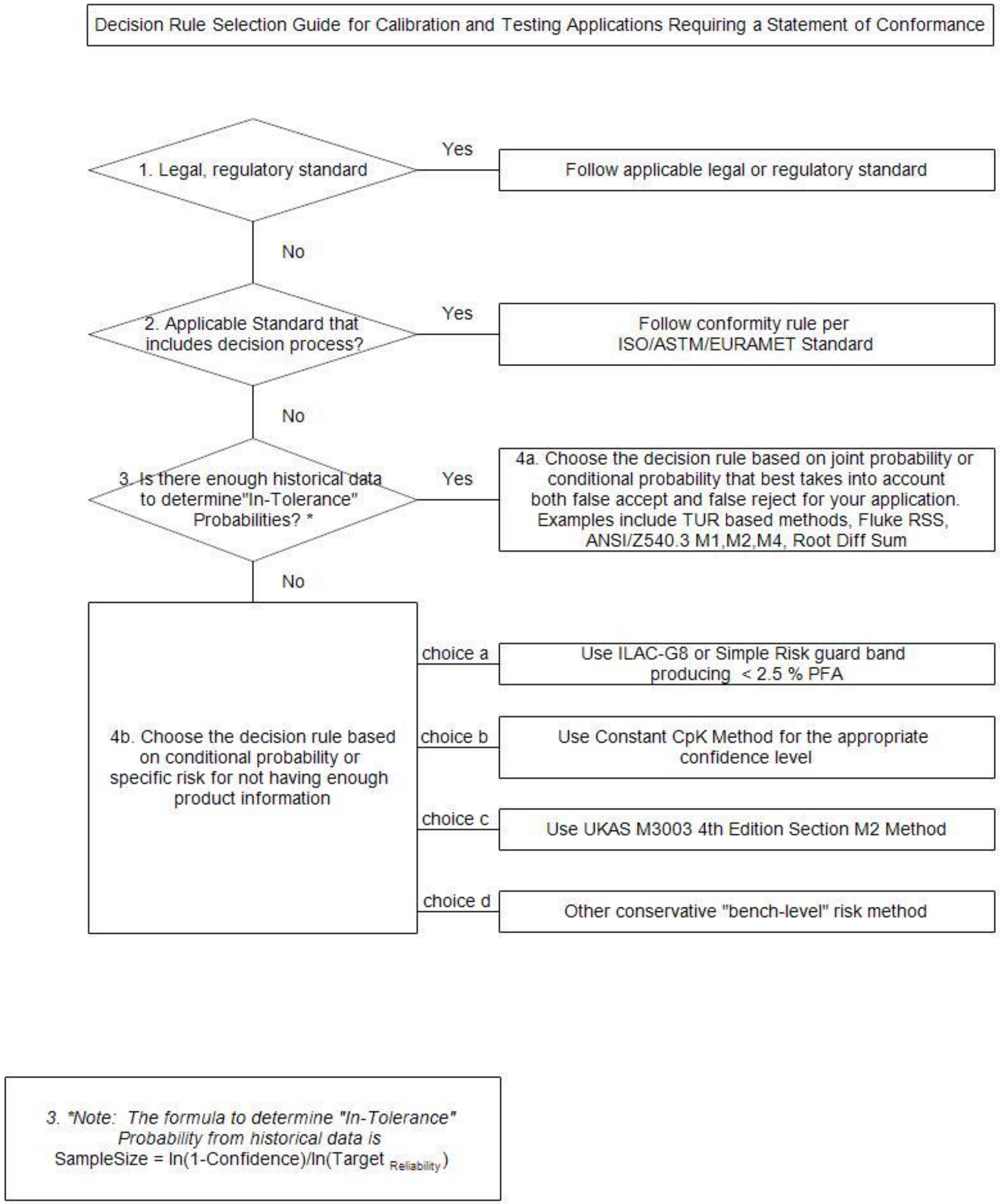
To that end can we all decide to take all red stop lights into account and start ignoring them?

Global Consumers' Risk in Evaluation of Decision Rules

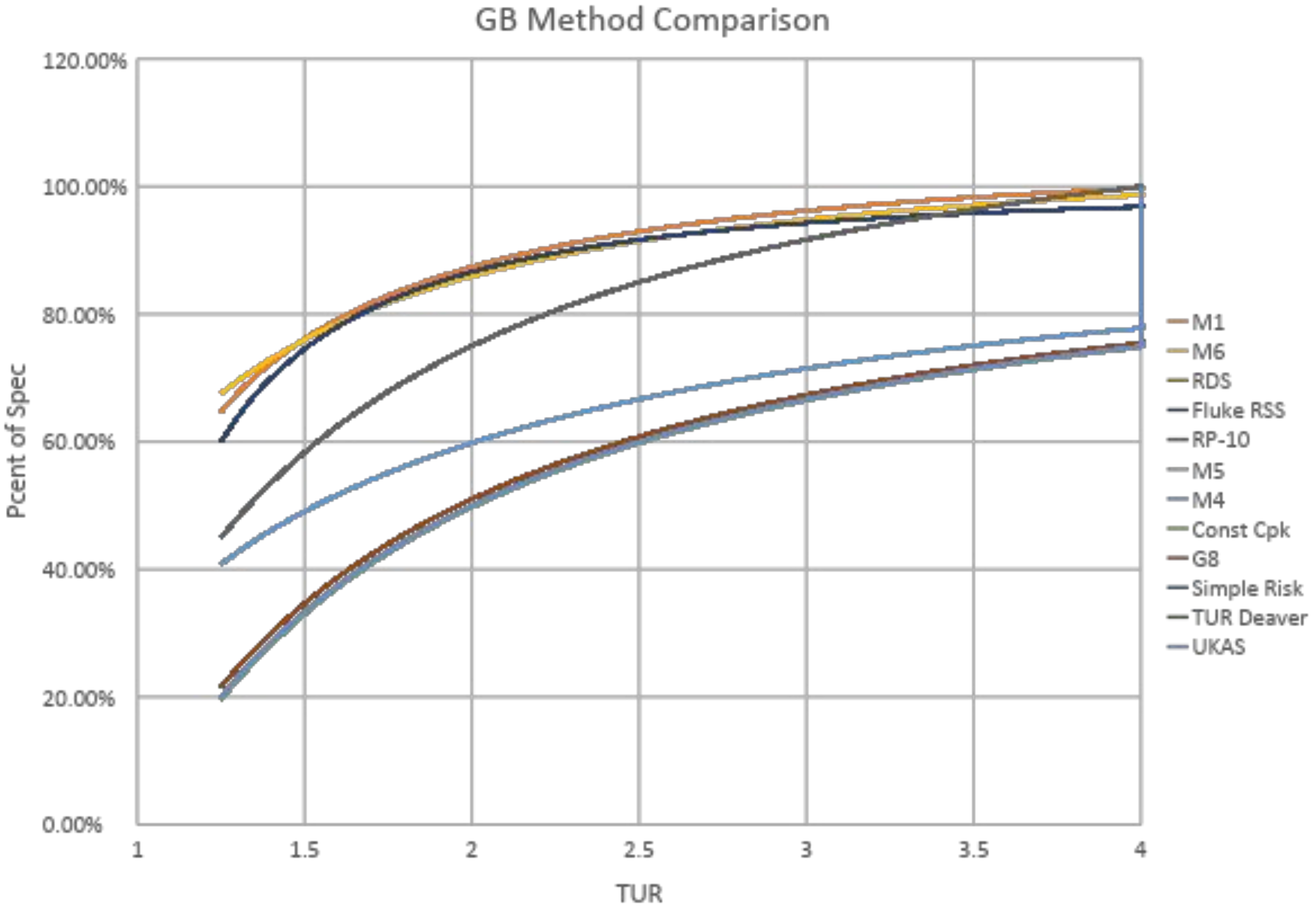
	Direct Measurements
Data Input	Reported Result
Nominal Value (Engineering Units)	100
Lower Specification Limit(±0.0045 %)	99.9949
Upper Specification Limit(±0.0045 %)	100.0051
Measured Value =	100.004 382
Combined Std. Uncty (k=1)	0.001275
In-Tolerance Probability =	71.338%
Total Risk =	**28.662%**
Upper Limit Risk =	28.661 850%
Lower Limit Risk =	0.000 000%
Test Uncertainty Ratio (TUR) =	2.00
Process Capability (C_{pk}) =	0.188
Customer (Consumer) Risk =	1.8513%
Lab (Producer) Risk =	1.3986%
Test Point PFR =	10.8513%
Beginning of Period Reliability =	98.1487%



Selecting the Appropriate Decision Rules

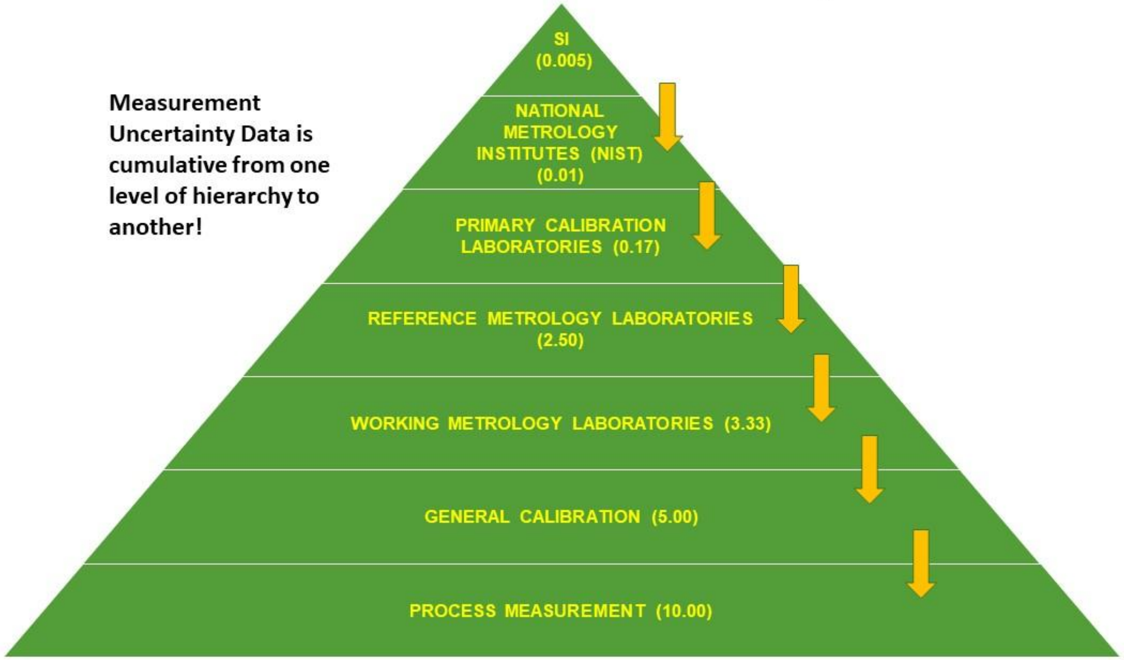


Selecting the Appropriate Decision Rules



Global Consumers' Risk in Evaluation of Decision Rules

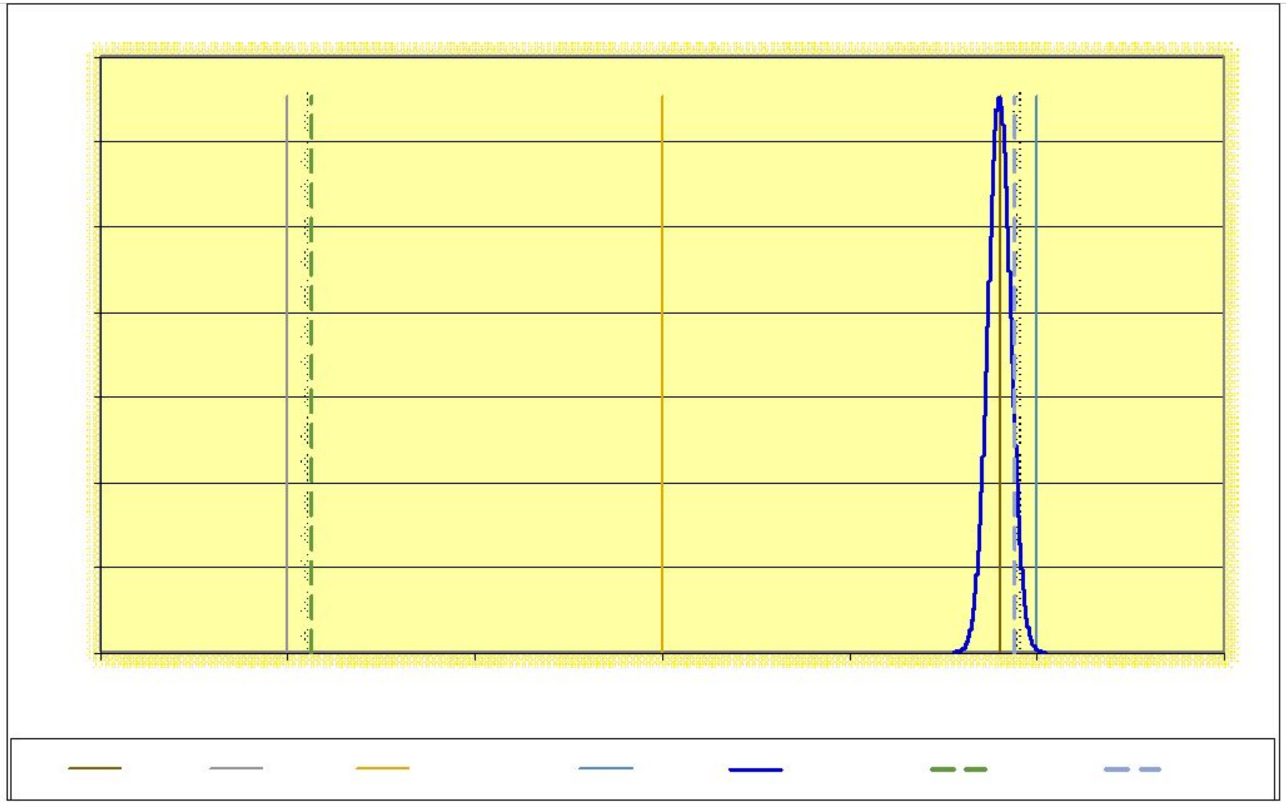
Global consumer's risk is defined in JCGM 106:2012. The role of CPU in conformity assessment is defined as "the probability that a non-conforming item will be accepted based on a future measurement result."



If only one tier of the calibration chain cares about the measurement decision risk, then the whole process is at risk. When this risk is propagated throughout succeeding tiers, can we expect the process to work properly?

Why Cpk Might be the Most Useful Tool in Making Conformity Decisions

Nominal Value	**1000.0**
Lower specification Limit	999.0
Upper Specification Limit	1001.0
Measured Value	**1000.9**
Measurement Error	0.9
Std. Uncert. (k=1)	**0.031**
Total Risk	**0.05%**
Upper Limit Risk	0.05%
Lower Limit Risk	0.000%
TAR=	50
TUR =	**16.36591312**
Cpk=	**1.669991134**
Simple Guard Band with Subtraction Uncertainty Only	
Guard Band LSL	**999.061**
Guard Band USL	**1000.9389**
Guard Band Limits for Risk of	2.00%
Guard Band LSL	**999.063**
Guard Band USL	**1000.937**



CpK = min(((USL-Measured Value)/ 3 x Std. Uncertainty)),((Measured Value – LSL)/3 x Std. Uncertainty)))

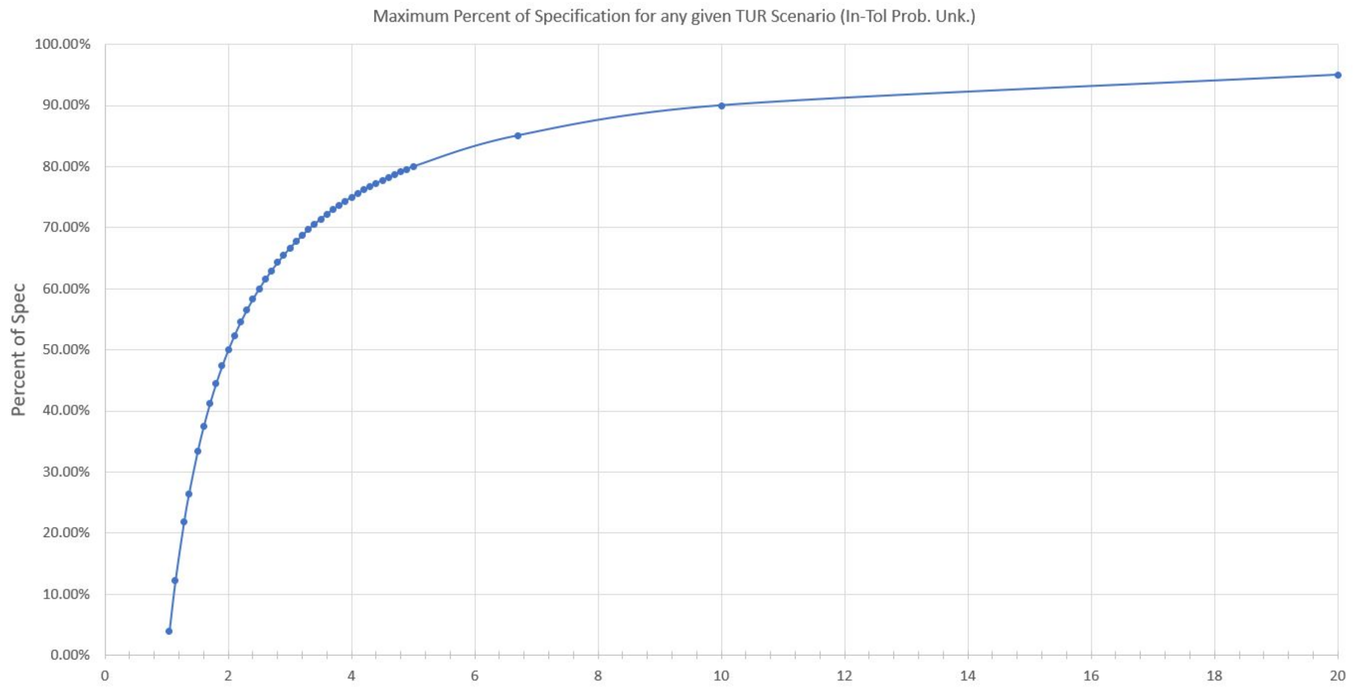
Why Cpk Might be the Most Useful Tool in Making Conformity Decisions

Std Unc

k = 1	TUR	Pcent	Lower Limit	Upper Limit	Measured Value	P(In-Tol)	P(OOT)	LL Risk	UL Risk	Total Risk	Cpk
0.004 808	1.04	3.85%	100.000	100.000	100.000	96.19%	3.81%	1.54%	2.27%	3.81%	0.6667
0.004 386	1.14	12.28%	99.999	100.001	100.001	97.20%	2.80%	0.52%	2.27%	2.80%	0.6667
0.003 906	1.28	21.87%	99.998	100.002	100.002	97.63%	2.37%	0.09%	2.28%	2.37%	0.6667
0.003 676	1.36	26.47%	99.997	100.003	100.003	97.70%	2.30%	0.03%	2.28%	2.30%	0.6667
0.003 333	1.5	33.33%	99.997	100.003	100.003	97.72%	2.28%	0.00%	2.27%	2.28%	0.6667
0.003 125	1.6	37.50%	99.996	100.004	100.004	97.72%	2.28%	0.00%	2.27%	2.28%	0.6667
0.002 941	1.7	41.18%	99.996	100.004	100.004	97.72%	2.28%	0.00%	2.27%	2.28%	0.6667
0.002 778	1.8	44.44%	99.996	100.004	100.004	97.72%	2.28%	0.00%	2.27%	2.28%	0.6667
0.002 632	1.9	47.37%	99.995	100.005	100.005	97.72%	2.28%	0.00%	2.27%	2.28%	0.6667
0.002 500	2	50.00%	99.995	100.005	100.005	97.72%	2.28%	0.00%	2.27%	2.28%	0.6667
0.002 381	2.1	52.38%	99.995	100.005	100.005	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.002 273	2.2	54.55%	99.995	100.005	100.005	97.72%	2.28%	0.00%	2.27%	2.28%	0.6667
0.002 174	2.3	56.52%	99.994	100.006	100.006	97.72%	2.28%	0.00%	2.27%	2.28%	0.6667
0.002 083	2.4	58.33%	99.994	100.006	100.006	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667
0.002 000	2.5	60.00%	99.994	100.006	100.006	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667
0.001 923	2.6	61.54%	99.994	100.006	100.006	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.001 852	2.7	62.96%	99.994	100.006	100.006	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.001 786	2.8	64.29%	99.994	100.006	100.006	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.001 724	2.9	65.52%	99.993	100.007	100.007	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.001 667	3	66.67%	99.993	100.007	100.007	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667
0.001 613	3.1	67.74%	99.993	100.007	100.007	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667
0.001 563	3.2	68.75%	99.993	100.007	100.007	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667
0.001 515	3.3	69.70%	99.993	100.007	100.007	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.001 471	3.4	70.59%	99.993	100.007	100.007	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.001 429	3.5	71.43%	99.993	100.007	100.007	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667
0.001 389	3.6	72.22%	99.993	100.007	100.007	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667
0.001 351	3.7	72.97%	99.993	100.007	100.007	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.001 316	3.8	73.68%	99.993	100.007	100.007	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.001 282	3.9	74.36%	99.993	100.007	100.007	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.001 250	4	75.00%	99.993	100.007	100.007	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667
0.001 217	4.11	75.67%	99.992	100.008	100.008	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667
0.001 190	4.2	76.19%	99.992	100.008	100.008	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667
0.001 163	4.3	76.74%	99.992	100.008	100.008	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667
0.001 136	4.4	77.27%	99.992	100.008	100.008	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.001 111	4.5	77.78%	99.992	100.008	100.008	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667
0.001 087	4.6	78.26%	99.992	100.008	100.008	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.001 064	4.7	78.72%	99.992	100.008	100.008	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.001 042	4.8	79.17%	99.992	100.008	100.008	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667
0.001 020	4.9	79.59%	99.992	100.008	100.008	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.001 000	5	80.00%	99.992	100.008	100.008	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.000 746	6.7	85.07%	99.991	100.009	100.009	97.72%	2.28%	0.00%	2.28%	2.28%	0.6667
0.000 500	10	90.00%	99.991	100.009	100.009	97.73%	2.27%	0.00%	2.27%	2.27%	0.6667

Why Cpk Might be the Most Useful Tool in Making Conformity Decisions

$$Cpk = \text{Minimum}\left(\frac{UpperSpec - MeasuredValue}{3 \times uCal}\right), \left(\frac{MeasuredValue - LowerSpec}{3 \times uCal}\right)$$



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- Giveaways

Resolution Sheet

Risk Sheet

SCAN ME

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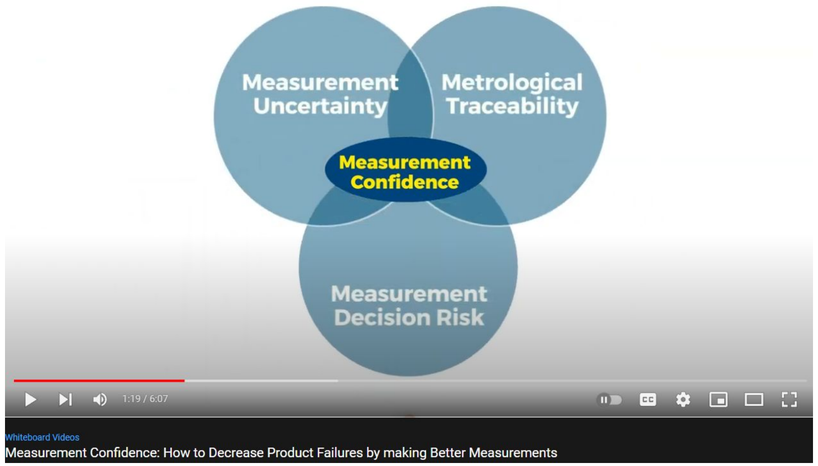
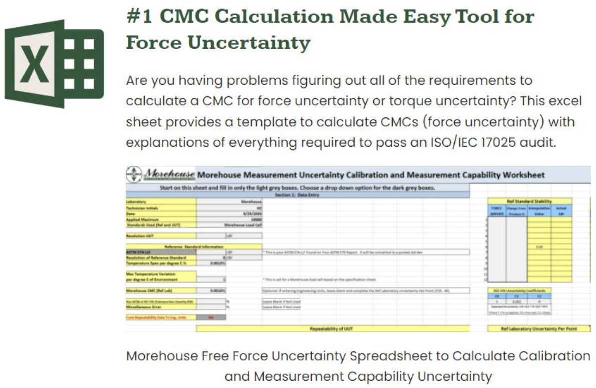


[YouTube Videos]



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