



**DOCUMENT 804-01
VOLUME I**

Signature Measurement Standards Group

**RADAR CROSS SECTION (RCS) CERTIFICATION FOR
STATIC AND DYNAMIC RCS MEASUREMENT FACILITIES**

**VOLUME I
CERTIFICATION PROCESS**

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KWAJALEIN MISSILE RANGE
YUMA PROVING GROUND
DUGWAY PROVING GROUND
ABERDEEN TEST CENTER
NATIONAL TRAINING CENTER**

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NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
NAVAL UNDERSEA WARFARE CENTER DIVISION, NEWPORT
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CERTIFICATION PROCESS**

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Prepared by

**SIGNATURE MEASUREMENT STANDARDS GROUP
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TABLE OF CONTENTS

	<u>Page</u>
ACRONYMS	v
FOREWORD	vii
EXECUTIVE SUMMARY	ix
CHAPTER 1 – INTRODUCTION TO THE ANSI/NCSL Z-540-1-1994 STANDARD.....	1-1
1.1 General	1-1
1.2 A Closer Look at ANSI/NCSL Z-540-1-1994.....	1-2
1.3 Using Z-540 to Establish an RCS Range Quality System.....	1-2
1.4 A Sectional Overview of Z-540 – Part I.....	1-3
1.5 Organizing the RCS Range Book to Comply with Z-540	1-5
1.6 RCS Range Registrations and Third Party Certification Review.....	1-6
CHAPTER 2 – THE RCS CERTIFICATION PROCESS STEP-BY-STEP IMPLEMENTATION.....	2-1
2.1 General	2-1
2.2 Defining Z-540 RCS Certification.....	2-2
2.3 The Detailed Z-540 RCS Certification Process	2-3
2.4 Organizing the RCS Range Book to Comply with the Evaluation Criteria.....	2-5
2.5 The Range Book Reviewers	2-6
CHAPTER 3 – FUTURE RCS CERTIFICATION REQUIREMENTS	3-1
3.1 General	3-1
3.2 Certifying to Z-540	3-1
3.3 RCS Certification.....	3-1
3.4 The Future for Z-540.....	3-2
APPENDIX I – RCS RANGE BOOK FORMAT	I-1
1.0 Introduction	I-2
2.0 RCS Range Book Outline	I-2
3.0 Range Book Content.....	I-4
4.0 Summary	I-9

APPENDIX II – EVALUATION CRITERIA FOR RCS RANGE BOOK.....	II-1
1.0 Background	II-2
2.0 Executive Summary	II-2
RCS RANGE BOOK CERTIFICATION REPORT	
GRADING AND PASSING CRITERIA.....	II-4
RCS RANGE BOOK EVALUATION CRITERIA.....	II-6
ATTACHMENT A – ACKNOWLEDGMENTS AND REFERENCES	A-1

LIST OF TABLES AND FIGURES

Figure 2-1 DoD RCS Demonstration Program Ranges.....	2-1
Figure 2-2 RCS Certification Review Process and Timeline	2-3
Table I-1 RCS Range Book Table of Contents.....	I-3
Table I-2 Section Table of Contents	I-4

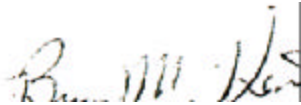
ACRONYMS

46TG	U.S. Air Force 46 th Test Group
ACR	Advanced Compact Range
AFRL	Air Force Research Laboratory
AIS	Automated Information System
AMTA	Antenna Measurement Techniques Association
ANSI	American National Standards Institute
APS	Antennas and Propagation Society
ATR	Atlantic Test Range, Patuxent River, MD
COTS	commercial off-the-shelf
DoD	Department of Defense
EC	European community
EMCC	Electromagnetic Code Consortium
HAFB	Holloman Air Force Base, NM
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Standards Organization
Mil Spec	military specifications
MQAP	measurement quality assurance program
MRC	Mission Research Corporation
NAWC-AD	Naval Air Warfare Center – Aircraft Division
NCSL	National Calibration Standards Laboratory
NIST	National Institute of Standards and Technology
NISTIR	National Institute of Standards and Technology Interagency Report
RAM	radar absorbing material
RCC	Range Commanders Council
RCC/SMSG	Range Commanders Council/Signature Measurement Standards Group
RCS	radar cross section
RVUMS	RAMS VHF/UHF Measurement System (46TG/TGR, HAFB)
SMSG	Signature Measurement Standards Group
SNS	Office Symbol for Signature Technology Office, AFRL, WPAFB, OH
SPP	Standard Practices and Procedures
SRC	Syracuse Research Corporation
WPAFB	Wright-Patterson Air Force Base, OH
Z-540	ANSI/NCSL Standard Z-540-1-1994

Foreword

This document summarizes the procedures required to obtain ANSI Z-540 Radar Cross Section (RCS) range certification as adopted by the Range Commanders Council Signature Measurement Standards Group (RCC/SMSG). The RCS certification demonstration program verified the feasibility and utility of RCS range certification and is documented in a separate volume. This specific report succinctly provides a quick "step-by-step" reference guide so that any government or RCS range can obtain RCS certification through the RCC/SMSG, thereby allowing a company or range to perform and deliver RCS data products to DoD.

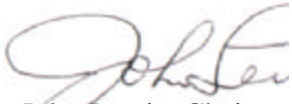
Organized around International Standards Organization (ISO) Guide 25 and its US equivalent standard (ANSI Z-540), the RCS certification process is designed to establish a technical and procedural quality system for any arbitrary RCS measurement facility. Z-540 is adopted to standardize the documentation, processes, and procedures used by all DoD and industrial RCS measurement facilities. Once a facility commits to obtaining range certification, this report provides the necessary information to guide any range through the process.



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EXECUTIVE SUMMARY

In January 1997, the Range Commanders Council Signature Measurement Standards Group (RCC/SMSG), in coordination with the Range Commanders Council (RCC) Taskmaster, established RCC/SMSG Task #08 titled, “DoD RCS Certification Feasibility Demonstration for Static and Dynamic RCS Measurement Facilities.” Referred to herein as the “DoD RCS Demonstration Program,” the task assessed the feasibility of establishing common documentation standards for describing the operation and capabilities of the Department of Defense’s (DoD) diverse radar cross section (RCS) measurement facilities located throughout the United States. Through the mutual efforts of the Air Force Research Laboratory (AFRL), the Naval Air Warfare Center Aircraft Division (NAWC-AD), and the U.S. Air Force 46 Test Group (46TG), in cooperation with the RCC/SMSG Radar Committee, the DoD RCS Demonstration Program was entirely successful and should lay the groundwork for similar technical or laboratory calibration certification efforts throughout DoD’s RCS measurement community [1].

This report describes how the American National Standards Institute/National Calibration Standards Laboratory ANSI/NCSL Z-540-1-1994 Standard [2] (referred to herein as Z-540) is applied to organize RCS range documentation for any DoD or industrial RCS measurement facility. This report is a follow-up to the DoD RCS Demonstration Program, as recently presented to the Antenna Measurement Techniques Association (AMTA) [12][13]. In June 2000, the RCC/SMSG certified that two facilities, the AFRL Advanced Compact Range (ACR), and the NAWC-AD Atlantic Test Range (ATR) Dynamic RCS Range measurement facilities met the Z-540 documentation standards established by the DoD RCS Demonstration Program. Since AFRL plans to unilaterally require mandatory Z-540 compliance for its DoD contractors performing RCS measurements after January 1, 2004 the RCS certification review process described in this report will likely be the model for industrial compliance. After reviewing the Z-540 standard, this report will summarize the certification review process and provide supplementary appendices documenting the RCS certification process.

CHAPTER 1

INTRODUCTION TO THE ANSI/NCSL Z-540-1-1994 STANDARD

1.1 General

This chapter presents a brief overview of the American National Standards Institute/ National Calibration Standards Laboratory ANSI/NCSL Z-540-1-1994 Standard [2] (referred to herein as Z-540). Z-540 offers a straightforward way to organize radar cross section (RCS) range documentation. We begin by discussing the major points of Z-540 and how to organize a format-universal RCS Range Book. Since Z-540 is the US equivalent of International Standard Organization (ISO) 25, it is especially useful for two reasons: (1) it is applicable to RCS ranges; and (2) its quality control requirements are consistent with the ISO 9000 series of quality standards. Properly applied, Z-540 will greatly improve the quality and consistency of RCS measurements produced by RCS measurement facilities and reported to range and DoD customers.

The signature measurement community is well aware of the complexities of a modern RCS measurement range. These electromechanical systems, regardless of range type, must contain a myriad of hardware and software in order to operate the range within its intended design parameters. Naturally, operating the range as designed helps assure that the range produces consistently high-quality data. Often, the job of keeping current range documentation may seem overwhelming, especially since there are currently no standards or guidelines for organizing such documentation.

During the process of examining various candidates for an RCS documentation standard, several factors were considered. First, from a DoD perspective, we examined typical military specifications and standard federal contract report deliverables to see if such standards could be exploited and customized for the documentation of RCS ranges. In light of the new DoD 5000 series of federal acquisition regulations, we are seeing significant federal procurement and acquisition reform. In the future, DoD will quickly move away from the use of rigid military specifications (Mil Specs) in federal contracts, in favor of more universally available and understood commercial grade standards. Since future DoD contracts will not rely exclusively on Mil Specs, they were ruled out as a possible RCS range standard model.

The RCC/SMSG Radar Committee also examined the ongoing work of the Institute of Electrical and Electronics Engineers Antennas and Propagation Society (IEEE-APS) Committee on RCS, of which the National Institute of Standards and Technology (NIST) is an active participant. While the work of this important committee was not complete in 1997 (and, as of the date of this publication, still is not complete), it is clear that the IEEE-APS will not focus on range documentation standards.

Finally, the RCC/SMSG Radar Committee examined ongoing work in the European community (EC), which already mandates most, if not all, of the ISO 9000/9002 series of

regulations for their commercial business transactions. While ISO 9000 by itself is not applicable to RCS ranges, the technical standard ISO 25 appeared to satisfy most of the requirements for a quality-oriented RCS range documentation system. We, therefore, looked into the US equivalent of ISO 25, which is ANSI/NCSL Z-540-1-1994.

1.2 A Closer Look at ANSI/NCSL Z-540-1-1994

The ANSI/NCSL Z-540-1-1994 Standard [2] is available for a nominal fee from the National Calibration Standards Laboratory (NCSL) (tel. # 303-440-3339). The title of the standard is Calibration Laboratories and Measuring and Test Equipment - General Requirements, and it provides a framework for collecting and maintaining information to support a quality-oriented system of documentation for any range that produces calibrated data. In essence, the standard is very general and could easily accommodate many types of calibrated scientific measurements (e.g., voltage, lumens, temperature, etc.). Basically a 13-page guide, Z-540 summarizes the general documentation requirements for any facility producing quality calibrated data.

Z-540 is organized into two parts. Part I is preceded by a three-section introduction and scope, and includes references and standard definitions. The definition section is especially helpful in establishing a common dialog for the remainder of the standard. The main thrust of the standard is Part I titled, "General Requirements For The Competence of Calibration Laboratories." It consists of 13 subsections outlining the basic standard and the information needed for a range to document to the standard. Part II of the standard titled, "Quality Assurance Requirements for Measuring and Test Equipment," pertains to the control, usage, and calibration of individual pieces of equipment used in producing calibrated data. As will be discussed later, Part I is the most applicable and appropriate portion of this standard when applied to the specific case of RCS ranges. Part II was not used in any part of the RCS certification efforts.

1.3 Using Z-540 to Establish an RCS Range Quality System

The central theme of Z-540 is the establishment and maintenance of an active and ongoing measurement quality assurance program (MQAP). Most ranges already incorporate "measurement assurance" as part of their normal range operations, although this phrase is rarely quantified. However, it may be helpful to briefly define the elements of a MQAP.

A typical MQAP consists of documented technical requirements designed to ensure repeatable RCS performance out of a given measurement range. The MQAP documents measurement procedures, data analysis procedures, range uncertainty and/or error estimation analysis, and data analysis procedures, while simultaneously identifying a sound management structure set up to efficiently operate and maintain the RCS range. It also strongly encourages an active interrange comparison program (within reasonable time and range availability constraints) and an ongoing research program to improve RCS data quality. At first reading, it may appear that standard Z-540 actually implies the development of a separate MQAP in addition to the documentation required by the standard. Actually, completion of the documentation required by Z-540 will, in effect, establish a documented MQAP. Therefore, we now review the elements of Z-540 section by section.

1.4 A Sectional Overview of Z-540 - Part I

Z-540 begins with a three-section “Foreword,” which defines the scope of the standard (Section 1), important references to the standards (Section 2), and a set of excellent baseline definitions (Section 3). These all help the reader define a common frame of reference for interpretation of the standard. After the Foreword, Part I (General Requirements for the Competence of Calibration Laboratories) presents the details of the standard itself. Part I consists of 13 individual sections (Sections 4-16), which present the ideal organization for a range documentation set paralleling the sections of the standard. Let us review each section by title, and provide some insight into their purpose. Later, we will define how each item is evaluated in practice.

Z-540 Section 4 (Organization and Management) briefly describes how to document the organization performing the calibrations. Using an open-ended format, the RCS range organization and personnel would be identified along with their typical supervisory reporting chain. This section also identifies the technical and quality leaders responsible for the respective technical and quality aspects of range operations. (Naturally in smaller RCS ranges, these two positions may be held by the same person.) Z-540 Section 4 requires all range individuals (and any alternates) to be specifically identified. Also, Section 4 requires that the RCS range be organized and operated in such a way as to assure that RCS data confidence, independent technical judgment, and data integrity are always maintained.

Z-540 Section 5 (Quality System, Audit, and Review) is one of the three major sections of Z-540 and sets the stage for the remainder of the document. It states that the range will establish and maintain an active “quality system” with appropriate internal audits and reviews suitably “appropriate to the type, range, and volume of calibration activities it maintains.” This sentence is very important as it distinguishes Z-540 and ISO 25 from the overall ISO 9000/9002 series in the important phrase “appropriate to the type, range, and volume of calibration activities...”. Subsection 5.2 is more specific and lays out the elements that should be included in the quality manual. Some examples include (5.2-d) procedures to control and maintain documentation; (5.2-g) procedures for achieving traceability; (5.2-h) scope of calibration and verification activities; (5.2-k) procedures for handling (calibration) devices; (5.2-l) references to major equipment and reference measurement standards; (5.2-n) references to quality assurance practices, including inter-laboratory comparisons, proficiency testing, and internal quality control practices; (5.2-o) procedures for corrective action when RCS data discrepancies are found; and (5.2-q) procedures for dealing with customer complaints. Although Sections 5.3-5.6 describe a few additional details on the audit and review process, the creation of the range-appropriate “quality manual” in Section 5.2, as it pertains specifically to RCS measurement ranges, is the main intent of standard Z-540.

Z-540 Section 6 (Personnel) describes how a range defines and maintains the appropriate staff needed to operate the RCS range. It also requires ranges to describe their initial and ongoing training programs used to maintain the technical competence of their operating staffs. This information should be easy to assemble, as most organizations routinely obtain and manage this type of information.

Z-540 Section 7 (Accommodation and Environment) requires a range to describe its environmental “accommodation” and to identify what environmental factors may affect measurement results. This latter category may be very short for some indoor ranges but lengthy for outdoor or dynamic measuring applications. For instance, an outdoor static range may wish to record temperature, winds, precipitation, inversions, or other phenomena which are known to affect the RCS measurement data. When the effects cannot be quantified (in RCS error terms), it is still very important to identify and record when such conditions occurred.

Z-540 Section 8 (Equipment and Reference Materials) describes how equipment, maintenance, and reference materials and records are tracked. Again, most organizations have systems to control and identify all equipment used by a typical range. By systematically organizing this information into a “range appropriate” configuration control document, one makes a good external record of the measurement system, as well as an excellent and useful internal document valuable to the range technicians and engineers. Note that the more complex the range, the more important the documentation becomes.

Z-540 Section 9 (Measurement Traceability and Calibration) and Section 10 (Calibration Methods) together define the information needed to establish traceability to “national, international, or intrinsic standards of measurement.” For RCS ranges, this is usually accomplished through indirect “ratio or reciprocity type measurements,” wherein an unknown target is measured, a “known” RCS “standard” is measured, and a ratio is computed with suitable adjustments using a highly accurate numeric RCS estimate of the “known” calibration target. Though every range performs calibrations in slightly different manners, the Z-540 requires that such procedures be rigorously documented, tested, and verified, whenever possible, with other RCS ranges. One of the most important aspects of these two sections is contained in paragraphs 10.2 - 10.4, which describe the need for written procedures to execute appropriate calibrations. Once again, having this procedural information universally available to your range staff, including archival results (e.g., what the “correct” calibration measurements should be) will greatly improve the quality and repeatability of RCS calibration values. In addition, specific calibration processes selected for use by a given range must be routinely tested. Calibration procedures discussed in [2, 3] are one way of meeting this requirement, though other documented methods may be used as well.

Z-540 Section 11 (Handling of Calibration Items) is self explanatory and essentially states the need for maintaining physical control over calibration items used to produce calibrated RCS range data. Such items should be appropriately stored and protected when not being used. In addition, it points out the need to uniquely identify each primary range calibration target, so that there is never confusion regarding the use of one calibration target over another.

Z-540 Section 12 (Records) is also self explanatory and basically states that the range must have a record keeping system consistent with “its particular circumstances.” It also specifically states that the record keeping system should be consistent with the overall range quality system.

Z-540 Section 13 (Certificates and Reports) describes the elements that must appear in a “range certificate,” otherwise called an RCS data or test report. It emphasizes that each range

should have a minimum subset of information in the report, including range identity (title, name, and address of range); customer identity (name and address of customer); description of the calibration item (target); dates of the calibration measurements, process, calibration techniques used, and so on. It is meant to provide consistency of data reporting from a specific range, as well as to establish more universal reporting standards from range to range.

Z-540 Sections 14 (Subcontracting of Calibration) and Section 15 (Outside Support Services and Suppliers) are both brief, but important. In essence, they state that if outside suppliers are used in any part of the process of supplying calibrated RCS data, such suppliers are subject to the requirements of the Z-540 standard, if the prime or supplying range conforms to this standard.

Finally, Z-540 Section 16 (Complaints) assures that the range has a formal, quality-oriented policy for responding to customer complaints regarding any aspect of range operation.

1.5 Organizing the RCS Range Book to Comply with Z-540

The following provides guidelines for the construction of the RCS Range Book used to document range characteristics in accordance with Z-540. The goal of these guidelines is to maintain consistency in the layout of the documentation from range to range. Appendix I of this document provides a detailed description of the layout of a typical range book, so only the general points will be repeated here.

The main goal of the range book is to create and organize the RCS system documentation into a format independent of that used by the ranges. However, within each section of the range book, company or local documentation formatting is strongly encouraged, whenever possible. In this manner, substantial costs for reformatting information to Z-540 are avoided to the extent possible, while at the same time affording a common document layout. The goal here is to create a "living breathing document" useful to the range staff for whom it was created. It is the range book that is reviewed technically by a third party and is the basis for granting a range certification. This factor will be discussed later in this report.

The range book sections will closely parallel the Z-540 standard, with few exceptions. However, it is emphasized that the importance of the RCS Range Book is in its basic utility as a general reference standard for range personnel and customers alike. Thus, the utility of the range book will largely depend on the currency and relevance of the information in it and the amount of effort expended to create it.

Before discussing the range book format, we consider the issue of universal availability and utility. Depending on the size and type of range, the documentation set may be physically small or large. For instance, we would expect the documentation for a highly complex dynamic signature measurement range to be substantially larger than a relatively simple indoor far field range. However, any range may want to carefully consider whether to produce their range book documentation in paper or electronic form. While a conventional paper copy would certainly meet all requirements of Z-540, an electronic version (available on a network server, internal or external web page, or a permanent CD-ROM) available to every range employee may be a better

option in the long run. Normally, if multiple hard copies of the range book are created, each must be separately updated to reflect changes in the range information over a range's natural lifetime. In the case of an electronic or web page version, only one copy (on the web page) would need to be updated and redistributed. Thus, maintaining current documentation electronically should prove easier than maintaining paper copies. In either case, the reader is encouraged to use whatever system is available or appropriate for their situation.

The RCS Range Book (paper or electronic) should be the ready range reference available for use by any range staff member. The range book also represents the official document set, reviewed by a third party RCS Certification Review Committee as discussed later in this report. Once a range book is completed and certified, it is the responsibility of the range to keep it current.

1.6 RCS Range Registrations and Third Party Certification Review

Compilation of the range book completes an important phase in the formal documentation of range performance. For an RCS range to become “certified,” it must first become “registered.” To become “registered,” the range forms its own internal review committee to check the RCS Range Book against the published RCS evaluation criteria provided in Appendix II of this document. This process is called an internal “self-review” audit or “registration” in ISO vernacular. Once a range book is “registered” internally and checked against the evaluation criteria, the range management normally places the appropriate names on the opening page. Their joint signatures attest that management has approved the overall quality assurance program and the RCS Range Book.

The next part of the certification process is the independent third party review. Z-540, Section 1.3, states, “the role of the purchaser in monitoring supplier (range) compliance with the requirements of this standard may be fulfilled by a third party such as a certification board.” When DoD tested and demonstrated a Z-540-based RCS certification process, it relied on an all-volunteer RCS Certification Review Committee formed by technical specialists drawn from Government, academia, and industry. In the future, all range book reviewers will be volunteer technical experts active in the RCS measurement business. Such a third party review committee “certifies” that a range complies with the Z-540 standard as it pertains to the specific RCS measurement range.

Of course, a third party review committee can never guarantee that a “certified” range will not make errors. Since Z-540 is extremely process-oriented, proper documentation of normal range processes and procedures will produce, in our opinion, a quality system that greatly reduces the occurrence of data problems related to poor procedural execution. The Z-540 standard is an excellent approach to organize, maintain, and present RCS range information. The RCS Range Book should be very useful to the range and range customer alike. Assuming that a well-managed RCS range has much of the required documentation in hand, complying with the Z-540 standard should be a gradual, transitional process as the range book is formalized. If omissions are found in the RCS range’s documentation, the process of implementing an MQAP as part of the Z-540 compliance process should fill those omissions, thereby improving the quality and consistency of RCS range data supplied to external customers.

CHAPTER 2

THE RCS CERTIFICATION PROCESS STEP-BY-STEP IMPLEMENTATION

2.1 General

This chapter provides a detailed overview of the RCS certification process. The process was thoroughly tested by the RCC/SMSG, in cooperation with the Air Force Research Laboratory and the Naval Air Warfare Center-Aircraft Division (NAWC-AD). The RCS ranges that participated in the original DoD RCS Demonstration Program [1] are shown in Figure 2-1. Although the original RCS-based quality assurance documentation handbook provided a context for the documentation standard, it provided few details regarding the evaluation criteria and certification review processes needed to complete RCS certification. The remainder of this report describes the certification review process and the evaluation criteria used in the RCS certification process by the RCS Certification Review Committee.

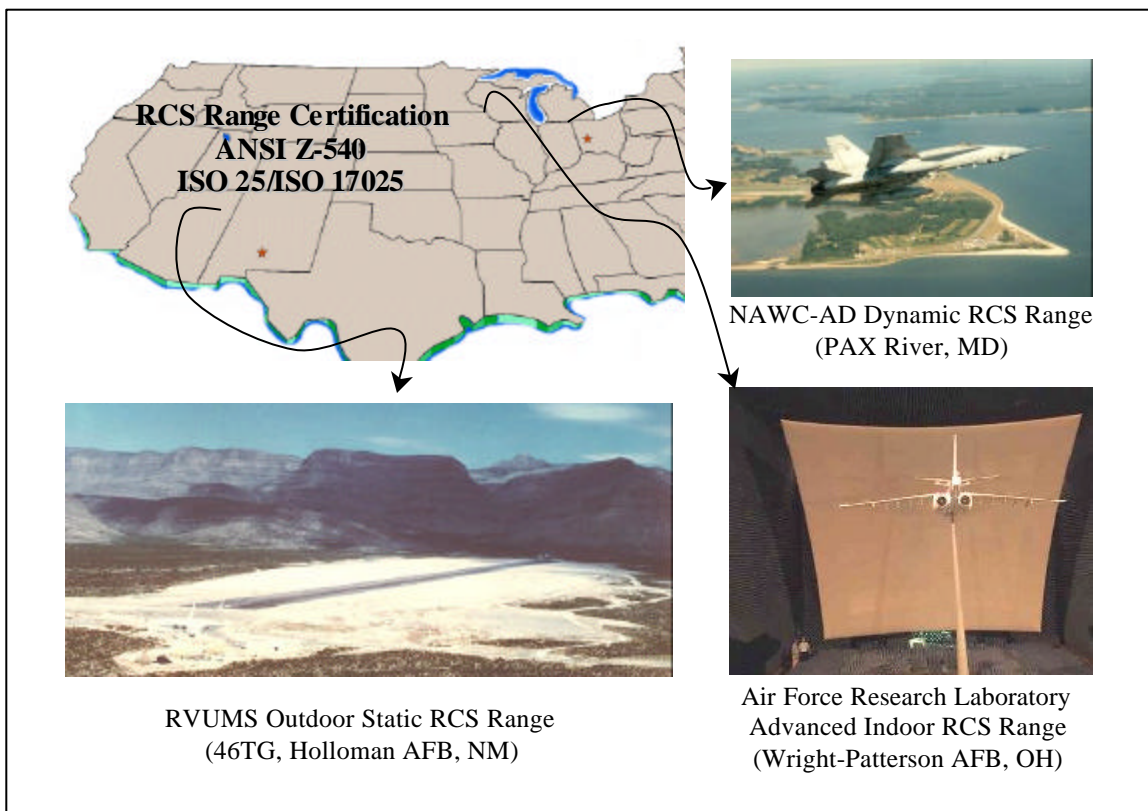


Figure 2-1. DoD RCS Demonstration Program Ranges.

2.2 Defining Z-540 RCS Certification

To avoid repeating the background information provided in Chapter 1, we begin by precisely defining “RCS certification.” From [1]: “RCS certification, as used in the RCS Certification Program, is hereby defined as having successfully completed a detailed review of an *RCS Range Book* by a *peer review committee* using *published evaluation criteria*.”

The detailed review is essentially a compliance assessment that a range has met the relevant quality assurance documentation standards of Z-540. In the earlier DoD RCS Demonstration Program [1], “certification” meant a review committee’s positive assessment of compliance with the Z-540 standard and an endorsement of the range’s measurement processes. RCS certification is NOT a rating system or a specific review committee endorsement of day-to-day quantitative capabilities (accuracy, uncertainty, and so forth). In the follow-on industrial RCS certification program, this definition and review process will be the same.

To better understand certification in context, let’s review each major element of the “RCS certification” definition above. We begin by defining the RCS Range Book. An “*RCS Range Book*” (Appendix I) is a detailed technical and quality assurance document written in accordance with the Z-540 standard by the range to be certified. The range book thoroughly describes all aspects of the RCS measurement range. Its 20 distinct sections describe every major aspect of range operations, procedures, calibration, and equipment. The range book also explains how the range is organized and operated on a day-to-day basis. The range book is meant to be a ready daily reference for the range staff, as well as a document a potential customer could review prior to using the RCS facility for a test.

The “*published evaluation criteria*” (Appendix II) are a set of approximately 145 specific written evaluation criteria that the range book must fulfill in order to become “RCS certified.” The evaluation criteria provide the minimum information required for each of the 20 range book sections. Since the range knows the evaluation criteria up front, the criteria provide a definitive guide for the range staff to help prepare the range book material. The evaluation criteria are also used by the range to “self review” or “register” the range book by the host organization prior to certification review by a third party.

The “*peer review committee*” consists of three volunteer RCS experts from Government, industry, and/or academia who review the RCS Range Book for compliance with the Z-540 standard using the evaluation criteria mentioned above. The volunteer reviewers provide feedback to the range on non-compliant range book sections, and work with the range in question to revise the range book to be fully compliant with the standard. Literally, the review committee is there to help the range complete the certification process. All range book reviewers must meet minimum qualifications set by the RCC/SMSG Radar Committee and be approved by the Chair of the RCC/SMSG.

In the DoD RCS Demonstration Program, the Air Force Research Laboratory (AFRL) and the Atlantic Test Range facilities were solely reviewed by RCS experts employed outside DoD to avoid any perceived conflict of interest. In future reviews, the reviewers may come from

any organization except the organization being reviewed for RCS certification. Also, as a courtesy, the names and present employers of the range book reviewers are provided to the RCC/SMSG, who may veto any potential reviewer for business or financial (real or perceived) conflicts of interest.

2.3 The Detailed Z-540 RCS Certification Process

The RCS certification process created by the RCC/SMSG may seem complicated at first glance, but it is actually a manageable, easy to follow step-by-step recipe. Figure 2-2 illustrates the overall certification review process. The process begins with the “Registered” Phase when an RCS range decides to become “registered” to the Z-540 standard. This involves generating an RCS Range Book (in paper or electronic format) that meets the published evaluation criteria (Appendix II) for RCS certification. For most ranges, this process can take 6-24 months depending on the complexity of the RCS range measurement system and the range’s initial state of documentation. If a range has organized documentation and thoroughly documented measurement and calibration procedures available at the onset, the process can be quickly completed. If these documents need to be created by the range staff, the process

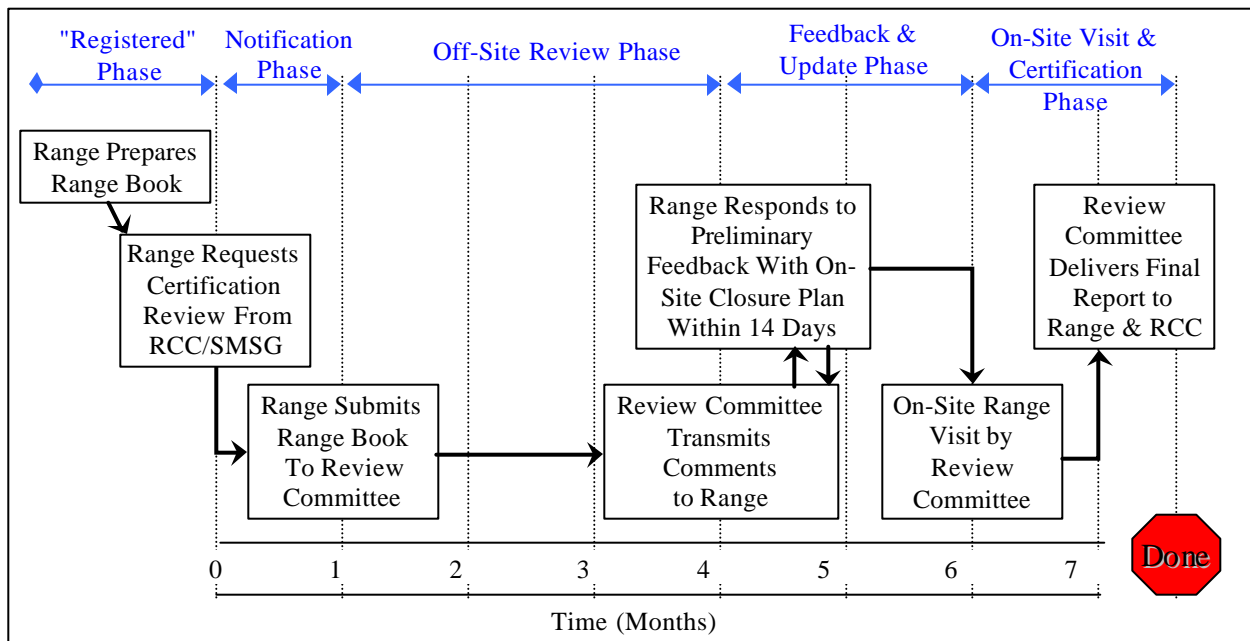


Figure 2-2. RCS Certification Review Process and Timeline.

obviously takes longer. Once the range book draft is generated, the range performs an internal “self review” of the range book, using the same evaluation criteria (Appendix II) used by the third party review committee. After this “self review” is successfully completed, the range quality manager normally endorses the range book in Section 1 (Introduction and Endorsements) along with a manager at least two levels above the quality manager. Once reviewed and signed internally, a range is considered “Registered to Z-540.” A range must become RCS “registered” prior to requesting a certification review from the RCC/SMSG Standards Committee, a practice consistent with ISO standard review procedures.

The next step in the certification process of Figure 2-2 is the Notification Phase. The range desiring certification contacts the RCC/SMSG Chair (as of the date of this publication, Mr. Dale Bradley, USAF Arnold Engineering Development Center, tel. # 931-454-4242, e-mail: dale.bradley@arnold.af.mil) and requests that an RCS Certification Review Committee be formed. Within 30 days of being contacted, the Chair will assign a third party team of three RCS experts to review the range book in question. This third party team will consist of experts in RCS recommended by the RCC/SMSG Radar Committee. The RCC/SMSG Chair assigns the members to assure there is no perceived conflict of interest between the reviewers and the range. Once the review committee membership has been named, the review committee meets among themselves to elect a chairperson. By charter, the review committee chairperson is the single focal point between the review committee and the range under review for the duration of the review process.

Once the review committee has been formed, the review timeline officially starts and the review proceeds into the Off-Site Review Phase. The range sends a copy of the range book to each review committee member. The review committee has three months to review the range book, and grade it in accordance with the evaluation criteria in Appendix II. The chairperson gathers the individual grades and issues “composite” or committee grades for each evaluation criteria. At the end of the three-month off-site review, the chairperson transmits the committee’s “mid-review” assessment to the range. The mid-review assessment will likely reveal areas where the reviewers require additional documentation, clarification, or improvement in some or all range book sections. Also, the review committee does not initially grade about 30% of the evaluation criteria, because these criteria are evaluated later during the on-site staff interviews. If the review committee identifies any marginal or unsatisfactory range book sections, the review committee must include positive corrective comments showing the range how to reach satisfactory compliance in each non-compliant area.

At this point, the review process moves into the Feedback and Update Phase. Once the range receives the mid-review report, the range responds to the feedback within 14 days and is given a minimum of 60 days to accomplish range book revisions and prepare for the on-site review. (More time may be requested at any time in the process by the range under review, if needed.) The range focuses its activities on correcting all high-priority deficiencies identified by the review committee. This is normally accomplished by adding written revisions to the range book to address specific deficiencies. The range also prepares for the upcoming review committee on-site visit. The on-site visit generally addresses three areas: (1) the summary presentations of the overall range organization and technical operations of the range, (2)

deficient areas and the steps the range has taken in the last 60 days to correct deficiencies, and (3) interviews with staff and the on-site audit questions from the evaluation criteria.



All on-site questions are known in advance. The on-site interviewers will not deviate or add additional on-site questions from those present in the evaluation criteria.

The final phase is identified as the On-Site Visit and Certification Phase. During this period, the review committee typically spends 2-4 days at the range for an on-site visit of the facility. In addition to going over the formal changes and revisions to the range book described previously, it provides an opportunity for the reviewers to get a “real world” feel for the day-to-day range operations. During this period, the “on-site” staff interview questions are asked, and any final questions and comments from the committee are addressed. At the conclusion of the on-site, the review committee is required to give the range an “out-brief” of the new composite evaluation scores. Under most circumstances, if the range makes the required revisions, the range “passes” and becomes RCS certified at this point. If, however, the review committee requires closure on a few evaluation criteria, the range may resubmit any final corrections to the committee. Once the range has met the sufficient number of evaluation criteria to “pass” (see Appendix II), the review committee issues a final report to the RCC/SMSG Chair with a copy to the range. This report provides the final composite grades and concludes with a statement that the range has passed sufficient criteria to become “Z-540 RCS certified.” The final range book Certification Report issued by the review committee also becomes a permanent part of the range book (in Section 5) at the conclusion of the review.

2.4 Organizing the RCS Range Book to Comply with the Evaluation Criteria

The following provides suggested guidelines for the construction of the RCS Range Book documentation. The goal is to maintain consistency in the layout of the documentation from range to range, thus reducing the time needed to review and assess compliance to the Z-540 standard. Although Appendix I provides a detailed description of the layout of a typical range book, there are several lessons learned in the construction of the first three DoD RCS Demonstration Program range books that are worth sharing. We hope range managers pay attention to these lessons so that ranges desiring certification in the future do not repeat the same mistakes encountered by AFRL and NAWC-AD during the DoD RCS Demonstration Program.

As stated many times earlier, the main goal of the range book is to create and organize the RCS system documentation into a useful format independent of the type used by the RCS range performing the measurements. While there is a great deal of latitude granted to the range organizing the information, we must be mindful of the time constraints of the range book reviewers. AFRL and NAWC-AD’s Atlantic Test Range had the unfortunate disadvantage of having their range books written before the evaluation criteria were formally released. It also meant that AFRL and NAWC-AD had many mid-review revisions to accomplish because their range books were not organized in exact line with the evaluation criteria.

The 46 Test Group (46TG) RAMS VHF/UHF Measurement Systems (RVUMS) drafted their initial range book much more efficiently. The book sections display specific chapters of information directly in parallel with the evaluation criteria (i.e., criteria 10.1: Does the range have documented system-wide calibration procedures?). The RVUMS range book listed each evaluation criteria, followed immediately by the information needed to address the criteria. By organizing in this manner, the 46TG made their range book sections considerably shorter in total length, and much more focused to the points of the evaluation criteria. This subtle change greatly reduced the time needed by the third party reviewers to evaluate the range book.

2.5 The Range Book Reviewers

The range book reviewers are volunteer experts from Government, academia, or industry who have documented experience in RCS measurements. The entire certification process is centered on the concept of a third party peer review. Consistent with ISO practices, the reviewers are specialists who understand the technical details of RCS ranges. In the earlier DoD RCS Demonstration Program, no DoD employees were used as reviewers to avoid the appearance of conflict of interest. Reviewers for the three DoD demonstration ranges (Figure 2-1) came from Boeing Phantom Works, Northrop Grumman, EG&G, Syracuse Research Corp., Mission Research Corp., and the National Institute of Standards and Technology (NIST).

The process of becoming an RCS Range Book reviewer is straightforward. Those interested in becoming reviewers, must prepare two documents: (1) a one-page resume of RCS design and/or measurement experience demonstrating a minimum of five years of relevant experience in RCS measurements, and (2) a corporate letter of commitment from the applicant reviewer's employer stating that the reviewer may participate in two range reviews in three years, and that release time will be granted the reviewer to support the on-site range reviews. The resume and corporate commitment letter are transmitted to the RCC/SMSG Radar Committee Chair. (As of the date of this publication, the Radar Committee Chair is Mr. John Lewis, NAWC-AD, tel. # 301-342-1193, e-mail lewisja@navair.navy.mil.) The Radar Committee Chair reviews and approves the resume with the SMSG Radar Committee. The applicant reviewer's name is then added to the pool of RCS reviewer candidates available for range book reviews, as discussed previously in this report. An applicant reviewer is selected for a specific range book review based on two main criteria: (1) the schedule availability of the reviewer for a specific review period, and (2) the lack of any perceived or financial conflict of interest between a reviewer and the range under review.

One may ask, "Why be a reviewer?" Anyone with an interest and technical background in RCS measurements is strongly encouraged to volunteer to be a reviewer. For ranges anticipating RCS certification in the future, it is strongly recommended that at least one person from that organization volunteer to be a reviewer for another range. To avoid inefficient, small-dollar money transfers between companies in the industrial RCS certification program, we have operated on the quid-pro-quo foundation that if a range wants to be reviewed (certified), it should be prepared to review (certify) another range. In this manner, solid RCS experience and best practices will migrate throughout the RCS measurement industry, raising both the overall quality of measurement practices while instilling "generally accepted measurement practices" throughout the RCS measurement industry.

CHAPTER 3

FUTURE RCS CERTIFICATION REQUIREMENTS

3.1 General

The primary emphasis of the DoD RCS Demonstration Program was to improve the quality of RCS data acquired at DoD RCS ranges. The program was designed to show both industry and the government ranges that this was a worthwhile, value-added quality assurance initiative. Presently, there are no DoD requirements to obtain RCS certification. However, beginning on January 1, 2004, all industrial RCS measurement facilities supplying deliverable RCS data to the Air Force Research Laboratory will be required to obtain RCS data on a certified RCS measurement range. Thus, the voluntary aspect of range certification will quickly revert to a requirement in 2004 for much of the RCS measurement industry. This is more than sufficient time for most ranges to create an RCS Range Book in accordance with Z-540. In addition, there is much documentation available from the demonstration program that can help any range quickly come up to speed on the certification process. Since industry is actively working to comply, it only makes sense for the remaining U.S. Army, Navy, and Air Force facilities performing RCS measurements to comply with the Z-540 certification requirements as well.

3.2 Certifying to Z-540

Certifying an RCS range to the Z-540 standard is an excellent approach to organizing, maintaining, and presenting RCS range information. Any RCS Range Book that passes the third party review to become “certified” will produce a document useful to the range and range customer alike. In addition, it will permanently capture critical process information that is retained by the range even as personnel turn over or are assigned to other duties.

We believe that with the overall emphasis on quality systems and ISO 9000 in the commercial sectors, Z-540 (ISO-25) is an appropriate technical standard for RCS measurement facilities. Certifying RCS ranges to this standard should greatly reduce measurement errors and generally improve the operational efficiencies of all RCS ranges. In addition, certification will allow a range to assemble, in one paper document or internal web-site, all the relevant information needed to operate an RCS measurement facility. This should help a range to sustain measurement quality during periods of personnel turnover, since the processes and procedures will be there even after the employee(s) has left. In light of career mobility, and a national aging technical workforce, this benefit alone should be a powerful incentive for any organization to get and stay RCS certified.

3.3 RCS Certification

Probably the most surprising aspect of the DoD RCS Demonstration Program is how robust the initial draft RCS certification process turned out to be. Despite early teething problems and the need to train the RCS reviewers on the process, in the end the evaluators and

ranges both agreed the process was fair, impartial, and value added. In addition, an examination of the review process (as a whole) and the individual evaluation criteria after the Advanced Compact Range (ACR) and Atlantic Test Range (ATR) reviews revealed that only minor changes to the RCS certification process were needed. For this reason, the RCS industrial certification program is nearly identical to the DoD program recently completed.

As for side benefits, AFRL and ATR range personnel who participated in the DoD RCS Demonstration Program remarked how much easier it was to find often-used information within the structure of their revised range books, as opposed to the prior “ad hoc” random access methods. As mentioned earlier, with the measurement community getting older, smaller, and more mobile, the resulting consolidation of documentation should help alleviate training and sustainment problems due to personnel turnover, thereby helping a range sustain its high-quality measurement efforts.

With more attention being paid within DoD to ISO 9000-like processes, the DoD RCS Demonstration Program for RCS certification is a relevant way for a range to preemptively hold off management dictates concerning quality processes. The RCS review process works, and the results make creating the range book worth the effort. It is our collective opinion that it’s time for this RCS certification effort to become the norm. Our RCS customers will only expect quality to improve in the future, and it’s our job to deliver the promise.

3.4 The Future for Z-540

Another conclusion of the DoD RCS Demonstration Program was that its certification approach is general. There is nothing about Z-540 that restricts the work to radio frequency RCS ranges. The processes and procedures are general enough to cover all types of scientific measurements, including laser cross section, infrared emissions and emissivity testing, radio frequency property of materials testing, antenna testing, pressure and temperature testing, and so forth. If government laboratories and measurement facilities hope to continue to sustain the finest test capability possible for supporting DoD’s future weapons system test and evaluation requirements, the Z-540 standard should be looked at in a broader context for application to these other diverse measurement problems.

It is clear to the RCC/SMSG Radar Committee that this standard may revolutionize the way DoD maintains and documents its in-house test capabilities. We strongly recommend that the RCC look for other opportunities and measurement system applications for Z-540 to establish and document quality systems for all technical measurement systems used in support of the acquisition of future U.S. military hardware.

APPENDIX I

RCS RANGE BOOK FORMAT

APPENDIX I

RCS RANGE BOOK FORMAT

1.0 Introduction

This appendix contains guidelines for the construction of the RCS Range Book used to document range characteristics and procedures in compliance with RCS range certification requirements. We describe a common organization for range documentation based on ANSI/NCSL Z-540-1-1994 Standard [2] (referred to herein as Z-540) and discuss the material the range book should contain. Within each range book section, however, company format may be used at the discretion of the individual range. In this manner, substantial costs for reformatting information is avoided, while at the same time the range books will have the same overall organization from range to range.

RCS ranges may consider developing their range books as electronic documents rather than as paper documents. While a conventional paper copy certainly meets all requirements of Z-540, an electronic version available on a network server or CD-ROM may be easier to develop and maintain.

The RCS Range Book should serve as an important general reference for range personnel and customers and will play an important part in the certification review. We believe that organizing range documentation and making it easy to access will produce better communications and more consistent practice within each range. Hence, great care should be exercised in developing and maintaining the range book.

2.0 RCS Range Book Outline

The range book is organized to parallel Part I of the Z-540 standard with additional sections added at the end to address important subsections of Z-540's Section 5. Table I-1 outlines the range book Table of Contents.

TABLE I-1
RCS RANGE BOOK
TABLE OF CONTENTS

SECTION	TITLE	PAGE
1	Introduction and Endorsement	
2	References	
3	Glossary	
4	Organization and Management	
5	Quality System, Audit, and Review	
6	Personnel	
7	Accommodation and Environment	
8	Equipment and Reference Materials	
9	Measurement Traceability and Calibration	
10	Calibration Methods	
11	Handling of Calibration Items	
12	Records	
13	Certificates and Reports	
14	Subcontracting of Calibration	
15	Outside Support Services and Suppliers	
16	Complaints	
17	Interrange Comparison Programs	
18	Data Processing Procedures	
19	Range-Specific Uncertainty Analysis	
20	Ongoing Research, Planned Improvements	

To aid in document maintenance, pages should be numbered by section. In addition to the main table of contents, each section may begin with a brief section table of contents listing the titles of the major subsections, and most importantly, the date of the most recent revision. A sample section table of contents is shown in Table I-2.

TABLE I-2	
SECTION TABLE OF CONTENTS	
SECTION 10	
CALIBRATION METHODS	
Last Revised: 23 July 1997	
CONTENT	PAGE
General Description	10-1
Measurement Procedures	10-2
Calibration Procedures	10-8
List of Calibration Objects	10-14
Monostatic Calibration Tables	10-15
Nominal Calibration Results – Rotators	10-17
Nominal Calibration Results – Foam	10-19
Uncertainty Policy, Estimation Procedures	10-21

3.0 Range Book Content

The following provides guidelines for the construction of the range book in accordance with ANSI/NCSL Z-540-1-1994. Before submitting a range book for review, range book authors should use the evaluation criteria in Appendix II to perform a “self review” of each section. The evaluation criteria will be used by the RCS Certification Review Committee to grade the range book.



While there is a great deal of latitude granted to the range book authors, we must be mindful of the time constraints of the range book reviewers. To expedite the grading process for the reviewers, range book authors may list each evaluation criteria followed immediately by the information needed to address the criteria.

1 – Introduction and Endorsement (see Appendix II, Section 1, Evaluation Criteria): This section should contain a brief statement of compliance with the standards set by this document in accordance with ANSI/NCSL Z-540-1-1994, as well as a policy statement regarding the organization's commitment to continuous quality improvement. The range book should be signed as “approved” by an appropriate manager or director at or near the top of the chain of command of the range quality manager or technical lead engineer. The exact format and wording may be customized by the organization.

2 – References (see Appendix II, Section 2, Evaluation Criteria): This section should list the documents cited in the range book. In particular, it may be convenient to include stand-alone reports covering various aspects of range operations (operational security, measurement procedures, uncertainty analysis procedures, equipment documentation, etc.), which could be included in the range book by reference only.

3 – Glossary (see Appendix II, Section 3, Evaluation Criteria): This section should list and define the specialized terms and acronyms used in the range book. All acronyms should be defined upon first use. Specialized terms related to the acquisition and processing of RCS data should also be defined. The information in this section should aid the reviewers in translating technical jargon from the body of the report.

4 – Organization and Management (see Appendix II, Section 4, Evaluation Criteria): This section should fully define the organization that is chartered to operate the range. The management hierarchy from the range line technicians and engineers up through the highest levels of range management should be defined. Lead personnel and approved signatories should be identified. The range quality manager and technical managers *must be identified*. Ideally, work phone numbers should be available for all critical range personnel. Standard company organization charts are acceptable. Also, a policy statement on customer confidentiality and or proprietary rights protection must be included here.

5 – Quality System, Audit, and Review (see Appendix II, Section 5, Evaluation Criteria): The purpose of this section is to ensure that a complete overview of the company quality system and self-auditing process is provided. This section should contain procedures for the control and maintenance of documentation, arrangements for ensuring that the range reviews all new work to ensure that it has the appropriate facilities and resources before commencing such work, management arrangements for permitting departures from documented policies and procedures or from standard specifications, procedures for protecting confidentiality and proprietary rights, procedures for audit and review, procedures for a management quality audit at least once a year, procedures for documentation of all audit processes, and procedures for tracking and monitoring the quality of the primary RCS calibration data. The RCS Certification Review Committee's Certification Report should be attached here upon completion of the certification review process.

6 – Personnel (see Appendix II, Section 6, Evaluation Criteria): This section should contain the qualifications of all personnel assigned to the range. Specialized training, training certificates, or other range-related qualifications should appear in this section. Company or resume format may be used. If an organization, due to personnel policy or union concerns, treats their records as

“company sensitive” or “company confidential,” the range book should so state, and indicate what individual and organization has these records, and who has the right to review and update them. It is the responsibility of the range to certify that their staff has the qualifications to do their jobs. Updated training records are one indicator of the currency of training. If the reviewers are not allowed to see these records, the range technical manager may certify, in a signed statement herein, that such records exist in a remote location, and that these records demonstrate that the employees meet the minimum qualification standards for their respective jobs.

7 – Accommodation and Environment (see Appendix II, Section 7, Evaluation Criteria): This section should document the range environment as well as any and all parameters of the range environment that may affect the outcome of measurements, and thereby should be monitored. Some environmental variables that could affect radar cross section measurements include: electromagnetic interference, temperature variations, mechanical vibrations, and seasonal variations in vegetation, sea state, moisture levels, winds, precipitation, inversions, etc. (Depending on the complexity of the range, this section may or may not be significant.)

8 – Equipment and Reference Materials (see Appendix II, Section 8, Evaluation Criteria): Configuration control is essential for maintaining a repeatable, quality RCS system. Therefore, this section of the range book may be one of the most significant. Here all electromechanical equipment that makes up the RCS range should be identified. References to appropriate equipment manuals should be given in sufficient detail so that a qualified technician can trace the major subsystems of the range. Maintenance and calibration histories should be kept for critical components, and complete system configuration should be tracked. The procedures for identifying equipment, maintenance, and configuration control should be documented here. Personnel responsible for following these procedures should be clearly identified. For electronic (digital/internet) range books, it is not essential to include an electronic version of critical range equipment. However, the titles and exact locations of the referenced documents must be included.

9 – Measurement Traceability and Calibration (see Appendix II, Section 9, Evaluation Criteria): This section should complement Section 8 as it specifically relates to primary RCS calibration. The range will document its calibration program that ensures that all equipment critical to RCS measurement calibrations operates within certified performance limits. Equipment and system calibration intervals should be clearly established. Whenever possible, traceability of system components and of total system calibration to a national standard should be maintained. Calibration certificates and reports should be referenced. System configuration used in RCS calibrations should be tracked using the method documented in Section 8. The system configuration used in interrange comparisons should be clearly documented together with the results of calibration comparisons. System components tracked under Section 8 need only be referenced here.

10 – Calibration Methods (see Appendix II, Section 10, Evaluation Criteria): Both measurement and calibration procedures should be fully documented. Separate documentation should be available for wideband calibration and measurement procedures, monostatic and bistatic (multistatic) procedures, and polarimetric (reciprocal or nonreciprocal) calibration procedures.

Procedures for deriving or assigning an RCS value to a primary target through the use of “transfer” calibration standards should be documented in this section. Calibration and measurement results to support the validity of procedures used should be displayed or referenced. The validity of such results should be supported by stated uncertainty bounds obtained through well-defined uncertainty procedures appropriately referenced. Calibration intervals should be clearly established.

11 – Handling of Calibration Items (see Appendix II, Section 11, Evaluation Criteria): This section should summarize how primary calibration items are protected during storage, handling, and use. Mechanical tolerance certificates or techniques for verifying tolerances of primary standards are appropriately placed in this section.

12 – Records (see Appendix II, Section 12, Evaluation Criteria): This section describes the range's procedures for creating and maintaining records of all aspects of range operations. Procedures for maintaining calibration records, measurement records, system configuration, etc. are especially important. Procedures to record interrange comparison results should be clearly defined.


13 – Certificates and Reports (see Appendix II, Section 13, Evaluation Criteria): This section should define the standard reporting formats used by the ranges when reporting RCS measurements to customers. While any report can be specialized to the requirements of the customer, this section should provide the baseline information that will always be available in a test report. A range may use its own format, provided that the minimum information required by the Evaluation Criteria in Appendix II, Section 13, is included.

14 – Subcontracting of Calibration (see Appendix II, Section 14, Evaluation Criteria): This section details aspects of the RCS calibration process that are subcontracted. All subcontracted work must satisfy the standards set by this document in accordance with ANSI/NCSL Z-540-1-1994. The main intent of this section is to address calibration activities sent to locations or personnel not located on-site within the range facility. When on-site contractors share complete responsibility for operating a range facility, as is often the case, we refer to this situation as an integrated product team. For example, AFRL hires an on-site contractor to assist in range operations. This is not considered subcontracting. However, if a primary range relies on an off-site secondary RCS range for calibration data or other measurements applicable to the primary range, this situation would be treated as a subcontracted measurement, and Section 14 would apply. For most ranges, these criteria probably will not apply.

15 – Outside Support Services and Suppliers (see Appendix II, Section 15, Evaluation Criteria): This section should document any services or suppliers used to produce calibrated RCS data. This section complements Section 14. For instance, if a range purchases an 8-inch calibration sphere from a vendor for primary calibration, this section would document the needed tolerances of such a standard, as well as the delivered tolerance of the calibration item. As an additional example, if radar absorbing material (RAM) is used on a calibrated target measurement and absolute RCS data is reported, it would be appropriate to create records of where the RAM was purchased, what characteristics were expected and delivered, and what, if any, repeatability would result from reusing the same material samples on the same target location.

16 – Complaints (see Appendix II, Section 16, Evaluation Criteria): This section should document the formal complaint procedure used to resolve disputes between the range and the customer. The complaint record keeping system also should be defined or referenced here.

17 – Interrange Comparison Programs (see Appendix II, Section 17, Evaluation Criteria): This section shall include the company policy regarding interrange comparisons. Records of participation in calibration interrange comparisons, the results obtained, and conclusions drawn from such studies are to be presented or referenced here. If the information is already included in Section 10, a reference to Section 10 is adequate. It is expected that interrange comparisons will be used regularly to improve measurement and calibration quality at the range. An interrange comparison schedule should be provided.

 <p>NOTE</p>	Participation in a national interrange comparison study is required for certification.
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Publication of interrange comparison results is strongly encouraged, and such publications should be referenced here. Procedures to record interrange comparison results should be clearly defined.

18 – Data Processing Procedures (see Appendix II, Section 18, Evaluation Criteria): Important details of processing measurement and calibration data should be documented here. Sample results of processing should be included. Standard data processing procedures should be referenced, and the validity of innovative processing should be documented. To evaluate the validity of its data processing procedures, the range should use a standard data set acceptable to the RCS industry. This standard data set should be used by the range to perform interrange comparison of its processing algorithms with those used by other ranges. This section should strongly support and complement the material in Section 17 above.

19 – Range-Specific Uncertainty Analysis (see Appendix II, Section 19, Evaluation Criteria): Policies and procedures for establishing range uncertainties need to be completely documented or referenced here. A sample uncertainty table together with system parameters or other adequate uncertainty method should be linked or available in this section. One approach to satisfy this requirement is the “Report of Measurement” described in [15]. Any system parameters should be displayed here. Any scientifically-based uncertainty analysis is acceptable, providing all appropriate assumptions and/or exclusions regarding the parameters comprising the analysis are clearly documented.

20 – Ongoing Research, Planned Improvements (see Appendix II, Section 20, Evaluation Criteria): The purpose of this section is to briefly summarize the three-year look ahead regarding any range research and/or other activities designed to improve range data quality, efficiency, repeatability, or traceability. A list of desirable research areas to be conducted in the future to improve specific and known deficiencies on the range or in the RCS industry should also be provided, as well as a single top-level roadmap. Ongoing plans for future upgrades of equipment

should be included. Such research information will allow customers to quickly identify and evaluate ongoing range improvements in the context of their current or planned use of the range. It also may offer the customer an opportunity to cost share or jointly sponsor range research of interest to the customer.

4.0 Summary

The RCS Range Book will be reviewed by the RCS Certification Review Committee and graded according to the evaluation criteria in Appendix II. Once completed, it is the responsibility of the range to keep the range book current. Fortunately, as mentioned previously, this will involve revising individual sections only, as needed. Since the book is numbered by section, it is modular in design, making updates a fairly straightforward process.

APPENDIX II

**EVALUATION CRITERIA
FOR
RCS RANGE BOOK**

APPENDIX II

EVALUATION CRITERIA FOR RCS RANGE BOOK

1.0 Background

This appendix summarizes a joint in-house research and development activity performed by the Air Force, Navy, Range Commanders Council, and the National Institute of Standards and Technology (NIST)¹. From 1997-1999, the Range Commanders Council Signature Measurement Standards Group (RCC/SMSG) and NIST worked on a joint Department of Defense (DoD) RCS Demonstration Program of a new radar cross section measurement range quality documentation standard based on the American National Standards Institute/National Calibration Standards Laboratory ANSI/NCSL Z-540-1-1994 Standard [2] (referred to herein as Z-540) as customized to the measurement of radar cross section.

2.0 Executive Summary

The purpose of the DoD RCS Demonstration Program was to improve the long-term quality of radar cross section measurement data taken in the United States by implementing a rigorous and uniform range system documentation standard for all facilities supplying RCS data to the Department of Defense. At the initiation of this demonstration program, it was decided that the commercial standard ANSI/NCSL Z-540-1-1994 was an appropriate structure to use in organizing and presenting this range documentation standard. The DoD facilities participating in this demonstration program were the Air Force Research Laboratory, USAF 46th Test Group, and the Navy's Dynamic Air RCS Measurement Facility². These facilities agreed to organize their range documentation around a quality standard written by the National Institute of Standards and Technology (NIST) and the Air Force Research Laboratory titled Quality Assurance Handbook For Radar Cross Section. For simplicity, the range documentation is now referred to as the RCS Range Book, the definitive document on the operations of the RCS range facility.

As part of the DoD RCS Demonstration Program, the three participating ranges agreed to have their range books reviewed by an outside third party review panel. This review panel consisted of three experienced and qualified individuals from the RCS measurement community. The reviewer's job was to assess how well the range books complied with the draft national quality assurance standard.

¹ Signature Technology Office, Air Force Research Laboratory (AFRL), Wright Patterson Air Force Base; Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland; Signature Measurement Standards Group of the Range Commanders Council (RCC/SMSG); and the National Institute of Standards and Technology (NIST), Boulder, Colorado.

² Advanced Compact Range, Wright Patterson Air Force Base (WPAFB), OH; RAMS Facility, Holloman Air Force Base (HAFB), NM; and Atlantic Test Range, Naval Air Warfare Center, Patuxent River, MD

The purpose of this appendix is to assist the range book reviewers and the ranges by providing a section-by-section set of evaluation criteria for use in the range review process. The original quality assurance standard identified 20 distinct chapters of information needed to comply with the intent of the Z-540 standard. This shorter version matches specific evaluation criteria with each of these sections using a loose checklist-like format.

As with the range book, these evaluation criteria were drafted to help evaluate the quality of the range books in accordance with the Z-540 standard. If the reader finds areas where these criteria can be improved or simplified, we welcome your comments. Please send any comments to the Air Force Research Laboratory Signature Technology Office, Attn: Dr. Brian Kent, brian.kent@wpafb.af.mil or fax 937-656-7074.

RCS RANGE BOOK
CERTIFICATION REPORT

GRADING AND PASSING CRITERIA

GRADING CRITERIA

The following scale applies to ALL grading criteria:

S = Fully Satisfactory - meets or exceeds standard (no reviewer comments required)

N = Needs Improvement - marginally satisfactory but needs improvement
(marginally meets standard but may be improved using mandatory reviewer comments as guidance)

U = Unsatisfactory - (does not meet standard and should be redone using mandatory reviewer comments as guidance)

N/A = Not Applicable - (reviewer comments needed if the reason for the N/A grade is not obvious)

All range books will be graded by three reviewers. **Composite grades**, defined as the combined grades from the three reviewers, will be derived as follows:

<u>Individual Grades from the Three Reviewers</u>	<u>Composite Grade</u>	<u>Reviewer Comments</u>
S,S,N -or- S,S,U	S	N or U minority comments required
S,N,N -or- S,N,U -or- N,N,U	N	N or U comments required
S,U,U -or- N,U,U -or- U,U,U	U	majority comments required

PASSING CRITERIA

Each range book section carries a priority based on the impact it has on the quality, accuracy, and repeatability of RCS range measurements. The range book sections have been divided into the following priorities:

Priority 1 - Sections 9, 10, 11, 17, 18, and 19

Priority 2 - Sections 5, 8, 13, and 20


Priority 3 - Sections 1, 2, 3, 4, 6, 7, 12, 14, 15, and 16

A **PASSING** Certification Report shall meet **all** the following criteria:

The **Priority 1** sections altogether shall receive a minimum composite grade of 85% Satisfactory (S). The balance shall be graded Needs Improvement (N); no Unsatisfactory (U) grades are allowed (e.g., 87%S and 13%N passes the Priority 1 criteria).

The **Priority 2** sections altogether shall receive a minimum composite grade of 75% Satisfactory (S) and not more than 10% Unsatisfactory (U) with the balance being Needs Improvement (N) (e.g., 77%S, 8%U, and 15%N passes the Priority 2 criteria).

The **Priority 3** sections altogether shall receive a minimum composite grade of 65% Satisfactory (S) and not more than 20% Unsatisfactory (U) with the balance being Needs Improvement (N) (e.g., 69%S, 18%U, and 13%N would pass the Priority 3 criteria).

 <p>NOTE</p>	"N/A" grades are excluded from the percentage count. Standard round-up techniques will be used (i.e., 84.5%=85%, 84.49%=84%).
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A final grade will be assigned to the overall Certification Report which will be either:

PASSING
or
REVISION REQUIRED BEFORE PASSING

A Certification Report receiving a **PASSING** grade will have met all the grading criteria above. A report receiving the **REVISION REQUIRED BEFORE PASSING** grade may be upgraded to **PASSING** upon closure of the requisite number of graded items that are under the passing criteria. Note that at the conclusion of the on-site review, the review committee will share with the range where it stands at that point and will give the range ample opportunity to respond to issues. If closure of these issues takes longer than 30 days, the range may ask for an additional 30-day extension to correct the requisite number of outstanding issues.

RCS RANGE BOOK **EVALUATION CRITERIA**

SECTION 1 – INTRODUCTION AND ENDORSEMENT (PRIORITY 3)

This section should contain a brief statement of compliance with the standards set by this document in accordance with ANSI/NCSL Z-540-1-1994, as well as a policy statement regarding the organization's commitment to continuous quality improvement. The range book should be signed as “approved” by an appropriate manager or director at or near the top of the chain of command of the range quality manager or technical lead engineer. The exact format and wording may be customized by the organization.

Evaluation Criteria:

- 1.1: Does the range book identify the host organization?
- 1.2: Is the endorsement signed by an appropriate manager or director who has the responsibility and authority to direct changes and corrections should range or product deficiencies be found?
- 1.3: Is there a clear commitment to quality in the introduction and endorsement?
- 1.4: On-site Review: Ask to meet the endorser. Is the endorser clearly committed to the quality process?

SECTION 2 - REFERENCES (PRIORITY 3)

This section should list the documents cited in the range book. In particular, it may be convenient to include stand-alone reports covering various aspects of range operations (operational security, measurement procedures, uncertainty analysis procedures, equipment documentation, etc.), which could be included in the range book by reference only.

Evaluation Criteria:

- 2.1: Does the range book include a list of documents and references external to the range book?
- 2.2: Are all references unambiguous enough to identify the documents?
- 2.3: Are the documents listed cross-referenced or linked to the appropriate range book section?
- 2.4: On-site Review: Ask to see five documents at random on the list.


SECTION 3 – GLOSSARY (PRIORITY 3)


This section should list and define the specialized terms and acronyms used in the range book. All acronyms should be defined upon first use. Specialized terms related to the acquisition and

processing of RCS data should also be defined. The information in this section should aid the reviewers in translating technical jargon from the body of the report.

Evaluation Criteria:

- ___ 3.1: Does the range book contain an appropriate glossary?
- ___ 3.2: Do acronyms (jargon) occur in any range book section that are not defined (immediately) in that section or listed here in the glossary?
(No On-site Review Criteria)

 <p>NOTE</p> <p><u>Reviewers:</u> Please list any undefined acronyms below.</p> <hr/> <hr/> <hr/> <hr/>

 <p>NOTE</p> <p><u>Range Book Authors:</u> After review, please include in the glossary any acronyms or terms identified by reviewers as undefined.</p>

SECTION 4 – ORGANIZATION AND MANAGEMENT STRUCTURE (PRIORITY 3)

This section should fully define the organization that is chartered to operate the range. The management hierarchy from the range line technicians and engineers up through the highest levels of range management should be defined. Lead personnel and approved signatories should be identified. The range quality manager and technical managers *must be identified*. Ideally, work phone numbers should be available for all critical range personnel. Standard company organization charts are acceptable. Also, a policy statement on customer confidentiality and or proprietary rights protection must be included here.

Evaluation Criteria:

- ___ 4.1: Does the range book contain a complete chain of command or organizational chart of the range?
- ___ 4.2: Does the range identify a range technical manager?
- ___ 4.3: Does the range identify the range quality manager?
- ___ 4.4: Does the range identify the management chain from the technician level to the highest

- level of the organization?
- ___ 4.5: Does the range quality manager have direct and unfettered access to the individual signing the endorsement in Section 1, Introduction and Endorsement?
 - ___ 4.6: Is there a clear policy on non-disclosure and/or company proprietary data or information?
 - ___ 4.7: If range operators, engineers, and/or technicians are from a different organization or company than the range owners, are the respective roles and responsibilities of the two organizations and their interfaces clearly spelled out?
 - ___ 4.8: Are personnel qualifications available or referenced in other range book sections?
 - ___ 4.9: In cases of absence, are alternate technical and quality managers identified?
 - ___ 4.10: On-site Review: Ask range technicians to identify the technical and quality managers.
 - ___ 4.11: On-site Review: Ask the quality manager if he/she has direct access to the endorser of Section 1.
 - ___ 4.12: On-site Review: Check to see whether the range technicians and engineers know who the primary and alternate technical and quality managers are.
 - ___ 4.13: On-site Review: Is the range supervision done by person(s) familiar with the calibration methods and procedures, the objective of the calibration, and how to assess the results?

SECTION 5 - QUALITY SYSTEM, AUDIT, AND REVIEW (PRIORITY 2)

The purpose of this section is to ensure that a complete overview of the company quality system and self-auditing process is provided. This section should contain procedures for the control and maintenance of documentation, arrangements for ensuring that the range reviews all new work to ensure that it has the appropriate facilities and resources before commencing such work, management arrangements for permitting departures from documented policies and procedures or from standard specifications, procedures for protecting confidentiality and proprietary rights, procedures for audit and review, procedures for a management quality audit at least once a year, procedures for documentation of all audit processes, and procedures for tracking and monitoring the quality of the primary RCS calibration data. The RCS Certification Review Committee Certification Report should be attached here upon completion of the certification review process.

Evaluation Criteria:

- ___ 5.1: Does the range book contain a top management quality statement here or in Section 1?
- ___ 5.2: Are appropriate organizational charts in place here or in Section 4?
- ___ 5.3: Are the roles and responsibilities of management, technical operations, support services, and quality systems identified here or in Section 4?
- ___ 5.4: Does the range book describe how documents are controlled and referenced?
- ___ 5.5: Does the range have a process to assess whether it has the technical capability and resources (schedule time) to accept new work?
- ___ 5.6: Is there a clearly established policy and process when measurement discrepancies are seen or departures from documented policies and procedures occur?
- ___ 5.7: Is there a management policy for permitted departures from documented policies?
- ___ 5.8: Are periodic review processes documented?



The RSC Certification Review Committee Certification Report should be attached here upon completion of the review process.

- ___ 5.9: Is the range policy for establishing and changing calibration intervals documented for systems or equipment it controls?
- ___ 5.10: Are the range's internal (annual) and external (every three year) audit processes documented? Have previous audit deficiencies been corrected by the next annual audit?
- ___ 5.11: Was a management quality audit performed within the previous 12 months?
- ___ 5.12: Are previous audits and their findings a permanent part of the range book?
- ___ 5.13: Does the range have a process for tracking and monitoring the quality of the primary RCS calibration data for calibration artifacts used in the normal measurement process? Is there a day-to-day pass/fail check criteria established for calibration measurements? Have the results been verified, either through repeated measurements, interrange comparisons or both?
- ___ 5.14: On-site Review: Ask range technicians what the pass/fail criteria for calibration is.
- ___ 5.15: On-site Review: Ask range technicians what is done if calibrations depart from expectations.
- ___ 5.16: On-site Review: Review internal range process of assessing new work (or a new customer requirement). Is it complete? Can it easily be provided to a customer on request?

SECTION 6 - PERSONNEL (PRIORITY 3)

This section should contain the qualifications of all personnel assigned to the range. Specialized training, training certificates, or other range-related qualifications should appear in this section. Company or resume format may be used. If an organization, due to personnel policy or union concerns, treats their records as "company sensitive" or "company confidential," the range book should so state, and indicate what individual and organization has these records, and who has the right to review and update them. It is the responsibility of the range to certify that their staff has the qualifications to do their jobs. Updated training records are one indicator of the currency of training. If the reviewers are not allowed to see these records, the range technical manager may certify, in a signed statement herein, that such records exist in a remote location, and that these records demonstrate that the employees meet the minimum qualification standards for their respective jobs.

Evaluation Criteria:

- ___ 6.1: Does the range employ an appropriate mix of technician, engineering, and management personnel with appropriate experience to perform their assigned functions?

- ___ 6.2: Does the range have a formal training program, and if so, are records kept up to date?
Is the training offered sufficient to ensure or maintain technical competence?
- ___ 6.3: Are the training records available to range management?



These records do not have to reside in the range book but must be identified by location.

- ___ 6.4: On-site Review: Ask to locate the personnel training records of 6.3.

SECTION 7 – ACCOMMODATION AND ENVIRONMENT (PRIORITY 3)

This section should document the range environment as well as any and all parameters of the range environment that may affect the outcome of measurements and thereby should be monitored. Some environmental variables that could affect radar cross section measurements include: electromagnetic interference, temperature variations, mechanical vibrations, and seasonal variations in vegetation, sea state, moisture levels, winds, precipitation, inversions, etc. (Depending on the complexity of the range, this section may or may not be significant.)

Evaluation Criteria:

- ___ 7.1: Are the measurement environmental factors specified for acceptable operations (e.g., allowable wind speeds, temperature variations, etc.)?
- ___ 7.2: Are appropriate environmental parameters recorded as a part of the test process?
- ___ 7.3: On-site Review: Are the environmental factors identified being recorded in a log or with the data? For recorded environmental measurements, review such data and operations with range technicians.
- ___ 7.4: On-site Review: Is there any measurement data showing system stability or repeatability versus stated control values for environmental variations? (In other words, are the factors in 7.1 derived based on data and if so, what data?)

SECTION 8 – EQUIPMENT AND REFERENCE MATERIALS (PRIORITY 2)

Configuration control is essential for maintaining a repeatable, quality RCS system. Therefore, this section of the range book may be one of the most significant. Here all electromechanical equipment that makes up the RCS range should be identified. References to appropriate equipment manuals should be given in sufficient detail so that a qualified technician can trace the major subsystems of the range. Maintenance and calibration histories should be kept for critical components, and complete system configuration should be tracked. The procedures for identifying equipment, maintenance, and configuration control should be documented here. Personnel responsible for following these procedures should be clearly identified. For electronic

(digital/internet) range books, it is not essential to include an electronic version of critical range equipment. However, the titles and exact locations of the referenced documents must be included.

Evaluation Criteria:

- ___ 8.1: Does the range have a list, data base, or other log or configuration control method for identifying and tracking the main range equipment systems and subsystems?
- ___ 8.2: For any range equipment identified in 8.1, is a maintenance schedule identified for periodic or preventative maintenance?
- ___ 8.3: Is there any evidence the equipment maintenance schedules are being followed (i.e., last “check-on” date, maintenance logs, etc.)?
- ___ 8.4: For major range systems or subsystems, are maintenance procedures clearly identified either in a reference manual or a printable procedure?
- ___ 8.5: Is any individual equipment in the range system identified as to whether its internal calibration status affects the level of range RCS calibrations? (This requirement is N/A if end-to-end system calibration is performed as a routine practice at the range.)
- ___ 8.6: For any equipment identified in 8.5, is the calibration status and interval of said equipment marked or displayed on the equipment? (If 8.5 is N/A, this section is N/A.)
- ___ 8.7: Is there an appropriate reference manual for each piece of range equipment identified in 8.1? (This requirement may be satisfied with a data base or listing cross-referencing the equipment with its manual and its exact physical location when not in use.)
- ___ 8.8: Does the document and equipment log show the name and current location of the equipment?
- ___ 8.9: Does the document(s) show the maintenance history of these pieces of equipment?
- ___ 8.10: Does the document show a history of damage, malfunction, modification, or repair of the items?
- ___ 8.11: If automated testing is used to verify subsystem performance (e.g., loop test modes, automated power supply monitoring, etc.), are non-compliant loop tests documented and corrected (or noted) prior to system use?
- ___ 8.12: On-site Review: Select, at random, five pieces of equipment from the log of 8.1 above. Can the pieces of equipment be located?
- ___ 8.13: On-site Review: Ask to see the maintenance procedures (if applicable) for those pieces of equipment. Are they up to date?
- ___ 8.14: On-site Review: Ask to see the reference manuals for the five pieces of equipment selected. Are the manuals readily available? Were those manuals found in the locations stipulated in the range book?
- ___ 8.15: On-site Review: For the five pieces of equipment selected, is there a historical log kept on damage, repair, or recalibration (if appropriate)?

SECTION 9 – MEASUREMENT TRACEABILITY AND CALIBRATION (PRIORITY 1)

This section should complement Section 8 as it specifically relates to primary RCS calibration. The range will document its calibration program that ensures that all equipment critical to RCS measurement calibrations operates within certified performance limits. Equipment and system calibration intervals should be clearly established. Whenever possible, traceability of system components and of total system calibration to a national standard should be maintained. Calibration certificates and reports should be referenced. The system configuration used in RCS calibrations should be tracked using the method documented in Section 8. The system configuration used in interranging comparisons should be clearly documented together with the results of calibration comparisons. System components tracked under Section 8 need only be referenced here.

Evaluation Criteria:

- ___ 9.1: Does the range have an established and documented program to ensure that its calibration program supports the stated calibration performance of its RCS measurement system(s)?
- ___ 9.2: Is the RCS range calibration process traceable to a published (AMTA, IEEE, etc.) calibration artifact standard or other national standard (when developed)?
Under normal circumstances, RCS measurement systems are calibrated as a total “end-to-end” system. In special RCS test cases where specific end-to-end calibration measurements are not the norm, Sections 9.3, 9.4, and 9.5 must be addressed for these cases.
- ___ 9.3: Does the range measurement and calibration program include a top-level schedule for calibration intervals for each piece of test equipment used to assess system performance?
- ___ 9.4: Is there documentary evidence the top-level schedule (9.3) is being rigorously followed?
- ___ 9.5: Does the range have a documented program to monitor test equipment and/or calibration artifacts between scheduled calibrations and verifications?
- ___ 9.6: When the range participates in interranging comparisons (see 5.13), is the range RCS system configuration employed in those comparisons clearly documented?
- ___ 9.7: On-site Review: For the primary calibration artifacts, are sample “acceptable” calibrations or verification records available within the range book?

SECTION 10 – CALIBRATION METHODS (PRIORITY 1)

Both measurement and calibration procedures should be fully documented. Separate documentation should be available for wideband calibration and measurement procedures, monostatic and bistatic (multistatic) procedures, and polarimetric (reciprocal or nonreciprocal) calibration procedures. Procedures for deriving or assigning an RCS value to a primary target through the use of “transfer” calibration standards should be documented in this section. Calibration and measurement results to support the validity of procedures used should be

displayed or referenced. The validity of such results should be supported by stated uncertainty bounds obtained through well-defined uncertainty procedures appropriately referenced. Calibration intervals should be clearly established.

Evaluation Criteria:

- ___ 10.1: Does the range have documented system-wide calibration procedures?
- ___ 10.2: Does the range have documented system-wide measurement procedures customized to specific targets mounts used by the range, including pylon rotators (if applicable), foam columns (if applicable), air columns (if applicable), strings (if applicable), or other mounting techniques?
- ___ 10.3: Are separate calibration and measurement procedures for each major measurement system or for each type of measurement conducted available (e.g., wideband, monostatic, bistatic, etc.)?
- ___ 10.4: Are the calibration measurement procedures consistent with the accuracy required for each type of calibration measurement (as defined in the uncertainty analysis in Section 19)?
- ___ 10.5: Are the procedures for deriving or assigning RCS values for a measured target through the use of transfer standards documented?
- ___ 10.6: Are system-wide calibrations scheduled on an appropriate cycle for the measurement system. Is this cycle defined? Is there evidence they are being performed when scheduled? Are the results of system-wide calibrations included or referenced in this section? Are these calibrations provided to the customer as part of their normal data report?
- ___ 10.7: If sampling is included as a part of calibration or measurements, is documentation available that describes the procedures and applied statistical techniques employed (detailed data processing implementations may be provided/discussed in Section 18, if applicable)?
- ___ 10.8: Do the results of acceptable system-wide calibrations support the uncertainty bounds established in Section 19?
Computers are currently an integral part of every RCS range. Since computers are used to record, store, retrieve, and process information, certain processes, procedures, and documentation need to be made available to the operator. Normal user manuals are crucial, and on-line “help” features of commercial off-the-shelf (COTS) software will fulfill a large portion of the requirements to follow. Specialized software written exclusively for range data acquisition and processing requires equally thorough documentation.
- ___ 10.9: For (any) computer software used to acquire and/or store the raw radar data, are user manual(s) available, either as automated help files or as separate document(s) that describe the correct operation and use of the software? If the manual is not embedded in the range book, is the physical location of the documentation clearly identified?
- ___ 10.10: For computer software used to store (locally or on a network) or transmit from one network location to another, are appropriate users manuals and/or COTS help files available?
- ___ 10.11: Is there a data base or other appropriate tracking list of the computer program(s) that

- are used in the end-to-end data acquisition, transmission, and processing steps?
- ___ 10.12: For computer software used to process the raw data files into final data products, are appropriate user manuals and/or COTS help files available? (This requirement may be satisfied one of two ways: if specifically written users manuals have detailed specific examples, these can be used; or, if such specific examples do not exist, the requirement may be satisfied by appending sample “step-by-step” processes that, if followed, produce the final data products.)
 - ___ 10.13: Is there an assigned computer support and/or network administrator available to maintain computer equipment used in the range data acquisition and processing?
 - ___ 10.14: Is there a diagram of the local area network within the range, if applicable?
 - ___ 10.15: Are critical environmental and/or operating procedures monitored to maintain the stated calibration accuracy and/or stay within the published calibration uncertainty of Section 19?
 - ___ 10.16: Are there procedures that ensure security of the data to prevent the unauthorized or inadvertent access, manipulation, or destruction of computer data or records?



An approved network automated information system (AIS) or standard practices and procedures (SPP) plan will satisfy this requirement. If the AIS/SPP is not electronically available in the range book, its physical location must be precisely identified.

- ___ 10.17: On-site Review: Ask the range manager to perform a system-wide calibration. Verify that the documented procedures are followed by range technicians.
- ___ 10.18: On-site Review: Compare the results of the system-wide calibration with the historical records found in Sections 12, 13, and/or 19. Are the results within the stated calibration uncertainty limits?
- ___ 10.19: On-site Review: Ask a technician if the observed documented procedures are up to date. Ask when the procedures were last reviewed for completeness and accuracy.

SECTION 11 – HANDLING OF CALIBRATION ITEMS (PRIORITY 1)

This section should summarize how primary calibration items are protected during storage, handling, and use. Mechanical tolerance certificates or techniques for verifying tolerances of primary standards are appropriately placed in this section.

Evaluation Criteria:

- ___ 11.1: Does the range have a system for uniquely identifying primary calibration artifacts?
- ___ 11.2: Does the range have a system for assessing the mechanical tolerances and electrical conductivity of the primary calibration artifacts upon initial receipt? Are visual inspections performed on the calibration artifacts as part of the calibration process? Is there a stated procedure for reacting to artifacts found or suspected to be damaged or out of tolerance? (A mechanical test and/or measurement certificate will satisfy the

initial receipt requirement.)

- ___ 11.3: Does the range have documented procedures and appropriate facilities to avoid deterioration or damage to calibration artifacts during storage, handling, preparation, and calibration?
- ___ 11.4: Does the range book identify the exact location of the calibration artifact standard when not in use?
The biggest threat posed to a standard RCS artifact device (sphere, cylinder, etc.) is physical damage. Most calibration artifact devices are fabricated from aluminum, which generally show damage (dents, scratches, etc.) fairly easily. Therefore, it makes sense to store the calibration artifacts in well identified, padded boxes or other suitable storage devices.
- ___ 11.5: Does the range take reasonable and appropriate measures to protect the calibration artifact(s) when not in use? Are there documented procedures for reporting suspected damage to a calibration artifact(s)? If the artifacts are repaired or replaced, are the procedures of 11.2 followed for the (repaired or replaced) unit?
- ___ 11.6: If the primary calibration artifacts employed by the range are used in any capacity other than to ensure the performance of the RCS measurement system(s), do such uses invalidate or degrade the calibration artifacts?
- ___ 11.7: On-site Review: Perform a visual inspection of the range's calibration artifacts to determine whether the conditions, procedures, and facilities assessed in 11.1 through 11.5 are as stated in the range book.

SECTION 12 – RECORDS (PRIORITY 3)

This section describes the range's procedures for creating and maintaining records of all aspects of range operations. Procedures for maintaining calibration records, measurement records, system configuration, etc., are especially important. Procedures to record interrange comparison results should be clearly defined.

Evaluation Criteria:

- ___ 12.1: Does the range have well-documented procedures for creating and maintaining records of range operations, to include records of calibration, measurements, and system configuration?
- ___ 12.2: Are these records indexed or stored so they are easily located and accessible to those with a need to review them?



This section may be evaluated in conjunction with the examination of the records required by other sections, such as 13, 14, 15, 16, 17, etc.

SECTION 13 – CERTIFICATES AND REPORTS (PRIORITY 2)

This section should define the standard reporting formats used by the ranges when reporting RCS measurements to customers. While any report can be specialized to the requirements of the customer, this section should provide the baseline information that will always be available in a test report. A range may use its own format, provided that the minimum information required by the Evaluation Criteria below is included.

Evaluation Criteria:

- ___ 13.1: Does the range book include a description of and purpose for each type of certificate or report used by the range to report RCS measurements to customers (e.g., measurement data and test summary reports)?
- ___ 13.2: Does each certificate or report include a title (e.g., Measurement Report); name and address of the facility, points of contacts, phone/fax numbers, and location(s) of the test(s); name, address, and points of contact of the customer; description and unambiguous identification of the measured item (including its configuration, as appropriate); characterization and condition of the measured item; date(s) and times(s) of the measurement(s); identification of the calibration procedure(s) used or unambiguous description of non-standard procedures employed; reference to sampling and/or data processing procedures, where relevant; any deviations from, additions to, or exclusions from documented operating procedures; and other information relevant to the measurement(s), such as environmental conditions or failures/anomalies encountered during the measurement(s)?
- ___ 13.3: Does each certificate or report include measurements, examinations, and derived results supported by tables, graphs, sketches, and photographs (and/or digital representations of such), as appropriate for the measurements conducted?
- ___ 13.4: Does each certificate or report include a statement of the estimated uncertainty of the primary calibration results and the traceability of the measurements?
- ___ 13.5: Does each certificate or report include a signature and title of the person(s) accepting responsibility for the content of the certificate or report, and the date of issuance?
- ___ 13.6: Does each certificate or report include a statement regarding any limitations on the use or interpretation of the measurement data?
- ___ 13.7: Are portions of the measurement data products performed by subcontractors? If so, are such portions clearly identified? (This will probably be N/A for most ranges.)
- ___ 13.8: Is there a procedure for amending a report? Is there a procedure for notifying customers promptly, in writing, of any event such as discovery of defective calibration equipment that may cast doubt on the validity of the results provided in any given report or certificate, including the magnitude of the errors that may exist?
- ___ 13.9: Is there a documented procedure for transmitting reports or certificates to customers or third party recipients such that confidentiality is preserved?



A hand receipt, computer receipt, registered mail receipt, or other appropriate tracking system may be used to fulfill this requirement.

On-site Review: None for this section.

SECTION 14 – SUBCONTRACTING OF CALIBRATION (PRIORITY 3)

This section details aspects of the RCS calibration process that are subcontracted. All subcontracted work must satisfy the standards set within this document in accordance with ANSI/NCSL Z-540-1-1994. The main intent of this section is to address calibration activities sent to locations or personnel that are not within the range facility (on-site). When on-site contractors share complete responsibility for operating a range facility, as is often the case, we refer to this situation as an integrated product team. For example, AFRL hires an on-site contractor to assist in range operations. This is not considered subcontracting. However, if a primary range relies on an off-site secondary RCS range for calibration data or other measurements applicable to the primary range, this situation would be treated as a subcontracted measurement, and Section 14 would apply. For most ranges, these criteria probably will not apply.

Evaluation Criteria:

- ___ 14.1: If the range employs any subcontracting in the performance of RCS measurements, is there a documented procedure or policy that stipulates and verifies that such subcontractors adhere to the standards set within this document? Does the range maintain records of the work accomplished by subcontractors?
- ___ 14.2: If the range employs a contractor to perform measurements, does the contract or other operational document bind the contractor to the procedures defined by the range book?
- ___ 14.3: On-site Review: Ask the range manager whether subcontractors/contractors support or perform RCS measurements. If applicable, review the contract(s) to verify compliance with the standards set within this document.

SECTION 15 – OUTSIDE SUPPORT SERVICES AND SUPPLIERS (PRIORITY 3)

This section should document any services or suppliers used to produce calibrated RCS data. This section complements Section 14. For instance, if a range purchases an 8-inch calibration sphere from a vendor for primary calibration, this section would document the needed tolerances of such a standard, as well as the delivered tolerance of the calibration item. As an additional example, if radar absorbing material (RAM) is used on a calibrated target measurement and absolute RCS data is reported, it would be appropriate to create records of where the RAM was

purchased, what characteristics were expected and delivered, and what, if any, repeatability would result from reusing the same material samples on the same target location.

Evaluation Criteria:

- ___ 15.1: If the range uses outside services or suppliers that might impact the quality and accuracy of RCS measurements, are there documented policies that ensure the quality of the calibrations and measurement products?
- ___ 15.2: Does the range book identify outside services or suppliers, or is there a definitive statement that no outside suppliers or services are employed in the calibration and measurement functions of the range?
- ___ 15.3: Where applicable, are there procedures for maintaining records associated with outside services or suppliers?
- ___ 15.4: On-site Review: If outside suppliers or services are used at the range under review, ask to see the associated records.

SECTION 16 – COMPLAINTS (PRIORITY 3)

This section should document the formal complaint procedure used to resolve disputes between the range and a customer. The complaint record keeping system also should be defined or referenced here.

Evaluation Criteria:

- ___ 16.1: Does the range have documented procedures for the resolution of customer complaints?
- ___ 16.2: Are records maintained of all complaints and of the actions taken by the range to resolve the complaints?
- ___ 16.3: If a customer complaint raises a concern regarding the range’s compliance with range policies or procedures, or with the requirements of this standard, does the range ensure that these complaints are reviewed and acted upon by a level of authority at least as high as the signatory identified in Section 1? Is this individual able to effect the required changes in range policy and procedures, if needed?
- ___ 16.4: If the customer complaint raises a concern regarding the quality of the range’s calibrations, does the range ensure that these complaints are reviewed and acted upon by a level of authority at least as high as the signatory identified in Section 1? Is this individual able to effect the required changes in range policy and procedures, if needed?
- ___ 16.5: On-site Review: Examine records of a random complaint (if applicable) to ensure that the complaints were reviewed and that appropriate action was taken and recorded.
- ___ 16.6: On-site Review: Ask range personnel if they are familiar with the range’s complaint resolution process.
- ___ 16.7: On-site Review: Ask the range quality manager if and how he/she is involved in the complaint resolution process. Does the range quality manager review all customer complaints for indications that current policies and procedures are in need of review?

SECTION 17 – INTERRANGE COMPARISON PROGRAMS (PRIORITY 1)

This section shall include the company policy regarding interranging comparisons. Records of participation in calibration interranging comparisons, the results obtained, and conclusions drawn from such studies are to be presented or referenced here. If the information is already included in Section 10, a reference to Section 10 is adequate. It is expected that interranging comparisons will be used regularly to improve measurement and calibration quality at the range. An interranging comparison schedule should be provided.



certification.

Participation in a national interranging comparison study is required for

Publication of interranging comparison results is strongly encouraged, and such publications should be referenced here. Procedures to record interranging comparison results should be clearly defined.

Evaluation Criteria:

- ___ 17.1: Does the range have a documented policy on interranging comparisons?
- ___ 17.2: Does the range participate in an interranging calibration comparison program at the national level?
- ___ 17.3: Are the results of the interranging calibration comparisons of Section 17.2 available for customer review?
- ___ 17.4: Are the results of the interranging comparisons used to evaluate and improve range operations?
- ___ 17.5: On-site Review: Review the range's documented interranging comparison policy. Is the available data current? Does the range have a schedule for participation in interranging comparisons?
- ___ 17.6: On-site Review: Ask the range technical manager how the results of the interranging comparisons are applied to improving the quality of range measurements.

SECTION 18 – DATA PROCESSING PROCEDURES (PRIORITY 1)

Important details of processing measurement and calibration data should be documented here. Sample results of processing should be included. Standard data processing procedures should be referenced, and the validity of innovative processing should be documented. To evaluate the validity of its data processing procedures, the range should use a standard data set acceptable to the RCS industry. This standard data set should be used by the range to perform interranging comparison of its processing algorithms with those used by other ranges. This section should strongly support and complement the material in Section 17 above.

Evaluation Criteria:

- ___ 18.1: Does the range have all primary RCS and image-based data processing procedures documented?
- ___ 18.2: Have the data processing modules been validated with a standard data set to ensure the correctness of the algorithms employed?



A generic set of C-29 model RCS data is available, if desired, to assist a range in assessing this requirement.

- ___ 18.3: Are the results of data processing compared against known quantities or standards to verify accuracy of the measurement and data processing process?
- ___ 18.4: On-site Review: Is there a procedure to collect, determine, and validate all customer data processing requirements, to include such key items as specific formats, parameters, and quantities? Is there a procedure for translating user requirements into the specific procedures to collect the data identified by the customer?
- ___ 18.5: On-site Review: Are procedures in place to coordinate target readiness and state with data collectors and data processors so that the target configuration is captured throughout the data collection and processing chain?
- ___ 18.6: On-site Review: Are procedures in place for validating the data in (near) real-time to ensure the proper data is being collected?
- ___ 18.7: On-site Review: Ask a range technician to process a file from a standard data set and compare the results to those known to be correct.
- ___ 18.8: On-site Review: Ask the range technical manager how new or improved data processing algorithms are validated.
- ___ 18.9: On-site Review: Review the results of any interranging data processing comparisons. Are these results available to range customers?

SECTION 19 – RANGE-SPECIFIC CALIBRATION UNCERTAINTY ANALYSIS (PRIORITY 1)

Policies and procedures for establishing range uncertainties need to be completely documented or referenced here. A sample uncertainty table together with system parameters or other adequate uncertainty method should be linked or available in this section. One approach to satisfy this requirement is the “Report of Measurement” described in [15]. Any system parameters should be displayed here. Any scientifically-based uncertainty analysis is acceptable, providing all appropriate assumptions and/or exclusions regarding the parameters comprising the analysis are clearly documented.

Evaluation Criteria:

- ___ 19.1: Does the range have a policy for the development and use of a calibration uncertainty analysis?
- ___ 19.2: For the primary calibration standard(s) used by the range, is there a nominal RCS measurement with estimated uncertainties in either graphical or tabular form for that standard?



A NIST calibration certificate may be used to fulfill this requirement, but other formats containing similar information are acceptable.

- ___ 19.3: Is the calibration uncertainty shown in 19.2 consistent with stated calibration capabilities of the range in other range book sections?



If the range's stated calibration accuracy is less than the accuracy shown in this nominal measurement, those capabilities must be changed to match those obtained in the Section 19.2 measurements.

- ___ 19.4: Are the results of the uncertainty analysis for primary calibration reflected in the day-to-day measure of calibration quality discussed in Section 10? In other words, are typical uncertainties used as a quality check for daily calibration measurements?
- ___ 19.5: Does the range have a "Report of Measurement" for its most commonly used calibration artifact stating its expected uncertainty under nominal operating conditions?
- ___ 19.6: On-site Review: Ask the radar technicians to show (in tabular or graphical form) the predicted uncertainty of the primary calibration standard. Can the technicians find the information?
- ___ 19.7: On-site Review: Do the technicians use the primary calibration target uncertainty bars to bracket acceptable (daily) calibration as a quality check?
- ___ 19.8: On-site Review: Ask the following question and assess answer: Are the actions taken by the technicians when calibration measurements fall outside expectations consistent with the stated range policy on exceptions to approved calibration process (See Sections 5 and 10)?

SECTION 20 – ONGOING RESEARCH, PLANNED IMPROVEMENTS (PRIORITY 2)

The purpose of this section is to briefly summarize the three-year look ahead regarding any range research and/or other activities designed to improve range data quality, efficiency, repeatability, or traceability. A list of desirable research areas to be conducted in the future to improve specific and known deficiencies on the range or in the RCS industry should also be provided, as well as a single top-level roadmap. Ongoing plans for future upgrades of equipment should be included. Such research information will allow customers to quickly identify and evaluate ongoing range improvements in the context of their current or planned use of the range. It also may offer the customer an opportunity to cost share or jointly sponsor range research of interest to the customer.

Evaluation Criteria:

- ___ 20-1: Is there a description or summary of a three-year look ahead into future plans, upgrades, and quality or range improvements?
- ___ 20-2: Is there a roadmap formatted to summarize the three-year plan?



The roadmaps may be longer than three years but must, at a minimum, look ahead three years.

- ___ 20-3: On-site Review: As a result of the review committee feedback, is there a summary of topics and issues that will be worked on a time-available basis over the succeeding three years?

ATTACHMENT A

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REFERENCES

- [1] Kent, Brian M. RCS Certification for Static and Dynamic RCS Measurement Facilities Volume II – Demonstration Program Results. Air Force Research Laboratory Technical Report AFRL/SNS-2000-03 (RCC/SMSG Task #08, Final Report, Volume II), 7 August 2000.
- [2] American National Standards Institute/National Calibration Standards Laboratory Standard. ANSI/NCSL Z-540-1-1994, Calibration Laboratories and Measuring and Test Equipment – General Requirements. August 1994. This document is available from NCSL, 1800 30th St., Suite 305B, Boulder, CO (tel # 303-440-3339).
- [3] Kent, B.M., and Lorant A. Muth. “Establishing a Common RCS Range Documentation Standard Based on ANSI/NCSL Z-540 and ISO Guide 20 – Invited Paper.” In Antenna Measurements Techniques Association 19th Meeting and Symposium, p. 291. Boston, MA: 17-21 Nov. 1997.
- [4] Muth, L.A., Ronald C. Wittmann, and B. M. Kent. “Interlaboratory Comparisons in Radar Cross Section (RCS) Measurement Assurance.” In Proceedings AMTA, Boston, MA: 1997.
- [5] Bushbeck, Mark D. “RCS Measurement Data Quality Assurance in the Boeing 9-77 Indoor RCS Range.” In Proceedings of the 1997 RCS Certification Meeting, Boulder, CO: National Institute of Standards and Technology, 4-6 March 1997.
- [6] American National Standards Institute/National Calibration Standards Laboratory. Handbook for the Interpretation and Application of American National Standards Institute/National Calibration Standards Laboratory Standard ANSI/NCSL Z-540-1-1994. October 1995. This document is available from NCSL, 1800 30th St., Suite 305B, Boulder, CO (tel # 303-440-3339).
- [7] RCC/SMSG Radar Committee. Handbook for the Assurance of Radar Cross Section Measurements (Draft). Certification Conference Proceedings, Boulder, CO: March 1997.
- [8] Muth, L. A., Ronald C. Whittmann, and Brian M. Kent. “Measurement Assurance and Certification of Radar Cross Section Measurements.” In Proceedings of the 1997 Workshop and Symposium for the National Conference of Standards Laboratory, Atlanta, GA: 27-31 July 1997.
- [9] Kent, B.M., and Randy J. Jost. “Evaluation Criteria for Range Book Compliance with ANSI Z-540-1-1994 as Amended, Version 5.0.” In 4th Annual RCS Certification Conference Proceedings, National Institute of Standards and Technology, Boulder, CO.
- [10] Kent, B.M., and L.A. Muth, et. al. 3rd Annual RCS Certification Conference Proceedings, Boulder, CO: National Institute of Standards and Technology, March 1999. (Proceedings available on CD-ROM – Call 303-497-5703 to obtain a copy.)
- [11] Kent, B.M., and L.A. Muth, et. al. 4th Annual RCS Certification Conference Proceedings, Boulder, CO: National Institute of Standards and Technology, 20-22

June 2000. (Proceedings available 8/1/00 on CD ROM – Call 303-497-5703 to obtain a copy.)

- [12] Kent, B.M., G. B. Melson, and T. Conn. “ANSI Z-540 / ISO 25 Certification Of The AFRL And Patuxent River Radar Cross Section Measurement Facilities – Range And Reviewer Perspectives (Part I-AFRL).” In Year 2000 AMTA Symposium, Philadelphia, PA.

- [13] Hestilow, T., Carl A. Mentzer, and Thomas J. Cleary. “ANSI Z-540 / ISO 25 Certification of the AFRL and Patuxent River Radar Cross Section Measurement Facilities – Range And Reviewer Perspectives (Part II-ATR).” In Year 2000 AMTA Symposium, Philadelphia, PA.

- [14] Kent, B. M., H. M. Chizever, and R. J. Soerens. “On Reducing Primary Calibration Errors in Radar Cross Section Measurements.” In Proceedings of the 18th Meeting and Symposium, pp. 383-388. Antenna Measurement Techniques Association, 1996.

- [15] Welsh, Byron M., and Brian M. Kent. “An RCS Uncertainty Analysis and Calibration Certificate for AFRL Calibration Cylinders.” In Year 2000 AMTA Symposium, Philadelphia, PA.