Procedure for Estimating Measurement Uncertainty

1.0 Purpose – To describe the methods used for estimating the uncertainty for barrel and overall length measurements performed by the Firearms Unit of the Physical Evidence Section.

2.0 Scope – This procedure will apply to any case involving a long gun that has had its barrel and/or stock shortened that is submitted to the Firearms Units located at the Raleigh Laboratory and the Western Regional Laboratory.

3.0 Definitions

- **Coverage probability** – The probability that the set of true quantity values of a measurand is contained within a specified coverage interval.
- **Measurand** – The unknown quantity subject to measurement.
- **Measurement** – A process of experimentally obtaining one or more quantity values, typically of physical, chemical, or biological nature. Implies comparison of quantities.
- **Standard deviation –** A statistic used as a measure of the dispersion or variation in a frequency distribution, equal to the square root of the arithmetic mean of the squares of the deviations from the arithmetic mean.
- **Standard uncertainty** – Measurement uncertainty expressed as a standard deviation.
- **Uncertainty of measurement** – A parameter associated with the result of a measurement that characterizes the distribution of values that may reasonably be attributed to that being measured. Sources contributing to the uncertainty include, but are not necessarily limited to, the reference standards and reference materials used, methods and equipment used, environmental conditions, properties and condition of the item being tested or calibrated, and the operator.

4.0 Equipment, Materials, and Reagents

- Digital Measuring Devices (DMD-48s)
- Hott-Rods™
- NIST-traceable 36” Rulers (rulers)
- Reference Collection Firearms

5.0 Procedure

5.1 The Firearms Unit shall estimate the uncertainty of measurement for barrel and overall firearm length measurements.

5.2 Traceability is established for these measurements through the calibration of the DMD-48s, Hott-Rods™, and rulers used to make the measurement.

5.3 This procedure describes the reproducibility study and follows the NIST 8-Step Process for Estimating and Reporting Measurement Uncertainty.

5.4 Reproducibility Study

5.4.1 The reproducibility study for the estimation of measurement uncertainty for barrel and overall length measurements consists of six (6) firearms taken from the Firearm Reference Collection.

5.4.1.1 These firearms are:

- FA 6931, Riverside Arms, 16 Gauge, single barrel shotgun, Serial Number SM211, Model Single Shot (Gun A)
- FA 5500, NR Davis & Sons, 20 Gauge, double barrel shotgun, Serial Number 19032, Model Ajax (Gun B)
- FA 952, Harrington & Richardson, 20 Gauge, single barrel shotgun, Serial Number A6252413, Model Topper 158 (Gun C)
- FA 3468, Remington, 12 Gauge, pump action shotgun, Serial Number W960694M, Model 870 Express (Gun D)
- FA 7062, Marlin, 410 Gauge, single barrel shotgun, Serial Number KN113366, Model 200 (Gun E)
- FA 5596, Remington, 12 Gauge, pump action shotgun, Serial Number B699441M, Model 870 Express (Gun F)

5.4.1.2 Each of the six firearms have shortened barrels: Guns A and B have barrel lengths below the legal limit of 18 inches, Guns C and D have barrel lengths near the legal limit, and Guns E and F have barrel lengths above the legal limit.

5.4.1.3 Each Forensic Scientist, including trainees, in the Firearms Units of the Raleigh Laboratory and the Western Regional Laboratory shall measure the barrel and overall lengths of two firearms each month of the study using the DMD-48, Hott-Rods™, and rulers. The Forensic Scientists in the Western Regional Laboratory shall use their own measuring instruments for the study.

5.4.1.4 Excel spreadsheets for each measurement process shall contain the appropriate Uncertainty Budget and the data compiled from the reproducibility study.

5.4.1.5 The estimation of measurement uncertainty shall be evaluated as part of the annual Management Review and updated or revised as needed. New study data shall be obtained and incorporated into the Uncertainty Budgets every five (5) years or when the Crime Laboratory (including both the Raleigh and Western Labs) undergoes a 25 % turnover of Firearms Forensic Scientists, whichever is sooner.

Note: This reproducibility study was originally performed from June 2012 to February 2013.

5.5 NIST 8-Step Process for Estimating and Reporting Measurement Uncertainty

5.5.1 Step 1: Specify the measurement process

5.5.1.1 Measurement uncertainty shall be estimated for barrel length measurements using the DMD-48s and Hott-Rods™ and for overall length measurements using the DMD-48s and 36" rulers.

5.5.1.1.1 Barrel and overall lengths shall be measured according the Firearms Unit Technical Procedure for Firearm Examination.

5.5.1.2 The range of measurement for the DMD-48s is up to ~39.5 inches, for the Hott-Rods™ is up to 24 inches, and for the rulers is up to 36 inches.

5.5.2 Step 2: Identify uncertainty components

5.5.2.1 In order to estimate uncertainty for barrel and overall length measurements, many factors must be taken into consideration. These factors include, but are not limited to, the following:

5.5.2.1.1 Measuring Instrumentation

- Instrument resolution
- Length scale readability at zero (for rulers)
- Multiple instruments of the same type
- Calibration uncertainty
- Calibrated scale error
- Coefficient of expansion of the measuring instruments
- Proper use, storage and handling

5.5.2.1.2 Forensic Scientists

- Multiple analysts
- Training
- Experience
- Visual acuity
- Time of day, day of week, interruptions, workload

5.5.2.1.3 Test Method

- The same test method is used to measure the length of all types of firearms
- Analysts may differ in establishing parallel and perpendicular with respect to a firearm
- Using rulers, the analyst must position measuring instrument at both the zero point at the butt end of the firearm and at the end of the muzzle

5.5.2.1.4 Facility

- Temperature variation inside the laboratories
- Lighting
- Space

5.5.2.1.5 Environment

- Variations in outside temperature, humidity, altitude, etc.

5.5.3 Step 3: Quantify uncertainty components

5.5.3.1 Each of the potential sources of uncertainty above was assessed and determined to be either a Type A or Type B evaluation of uncertainty.

5.5.3.1.1 Type A evaluations involve the statistical analysis of series of observations (i.e., uncertainty inherently present in the collection of data from a reproducibility study).

5.5.3.1.2 Type B evaluations involve means other than statistical analysis of series of observations.

Uncertainty Component	Method of Evaluation
Measuring Instrumentation	
Instrument resolution	Type B
Length scale readability at zero (for rulers)	Type B
Multiple instruments of the same type	Type A – covered in reproducibility data
Calibration uncertainty	Type B
Calibrated scale error	Type B
Coefficient of expansion of instruments	Type A – covered in reproducibility data
Proper use, storage and handling	Type A – covered in reproducibility data
Forensic Scientists	
Multiple analysts	Type A – covered in reproducibility data
Training	Type A – covered in reproducibility data
Experience	Type A – covered in reproducibility data
Visual acuity	Type A – covered in reproducibility data
Time of day, day of week, interruptions, workload	Type A – covered in reproducibility data
Test Method	
Same test method used to measure all firearms	Type A – covered in reproducibility data
Differences in establishing parallel and perpendicular	Type A – covered in reproducibility data
Analyst positioning of measuring instrument	Type A – covered in reproducibility data
Facility	
Temperature variation inside the laboratories	Type A – covered in reproducibility data
Lighting	Type A – covered in reproducibility data
Space	Type A – covered in reproducibility data
Environment	

Variations in outside temperature, humidity, altitude, etc.	Type A – covered in reproducibility data

5.5.3.2 The reproducibility study data represents uncertainty components with Type A evaluations. The data has a normal distribution and is quantified using the standard deviation.

5.5.3.3 Uncertainty components with Type B evaluations are quantified using parameters of the instruments, such as readability, and certificates of calibration obtained for the instruments. Each uncertainty budget contains details specific to its measurement process regarding the source of this information.

5.5.4 Step 4: Convert quantities to standard uncertainties

5.5.4.1 Standard uncertainty for each component is expressed as one standard deviation.

5.5.4.2 Type A component

5.5.4.2.1 For each measurement process (e.g., overall length using a ruler), the standard deviation shall be calculated for each firearm measured. The largest standard deviation shall be used as the standard uncertainty for this component.

5.5.4.3 Type B components

5.5.4.3.1 For the reported calibration uncertainty of the measuring instrument, the calibration certificate shall be consulted to determine the divisor (e.g., for reported uncertainties that were provided by the external calibration laboratory using a coverage factor of k=2, the divisor used to calculate the standard uncertainty shall be 2).

5.5.4.3.2 For each Type B component with a rectangular distribution, a divisor of $\sqrt{3}$ shall be used to calculate the standard uncertainty.

5.5.5 Step 5: Calculate the combined standard uncertainty

5.5.5.1 The combined standard uncertainty shall be calculated by taking the square root of the sum of each standard uncertainty squared:

$$u_c = \sqrt{u_1^2 + u_2^2 + \ldots + u_i^2}$$

5.5.6 Step 6: Expand the combined standard uncertainty by coverage factor (k)

5.5.6.1 The combined standard uncertainty, calculated in Step 5, is an estimated standard deviation and characterizes the dispersion of the values that could reasonably be attributed to the measurement result at the equivalent of one standard deviation, a coverage probability of 68.26 %.

5.5.6.2 The Firearm and Tool Section shall use a coverage factor of k=3, which represents a coverage probability of 99.73 %.

5.5.6.3 Therefore, the expanded combined standard uncertainty shall be calculated by multiplying the combined standard uncertainty by 3.

5.5.7 Step 7: Evaluate the expanded uncertainty

5.5.7.1 The expanded uncertainty shall be evaluated to determine the presence of any calculation errors, if the results are appropriate for the test method, and if the expanded uncertainty meets the customer's needs.

5.5.7.2 If the expanded uncertainty is not determined to be acceptable, areas of method improvement, including, but not limited to, measurement method standardization, improved calibration of instrumentation, and increased readability of the measuring instrument, can be identified and evaluated for the impact that a change would have on the estimation of uncertainty using the information available from Steps 3 and 4.

5.5.7.3 Any changes to a test method, once validated, may lead to appropriate edits to Steps 1-6 and the reevaluation of the estimation of uncertainty.

5.5.8 Step 8: Report the uncertainty

5.5.8.1 The expanded uncertainty shall be rounded to two significant figures for the DMD-48s as those instruments give a decimal measurement. For the Hott-Rods™ and rulers, the expanded uncertainty shall be rounded to two significant figures before conversion to a fraction. The fraction reported shall be the nearest greater $1/32^{nd}$ inch scale mark.

5.5.8.2 Rounding the expanded uncertainty shall be accomplished by the following method:

5.5.8.2.1 If the third decimal place (thousandth place) is a 0, the second decimal place (hundredth place) shall not change. For example, 0.260″ would round to 0.26″.

5.5.8.2.2 If the third decimal place is any other digit, the second decimal place shall round up. For example, 0.261″ would round to 0.27″.

5.5.8.3 The reported measurement result shall include the measured quantity value, y, along with the associated expanded uncertainty, U, and this measurement result shall be reported as $y \pm U$ where U is consistent with the units of y (see Firearms Unit Technical Procedure for Firearm Examination for specific examples of report wording).

6.0 Limitations – N/A

7.0 Safety – N/A

8.0 References

ASCLD/LAB Guidance on the Estimation of Measurement Uncertainty – ANNEX C, Firearms/Toolmarks Discipline Firearms Category of Testing Example – Overall Length of a Firearm, Version 1.

9.0 Records

- Uncertainty Budget for Barrel Length using the DMD-48
- Uncertainty Budget for Barrel Length using Hott-Rods™
- Uncertainty Budget for Overall Length using the DMD-48
- Uncertainty Budget for Overall Length using NIST-traceable Rulers
- Calibration Certificates for the DMD-48s, Hott-Rods™, and Rulers

10.0 Attachments – N/A

Revision History		
Effective Date	Version Number	Reason
03/14/2014	1	Original Document
09/05/2014	2	**1.0, 2.0, 5.1, 5.4.1.3, 5.4.1.5, 5.5.1.1.1, 5.5.8.3** – changed to reflect organizational change