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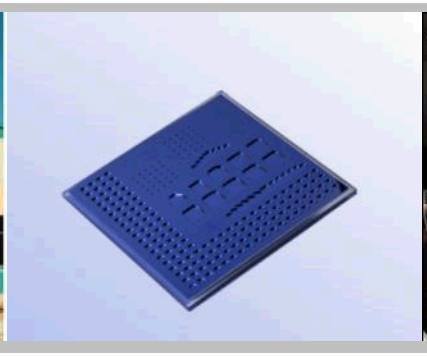

Uncertainty in Mass Dissemination Process

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Primary Standards Lab

STAR Fellow Final Presentations
7/27/17

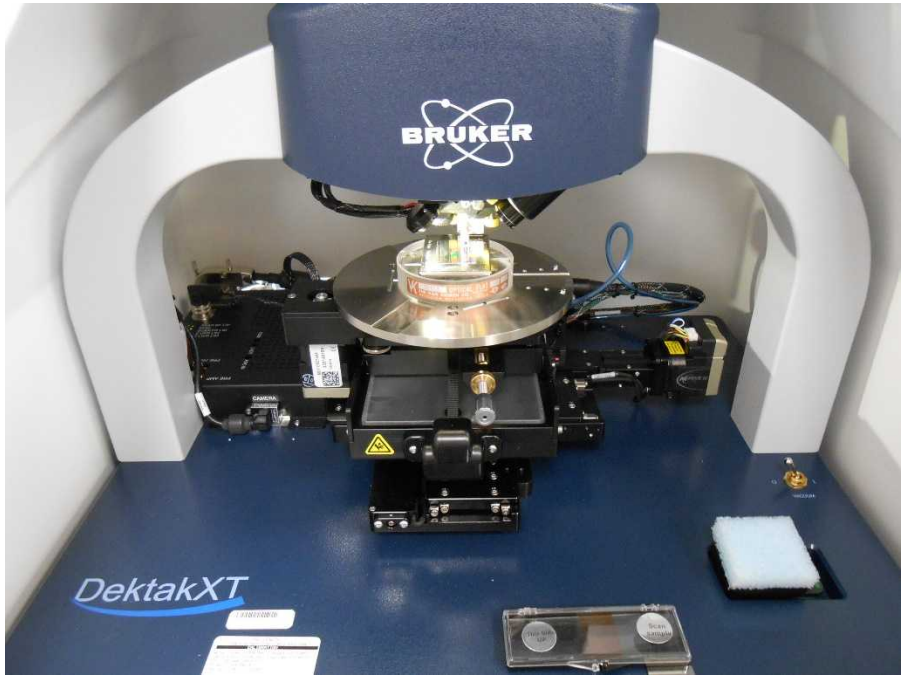
Outline

- Metrology
- Automation of Mass Comparators
- Mass Dissemination Monte Carlo
- What I learned

Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately describe the experimental procedure. Such identification does not imply recommendation or endorsement by the authors or their employers, nor does it imply that the materials or equipment identified are the only or best available for the purpose.

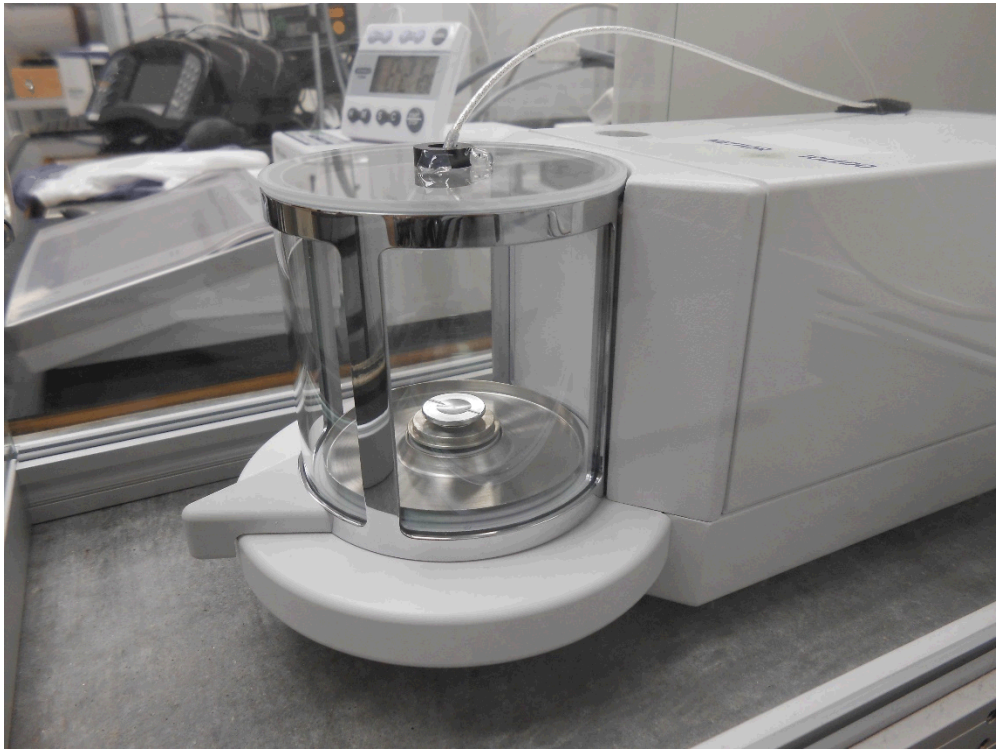
Metrology

- The scientific study of measurement.
- Commerce, science.
- Primary Standards Lab.
- Length, Mass, Force Lab.



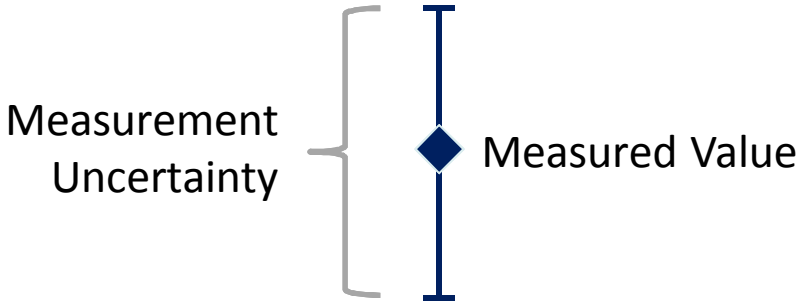
Automation of Mass Comparators

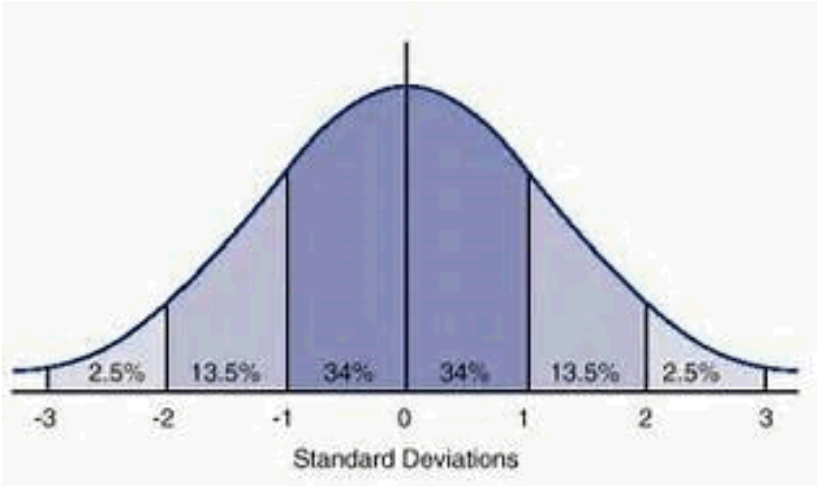
- Mass Comparators
- Automation
- Reduction of uncertainty



Measurement Uncertainty

- Measurement error.
- Sources of uncertainty.



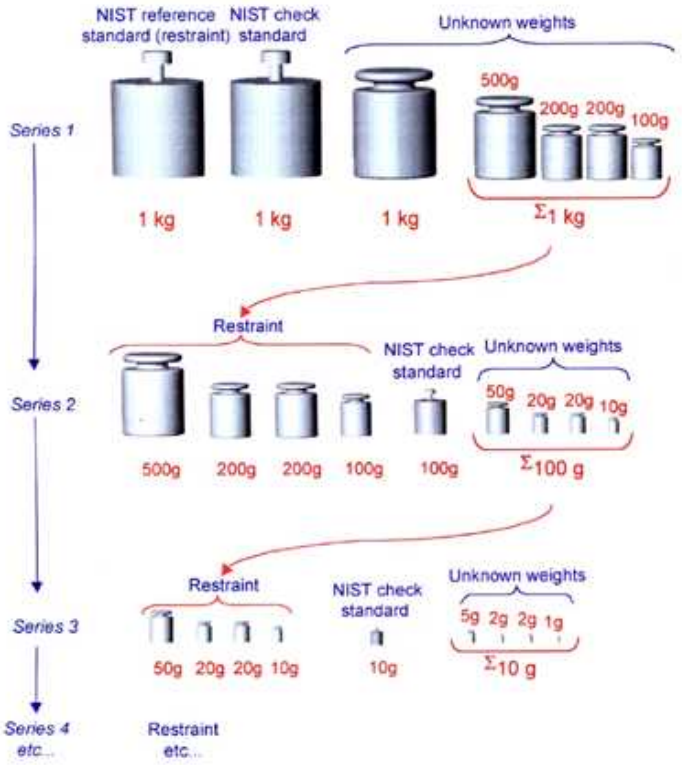


Correlated vs Uncorrelated

- Uncertainty of standard correlated to uncertainty of measurement?

Mass Dissemination

- One standard compared to several smaller weights.
- C.10 Weighing design
  - 5,2,2,1



C.10 Design

$$Y(1) = m_{500} - m_{200_1} - m_{200_2} - m_{100} - m_{\sum 100} + m_{Chk\ Std\ 100}$$

$$Y(2) = m_{500} - m_{200_1} - m_{200_2} - m_{100} + m_{\sum 100} - m_{Chk\ Std\ 100}$$

$$Y(3) = m_{500} - m_{200_1} - m_{200_2} + m_{100} - m_{\sum 100} - m_{Chk\ Std\ 100}$$

$$Y(4) = m_{500} - m_{200_1} - m_{100} - m_{\sum 100} - m_{Chk\ Std\ 100}$$

$$Y(5) = m_{500} - m_{200_2} - m_{100} - m_{\sum 100} - m_{Chk\ Std\ 100}$$

$$Y(6) = m_{200_1} - m_{200_2} + m_{100} - m_{\sum 100}$$

$$Y(7) = m_{200_1} - m_{200_2} - m_{100} + m_{Chk\ Std\ 100}$$

$$Y(8) = m_{200_1} - m_{200_2} + m_{\sum 100} - m_{Chk\ Std\ 100}$$

$$Restraint = m_{500} + m_{200_1} + m_{200_2} + m_{100} - m_{Restraint}$$

$$m_{500} = 500 + {}^{(15 \times Y(1) + 15 \times Y(2) + 5 \times Y(3) - 5 \times Y(6) + 5 \times Y(7) + 35 \times Restraint)}/_{70}$$

$$m_{200_1} = 200 + {}^{(-8 \times Y(1) - 8 \times Y(2) - 12 \times Y(3) + 2 \times Y(4) + 12 \times Y(5) + 8 \times Y(6) + 12 \times Y(7) + 10 \times Y(8) + 14 \times Restraint)}/_{70}$$

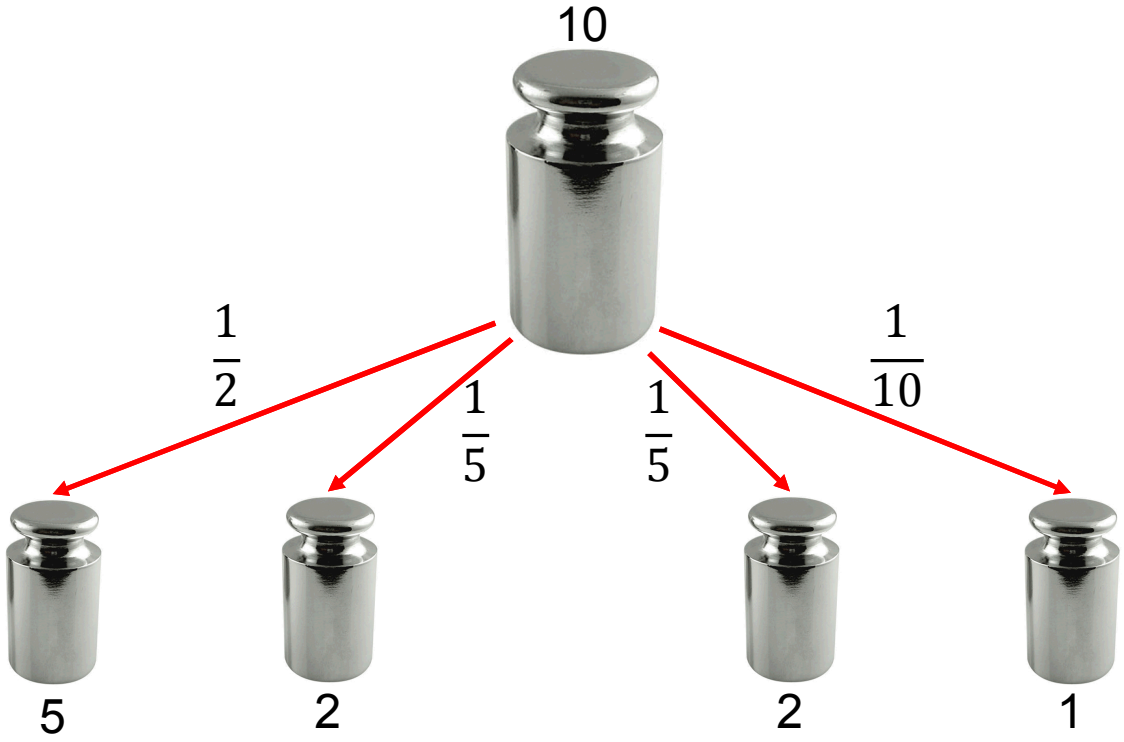
$$m_{200_2} = 200 + {}^{(-8 \times Y(1) - 8 \times Y(2) - 12 \times Y(3) + 12 \times Y(4) + 2 \times Y(5) - 12 \times Y(6) - 8 \times Y(7) - 10 \times Y(8) + 14 \times Restraint)}/_{70}$$

$$m_{100} = 100 + {}^{(Y(1) + Y(2) + 19 \times Y(3) - 14 \times Y(4) - 14 \times Y(5) + 9 \times Y(6) - 9 \times Y(7) + 7 \times Restraint)}/_{70}$$

Jones, Frank E, and Schoonover, Randall M. *Handbook of Mass Measurements.* CRC Press, 2002.

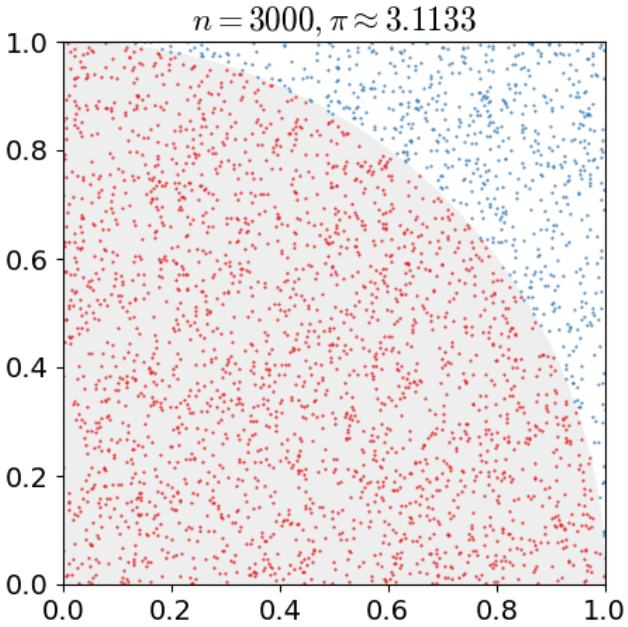
My Question

- In C.10 design, is uncertainty of standard correlated to uncertainty of measurement?
  - Use a Monte Carlo simulation to find out



Monte Carlo Simulations

- Allow you to quickly simulate many measurements.
- A random number generator applies uncertainties to all values in the process.
- Standard deviation of all the results equals the uncertainty of the result.



Monte Carlo

$$Y(1) = m_{500} - m_{200_1} - m_{200_2} - m_{100} - m_{\sum 100} + m_{Chk\ Std\ 100}$$

$$Y(2) = m_{500} - m_{200_1} - m_{200_2} - m_{100} + m_{\sum 100} - m_{Chk\ Std\ 100}$$

$$Y(3) = m_{500} - m_{200_1} - m_{200_2} + m_{100} - m_{\sum 100} - m_{Chk\ Std\ 100}$$

$$Y(4) = m_{500} - m_{200_1} - m_{100} - m_{\sum 100} - m_{Chk\ Std\ 100}$$

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$$Y(7) = m_{200_1} - m_{200_2} - m_{100} + m_{Chk\ Std\ 100}$$

$$Y(8) = m_{200_1} - m_{200_2} + m_{\sum 100} - m_{Chk\ Std\ 100}$$

$$Restraint = m_{500} + m_{200_1} + m_{200_2} + m_{100} - m_{Restraint}$$

$$m_{500} = 500 + {(15 \times Y(1) + 15 \times Y(2) + 5 \times Y(3) - 5 \times Y(6) + 5 \times Y(7) + 35 \times Restraint)}/{70}$$

$$m_{200_1} = 200 + {(-8 \times Y(1) - 8 \times Y(2) - 12 \times Y(3) + 2 \times Y(4) + 12 \times Y(5) + 8 \times Y(6) + 12 \times Y(7) + 10 \times Y(8) + 14 \times Restraint)}/{70}$$

$$m_{200_2} = 200 + {(-8 \times Y(1) - 8 \times Y(2) - 12 \times Y(3) + 12 \times Y(4) + 2 \times Y(5) - 12 \times Y(6) - 8 \times Y(7) - 10 \times Y(8) + 14 \times Restraint)}/{70}$$

$$m_{100} = 100 + {(Y(1) + Y(2) + 19 \times Y(3) - 14 \times Y(4) - 14 \times Y(5) + 9 \times Y(6) - 9 \times Y(7) + 7 \times Restraint)}/{70}$$

Jones, Frank E, and Schoonover, Randall M. *Handbook of Mass Measurements.* CRC Press, 2002.

Results of Monte Carlo

- In C.10 design, the uncertainty of the standard is correlated to the uncertainty of the measurement.

Std uncertainty reference	Standard Uncertainty A	Standard Uncertainty B	Standard Uncertainty C	Standard Uncertainty D
5.7735E-05	2.87744E-05	1.15098E-05	1.15098E-05	5.75489E-06
	50%	20%	20%	10%
Sum of std unc's A thru D				
5.75489E-05				
Sum as %				
100%				

What I learned

- Importance of metrology.
- Double check everything.
  - Impact of small errors.
- Ask questions.

Acknowledgements

- Huge thanks to
  - Hy Tran, Rick Mertes, and Jeremy Gray
  - Cheryl Garcia and the STAR Program

Questions?