# Measurement Science & Standards in Forensic Firearms Analysis

## Physical Standards, Calibrations and Traceability

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# Outline

- Metrology from an International perspective
- Metrological Traceability
- NIST's role and response to the measurement needs of the Forensic Firearms community: SRMs
- Design, manufacture & analysis of Standard Bullets/Casings
- Calibration & Quality Control

# Metrology from an International Perspective

- The Bureau International des Poids et Mesures (BIPM) is the International Bureau of Weights and Measures

- The BIPM:
  - Established by the Metre Convention (1875)
  - Headquartered near Paris
  - Financed by the Member States
    - US as an original member of the treaty of the meter
  - Provides a single, coherent system of measurements throughout the world traceable to the International System of Units (SI)
    - Direct dissemination for mass and time
  - Coordinates intercomparisons of national measurement standards
    - Ionizing radiation and electricity

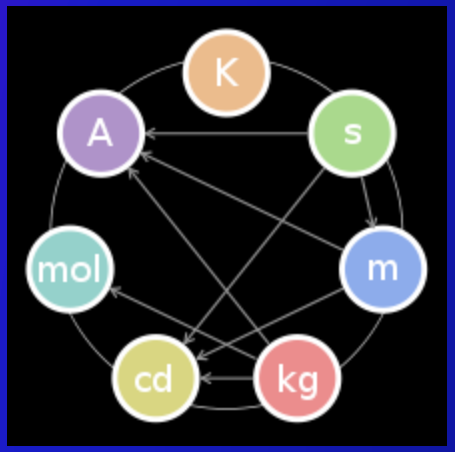
http://www.bipm.org/en/home/

# International metrology

- The International Committee for Weights and Measures (CIPM) executes the supervision of the BIPM
  - In 1999, the CIPM Mutual Recognition Arrangement (MRA) was signed by NIST and 37 other National Metrology Institutes to ensure:
    - Acceptance of measurement results of the signatories
    - Providing a framework of intercomparisons to ensure the acceptance of the national standards
    - Enabling the institutes to maintain quality management systems for the measurement services
- NIST representation at CIPM:
  - NIST Associate Director for Laboratory Programs, Dr. Willie May, is the Vice President of the CIPM
  - PML Deputy Director, Dr. James Olthoff, is the chair of the Quality System Task Force (QSTF) of SIM (the regional metrology organization of the Americas)
  - NIST technical experts provide leadership and representation on the consultative committees established by the CIPM in the given measurement areas (typically mirror the SI units)

## The seven base SI units as defined by the Metre Convention:

- **Length (meter)**
- Mass (kilogram)
- Time (second)
- Electrical current (ampere)
- Temperature (kelvin)
- Amount of substance (mole)
- Luminous intensity (candela)



SI dependency

- Length is no longer defined in terms of the meter bar
- Redefined in 1983 to be the distance light travels in a vacuum in 1 / 299,792,458 of a second

## 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.

International Vocabulary of Metrology (VIM), JCGM 200:2012
http://www.bipm.org/en/committees/jc/jcgm/wg2.html

# NIST role

- The mission of NIST is to promote US innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.
- NIST is the National Metrology Institute (NMI) for the United States.
- NIST's calibrations and measurement capabilities (CMCs) are internationally recognized
  - Appendix C of the CIPM MRA (NIST has more capabilities than any other NMI)

# Needs for calibration & traceability in Forensic Firearms Analysis

- Testing Laboratories need an artifact/standard to calibrate instrumentation and/or verify operation of their measurement systems thereby ensuring a means to provide:
  - Quality Assurance aspects to the measurement process
  - Metrological Traceability

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# NIST Standard Reference Materials

- Standard Reference Materials (SRMs) are certified reference materials issued under the NIST trademark
- All SRMs have a certified value and associated uncertainty estimate
- NIST has several thousand different SRMs covering many different scientific areas

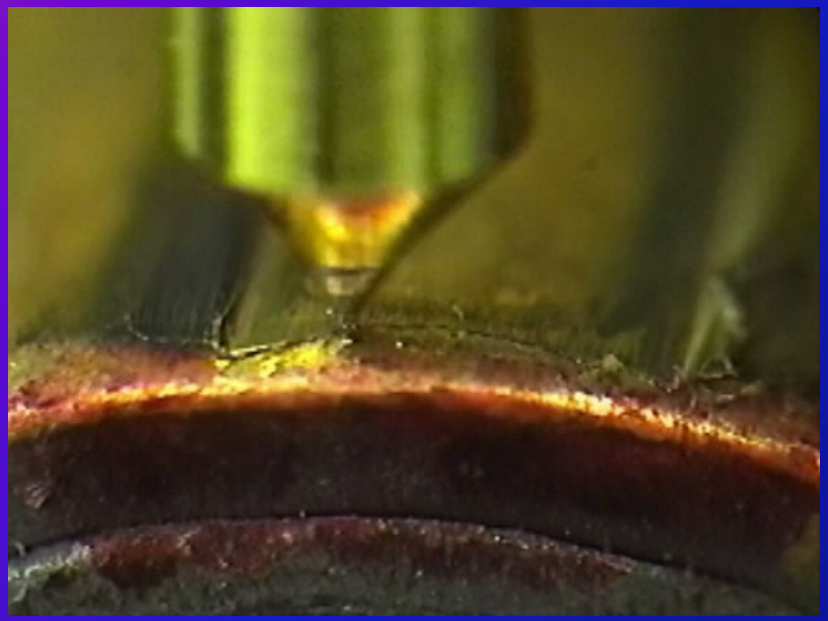
http://www.nist.gov/srm/

# SRM 2460 Standard Bullet

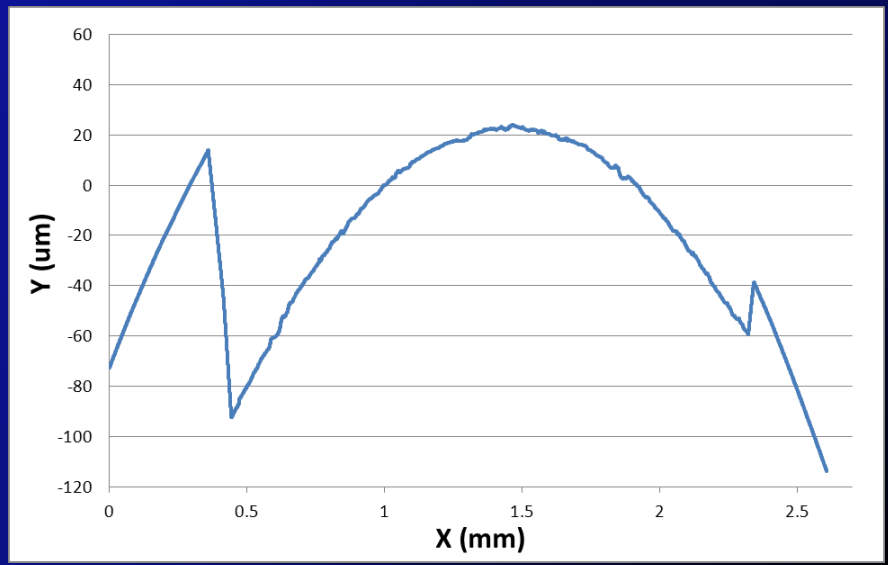
**Design Requirements:**

- Needs to look like a “real” bullet (physical shape, color, etc.)
- Similar land impressions to those of real bullets
- High degree of similarity from one standard bullet to the next
- Durable

Six master bullets used for topography measurements
Three from ATF, Three from FBI



Stylus profilometer measurements of master bullets result in digital profiles of bullet LEA's



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Standard Bullets manufactured using a numerically controlled diamond turning operation

# SRM 2460 Standard Bullet

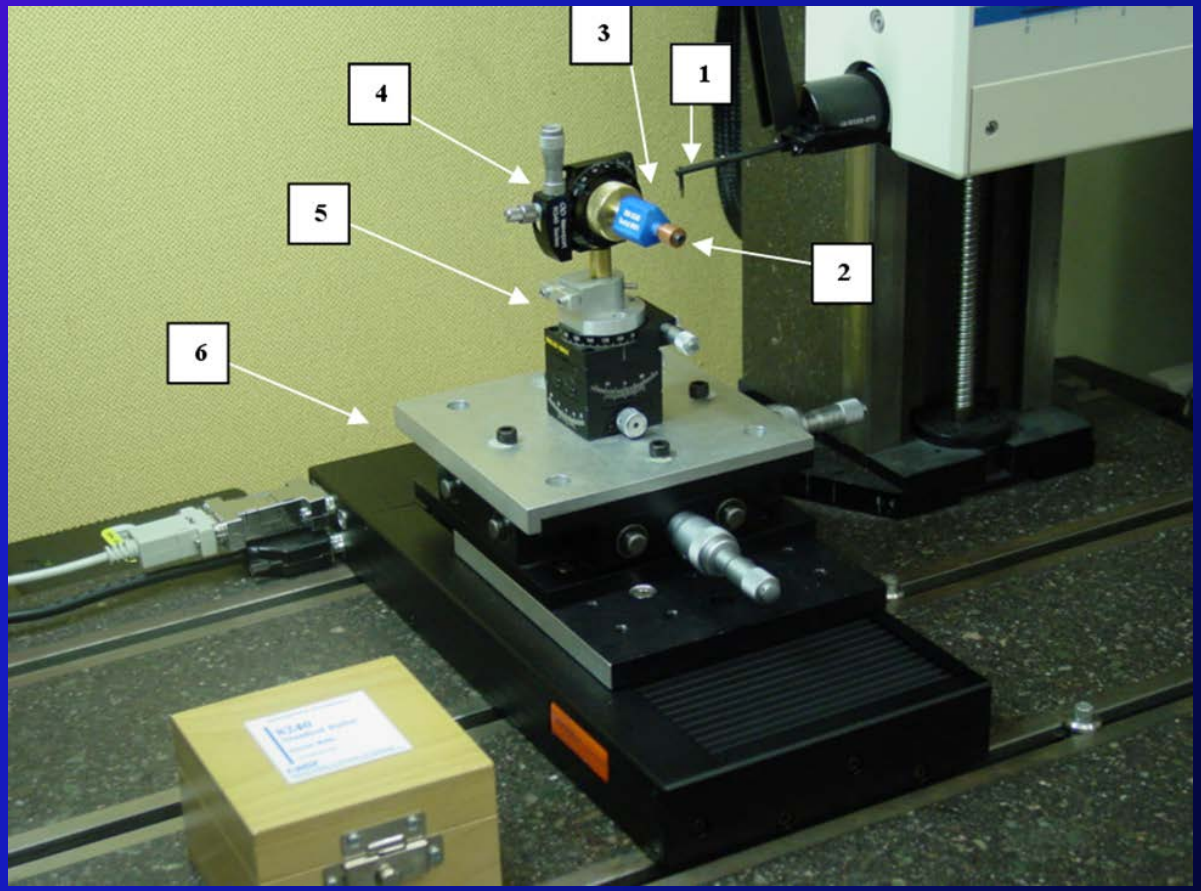


Standard Bullet mounted on holder

A) One of the six master bullets used for topography measurements
B) Prototype standard bullet
C) SRM 2460 Standard Bullet

# SRM 2460 Standard Bullet

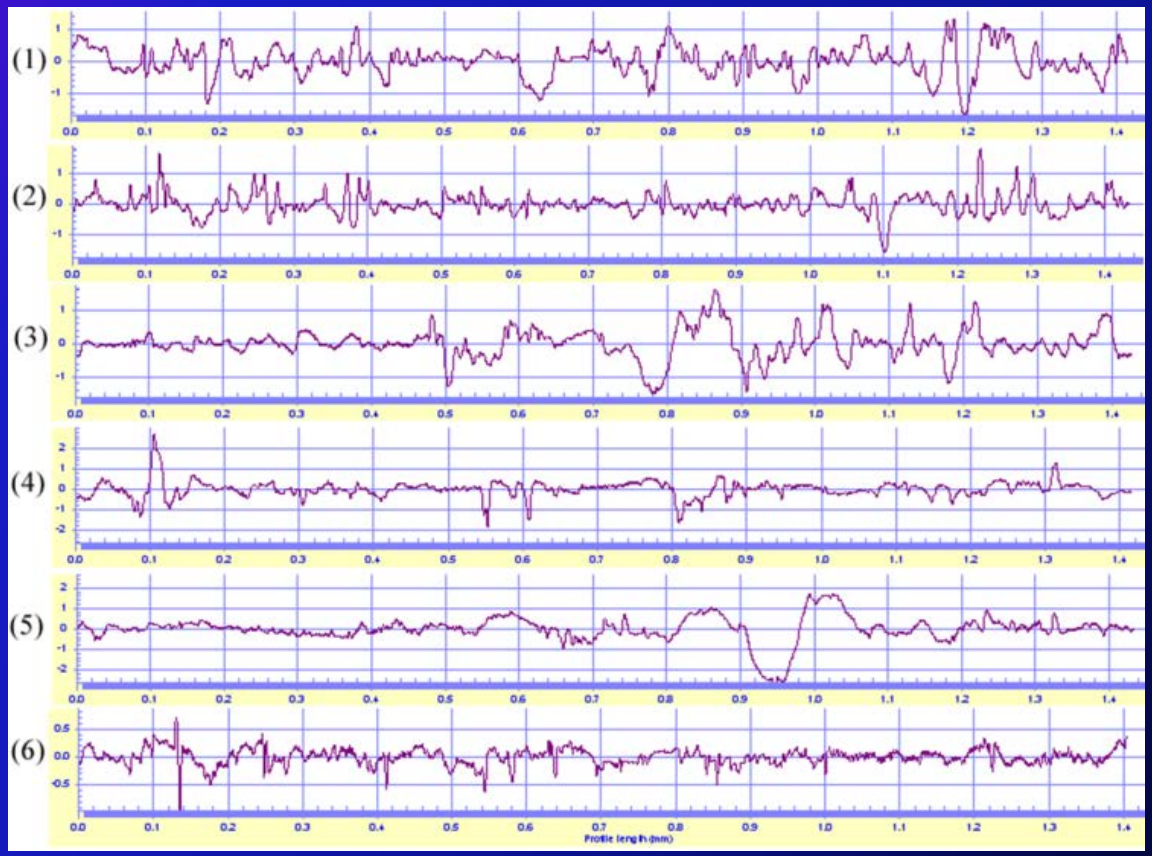
## 2D measurements by calibrated stylus profilometer




Measurement setup for NIST bullet signature measurement system: 1) Diamond stylus; 2) Standard bullet; 3) Bullet holder; 4) Rotary stage; 5) Horizontal rotary stage; 6) *X*-*Y* stage.

# SRM 2460 Standard Bullet

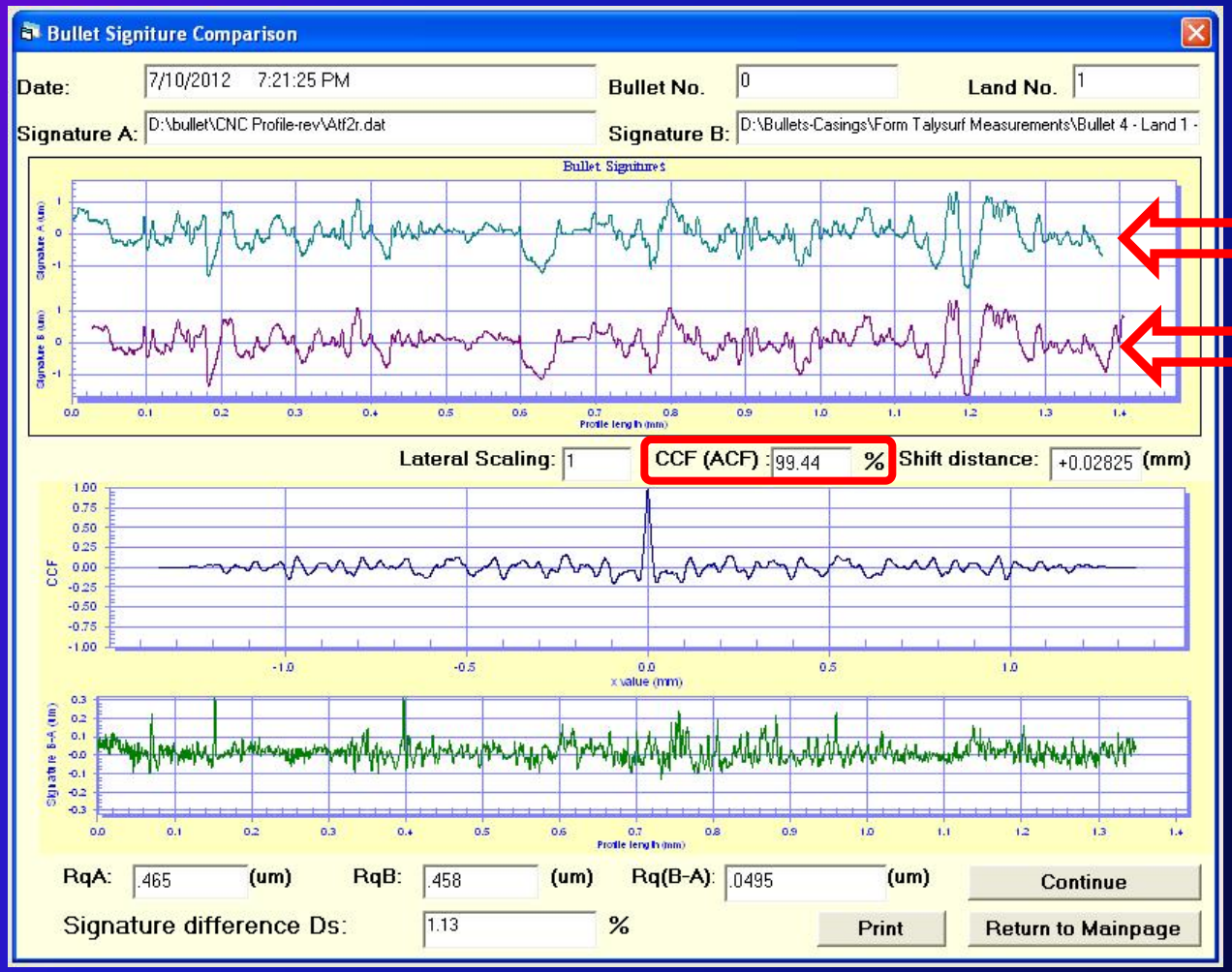
## Virtual Signature Standards for the Standard Bullet




Surface Profile measurements from the six lands on the Standard Bullet
(after digital Gaussian filtering and curvature removal)

# SRM 2460 Standard Bullet

## Example Correlation Analysis of a Standard Bullet (Land 1) versus the Virtual Signature Standard




Virtual Signature Standard

SRM 2460-004

**CCF = 99.44%**

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# SRM 2460 Standard Bullet

Correlation Analysis of the Standard Bullets versus the Virtual Signature Standards

| | Measurements | | Production | |
|---|---|---|---|---|
| | **Repeatability** | **Reproducibility** | **Repeatability** | **Reproducibility** |
| CCF % | Same bullet land<br>Same meas. day<br>Same meas. setup<br>Same calib. | Same bullet land<br>Dif. meas. days<br>Dif. meas. setup<br>Dif. calib. | 1st 20 bullets made with same setup | 2nd 20 bullets made and measured by dif. people with the same procedures |
| Mean<br>S.D. | 99.47%<br>0.06% | 99.29%<br>0.26% | 99.26%<br>0.54% | 99.47%<br>0.24% |

Statistical Analysis of SRM2460 bullets # 1-40 showing above 99% correlation to the virtual signature standard

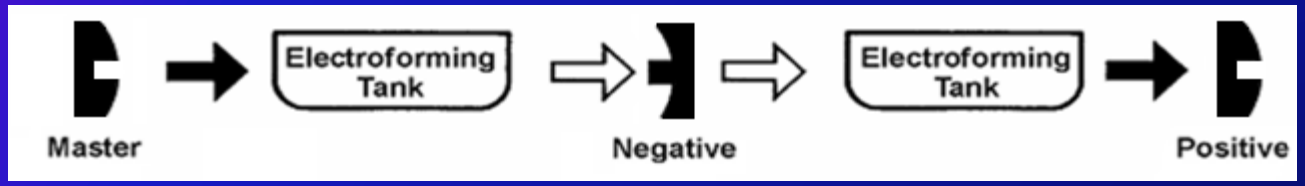
# SRM 2461 Standard Casing

**Design Requirements:**

- Needs to look like a “real” casing (shape, size, color, etc.)
- Must contain the three commonly used regions of interest (Breech Face, Firing Pin, Ejector Mark)
- High degree of similarity from one standard casing to the next
- Durable

# SRM 2461 Standard Casing

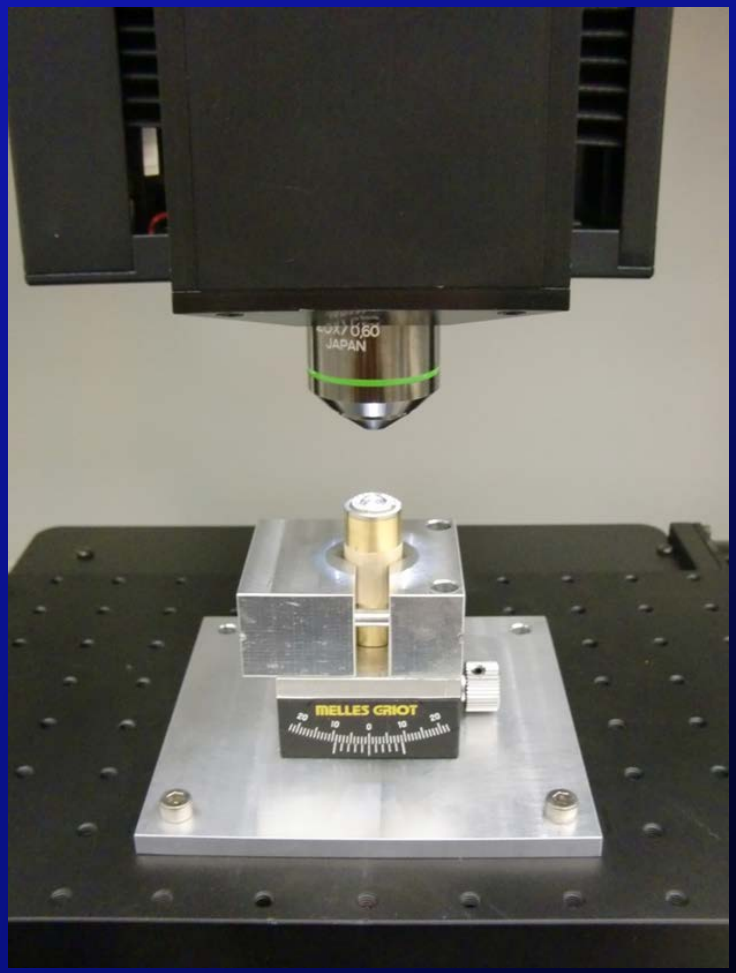
- Casings made using a metal electroforming process:
  - Negatives are made from a master casing
  - Positive replicas are then made from the negatives




SRM Casings made from electroform process

# SRM 2461 Standard Casing

Confocal microscope used to image 3D casing topography

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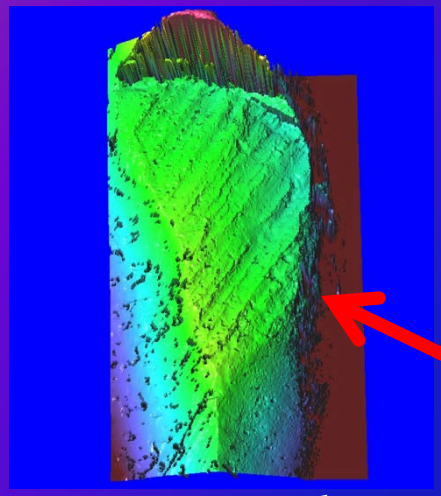
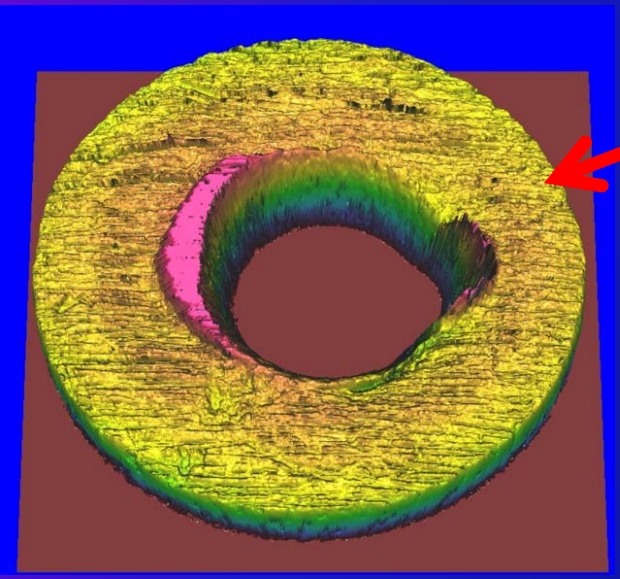
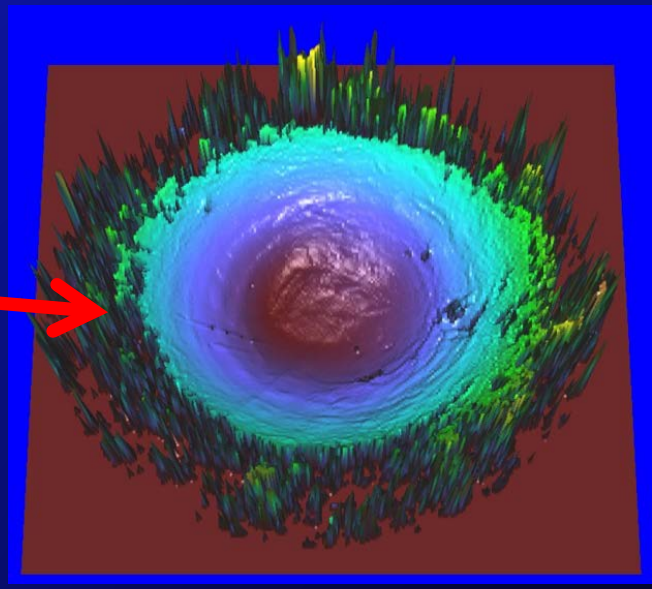
# Topography Images for the Standard Casing



Ejector mark

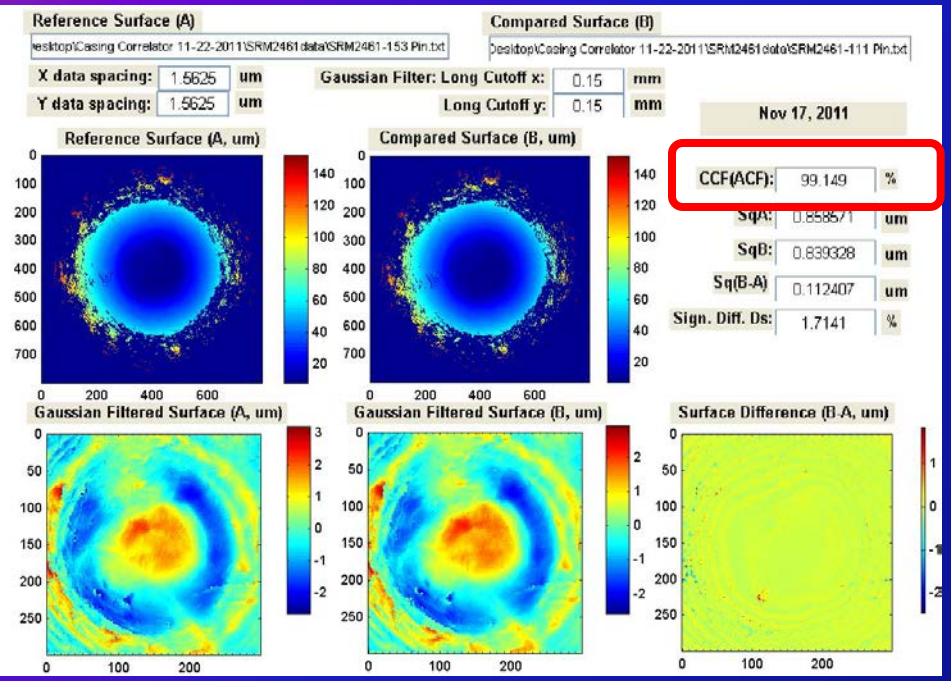


Breech Face

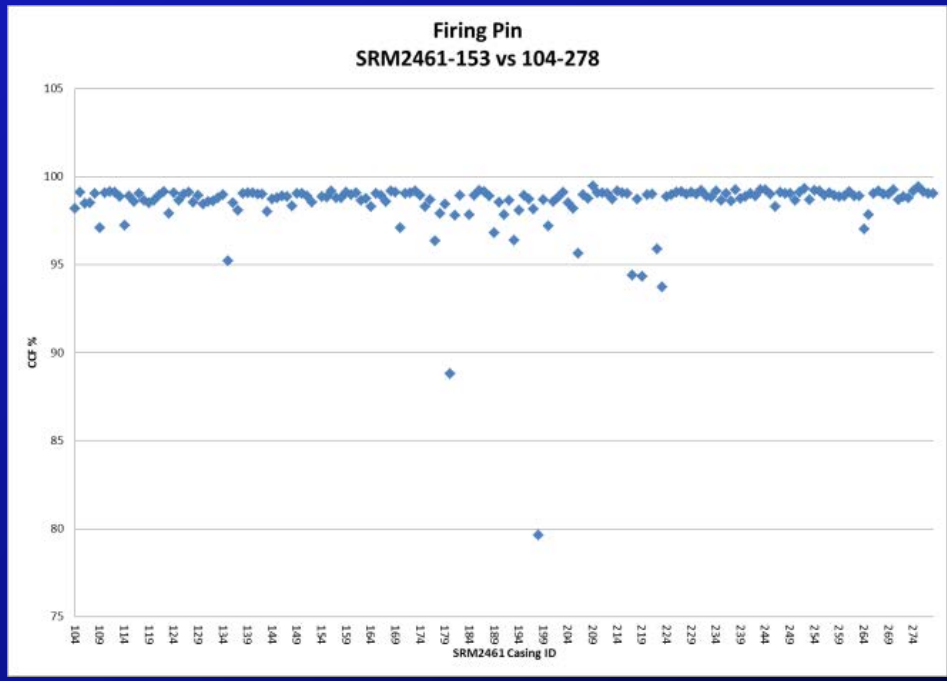



Firing Pin

# SRM 2461 Analysis – Firing Pin




Correlation program showing an example Firing Pin correlation

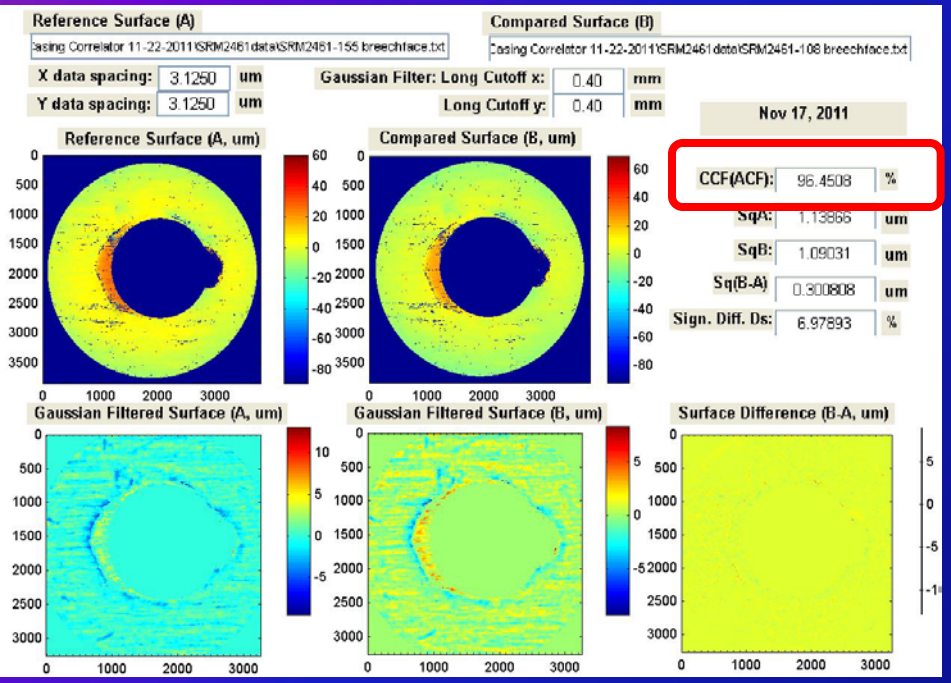



Correlation scores of 2461-153 (Firing Pin Master) versus population set

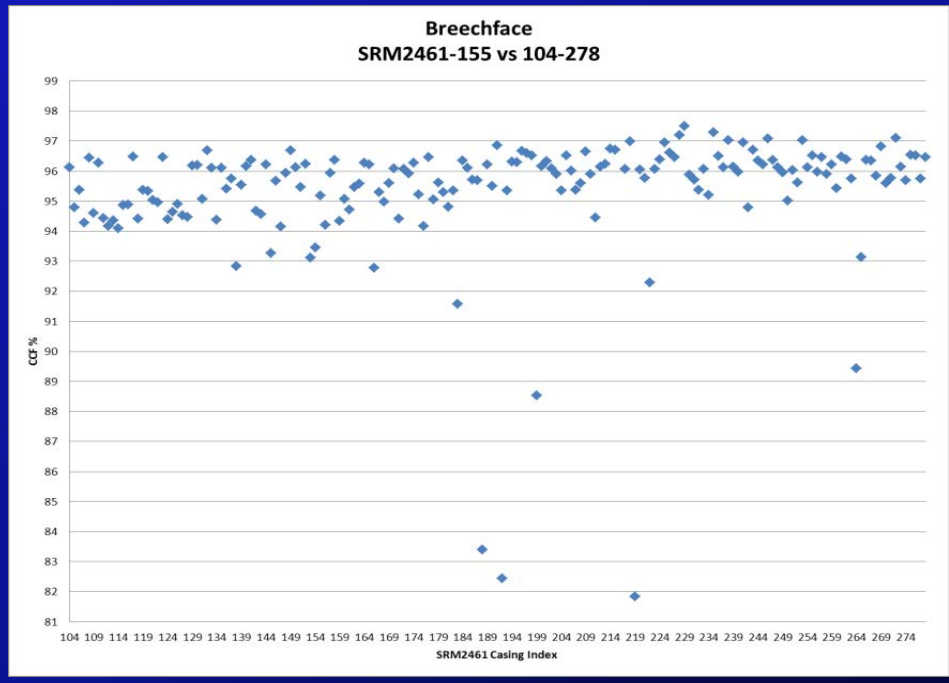
Processing steps:

- Removal of outlier data
- Digital Gaussian Filtering
- Image registration
- Correlation

# SRM 2461 Analysis – Breech Face




Correlation program showing an example Breech Face correlation

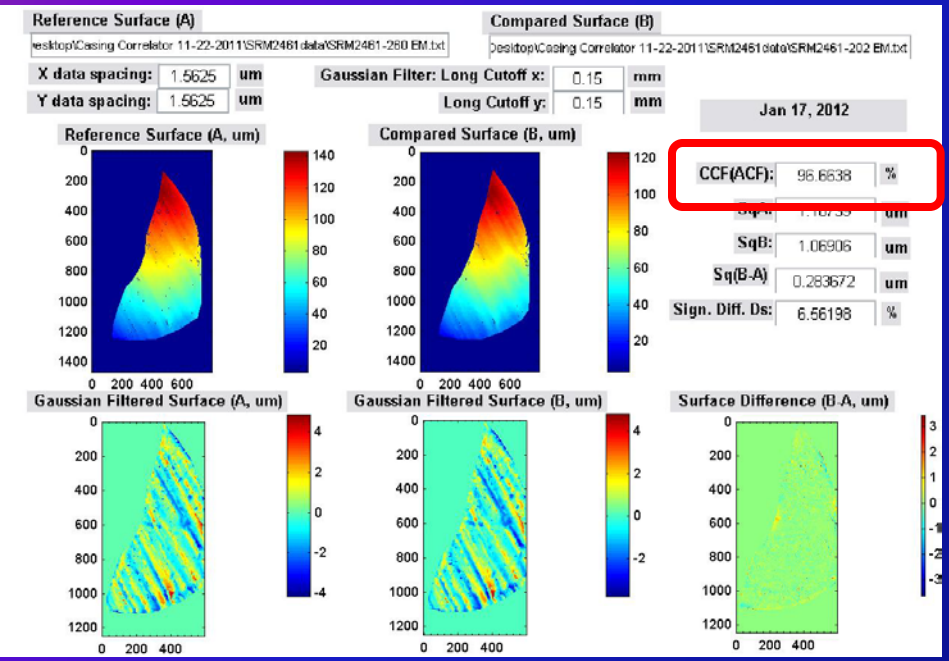



Correlation scores of 2461-155 (Breech Face Master) versus population set

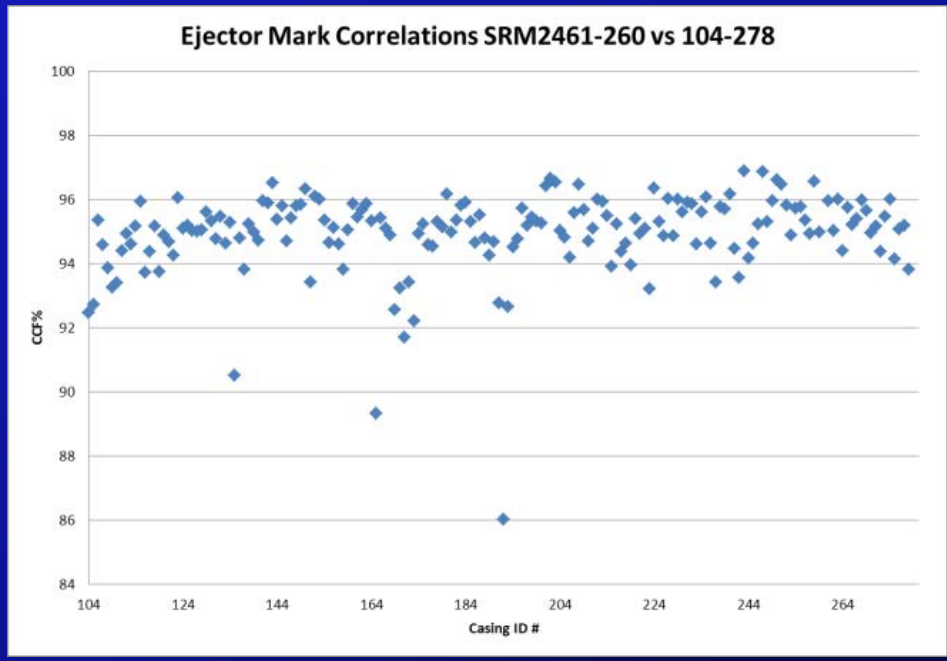
Processing steps:

- Trimming
- Removal of outlier data
- Digital Gaussian Filtering
- Image registration
- Correlation

# SRM 2461 Analysis – Ejector Mark




Correlation program showing an example Ejector Mark correlation




Correlation scores of 2461-260 (Ejector Mark Master) versus population set

Processing steps:

- Trimming
- Removal of outlier data
- Digital Gaussian Filtering
- Image registration
- Correlation

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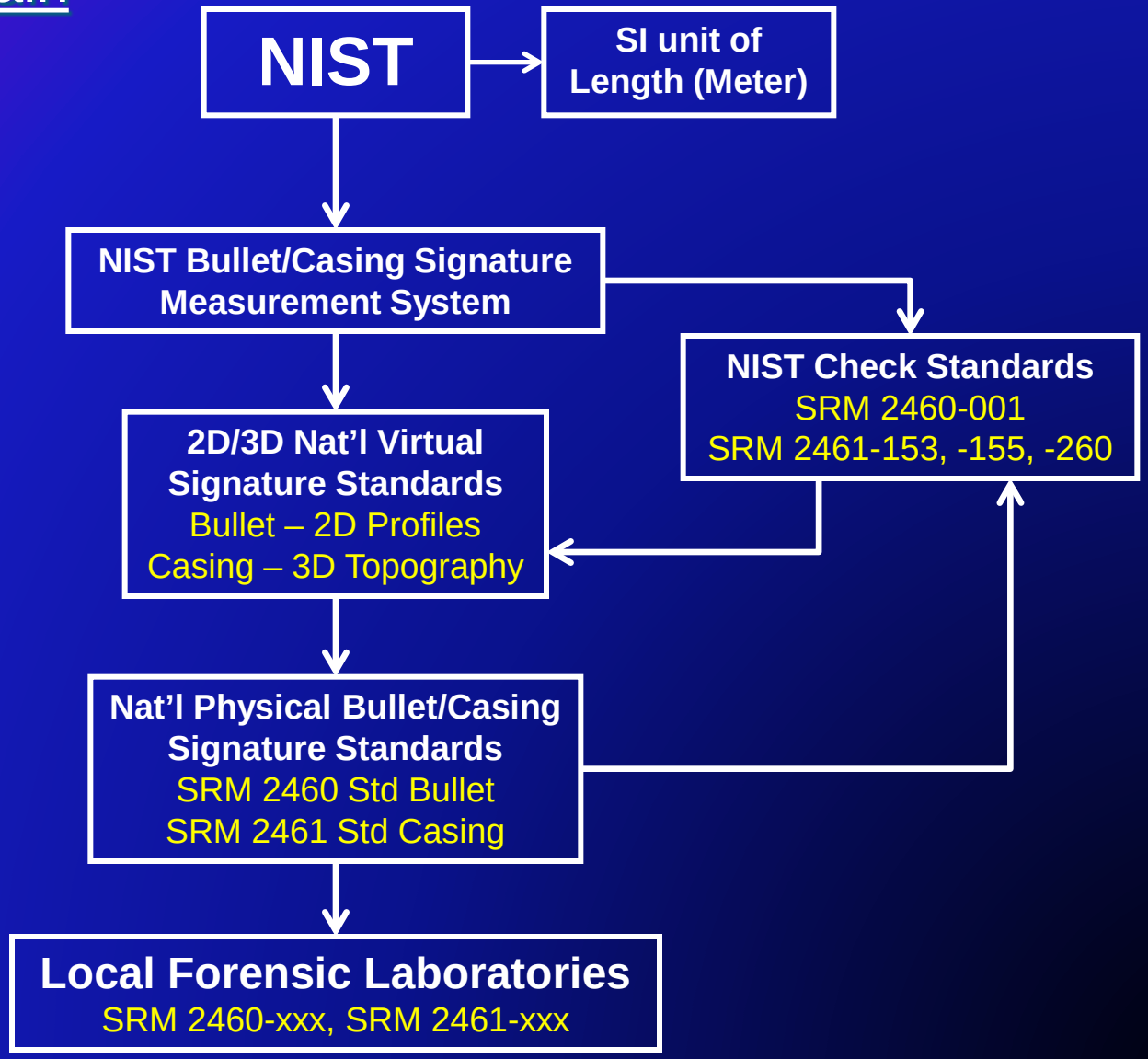
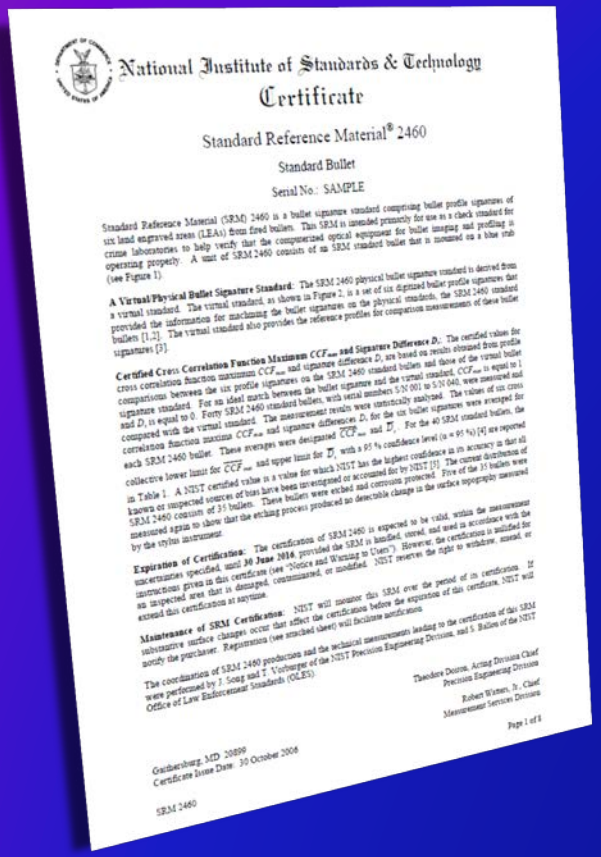
# Traceability Chain





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Certificate

Standard Reference Material® 2460

Standard Bullet

Serial No.: SAMPLE

Standard Reference Material (SRM) 2460 is a bullet signature standard comprising bullet profile signatures of six land engraved areas (LEAs) from fired bullets. This SRM is intended primarily for use as a check standard for crime laboratories to help verify that the computerized optical equipment for bullet imaging and profiling is operating properly. A unit of SRM 2460 consists of an SRM standard bullet that is mounted on a blue stub (see Figure 1).

**A Virtual Physical Bullet Signature Standard:** The SRM 2460 physical bullet signature standard is derived from a virtual standard. The virtual standard, as shown in Figure 2, is a set of six digitized bullet profile signatures that provided the information for machining the bullet signatures on the physical standards. The SRM 2460 standard bullets [1,2]. The virtual standard also provides the reference profiles for comparison measurements of these bullet signatures [3].

**Certified Cross Correlation Function Maximum $CCF_{max}$ and Signature Difference $D_j$:** The certified values for cross correlation function maximum $CCF_{max}$ and signature difference $D_j$ are based on results obtained from profile comparisons between the six profile signatures on the SRM 2460 standard bullets and those of the virtual bullet signature standard. For an ideal match between the bullet signature and the virtual standard, $CCF_{max}$ is equal to 1 and $D_j$ is equal to 0. Forty SRM 2460 standard bullets, with serial numbers S/N 001 to S/N 040, were measured and compared with the virtual standard. The measurement results were statistically analyzed. The values of six cross correlation function maxima $CCF_{max}$ and signature differences $D_j$ for the six bullet signatures were averaged for each SRM 2460 bullet. These averages were designated $\overline{CCF}_{max}$ and $\overline{D}_j$. For the 40 SRM standard bullets, the collective lower limit for $\overline{CCF}_{max}$ and upper limit for $\overline{D}_j$ with a 95 % confidence level ($\alpha = 95$ %) [4] are reported in Table 1. A NIST certified value is a value for which NIST has the highest confidence in its accuracy in that all known or suspected sources of bias have been investigated or accounted for by NIST [5]. The current distribution of SRM 2460 consists of 35 bullets. These bullets were etched and corrosion protected. Five of the 35 bullets were measured again to show that the etching process produced no detectable change in the surface topography measured by the stylus instrument.

**Expiration of Certification:** The certification of SRM 2460 is expected to be valid, within the measurement uncertainties specified, until **30 June 2016**, provided the SRM is handled, stored, and used in accordance with the instructions given in this certificate (see "Notice and Warning to Users"). However, the certification is nullified if the SRM is damaged, contaminated, or modified. NIST reserves the right to withdraw, amend, or extend this certification at anytime.

**Maintenance of SRM Certification:** NIST will monitor this SRM over the period of its certification. If substantive surface changes occur that affect the certification before the expiration of this certificate, NIST will notify the purchaser. Registration (see attached sheet) will facilitate notification.

The coordination of SRM 2460 production and the technical measurements leading to the certification of this SRM were performed by J. Song and T. Vorburger of the NIST Precision Engineering Division, and S. Ballou of the NIST Office of Law Enforcement Standards (OLES).

Theodore Doiron, Acting Division Chief
Precision Engineering Division

Robert Watters, Jr., Chief
Measurement Services Division

Gaithersburg, MD 20899
Certificate Issue Date: 30 October 2006

SRM 2460

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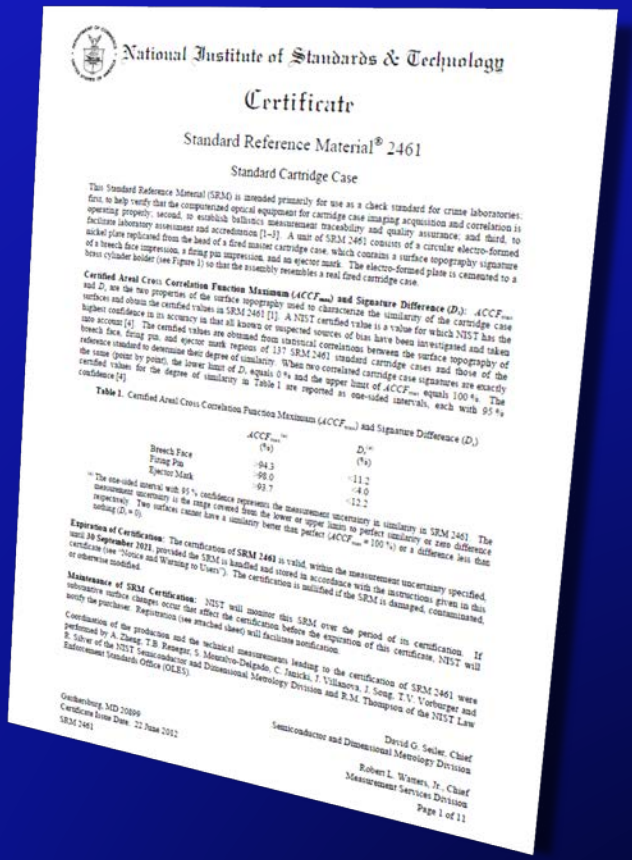

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Certificate

Standard Reference Material® 2461

Standard Cartridge Case

This Standard Reference Material (SRM) is intended primarily for use as a check standard for crime laboratories: first, to help verify that the computerized optical equipment for cartridge case imaging acquisition and correlation is operating properly; second, to establish ballistics measurement traceability and quality assurance; and third, to facilitate laboratory assessment and accreditation [1–3]. A unit of SRM 2461 consists of a circular electro-formed nickel plate replicated from the head of a fired ammo cartridge case, which contains a surface topography signature of a breech face impression, a firing pin impression, and an ejector mark. The electro-formed plate is cemented to a brass cylinder holder (see Figure 1) so that the assembly resembles a real fired cartridge case.

**Certified Areal Cross Correlation Function Maximum ($ACCF_{max}$) and Signature Difference ($D_j$):** $ACCF_{max}$ and $D_j$ are the two properties of the surface topography used to characterize the similarity of the cartridge case surfaces and obtain the certified values in SRM 2461 [1]. A NIST certified value is a value for which NIST has the highest confidence in its accuracy in that all known or suspected sources of bias have been investigated and taken into account [4]. The certified values are obtained from statistical correlations between the surface topography of breech face, firing pin, and ejector mark regions of 137 SRM 2461 standard cartridge cases and those of the reference standard to determine their degree of similarity. When two correlated cartridge cases are exactly the same (point by point), the lower limit of $D_j$ equals 0 % and the upper limit of $ACCF_{max}$ equals 100 %. The certified values for the degree of similarity in Table 1 are reported as one-sided intervals, each with 95 % confidence [4].

**Table 1.** Certified Areal Cross Correlation Function Maximum ($ACCF_{max}$) and Signature Difference ($D_j$)

| | $ACCF_{max}$[a] (%) | $D_j$[a] (%) |
|---|---|---|
| Breech Face | ≥94.3 | ≤11.2 |
| Firing Pin | ≥98.0 | ≤4.0 |
| Ejector Mark | ≥93.7 | ≤12.2 |

[a] The one-sided interval with 95 % confidence represents the measurement uncertainty in similarity in SRM 2461. The measurement uncertainty is the range covered from the lower or upper limits to perfect similarity or zero difference respectively. Two surfaces cannot have a similarity better than perfect ($ACCF_{max} = 100$ %) or a difference less than zero ($D_j = 0$).

**Expiration of Certification:** The certification of **SRM 2461** is valid, within the measurement uncertainty specified, until **30 September 2021**, provided the SRM is handled and stored in accordance with the instructions given in this certificate (see "Notice and Warning to Users"). The certification is nullified if the SRM is damaged, contaminated, or otherwise modified.

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Coordination of the production and the technical measurements leading to the certification of SRM 2461 were performed by A. Zheng, T.B. Renegar, S. Mercado-Delgado, C. Janicki, T. Villanova, J. Song, T.V. Vorburger and B. Silver of the NIST Semiconductor and Dimensional Metrology Division and R.M. Thompson of the NIST Law Enforcement Standards Office (OLES).

David G. Seiler, Chief
Semiconductor and Dimensional Metrology Division

Robert L. Watters, Jr., Chief
Measurement Services Division

Gaithersburg, MD 20899
Certificate Issue Date: 22 June 2012
SRM 2461

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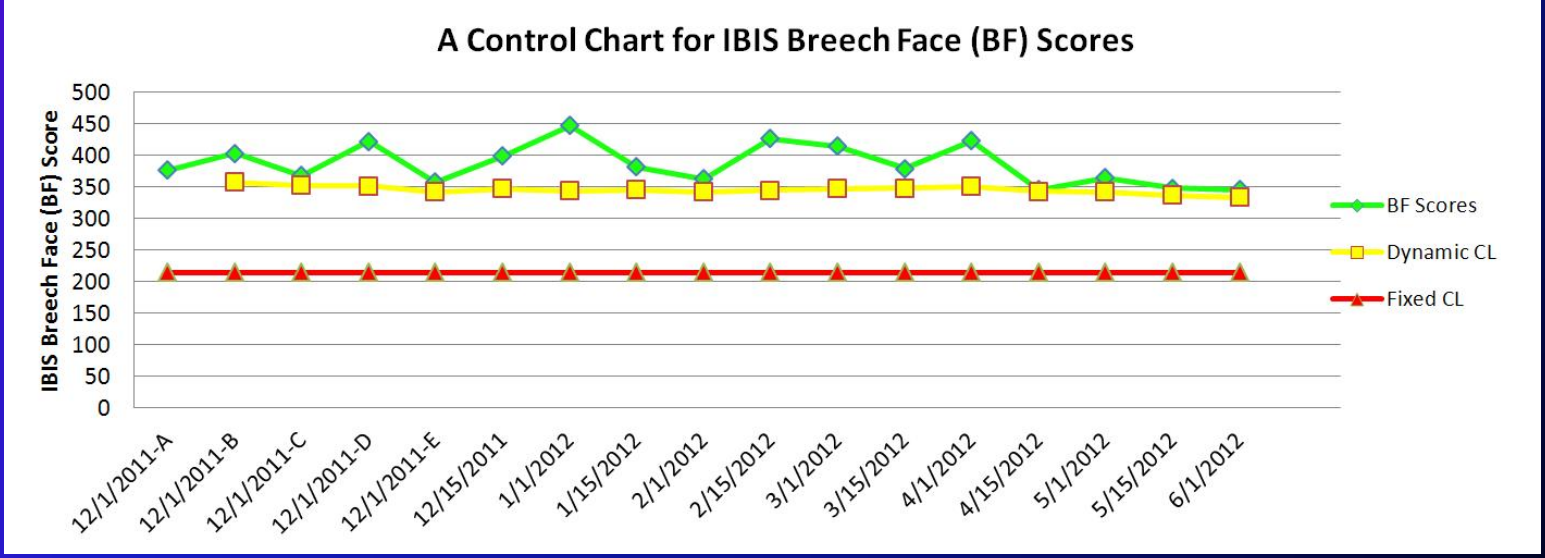
NIST Statisticians participated in the analysis of the uncertainty estimates and control values, and preparation of the Certificate.

Both SRMs and their Certificates include User Guides as appendices

# Quality Control

Example control chart showing day to day measurements of the SRM 2460 Standard Casing

- Dynamic Control Limit provides early warning that there may be a problem with the measurements or process.
- Fixed Limit is the lower boundary. Measurements below this should be investigated immediately for root cause.




Breech Face scores shown, using FTI's IBIS microscope system

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# Thank you

# Questions?

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