Springer
Book Proposal & Author Questionnaire
Business, Economics & Statistics

1. Author(s)/Editor(s) (CVs attached):

Stephen Crowder
Sandia National Laboratories
Principal Member of Technical Staff
Albuquerque, NM 87185

(505) 844-0322
svcrowd@sandia.gov

Colin Delker
Sandia National Laboratories
Principal Member of Technical Staff
Albuquerque, NM 87185

(505) 845-7431
cjdelke@sandia.gov

Eric Forrest
Sandia National Laboratories
Principal Member of Technical Staff
Albuquerque, NM 87185

(505) 844-1377
ecforre@sandia.gov

Nevin Martin
Sandia National Laboratories
Senior Member of Technical Staff
Albuquerque, NM 87185

(505) 203-1547
nevmart@sandia.gov

2. Title: Introduction to Statistics in Metrology

3. Specifications:

Type of book:
[**x**] monograph
[ ] edited volume
[ ] conference proceedings
[**x**] reference work
[ ] translation
[ ] other, namely:

Estimated number of:
manuscript pages or total words: **250-300 pages (approximately 70,000 words)**
photographs: **5-10**
line drawings:
tables: **35-40**
figures: **60-70**
maps:
other:

Manuscript will contain:
[x] Preface, Foreword or Introduction
[x] Glossary of Terms
[x] Bibliography of selected titles
[x] Subject and/or Name Index
[ ] Other items

Manuscript delivery date: We are currently finalizing an internal Metrology Handbook for the Nuclear Security Enterprise. This document will provide large portions of the book, so a completed manuscript could be delivered within one year of acceptance of the manuscript.

Format:
[x] Word
[ ] LaTeX

Electronic Supplementary Material:
Data sets and R Code will be embedded in the manuscript, not supplementary.

Keywords:

International System of Units, Measurement Standards, Traceability Chain, Uncertainty Analysis, Propagation or Error, Design of Experiments, ANOVA, Binary Measurement Systems

Peer Reviewers Recommended

Dr. Hy Tran
Primary Standards Laboratory
Sandia National Laboratories
hdtran@sandia.gov

Dr. Harold Parks
Senior Research Officer, Metrology Research Centre
National Research Council Canada
Harold.Parks@nrc-cnrc.gc.ca

Dr. Caleb King (Statistician)
Research Statistician Tester
JMP Division, SAS Institute Inc.
Caleb.King@jmp.com

Dr. Raju Dandu (Professor of Mechanical Engineering)
Director of Bulk Solids Innovation Center
Kansas State University
rdandu@ksu.edu

4. Project Description

Type of publication: The monograph is intended as a textbook/reference book. As a textbook, it is intended for junior or senior level college students studying statistics or a related engineering discipline. The material is specifically for those students who desire to learn the basics of metrology and the statistical methods behind the quantification of uncertainty in measurement. The book could also be used as a first-year graduate course in a statistics curriculum emphasizing industrial statistics. The material in the book is also intended to be used as reference material for practicing statisticians or metrologists, and for the training of practitioners in statistics and/or metrology.

Statistical techniques are emphasized throughout, with appropriate engineering and physics background provided as needed. Extensive knowledge of statistics is not required, as knowledge of the basics will make the methods accessible for most readers. One of the strengths of the book is the number of actual case studies provided. The statistical topics with applications in metrology are presented by first introducing the theory/models necessary to complete an uncertainty analysis. This presentation is then followed by an actual case study from our work (in most cases) to illustrate how to use the methodologies on real problems.

Overview: The book covers the application of statistical methods to problems in metrology, with

emphasis on the characterization of measurement systems and the quantification of measurement uncertainty. It provides coverage of the subject from basic concepts to special topics not generally covered, each illustrated with case studies from our work in the Nuclear Security Enterprise (NSE). The goal is to provide the reader a solid foundation for applying the techniques to a wide variety of metrology problems.

The book brings together in one place most of the basic statistical methods that have been applied to problems in metrology, plus much more. It includes the methods presented in the JCGM 100 "*Guide to the Expression of Uncertainty in Measurement*," (aka, the GUM), but also presents material on topics in metrology seldom covered elsewhere. In particular, the book includes more details on design of experiments (DOEx) in metrology than have been presented before. Special topics include statistical process control (SPC) in metrology, assessment of binary measurement systems, uncertainty quantification for "one-shot" devices, and new material on sample size selection in metrology studies. A detailed explanation of uncertainty analysis using the Monte Carlo method is also given.

The methodologies presented in the book are supported with R script when needed, and the code has been made available to the readers for use in their own applications. The emphasis on statistics in metrology, the treatment of DOEx, SPC and special topics, the case studies, and the associated R code set the book apart and fill a gap in the existing literature.

Metrology has traditionally been learned as a discipline through on-the-job training. Educational materials have consisted mostly of short-courses and guidelines published by metrology societies. Books that do have a blend of metrology and statistics place the majority of the emphasis on the details of metrology, with little attention given to the details of the statistical methodologies. These books are written primarily by engineers for professional metrologists. The emphasis of the proposed book is different. Our emphasis is on statistical methods that are used in support of metrology, including topics that have received little or no previous attention.

Common academic backgrounds of practicing metrologists include mechanical and electrical engineering. Practicing statisticians and industrial engineers also frequently work on problems in metrology. The primary market for the textbook is thus students/practitioners, especially statisticians and engineers, who want to learn the statistics of metrology to support the study of increasingly complex measurement systems. Statistics departments such as Iowa State University or Virginia Tech University, with strong programs in industrial statistics, would find this to be a useful textbook. The book would also be a welcome addition in numerous engineering programs and existing metrology programs. Beyond the academy, the book would be a valuable reference for practitioners.

Another goal of the book is to promote greater collaboration between the disciplines of statistics and metrology, resulting in the practice of better measurement science. Collaborations between these two disciplines have not appeared often in the literature. In the proposed book, the case studies we present come from such collaborations.

Professional societies that will have an interest in this book include both national and international statistical societies such as the American Statistical Association and the International Society for Business and Industrial Statistics. The material will also be of great interest to members of the American Society for Quality and other societies such as the Automotive *Industry Action Group* that focus on

applications of metrology in manufacturing. Metrology societies that will be interested in the book include the National Conference of Standards Laboratories International (NCSLI), the IEEE Instrumentation and Measurement Society, and the European Association of National Metrology Institutes.

We are not aware of any textbooks that have the same emphasis on statistics in metrology. Books such as those written by Kimothi (2002), Placko (2013), and Dotson (2015) all address the use of statistics in metrology, but the coverage is very limited (often just a single chapter) with no mention of topics such as design of experiments or statistical process control. The topic of sample size determination and other important special topics are also not addressed in these previous books.

Table of Contents/Outline

Table of Contents: The chapters were chosen to provide a blend of topics that will inform and challenge students and practitioners of statistics and metrology.

Four of the chapters (1, 2, 3, and 5) focus on basic concepts of metrology. These chapters are included to establish the language of metrology used in the book. The discussion topics include base units, traceability, standards, calibration, and measurement uncertainty in decision making. Many of these terms will be new to statisticians and engineers and will help provide context when collaborating with metrologists. The appendices include additional case studies involving traceability and uncertainty budgets, and a discussion of R code and its use solving problems in metrology.

Seven of the chapters (4, 6, 7, 8, 9, 10, and 11) focus on the use of statistics in metrology. The material in these chapters includes basics of probability and statistics, uncertainty of both direct and indirect measurements, mathematical bases for the analytical approaches, Monte Carlo methods, uncertainty in fitted curves, design of experiments, and special topics in metrology.

The special topics section (Chapter 11) includes the application of statistical process control (SPC) in metrology. The activity of making a measurement is presented as a *process* that can be monitored and controlled using well-developed techniques of SPC. Another special topic that has received little attention in the metrology literature is the assessment of a binary measurement system (BMS), where the "measurement" is a binary response (Pass/Fail) variable. This material is especially relevant in applications where a "go/no-go" gage is used for disposition of manufactured product or other binary decisions. We also discuss uncertainty quantification for "one-shot" devices, where the taking of the measurement degrades or destroys the device, preventing replication of the measurement. New guidance is also presented for the selection of sample size in metrology studies, as well as new recommendations for the design and analysis of Gage R&R studies.

The appendices include additional case studies involving traceability and uncertainty budget analyses. Appendix A deals with both the traceability and the uncertainty analysis associated with the measurement of neutron yield produced by a neutron generator, a component manufactured within the NSE. Other sections of Appendix A deal with the uncertainty of measurements made with a coordinate measuring machine (CMM), and the uncertainty of high-precision voltage measurements. Appendix B deals with the use of R in support of metrology studies.

We have not covered the use of Bayesian statistical analysis in the book, as our experience is that it has not yet moved into the mainstream of metrology analyses performed by practitioners. We do, however, recognize the potential for the use of Bayesian methods in metrology and include several important references.

- For edited volumes, please provide name and affiliation for each contributor.
- For revised editions, please indicate the specific nature and extent of new/revised material.
- For textbooks, please highlight: (1) courses for which the book could be adopted; (2) pedagogical features for students (e.g., discussion questions, case studies, worked examples, online supplements) and instructor resources (e.g., solution manual, lecture notes, syllabus outline); and (3) reviewers to comment on content presentation with particular emphasis on adoption potential.

Table of Contents

12.4 Acknowledgements……..

APPENDIX A: Traceability and Uncertainty Budget Case Studies
A1. Neutron Yield Measurements
A2. Gage Block Interferometer
A3. CMM Measurements
A4. Josephson Volt Measurements
A5. Resistor Drift

APPENDIX B: Statistics in Metrology using R

REFERENCES

INDEX

Sample Chapter(s)/Writing Sample
If available, please attach an excerpt, sample chapter, or writing sample that reflects the content and/or presentation style of the proposed book.

5. Open Access: (Content published under a Creative Commons license and made freely available to readers via the online SpringerLink platform, in return for OA sponsorship from a funding agency; See: https://www.springer.com/gp/open-access/open-access-funding):

Springer Nature is one of the world's foremost publishers of Open Access content. We strongly encourage conference and volume organizers to consider the OA option for publication.

Please indicate if your research was funded, and if applicable provide the name of the funder.
[x] Funded
[ ] Not funded:

Name of funding organization/institution (if applicable): **Sandia National Laboratories**

Please indicate if you are interested in making your publication available open access:
[ ] My funder requires open access publication
[ ] Open access publication is not required, but I wish to explore this route
[x] I am not required/do not wish to publish open access

6. Market and Competition

Key selling points:
Please list 3-5 distinguishing characteristics—bullet points—that reflect the book's unique content and/or

presentation.

Unique Content/Emphasis

1. **Emphasis on Design of Experiments in Metrology Studies**
2. **Statistical Process Control applied to Measurement Processes**
3. **Uncertainties in Fitted Curves**
4. **Performance of Binary Measurement Systems**
5. **Measurement Uncertainty When Measuring the Output of "One-Shot" Devices**
6. **Sample Size Determination for Metrology Experiments/Studies**
7. **Numerous Case Studies from Our Work in the Nuclear Security Enterprise**
8. **R-Code in Support of the Methodologies**

Primary and secondary markets:

In addition to engineering and statistics students and practitioners, professional societies will have an interest in this book, including both national and international statistical societies such as the American Statistical Association and the International Society for Business and Industrial Statistics. The material will also be of great interest to members of the American Society for Quality and other societies such as the Automotive *Industry Action Group* that focus on applications of metrology in manufacturing. Metrology societies that will be interested in the book include the National Conference of Standards Laboratories International (NCSLI), the IEEE Instrumentation and Measurement Society, and the European Association of National Metrology Institutes.

Competitive/complementary titles:

We are not aware of any textbooks that have the same emphasis on statistics in metrology. Books such as those written by Kimothi (2002), Placko (2013), and Dotson (2015) all address the use of statistics in metrology, but the coverage is very limited (often just a single chapter) with little or no mention of topics such as design of experiments or statistical process control. The topic of sample size determination, binary measurement systems and other important special topics are also not addressed in these previous books.

Dotson, C. L. (2015). Fundamentals of Dimensional Metrology. Cengage Learning.

Kimothi, S. K. (2002). The Uncertainty of Measurements. ASQ Quality Press, Milwaukee, WI.

Placko, D. (2013). Metrology in Industry: The Key for Quality. Wiley-ISTE.

Promotional opportunities:

Potential review journals include *Journal of Quality Technology*, *Technometrics*, *Measure*, and *Metrologia*. Professional conferences include the Joint Statistical Meetings, Fall Technical Conference, and NCSL. Short courses, internal corporate classes such as those taught at Sandia National Laboratories

would also be interested in the book.

Endorsements:
We have not yet solicited endorsements, but will do so prior to publication.

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.