Appendix C

NIST Technical Communications Program

APPENDIX E

STATEMENTS OF UNCERTAINTY ASSOCIATED WITH MEASUREMENT RESULTS

A measurement result is complete only when accompanied by a quantitative statement of its uncertainty. This policy requires that NIST measurement results be accompanied by such statements and that a uniform approach to expressing measurement uncertainty be followed.

1. Background

Since the early 1980s, an international consensus has been developing on a uniform approach to the expression of uncertainty in measurement. Many of NIST's sister national standards laboratories as well as a number of important metrological organizations, including the Western European Calibration Cooperation (WECC) and EUROMET, have adopted the approach recommended by the International Committee for Weights and Measures (CIPM) in 1981 [1] and reaffirmed by the CIPM in 1986 [2].

Equally important, the CIPM approach has come into use in a significant number of areas at NIST and is also becoming accepted in U.S. industry. For example, the National Conference of Standards Laboratories (NCSL) is using it to develop a Recommended Practice on measurement uncertainty for NCSL member laboratories.

The CIPM approach is based on Recommendation INC-1 (1980) of the Working Group on the Statement of Uncertainties [3]. This group was convened in 1980 by the International Bureau of Weights and Measures (BIPM) in response to a request by the CIPM. More recently, at the request of the CIPM, a joint BIPM/IEC/ISO/OIML working group developed a comprehensive reference document on the general application of the CIPM approach titled *Guide to the Expression of Uncertainty in Measurement* [4] (IEC: International Electrotechnical Commission; ISO: International Organization for Standardization; OIML: International Organization of Legal Metrology). The development of the *Guide* is providing further impetus to the worldwide adoption of the CIPM approach.

2. Policy

All NIST measurement results are to be accompanied by quantitative statements of uncertainty. To ensure that such statements are consistent with each other and with present international practice, this NIST policy adopts in substance the approach to expressing measurement uncertainty recommended by the International Committee for Weights and Measures (CIPM). The CIPM approach as adapted for use by NIST is:

1) *Standard Uncertainty*: Represent each component of uncertainty that contributes to the uncertainty of the measurement result by an estimated standard deviation u_i, termed **standard uncertainty**, equal to the positive square root of the estimated variance u_i^2.

2) *Combined Standard Uncertainty*: Determine the **combined standard uncertainty** u_c of the measurement result, taken to represent the estimated standard deviation of the result, by combining the individual standard uncertainties u_i (and covariances as appropriate) using the usual "root-sum-of-squares" method, or equivalent established and documented methods.

   Commonly, u_c is used for reporting results of determinations of fundamental constants, fundamental metrological research, and international comparisons of realizations of SI units.

3) *Expanded Uncertainty*: Determine an **expanded uncertainty** U by multiplying u_c by a **coverage factor** k: $U = ku_c$. The purpose of U is to provide an interval $y - U$ to $y + U$ about the result y within which the value of Y, the specific quantity subject to measurement and estimated by y, can be asserted to lie with a high level of confidence. Thus one can confidently assert that $y - U \le Y \le y + U$, which is commonly written as $Y = y \pm U$.

   Use expanded uncertainty U to report the results of all NIST measurements other than those for which u_c has traditionally been employed. To be consistent with current international practice, the value of k to be used at NIST for calculating U is, by convention, $k = 2$. Values of k other than 2 are only to be used for specific applications dictated by established and documented requirements.

4) *Reporting Uncertainty*: Report U together with the coverage factor k used to obtain it, or report u_c.

   When reporting a measurement result and its uncertainty, include the following information in the report itself or by referring to a published document:

   – A list of all components of standard uncertainty, together with their degrees of freedom where appropriate, and the resulting value of u_c. The components should be identified according to the method used to estimate their numerical values:
      A. those which are evaluated by statistical methods,
      B. those which are evaluated by other means.

   – A detailed description of how each component of standard uncertainty was evaluated.

   – A description of how k was chosen when k is not taken equal to 2.

   It is often desirable to provide a probability interpretation, such as a level of confidence, for the interval defined by U or u_c. When this is done, the basis for such a statement must be given.

Additional guidance on the use of the CIPM approach at NIST may be found in *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results* [5]. A more detailed discussion of the CIPM approach is given in the *Guide to the Expression of Uncertainty in Measurement* [4]. Classic expositions of the statistical evaluation of measurement processes are given in references [6-8].

3. Responsibilities

a. Operating Unit Directors are responsible for compliance with this policy.

b. The Statistical Engineering Division, Computing and Applied Mathematics Laboratory, is responsible for providing technical advice on statistical methods for evaluating and expressing the uncertainty of NIST measurement results.

c. NIST Editorial Review Boards are responsible for ensuring that statements of measurement uncertainty are included in NIST publications and other technical outputs under their jurisdiction which report measurement results and that such statements are in conformity with this policy.

d. The Calibrations Advisory Group is responsible for ensuring that calibration and test reports and other technical outputs under its jurisdiction are in compliance with this policy.

e. The Standard Reference Materials and Standard Reference Data programs are responsible for ensuring that technical outputs under their jurisdiction are in compliance with this policy.

f. Authors, as part of the process of preparing manuscripts and other technical outputs, are responsible for formulating measurement uncertainty statements consistent with this policy. These statements must be present in drafts submitted for NIST review and approval.