NIST NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

Date of Issue:
28 May 2025

Standard Reference Material® 2460a

Standard Bullet Replica

CERTIFICATE

Purpose: The certified values delivered by this Standard Reference Material (SRM) are intended primarily for use as a check standard for forensic laboratories to help verify that the computerized optical equipment for bullet imaging and profiling is operating properly to measure bullet topography signatures.

Description: A unit of SRM 2460a consists of a nickel and gold-coated standard bullet replica that is mounted on a plastic holder (see Figure 1 below and the Flyer accompanying this Certificate). SRM 2460a is a bullet signature standard comprising bullet profile signatures of six Land Engraved Areas (LEAs) from fired bullets. It is replicated from the original SRM 2460 *Standard Bullet* [1,2].

Certified Values: The certified values for the normalized CCF_{max} (correlation coefficient) and D_s [2,3] are based on results obtained from profile comparisons between the six profile signatures on the SRM 2460a Standard Bullet Replicas and those of the digital reference bullet signature standards. For an ideal match between a measured bullet signature and the reference standard, CCF_{max} is equal to 1 and D_s is equal to 0. Sixty-five SRM 2460a Standard Bullet Replicas were measured and compared with the reference standards. The values of six cross correlation function maxima CCF_{max} and signature differences D_s for the six bullet signatures of all 65 SRM bullets were statistically analyzed. For the 65 standard bullet replicas, the resulting lower limit for CCF_{max} and upper limit for D_s with a 95 % confidence level [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 taken into account [5]. For each SRM 2460a LEA, a user can establish traceability of a measurement result for the respective surface profile through comparison with the digital reference profile. The set of six reference profiles were produced from traceable NIST measurements of the SRM 2460a LEAs. The certified values are valid for all units of SRM 2460a.

Table 1. Certified CCF_{max} [(a)] and D_s [(a)] for each LEA

LEA #	CCF_{max} (%)	D_s (%)
1	>96.0	<8.2
2	>86.2	<26.1
3	>96.8	<6.3
4	>95.5	<11.0
5	>95.0	<10.8
6	>80.8	<35.4

[(a)] The one-sided interval with 95 % confidence represents the effects of replication variations and measurement uncertainty on the similarity of SRM 2460a to the reference signature standards. The interval 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 (CCF_{max} = 100 %) or a difference less than nothing (D_s = 0 %). The measurands are the CCF_{max} and D_s values listed in Table 1.

Additional Information: Additional information can be found in the Appendices.

Period of Validity: The certified values delivered by **SRM 2460a** are valid within the measurement uncertainty specified until **01 October 2033**. The certified values are nullified if the material is stored or used improperly, damaged, contaminated, or otherwise modified.

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Maintenance of Certified Values: NIST will monitor this SRM over the period of its validity. If substantive technical changes occur that affect the certification, NIST will issue an amended certificate through the NIST SRM website (https://www.nist.gov/srm) and notify registered users. SRM users can register online from a link available on the NIST SRM website or fill out the user registration form that is supplied with the SRM. Registration will facilitate notification. Before making use of any of the values delivered by this material, users should verify they have the most recent version of this documentation, available through the NIST SRM website (https://www.nist.gov/srm).

A Virtual/Physical Bullet Signature Standard: The SRM 2460a virtual bullet signature standards (see Figure 2) are a set of six digitized bullet profile signatures, one for each LEA. The LEA profile signature of a physical SRM 2460a bullet has a certified similarity to the respective virtual bullet signature standard. The virtual bullet signatures provide a comparison reference for the topography measurements of SRM 2460a. These signatures may be obtained from the website for the NIST Ballistics Toolmark Research Database (NBTRD) [6]. The signatures are similar, but not identical, to those of SRM 2460.

Safety: Consult the Safety Data Sheet (SDS) for hazard information.

Storage: The SRM 2460a must be used and stored in a dry and clean environment at temperatures between 10 °C and 30 °C. Touching the surface of the SRM 2460a with bare hands may cause irreversible contamination and/or surface damage to the bullet signatures. Therefore, handling of the bullet must only be done while wearing powderless latex or nitrile gloves. In addition, mechanical force on the bullet surfaces, or handling using tools such as tweezers, may cause irreversible damage to the bullet signatures. Users should avoid touching the land engraved areas of the bullet surfaces. Only handle by the nose or base of the bullet. See Appendix A for usage and cleaning procedures.

Use: The SRM 2460a Standard Bullet Replicas (example shown in Figure 1 and in the Flyer accompanying this Certificate) are made of polyurethane coated with a thin layer (≈ 10 nm) of nickel and another thin layer (≈ 20 nm) of gold. The bullets are 9 mm in diameter and include six LEAs. Each LEA has a unique bullet signature in accordance with the reference bullet signature standards (see Figure 2). The SRM bullet signatures are intended to be essentially identical to the reference bullet signature standards. The bullet LEAs are produced with a 5° right hand twist (see Figure 1), which makes the SRM 2460a resemble a real 9 mm Luger type bullet. There is an impressed dot (see Figure 1, A) located close to the nose of each bullet that designates the No. 1 LEA. The SRM 2460a Standard Bullet Replica is mounted on a plastic holder. A notch on the holder (see Figure 1, B, and the Flyer accompanying this Certificate) is also approximately aligned with the No. 1 LEA. The subsequent LEA's continue around the bullet in a counter-clockwise direction, as viewed from the base of the bullet. The NIST measurements, using a stylus instrument, were performed near the middle section of each bullet LEA (see Figure 1, D). For optimal correlation results with NIST measurements, it is strongly recommended to perform measurements in the same general area because the CCF_{max} and D_s values are certified for measurements in that region.

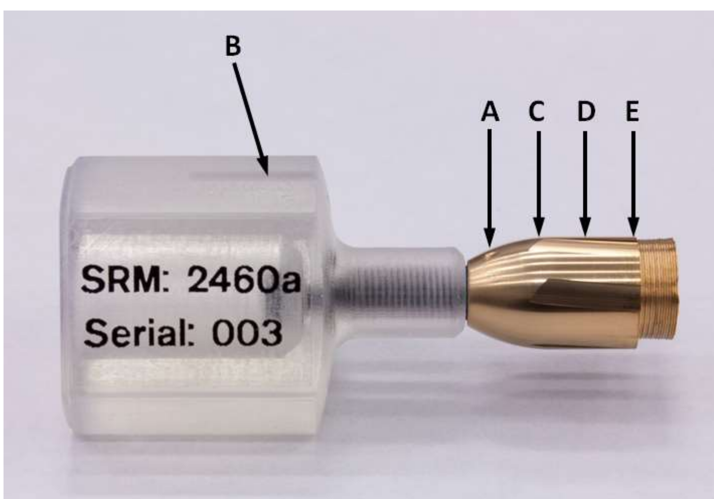

Figure 1. A NIST SRM 2460a Standard Bullet Replica mounted on a plastic holder. A dot (A) indicates the No. 1 land engraved area (LEA) of the bullet. A notch (B) on the bullet holder is approximately aligned with respect to Land 1. Also visible is the top (C), middle (D), and bottom (E) of the LEA. The NIST stylus measurements are traced at the middle section (D) of each LEA. For optimal correlation results, it is strongly recommended to perform measurements in the same general area. Also, see the Flyer accompanying this Certificate.

The reference bullet signature standards, obtained from measurements of the SRM 2460a Standard Bullet Replicas, are illustrated in Figure 2. They may be obtained from the NBTRD website (https://tsapps.nist.gov/NRBTD/Home/SRMBulletCC) [6]. The files may be downloaded for testing and comparison with profiles of the LEAs measured by the user on SRM 2460a and modified by a Gaussian filter [7] with a short-wavelength cutoff of 0.0025 mm, a curvature removal program, and a Gaussian filter with a long-wavelength cutoff of 0.25 mm.

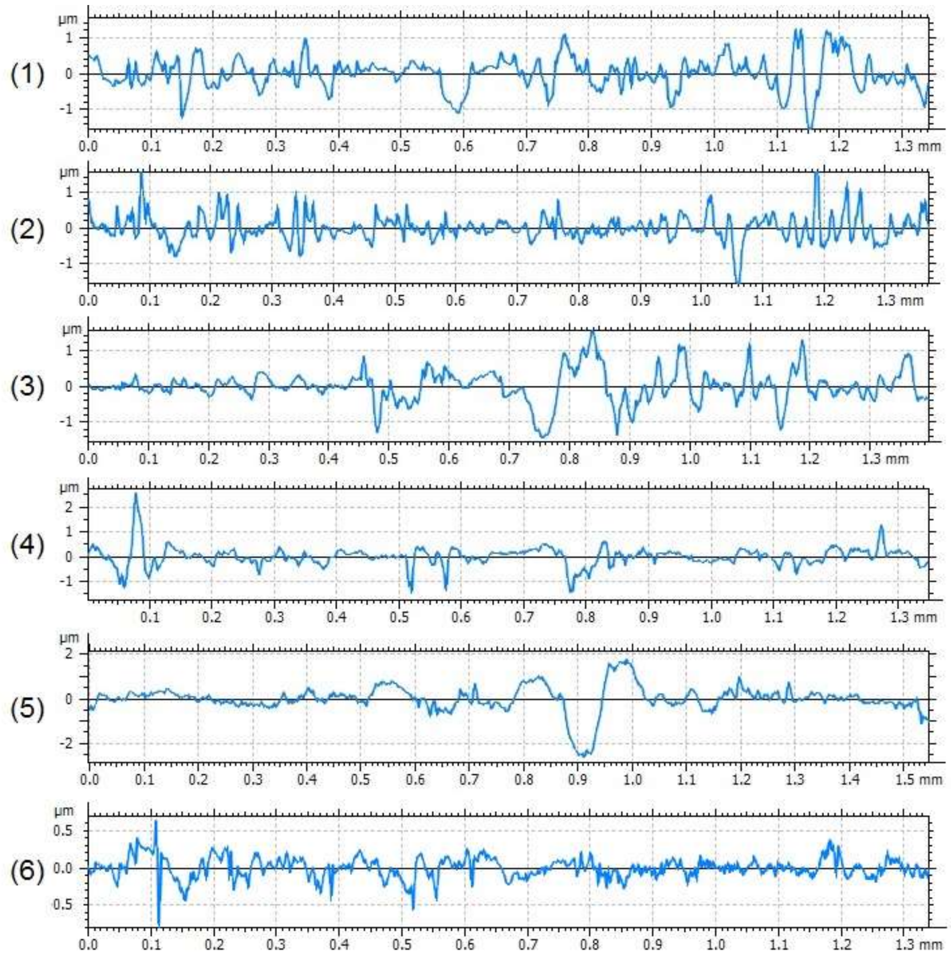

Figure 2. The reference bullet signatures consist of six digitized bullet profile signatures measured by a stylus instrument from LEA's 1 through 6. The reference profiles shown above are modified profiles after curvature removal and Gaussian filtering with a short-wavelength cutoff of 0.0025 mm and a long-wavelength cutoff of 0.25 mm [3]. The vertical scale is in µm; the horizontal scale is in mm.

Appendix A contains a "User Guide for NIST SRM 2460a Standard Bullet Replica" for customers using the SRM 2460a bullet to check instrument calibration and measurement quality control of 3D optical instruments for bullet topography signature acquisitions and correlations.

REFERENCES

[1] Song, J.; Vorburger, T.; Ols, M.; *Establishment of A Virtual/Physical Standard for Bullet Signature Measurements*; NCSL Conference Proceedings, Washington, D.C. (2001).
[2] Song, J.; Whitenton, E.; Kelley, D.; Clary, R.; Ma, L.; Ballou, S.; Ols, M.; *SRM 2460/2461 Standard Bullets and Casings Project*; J. Res. Natl. Inst. Stand. Technol. Vol. 109, pp. 533–542 (2004).
[3] Ma, L.; Song, J.; Whitenton, E.; Zheng, A.; Vorburger, V.; Zhou, J.; *NIST Bullet Signature Measurement System for RM (Reference Material) 8240 Standard Bullets*; J. Forensic Sci., Vol. 49, No. 4, pp. 649–659 (2004).

[4] JCGM 100:2008; *Evaluation of Measurement Data - Guide to the Expression of Uncertainty in Measurement*; (GUM 1995 with Minor Corrections), Joint Committee for Guides in Metrology (JCGM) (2008); available at https://www.bipm.org/en/committees/jc/jcgm/publications (accessed May 2025); see also Taylor, B.N.; Kuyatt, C.E.; *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*; NIST Technical Note 1297, U.S. Government Printing Office: Washington, DC (1994); available at https://www.nist.gov/pml/nist-technical-note-1297 (accessed May 2025).

[5] Beauchamp, C.R.; Camara, J.E.; Carney, J.; Choquette, S.J.; Cole, K.D.; DeRose, P.C.; Duewer, D.L.; Epstein, M.S.; Kline, M.C.; Lippa, K.A.; Lucon, E.; Molloy, J.; Nelson, M.A.; Phinney, K.W.; Polakoski, M.; Possolo, A.; Sander, L.C.; Schiel, J.E.; Sharpless, K.E.; Toman, B.; Winchester, M.R.; Windover, D.; *Metrological Tools for the Reference Materials and Reference Instruments of the NIST Material Measurement Laboratory*; NIST Special Publication (NIST SP) 260-136, 2021 edition; National Institute of Standards and Technology, Gaithersburg, MD (2021); available at https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.260-136-2021.pdf (accessed May 2025).

[6] Website for the NIST Ballistics Toolmark Research Database (NBTRD) available at https://tsapps.nist.gov/NRBTD/Home/SRMBulletCC (accessed May 2025).

[7] ASME B46.1-2019; *Surface Texture (Surface Roughness, Waviness and Lay)*; American Society of Mechanical Engineers, New York (2020).

Certificate Revision History: 28 May 2025 (Change of period of validity; bullet modification note added in Appendix A; updated format; editorial changes); **06 September 2018** (Original certificate date).

Certain commercial equipment, instruments, or materials may be identified in this Certificate to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

Users of this SRM should ensure that the Certificate in their possession is current. This can be accomplished by contacting the Office of Reference Materials 100 Bureau Drive, Stop 2300, Gaithersburg, MD 20899-2300; telephone (301) 975-2200; e-mail srminfo@nist.gov; or the Internet at https://www.nist.gov/srm.

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APPENDIX A

User Guide for NIST SRM 2460a Standard Bullet Replica: For customers using the SRM 2460a bullet to check instrument calibration and measurement quality control of 3D optical instruments for bullet topography signature acquisitions and correlations.

1. **Usage:** The NIST SRM 2460a Standard Bullet Replica is intended for use as a check standard for verifying that bullet topography measurement systems are operating properly. It is up to the user to establish a measurement procedure based on their equipment, laboratory policies and any requirements of their Quality System. However, comparison of observed CCF_{max} and D_s values with the NIST certified values requires that profile data is sampled and processed according to the procedures described in the Certificate. Measurements of the standard bullet should be performed on a routine basis, the frequency of which should again be determined based on laboratory requirements. A control chart should be kept, and measurements/correlations of the standard bullet should be recorded along with lab developed uncertainty or control limits. These must be individually developed, as the equipment used for measurements and the software used for correlations can impact the CCF_{max} and D_s values obtained. Once baseline values have been established with control limits, then these can be monitored routinely for any possible problems in the system. This procedure can help meet the requirements of a quality system which is important for laboratory accreditation.

2. **LEA orientation:** The standard bullet includes six land engraved areas (LEA's) evenly distributed on the surface of the bullet. The bullet has a diameter of 9 mm and resembles a real 9 mm Luger type bullet. Land 1 is indicated by a small dot near the nose of the bullet (see Fig. A2). The lands are numbered 1 through 6 in a counter-clockwise direction, as viewed from the base of the bullet (Fig. A1).

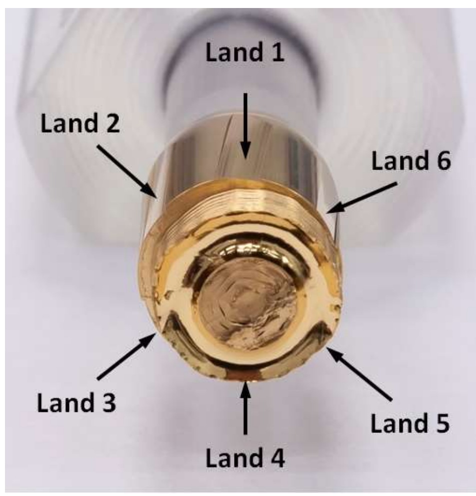

Figure A1. Location of Lands 1 through 6 depicted when looking towards the base of the bullet.

3. **Measurement locations.** All six lands of the 65 standard bullets were measured at NIST using a stylus profilometer. Measurements were performed near the middle of the lands (at 3.5 mm, Fig. A2). To ensure the highest possible correlation results, it is strongly recommended that user measurements be performed in approximately the same location (+/- 1 mm), because the CCF_{max} and D_s values are certified for measurements in that region.

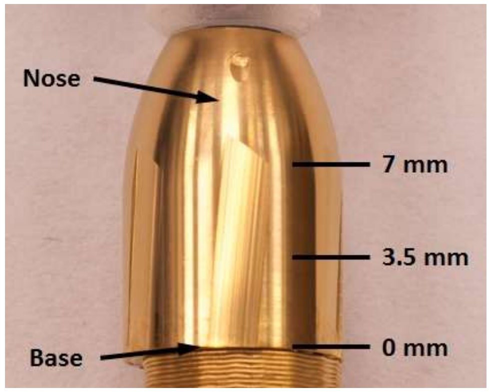

Figure A2. Location of measurements recommended near the middle (3.5 mm) area of lands.

4. **Reference Signature Standards:** The reference signature standards that are used to compare measurements of the 2460a Standard Bullet Replica (see Fig. 2) are available online at the following website: https://tsapps.nist.gov/NRBTD/Home/SRMBulletCC. Note that virtual signatures for the original SRM 2460 *Standard Bullets* are also available at this website. <u>These should not be interchanged</u>. While the SRM 2460a bullets are produced from the original SRM 2460 bullets, and their respective signatures are similar in shape, there are minor differences in the topography of the signatures that will cause significant errors if one attempts to correlate a SRM 2460a measurement with a virtual signature for the SRM 2460 *Standard Bullets*. Therefore, for correlations of SRM 2460a measurements, only use the reference signature standards for SRM 2460a Standard Bullet Replica.

5. **Bullet mounting:** The standard bullet is mounted to a plastic holder. The holder has a 9.6 mm (3/8") hole in the bottom that allows mounting to a rotational stage with a stub or standoff of the same diameter. Alternatively, a three-jaw chuck can be used to secure the plastic holder's three sides.

If the measuring equipment being used requires removal of the bullet from its holder, this can be accomplished as well. The bullet is held in place using an M3 screw, threaded into the nose. Only a small amount of force is required to unscrew the bullet from the holder. This should be done <u>extremely carefully</u>. Using gloves, unscrew the bullet in a counter-clockwise direction from the holder by gripping either the nose or base/stub portion of the bullet. <u>Never</u> touch the LEA's of the bullet as irreversible damage can occur (see Fig. A3).

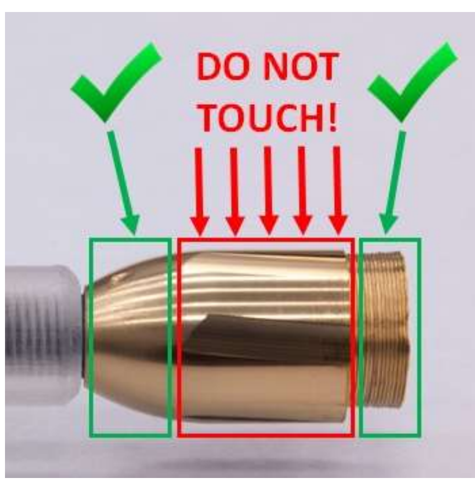

Figure A3. Locations where it's acceptable to handle the bullet with gloves are depicted.

After measurements are completed, re-install the bullet on its holder. Thread the bullet back onto the M3 screw in a clockwise direction. Use only a very small amount of force to secure the bullet in place.

Note: NIST can provide a modification to the standard bullet that improves the ease of installation and alignment in newer style microscope systems. The original holder is replaced by a set of caps that are installed on the nose and base of the bullet. For more information, see the Flyer accompanying this Certificate.

6. **Cleaning Procedure:** Cleaning of the standard bullet should be avoided as much as possible because the cleaning process itself can introduce irreversible changes in the surface topography of the bullet. If contamination is visible on the surface, the suggested cleaning procedure is to use dry, clean, compressed nitrogen to lightly blow any dust or debris off the bullet surfaces. Cleaning using mild detergents should be avoided as this may cause irreversible damage to the bullet signatures.

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APPENDIX B

Preparation and Analysis: The SRM 2460a Standard Bullet Replica was produced using a two-step polymer replication process. Three original SRM 2460 *Standard Bullets* [2] (S/N's 006, 014, 015) were used as masters to produce silicone negative molds. From these, positive replicas were produced from polyurethane. These were then metal coated (using a sputter coating process) with a thin layer of nickel (≈ 10 nm) and then another thin layer of gold (≈ 20 nm). The nickel and gold coatings were added to increase the durability of the bullets and to allow sufficient optical reflection required for optical microscopy.

The reference bullet signature standards were obtained from topographic profiles traced on six master SRM 2460a bullets. To evaluate the uniformity and reproducibility of bullet signatures between SRM 2460a and the reference signatures, the NIST bullet signature measurement system was developed [2,3]. This system includes a stylus instrument to measure the profile signature following procedures in ASME B46.1 [7]. The nominal stylus radius is 1.46 µm. The nominal contact force is 0.001 N with a vertical resolution of 0.8 nm. The lateral sampling interval is 0.125 µm over the evaluation length. Before the comparison of the bullet signatures, a Gaussian filter [7] with a short-wavelength cutoff of 0.0025 mm is used to attenuate the high frequency noise. Then the curvature on the traced signature profile is removed, and a Gaussian filter with a long-wavelength cutoff of 0.25 mm is used to attenuate long surface spatial wavelengths. The Gaussian filter truncates the measured profile across the LEA from a measured length of about 1.8 mm to an evaluation length of about 1.3 mm (1.5 mm for Land 5). Detailed information for the NIST measurement system can be found in references [2,3].

The reference bullet signatures (see Figure 2) are used as reference standards against which the corresponding measured profile signatures of each SRM 2460a bullet are compared. Two parameters are used to express the similarity of two compared profile signatures. One of these is called CCF_{max}. This is the maximum value of the normalized cross-correlation function CCF [2,3] (correlation coefficient), which occurs when the compared bullet signature $Z_{(B)}$ of the SRM bullet and the reference signature standard $Z_{(A)}$, are in phase. At this position, a signature difference profile $Z_{(B-A)}$ is calculated, which equals the difference between signature $Z_{(B)}$ and $Z_{(A)}$.

$$Z_{(B-A)} = Z_{(B)} - Z_{(A)} \tag{1}$$

The second parameter, the signature difference, D_s [2, 3], is defined as a ratio of the mean-square roughness Rq^2 [7] of the signature difference profile $Z_{(B-A)}$ and the mean-square roughness of the reference signature standard $Z_{(A)}$:

$$D_s = Rq^2_{(B-A)} / Rq^2_{(A)} \tag{2}$$

The CCF_{max} is given as:

$$CCF_{\max} = \frac{\sum_n (Z_{(A),n} - \overline{Z_{(A)}}) \cdot (Z_{(B),n} - \overline{Z_{(B)}})}{\left[\sum_n (Z_{(A),n} - \overline{Z_{(A)}})^2 \cdot \sum_n (Z_{(B),n} - \overline{Z_{(B)}})^2\right]^{\frac{1}{2}}} \tag{3}$$

where the summations and averages $\overline{Z_{(A)}}$ and $\overline{Z_{(B)}}$ are calculated for the overlapping profile segments. When the measured signature $Z_{(B)}$ is exactly the same as the virtual signature standard $Z_{(A)}$ (point by point), CCF_{max} is equal to 100 %, and D_s is equal to 0 %. Both parameters are given here because the value of CCF_{max} is not sensitive to a difference in height scale between two profiles whereas the value of D_s is sensitive to a scale difference.

The six bullet signatures of each SRM 2460a bullet were measured by the signature measurement system and correlated with the reference signature standards.

The CCF_{max} and D_s values from the measurements of the six LEAs of all 65 SRM 2460a bullets were statistically analyzed and a specific control limit for each LEA was developed. This includes any significant sources of measurement uncertainty and is reported with a confidence level of 95 % [4]. This means that for every SRM 2460a, each LEA has a CCF_{max} value that exceeds the respective control limit with 95 % confidence, and a D_s value that is lower than the respective control limit with 95 % confidence. Table 1 gives a summary of the CCF_{max} and D_s control limits for each LEA.

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