OSAC 2024-S-0014
Best Practice Recommendation for Muzzle to Witness Panel Distance Measurement and Estimation of Uncertainty

Firearms & Toolmarks Subcommittee
Physics/Pattern Interpretation Scientific Area Committee
Organization of Scientific Area Committees (OSAC) for Forensic Science

DRAFT OSAC Proposed Standard

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Keywords: *measurand, readings, measurement, distance determination, uncertainty of measurement, muzzle to witness panel, witness panel, gunshot residue*

Foreword

This best practice recommendation describes procedures for measuring the distance of the muzzle of a firearm to the witness panel and for estimating the uncertainty associated with those distance measurements. Estimation of uncertainty is achieved through a process study of repeated measurements over multiple days by all laboratory personnel responsible for muzzle to witness panel distance measurements. Annex A provides an example illustrating muzzle to witness panel measurement data, components of uncertainty, and calculations for estimating muzzle to witness panel uncertainty of measurement.

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Best Practice Recommendation for
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1 Scope

This document provides procedures for measuring the distance from the muzzle of a firearm to witness panels and for estimating the measurement uncertainty associated with those measurements.

2 Normative References

2.1 *Best Practice Recommendations for the Safe Handling of Firearms and Ammunition [16].*

2.2 *Standard Test Method for the Forensic Examination and Testing of Firearms [17]*

2.3 *Standard Test Method for Muzzle-to-Garment Distance Determination (or Gunshot Residue Distance Determinations) [REF]*

3 Terms and Definitions

For purposes of this document, the following definitions apply.

3.1
measurand
Quantity intended to be measured [12, 14]

NOTE For the purpose of this document, the measurand is the distance from the muzzle of the firearm to the witness panel measured along the axis of the bore.

3.2
witness panel (target)
Any one of a variety of substrates positioned and mounted to record gun powder deposition and/or shot patterns.

NOTE For the purposes of this document, witness panel and target may be used interchangeably.

3.3
terms specific to firearms
Other terms specific to firearms, such as muzzle, bore and barrel are described in Association of Firearm & Tool Mark Examiners (AFTE) *Glossary* [6] and the Sporting Arms and Ammunition Manufacturers' Institute (SAAMI) Glossary [10].

4 Recommendations

4.1 Background

This document details procedures for measuring the distance from the muzzle of a firearm to witness panels and for estimating the uncertainty of measurement. Witness panels serve as gunshot pattern distance exemplars for comparison purposes when conducting muzzle to target distance determination.

4.2 General

4.2.1 When handling a firearm, safety is paramount. The examiner shall verify that the firearm is unloaded prior to conducting a distance measurement. Always verify that the firearm is handled safely according to 2.1.

4.2.2 When producing witness panels for distance determination, ensure that the firearm is hand-held or secured in a fixture so that the firearm is stable, free from extraneous movement and in an area with proper lighting.

4.2.3 The examiner shall ensure that the distance measurement device has a current calibration certificate that provides traceability to the International System of Units (SI) unit of length through a laboratory accredited to perform the calibration.

4.3 Setup

4.3.1 General

Common methods used to generate setup distance witness panels include, but are not limited to, portable firearm securing devices, fixed devices for remote shooting and hand holding using a standard shooter position. The setups differ depending on the equipment and firing range. Setup recommendations common to all methods are described in Sections 4.3.2 through 4.3.5.

4.3.2 Portable or Fixed Shooting Rests

The firearm is secured in the device as prescribed by the manufacturer with the barrel positioned horizontally.

4.3.3 Hand Held

The firearm is held using a two-handed hold with the barrel positioned horizontally.

4.3.4 Witness Panel Placement

The witness panel should be secured vertically using laboratory equipment which will prevent extraneous movement. The witness panel is positioned perpendicular to the bore axis of the firearm and at the predetermined distance from the muzzle of the firearm.

NOTE: Section 4.6.10 provides additional guidance for casework involving angled shots.

4.3.5 Measurement

When measuring the distance from the muzzle of a firearm to the witness panel, the measurement device identified by the laboratory's distance determination protocol shall be used.

4.4 Process Study for Estimation of Uncertainty

4.4.1 A laboratory's uncertainty of measurement for the distance from the muzzle of a firearm to a witness panel should be estimated with data from a process study of repeated measurements. The repeated measurements should be conducted by all individuals responsible for measuring muzzle to witness panel distances during casework. These repeated measurements should be obtained over several days to account for operator fatigue and environmental variations.

4.4.2 The firearm(s) chosen for the process study should represent a type(s) routinely submitted to the laboratory for distance determination. The material of the witness panel is not a variable that needs to be controlled in this study. The process study should be performed in accordance with the procedures outlined in 4.3.2 through 4.3.5 and the laboratory's standard operating procedures (SOPs), using the same equipment for securing the firearm and witness panels.

4.4.3 A minimum of three muzzle-to-witness panel measurements should be obtained by each participant for each selected distance.

4.4.4 The selected setup distances to be measured should be spaced to cover the range of distances typically encountered in casework (e.g., 6", 18", 36", 54", 72"). The order of the distances to be measured should be randomized.

NOTE Ensure that the maximum distance reflects the maximum distance regularly encountered in casework. For casework involving an extended distance, an abbreviated process study may be performed. Refer to Section 4.6.8.

4.4.5 Study protocol for a firearm secured in a firearm rest:

4.4.5.1 A witness panel is placed at a desired nominal distance from the firearm's muzzle, preferably by a person who will not participate in the process study.

4.4.5.2 All process study participants should obtain at least three muzzle to witness panel distance measurements. The participant should be changed after each measurement.

4.4.5.3 After all measurements have been completed, the witness panel or firearm rest is moved to the next distance.

4.4.6 Study protocol for a hand-held firearm setup:

4.4.6.1 A process study participant positions and holds the firearm muzzle at the desired setup distance to the witness panel. This process typically requires usage of the measurement device.

4.4.6.2 A different process study participant measures the distance from the firearm muzzle to the witness panel.

4.4.6.3 Steps 4.4.6.1 and 4.4.6.2 are repeated with participants alternating between holding the firearm and taking the measurements until each study participant has obtained at least three measurement values for the desired setup distance.

4.4.7 An example for the process study is shown below. This example is based on a laboratory with five staff members who conduct muzzle to witness panel measurements in casework.

(1 firearm) x (5 participants) x (5 distances evaluated, e.g., 6”, 18”, 36”, 54”, 72”) x (3 repeated measurements) = 75 measurements.

NOTE: For laboratories with fewer participants, the number of repeated measurements should be increased

4.5 Calculations for the Estimation of Uncertainty

4.5.1 The “Blank Measurement Uncertainty Estimation” Template[7] should be used to estimate uncertainty of measurement. Example spreadsheets of simulated data and analyses for a process study to establish measurement uncertainty are available via Annex A.

4.5.2 The laboratory should identify and estimate uncertainty components that may significantly affect the uncertainty of measurement. There are two categories of uncertainties. Type A uncertainty components are those that are evaluated by the statistical analysis of a series of observations (e.g., process study data). Type B uncertainty components are those that are evaluated by means other than the statistical analysis of a series of observations [11].

4.5.2.1 Common uncertainty components included in Type A evaluation:

- Use, storage and handling of measurement device
- Multiple participants, to include positioning of measuring equipment and visual acuity
- Training and experience
- Time factors such as day and week, workload and interruptions
- Lighting and space
- Capability of participant to hold firearm steady
- Position/alignment of the measurement device with barrel and witness panel
- Manner by which a firearm is secured/positioned
- Movement of the witness panel
- Angle of the shot [Shot accuracy (aim)]

4.5.2.2 Common uncertainty components included in Type B evaluation:

- Measurement device increments and readability
- Measurement device calibration uncertainty
- Thermal expansion and other environmental effects

4.5.3 The uncertainty components are expressed as standard uncertainties that are pooled into a combined standard uncertainty. A divisor is used to convert the value of an uncertainty component into a standard uncertainty. The values of these divisors vary:

4.5.3.1 For a rectangular error distribution where the uncertainty component is represented as a +/- specification (e.g., +/- 0.0625 inches), the divisor is the square root of three.

4.5.3.2 For a rectangular error distribution where the uncertainty component is represented as a range of specifications (e.g., 0.0325 inches -0.0624 inches), the divisor is twice the square root of three.

4.5.3.3 If the expanded uncertainty of measurement is provided by a calibration laboratory with a coverage factor *k*, the divisor is *k*.

4.5.3.4 For the standard deviation from the process study, the divisor is one.

4.5.4 Measurement process repeatability

This uncertainty component describes the uncertainty resulting from variations in the measurement process. This Type A uncertainty component is estimated as follows from the process study data described in 4.4:

4.5.4.1 Calculate the standard deviation of the measurement values at each setup distance.

4.5.4.2 Identify the setup distance with the highest standard deviation. This standard deviation is the estimated standard uncertainty for process repeatability. The associated number of degrees of freedom equals the number of distance measurements performed at that setup distance minus one.

4.5.4.3 The variations in measurements from the process study are assumed to be consistent with a normal distribution.

4.5.5 Length Scale Readability

The length scale readability component describes the uncertainty due to the limited resolution of the measurement system. It is determined by the smallest change ΔL in measurement value that can be observed. To evaluate the respective standard uncertainty, we assume that the resulting length measurement error can take any value in the interval $\pm 0.5\,\Delta L$ with equal probability. For this rectangular distribution, the respective standard uncertainty is obtained by dividing the width of the distribution, ΔL by $\sqrt{12}$.

4.5.6 Measuring Scale Calibration Uncertainty

The measuring scale calibration uncertainty describes the uncertainty due to errors in the length measuring device or scale. The uncertainty can be obtained from the calibration report of the device. Often, the uncertainty is reported as +/- an expanded uncertainty. The standard uncertainty is obtained by dividing this expanded uncertainty by the respective coverage factor k, which is often specified in the calibration report. Typical values for k are 2 and 3 for levels of confidence of ~95% and ~99%, respectively, assuming a normal distribution.

Standard uncertainty = reported certificate expanded uncertainty/k

NOTE Convert the expanded uncertainty on the certificate to the same unit as the measured value.

4.5.7 Ruler Scale Error

The ruler scale error is the difference between the ruler nominal value and the calibrated value on the calibration certificate. Assuming a rectangular distribution of the ruler scale error, with a half width equal to the maximum observed error, the respective standard uncertainty is obtained by dividing the maximum error by $\sqrt{3}$.

NOTE Scale calibration uncertainty and ruler scale error may be reported as one value on the calibration certificate.

4.5.8 Thermal Expansion

The accuracy of a length measurement device, e.g. a tape measure, is usually defined at a reference temperature of 68 °F. If measurements are performed at a different temperature, small errors may occur due to the thermal expansion of the measurement device scale. To illustrate this error, we assume the following example conditions.

- a stainless-steel measuring scale with a coefficient of thermal expansion of 9.6×10^{-6} per °F
- a muzzle to witness panel distance of 54 inches
- a temperature anywhere between 32 °F and 72 °F

Under these conditions, the maximum error in length measurement due to thermal expansion equals (9.6×10^{-6} per °F) × (4 °F) × (54 inches) = 0.0020736 inches. Assuming a rectangular distribution for the temperature, we obtain the standard uncertainty as 2 × 0.0020736 inches × $1/\sqrt{12}$ = 0.001199 inches

4.5.9 Combined Standard Uncertainty

The combined standard uncertainty of the measurement value is obtained as the square root of the sum of the squared standard uncertainties. This formula assumes that the uncertainty components are independent of each other, and that the measurement error is the sum of the component errors.

$$u_c = \sqrt{u_{process}^2 + u_{readability}^2 + u_{calibration}^2 + u_{thermal\ expansion}^2}$$

- u_c: the combined standard uncertainty
- $u_{process}$: measurement process repeatability; the largest standard deviation calculated from the process study repeatability data
- $u_{readability}$: standard uncertainty due to length scale readability
- $u_{calibration}$: standard uncertainty of the measurement device calibration
- $u_{thermal\ expansion}$: standard uncertainty due to thermal expansion of the measurement scale (this is often negligible, but should be included)

4.5.10 Expanded Uncertainty

The expanded uncertainty defines an interval about the measurement result that may be expected to encompass a large fraction of the values that could reasonably be attributed to the measurand[11]. In order to determine the expanded uncertainty, the combined standard uncertainty is multiplied by the coverage factor (*k*). The coverage factor is dependent upon the number of degrees of freedom associated with the Type A uncertainties. The coverage factor can be determined by specifying a level of confidence, typically 95%, that the true value lies within the uncertainty limits. Table G.1 [13] (*t*-distribution and degrees of freedom) may be used to determine the coverage factor from the degrees of freedom and the specified level of confidence.

The result of the measurement is expressed as the measurement value +/- U, where U equals the expanded uncertainty:

$$U = u_c \times k$$

u_c: combined standard uncertainty

k: coverage factor (k = 1 ~ 68% level of confidence; k = 2 ~ 95% level of confidence k = 3 ~ 99% level of confidence)

4.6 Process Study Special Considerations

4.6.1 If a laboratory utilizes more than one type of measurement device, a separate process study and uncertainty analysis should be conducted for each measurement device.

4.6.2 If a laboratory utilizes more than one measurement device of the same manufacturer/model, the uncertainty of measurements may be estimated using data from one device. However, for the measuring scale calibration uncertainty, the calibration certificate of the utilized measurement device should be used.

4.6.3 For forensic organizations that have multiple laboratory locations, the process study and uncertainty analysis described in 4.4.1 through 4.4.6 should be performed by participants at each laboratory location using the measurement device utilized at that location. Each laboratory location should estimate the measurement uncertainty independently of the others. The highest expanded uncertainty for all devices may be used when the same manufacturer/model of measurement device and the same procedures are used by all laboratory locations.

4.6.4 The process study and data evaluation described in Sections 4.4 and 4.5 should be repeated when a change occurs in the laboratory procedure, such as the acquisition of a new measurement device.

4.6.5 If new laboratory personnel responsible for measuring and reporting muzzle to witness panel measurements are hired by the laboratory, the process study should be repeated by the new participants, their data combined with the data from all other participants, and the uncertainty of measurement re-estimated.

4.6.6 If a participant responsible for measuring and reporting muzzle to witness panel measurements no longer performs distance determinations, their data should be removed from the combined laboratory data and the uncertainty of measurement re-estimated.

4.6.7 For a casework scenario where the muzzle to witness panel distance falls outside the range of distances from which the uncertainty of measurements was estimated, an abbreviated process study as described in 4.6.8 should be performed and the uncertainty of measurement should be estimated for the casework firearm.

4.6.8 For the abbreviated process study, the same number of muzzle to witness panel measurements should be obtained as in the process study at each setup distance that falls outside the range of distances from which the uncertainty of measurements was estimated. Measurements shall be performed by the laboratory personnel assigned to the case using the evidence firearm. An uncertainty of measurement should be estimated from these data.

4.6.9 For a laboratory standard operating procedure that allows for both hand-held and secured firearm setups, the laboratory shall conduct a separate process study and uncertainty estimation for each setup type.

4.6.10 For casework involving angled shots, a protractor or similar device may be used to position the witness panel at a predetermined angle to the bore axis of the firearm. A mark should be placed on the witness panel at the intersection of the bore axis with the witness panel to indicate the point of aim. After each shot, the distance from the firearm muzzle to the point of impact on the witness panel shall be measured. Measurements shall be performed by the laboratory personnel assigned to the case using the evidence firearm. The predetermined angle, the measured distance, and the corresponding uncertainty of measurement from the process study shall be recorded.

5 Records

The laboratory should maintain the following records for each estimation of uncertainty for distance determination:

a) Statement defining the measurand;

b) Statement of how traceability is established for the measurement;

c) The equipment (e.g. measurement device used);

d) All uncertainty components considered;

e) All uncertainty components of significance and how they were evaluated;

f) Data used to estimate repeatability, intermediate precision, and/or reproducibility;

g) All calculations performed; and

h) The combined standard uncertainty derived from the process study

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Annex A

(informative)

Example Spreadsheets for Estimating Uncertainty of Measurement for Muzzle to Witness Panel Distance

A.1 General

Spreadsheets, located at [url to be determined], provide example data, calculations, and component estimates for a process study to estimate uncertainty of muzzle to witness panel distance. Because errors can find their way into such documents when data are added or substituted, users must verify for themselves that the numerical formulas do not contain omissions or errors and that the calculated results are accurate.

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Annex B

(informative)

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