SDPD Forensic Science Section
Forensic Chemistry – Uncertainty of Measurement for Denver Instrument S-403 Precision Balances

Introduction

The Forensic Chemistry Unit performs forensic drug analysis on samples impounded at the San Diego Police Department. Part of the analytical process is the determination of the net or gross weights of individual items of evidence. The net weight of evidence is of particular concern when it is specifically addressed in legislation.

It is standard practice to obtain, record, and report weights to 2-decimal places for most forensic drug samples. The Forensic Chemistry Unit currently utilizes six top-loading precision balances, Denver Instrument model S-403, for obtaining gross and net weights during standard forensic drug analysis. Individual balances are assigned to each of the five Criminalists employed in the unit. A sixth balance is currently unassigned and housed at a mutual-use laboratory bench. All balances have been calibrated to their positions in the laboratory, and all Criminalists are competent in the use of these balances.

Forensic Chemistry unit personnel conducted a study to establish an encompassing uncertainty of measurement determination for the use of these balances in standard forensic drug analyses, and to incorporate the uncertainty of measurement of these balances in the reporting of weights for forensic samples.

Method

In order to establish measurement uncertainty for the balances, the following contributing factors were evaluated:

- **Sensitivity to drift:** The ability of the balance to measure accurately with temperature change. This value is relevant with micro-balances and will not be included in the overall uncertainty of measurement calculation.

- **Readability:** The incremental changes the balance will display. This was defined as the 3-decimal place value the balance is capable of reading. For this study, each balance was set to report weights to 3-decimal places, although it is standard procedure to report a readability of 2-decimal places for forensic case samples.

- **Repeatability:** The ability of the balances to consistently deliver the same reading of a known object. This measurement was established using the standard deviation of repeated measurements of NIST-traceable weights, including: ten replicates of each 0.010 g, 1.000 g, 10.000 g, 50.000 g, and 100.000 g; and 20 replicates of each 0.020 g, 2.000 g, and 20.000 g. The maximum standard deviation from all of the weights on all the balances was used in the uncertainty of measurement calculations.

- **Linearity:** The ability of the balance to measure weights accurately throughout its capacity range. The weighing capacity of the model S-403 balance is 400 g; however, the drug items received by the San Diego Police Department Crime Laboratory are typically less than 200 grams. Four different combined-weight totals were evaluated, including ten replicates of each: 0.050 g (0.020 g, 0.020 g, 0.010 g weights combined), 5.000 g (2.000 g, 2.000 g, 1.000 g weights combined), 40.000 g (two 20.000 g weights combined), and 200.000 g (100.000 g, 50.000 g, 20.000 g, 20.000 g, 10.000 g weights combined). The sum of the individual weights was evaluated against the combined-weight totals. The maximum difference between these two measurements for all balances was used in the uncertainty of measurement calculations.

- **Analyst Variability:** Each Criminalist evaluated their assigned balance and performed part of the evaluation of the mutual-use balance. Measurements were taken twice per day, over the course of 5 days, not necessarily consecutive, using NIST traceable weights. Criminalists placed the weights in different positions on the weighing pan, and recorded individual weight values and combined-weight values.

Results

Analysts recorded their results on worksheets which contained information on the date and time of the measurements, placement of the weights on the weigh pan, and target values and measured values of the weights. See Appendix 1 for the worksheet these results.

The mean and standard deviations of weight values were calculated for individual and combination-weights for each balance. The absolute value difference between the expected results and the actual results of the combined –weights and the average and maximum differences of those results were calculated for each balance. See Appendix 2 for these calculations.

Conclusions

The specifications set forth by the manufacturer for the S-403 precision balance are listed below.

Weighing Capacity	**400 g**
Readability	**0.001 g**
Repeatability	**0.001 g**
Linearity	**0.002 g**

The Uncertainty Budget Table summarizes the maximum calculated results of repeatability and linearity from all the balances in our study. Readability was established from manufacture specifications and the decimal-place readings of weight values in our study.

Uncertainty Budget Table

Factors	Value (x)	Standard Uncertainty (u)	Distribution	Relative Contribution
Readability[1]	0.001	$\frac{x/2}{\sqrt{3}} = 0.00029$ g	Rectangular	8.56%
Repeatability[2]	0.0017	0.0017 g	Normal	50.14%
Linearity[3]	0.005	$\frac{x/2}{\sqrt{3}} = 0.0014$	Rectangular	41.30%

[1]*Manufacturer's literature*
[2]*Maximum Standard deviation*
[3]*Maximun difference between sum of individual weights and combined-weight totals*

The maximum calculated repeatability and linearity measurements from our study and manufacturer specified readability were incorporated in the calculation of combined standard uncertainty. Expanded uncertainties were calculated for both the 95% and 99.7% confidence intervals.

Combined Standard Uncertainty:

$$U_c = \sqrt{u(readability)^2 + u(repeatability)^2 + u(linearity)^2}$$

$$U_c = \sqrt{(0.00029)^2 + (0.0017)^2 + (0.0014)^2} = \mathbf{0.0022\ g}$$

Expanded Uncertainty:

$$U = k * u_c$$

Where U is the expanded uncertainty and k is the coverage factor.

Approximate 95% where k= 2 +/- 0.0044 g
Approximate 99.7% where k= 3 +/- 0.0066 g

SDPD Forensic Science Section
Forensic Chemistry – Uncertainty of Measurement for Denver Instrument S-403 Precision Balances

A single combined standard uncertainty of measurement was calculated to encompass the maximum uncertainty of all the Denver Instrument model S-403 top-loading precision balances used in the Forensic Chemistry unit. The combined standard uncertainty and the expanded uncertainties demonstrate that the variation in measurement occurs within the third decimal place. Standard measurement results for casework in the Forensic Chemistry Unit are reported to 2-decimal places. The balances display a 2-decimal place result as a truncated value of the 3-decimal place result. Therefore, the expanded uncertainty cannot be incorporated directly into the measured result.

Integrating the uncertainty of measurement at the 99.7% confidence interval into our 2-decimal place reported results creates a maximum uncertainty of +/- 0.01g. Specifically, the addition of the uncertainty of measurement at a 99.7% confidence interval to a third-decimal place result between 4 and 9 produces a result increasing the 2-decimal result by 0.01g. Accordingly, the subtraction of this uncertainty from a third-decimal place result between 0 and 6 produces a result decreasing the 2-decimal measurement by 0.01g. Measurements utilizing the S-403 top-loading precision balances will be reported to 2-decimal places in casework notes and reports. A statement of the effect of the expanded uncertainty at the 99.7% confidence interval on results will be incorporated into the report.

The combined standard uncertainty and the expanded uncertainty were calculated from measurements taken from individual analysts and specified balances. New analysts introduced into the Forensic Chemistry unit will complete a set of analogous measurements, with a resulting calculation of repeatability and linearity. Similarly, repeatability and linearity will be established on new balances introduced into the Forensic Chemistry unit, and on current balances receiving service or parts affecting its weighing ability. A new combined uncertainty of measurement will be calculated only when the results of new analysts, new balances, or repaired balances expand the currently defined parameters.

Technical Review _____ Date 1-12-12

Administrative Review _____ Date 1/12/12

Quality Assurance Manager _____ Date 1/12/12