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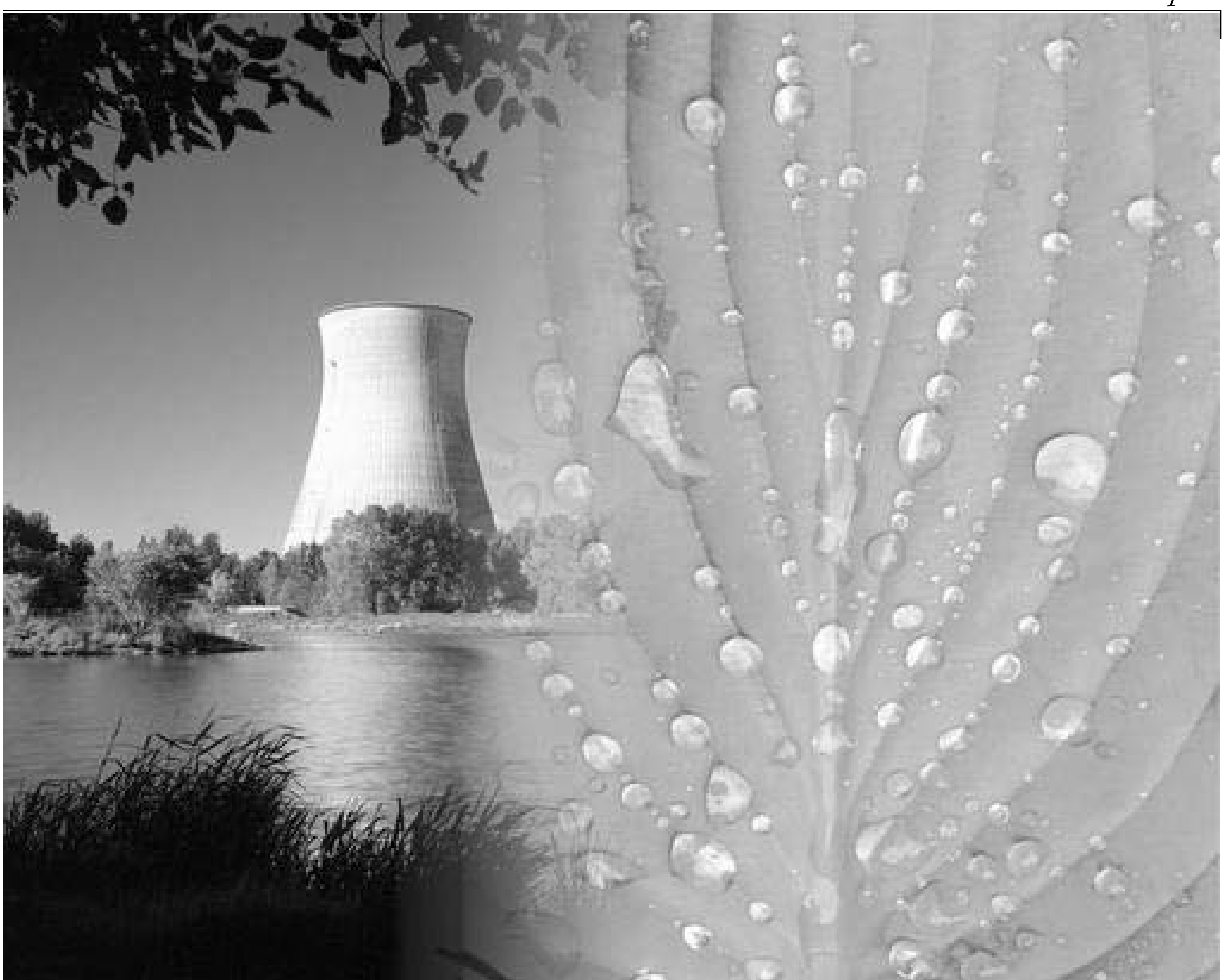
Plant Application of On-Line Monitoring for Calibration Interval Extension of Safety-Related Instruments: Volume 1

Technical Report



Plant Application of On-Line Monitoring for Calibration Interval Extension of Safety-Related Instruments: Volume 1

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Final Report, December 2006

British Energy Group PLC
Sizewell B Nuclear Power Station
Near Leiston, Suffolk, IP16 4UR
United Kingdom

Project Manager
D. Lillis

EPRI Project Manager
J. Naser

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Analysis and Measurement Services Corporation

Electric Power Research Institute (EPRI)

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

CITATIONS

This report was prepared by

Analysis and Measurement Services Corporation
AMS 9111 Cross Park Drive
Knoxville, TN 37923

Principal Investigator
H. Hashemian

Electric Power Research Institute (EPRI)
Instrumentation & Control Center
714 Swan Pond Rd.
Harriman, TN 37748

Principal Investigator
B. Rasmussen

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PRODUCT DESCRIPTION

Temperature, pressure, and other instruments in important applications in nuclear power plants are calibrated periodically to ensure reliable measurements and plant safety. Calibrations are typically performed once every fuel cycle (that is, once every 18 to 24 months). Through calibration activities, substantial labor is devoted to isolating the instruments, calibrating them, and returning them to service. In recent years, reviews of calibration histories of process instruments in nuclear power plants have shown that high-quality instruments, such as nuclear-grade pressure transmitters, typically maintain their calibration for more than a fuel cycle of 18 to 24 months and do not, therefore, need to be calibrated as often. The inconsistency in calibration intervals between different instruments motivated the nuclear industry to search for a way to be able to switch from periodic, time-based calibration of transmitters to a condition-based calibration strategy. Over the past decade, on-line monitoring (OLM) techniques have been developed and proven to extend the calibration intervals of instrument channels. This report describes the successful application of OLM to extend the calibration interval of safety-related transmitters at British Energy's (BE's) Sizewell B nuclear generating station.

Results and Findings

During the first outage, 70% of the transmitters that were candidates for calibration interval extension were in fact extended. An additional 10% of the candidate transmitters were scheduled for calibration to maintain conservatism during the initial implementation; however, these 10% of transmitters could have been extended if desired. Overall, 80% of the transmitters evaluated during the first cycle of OLM for calibration interval extension at Sizewell B were found to be within calibration throughout the fuel cycle.

The savings from calibration interval extension and OLM are expected to amount to more than $1 million per avoided outage day, or $5 million per operating cycle when the project is completed. The project will have covered at least 200 primary protection transmitters by 2008. Additional savings will also result from reducing other direct and indirect costs, such as labor costs, radiation exposure, and the frequency of calibration errors.

Challenges and Objectives

This report documents a successful implementation of OLM technology for calibration interval extension so that other EPRI-member utilities can benefit from the experience. Because this is the first commercial implementation of calibration interval extension in a nuclear power plant in more than a decade, a variety of technical issues are addressed throughout the project. These issues and their resolutions are described in this report.

Applications, Value, and Use

The implementation of OLM for calibration interval extension of safety-related transmitters in a nuclear power plant is the first commercial implementation of this technology in more than a decade. The methodology applied will serve as a guide for other utilities that wish to pursue similar extension of calibration intervals. Over time, BE's goal is to expand the application of on-line calibration monitoring to nearly 2500 transmitters, including many in the secondary system (steam side) of the plant. This report will be supplemented with additional results through 2009 as available.

EPRI Perspective

EPRI's strategic role in OLM is to facilitate the implementation and use of OLM in numerous applications at power plants. OLM of instrument channels provides increased information about the condition of monitored channels through accurate, more frequent evaluations of each channel's performance over time. This type of performance monitoring offers an alternative approach to traditional time-directed calibration. EPRI remains committed to the development and implementation of OLM as a tool for extending calibration intervals and evaluating instrument performance.

Approach

This report presents the details of implementation of an OLM project performed at the Sizewell B nuclear power plant in the United Kingdom, the goal of which is to optimize the frequency of calibration of pressure, level, and flow transmitters in the primary and secondary protection systems of the plant. The methodology and application are described along with a current set of supporting analyses and results for this implementation.

Keywords

On-line monitoring (OLM)
Calibration monitoring
Calibration interval extension
Instrumentation and contol

ABSTRACT

This report presents the details of implementation of an on-line monitoring (OLM) project performed at the Sizewell B nuclear power plant in the United Kingdom. The goal of this ongoing project is to optimize the frequency of the calibration of pressure, level, and flow transmitters in the primary and secondary protection systems of the plant. The project has involved the following three sets of activities:

1. Establish the validity of OLM techniques to determine if and when a transmitter must be calibrated.
2. Use OLM data from the plant computer to distinguish the transmitters that have drifted out of tolerance from those that have not.
3. Obtain approval from the British Nuclear Installation Inspectorate to use the on-line calibration monitoring technique for extension of calibration intervals of safety-related transmitters at the Sizewell B plant.

The first two activities have been carried out successfully by Analysis and Measurement Services Corporation (AMS), the author of this EPRI report. The third activity was successfully performed by British Energy (BE), which operates the Sizewell B plant.

The project began in 2001 and targeted first the calibration of in-containment transmitters in the plant primary protection system (PPS). The time that it takes to calibrate these transmitters is approximately 25 days and, because BE is targeting a 20-day outage, will have a direct impact on the duration of the plant outage. It is anticipated that on-line calibration monitoring will help reduce the plant outage time by as much as five days by 2008, when OLM will be fully implemented for the PPS transmitters.

During the first outage, the intervals for 70% of the transmitters that were candidates for calibration interval extension were in fact extended. An additional 10% of the candidate transmitters were scheduled for calibration to maintain conservatism during the initial implementation; however, these 10% of transmitters could have had their calibration intervals extended if desired. Overall, 80% of the transmitters evaluated during the first cycle of OLM for calibration interval extension at Sizewell B were found to be within calibration throughout the fuel cycle.

The savings from calibration interval extension and OLM are expected to amount to more than $1 million per avoided outage day, or $5 million per operating cycle when the project is completed. The project will have covered at least 200 primary protection transmitters. Additional savings will result from reducing other direct and indirect costs, such as labor costs, radiation exposure, and the frequency of calibration errors. EPRI plans to issue two updates to this report to cover the Sizewell project through its completion.

Over time, BE’s goal is to expand the application of on-line calibration monitoring to nearly 2500 transmitters, including many in the secondary system (steam side) of the plant. Of these, about 500 are Category 1 transmitters and 700 are Category 2 transmitters, which are normally calibrated once every cycle. The remaining 1300 are Category 3 transmitters, which are normally calibrated only when a defect is found. To accomplish this goal, work has already started at AMS to apply empirical modeling techniques for calibration monitoring of non-redundant transmitters in the steam side of the plant. The implementation of OLM at Sizewell B is expected to expand well beyond calibration monitoring to cover equipment and process condition monitoring using existing as well as new instruments, such as wireless sensors.

ACKNOWLEDGMENTS

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Finally, EPRI acknowledges British Energy, the co-sponsor of this report. EPRI applauds their use of technology to improve the safety and economic performance of Sizewell B.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Temperature, pressure, and other instruments in important applications in nuclear power plants are calibrated periodically to ensure reliable measurements and plant safety. These calibrations are typically performed once every fuel cycle; in most nuclear power plants, fuel cycles have a duration of about 18 to 24 months. Through calibration activities, substantial labor is devoted to isolating the instruments, calibrating them, and returning them to service. In recent years, reviews of calibration histories of process instruments in nuclear power plants have shown that high-quality instruments—such as nuclear-grade pressure transmitters—typically maintain their calibration for more than a fuel cycle of 18 to 24 months and do not, therefore, need to be calibrated as often [1–3]. The inconsistency in calibration intervals motivated the nuclear industry to search for a way to switch from periodic, time-based calibration of transmitters to a condition-based calibration strategy. This search has led to the development of on-line drift monitoring and cross-calibration techniques that have been validated through a number of research and development (R&D) programs and are now ready for use in nuclear power plants. These techniques can be used to extend the calibration intervals of process instruments and can cover an entire instrument channel, including sensors, transmitters, and the associated signal conversion and signal conditioning equipment.

Since the early 1980s, EPRI has been active in sponsoring and promoting the development and use of on-line monitoring (OLM) in nuclear power plants to reduce the frequency of instrument calibration and to monitor equipment condition. Further, EPRI helped obtain the approval of the U.S. Nuclear Regulatory Commission (NRC) to use OLM to optimize the frequency of calibration of pressure, level, and flow transmitters in nuclear power plants. This approval was given in a safety evaluation report (SER) published by the NRC in July 2000 [4]. The details of the NRC review and approval, along with a summary of EPRI's technical developments in the area of OLM, are presented in several EPRI reports [5–8]. The SER provides only generic approval, whereas a site-specific license amendment is required for each plant to switch from the traditional calibration approach to the OLM approach.

In 2001, British Energy (BE) performed an evaluation of the calibration history of its pressure, level, and flow transmitters. This effort revealed that almost all Sizewell transmitters maintained their calibration far beyond a single operating cycle of about 18 months. This information was used as the justification to extend the calibration intervals of the transmitters to a maximum of eight years. BE decided that in spite of this positive trend in calibration stability, OLM should be implemented at the Sizewell B plant to provide additional confidence that calibration problems are being identified and resolved in a timely manner.

In fall 2001, BE contracted Analysis and Measurement Services Corporation (AMS) to implement an on-line calibration monitoring project at the Sizewell B plant, starting with 200 transmitters from the primary coolant system of the plant. First, the calibration drift of these transmitters as identified through OLM was compared with the drift calculated from manual calibrations. This showed nearly 100% agreement between the results of the OLM and manual calibrations, testifying to the validity of the OLM approach to identify the transmitters that might drift beyond their allowable limits.

Next, approval was sought from the British Nuclear Installation Inspectorate (NII) to extend transmitters' calibration intervals based on the historical performance of the transmitters and implementation of on-line calibration monitoring. After gaining approval from NII, BE established a long-term plan to implement OLM for calibration interval extension at Sizewell B over three fuel cycles, starting with those transmitters in the harsh environments of the plant (those in reactor containment, for example). During the first outage (the first of three scheduled fuel cycles), the calibration intervals for 70% of the transmitters that were candidates for interval extension were in fact extended. To be conservative in the initial implementation, an additional 10% of the candidate transmitters were scheduled for calibration; however, these 10% could have been extended if desired. Overall, 80% of the transmitters that were candidates for calibration extension during the first cycle of OLM at Sizewell B were found to be within calibration throughout the fuel cycle.

Note that over the three cycles, the number of candidate transmitters being monitored is 25% in the first cycle, 50% in the second cycle, and 75% in the third cycle. Table 1-1 shows how on-line calibration monitoring is being phased in at Sizewell B, starting in 2005 with the transmitters in one of the four safety channels and increasing to three safety channels in 2008. In Table 1-1, each operating cycle is identified by the ensuing refueling outage (RF07, RF08, and so on), and in BE terminology, a safety channel is referred to as a *guardline*.

Table 1-1
Schedule of Implementation of Calibration Extension of Pressure Transmitters at Sizewell B

Guardline (Safety Channel)	RF07 (2005)	RF08 (2006)	RF09 (2008)	RF10 (2009)	RF11 (2011)	RF12 (2012)	RF13 (2014)
1	Calibrate	Calibrate	Calibrate	Monitor	Monitor	Monitor	Calibrate
2	Calibrate	Calibrate	Monitor	Monitor	Monitor	Calibrate	Monitor
3	Calibrate	Monitor	Monitor	Monitor	Calibrate	Monitor	Monitor
4	Monitor	Monitor	Monitor	Calibrate	Monitor	Monitor	Monitor

As shown in Table 1-1, after 2008, the transmitters in only one of the four safety channels will be calibrated at each refueling outage on a rotational basis; in this way, all transmitters will be calibrated at least once every eight years. Of course, any transmitter that is found by OLM or any other means to have exceeded its calibration limits will also be calibrated during the ensuing outage. The eight-year maximum between calibrations has been arrived at based on two-year fuel cycles, although Sizewell is currently on 18-month fuel cycles.

Table 1-1 was extracted from a BE document [9] and is merely illustrative. To align with the outage work scopes at the plant, during RFO7, the unattended channel was Guardline 2; for RF08, the unattended channels were Guardlines 2 and 3.

On-Line Calibration Monitoring

On-line calibration monitoring refers to the monitoring of the normal output of process instruments during plant operation and a comparison of the data with an estimate of the process parameter that the instrument is measuring. With this method, sensor outputs are monitored during process operation to identify drift. If drift is identified and is significant, the transmitter is scheduled for a calibration during an ensuing outage. On the other hand, if the transmitter drift is insignificant, no calibration is performed for as long as eight years, typically. This eight-year period is based on a two-year operating cycle and a redundancy level of four transmitters, and the interval has been adopted by Sizewell as the maximum period between manual calibrations of a transmitter. One redundant transmitter is calibrated each cycle on a staggered basis to account for common mode drift.

OLM covers the calibration of an entire instrument channel in the same test and includes the sensor or transmitter, the signal conversion equipment, the signal conditioning modules, and so forth. Although *OLM* is a generic term for a set of methodologies that can be applied to instrument calibration monitoring and equipment and process condition monitoring, the sole concern of this report is the application of OLM for calibration monitoring of pressure transmitters. In this application, OLM is not a substitute for traditional calibration of pressure transmitters; rather, it is a means for determining when to schedule a traditional calibration for a pressure transmitter. The methods used to obtain process parameter estimates under this work are averaging techniques applied directly to the measured data rather than the other types of empirical OLM models, such as neural networks, nonparametric regression, and factor-based techniques.

Organization of This Report

Throughout this report, the terms *pressure transmitter* and *transmitter* are used interchangeably to refer to pressure, level, and flow transmitters, and *Sizewell* and *Sizewell B* are used interchangeably to refer to Unit B at the Sizewell nuclear power station, currently operated by BE.

This report has two volumes. Volume 1, the main text, presents the details of implementation of on-line calibration monitoring at Sizewell B, and Volume 2 is a compilation of the supporting data for this implementation. Volume 2 will serve as a reference by providing all the necessary supporting information for the results presented in Volume 1.

Section 2 of this volume is a summarized history of the implementation of on-line calibration monitoring technologies in nuclear power plants. Section 3 presents the related technical, economic, and safety-related justifications for calibration interval extension and OLM. The methodology is presented in Section 4, along with a discussion of related technical issues. Section 5 presents specific details regarding the application of OLM at Sizewell, including data collection and analysis, and describes the procedures followed herein to obtain and analyze the results. Other sections of Section 5 briefly describe the validation of the applied methodology and present examples and interesting observations. Methods to establish appropriate acceptance criteria for OLM are presented in Section 6. Section 7 is a summary of the major results of the implementation, and Section 8 investigates instances in which the OLM conclusion appeared to be non-conservative. Regulatory aspects of OLM implementation are addressed in Section 9, and conclusions are drawn in Section 10.

The two volumes of this report cover the implementation of OLM at Sizewell B through the end of Cycle 7. EPRI plans to issue updates to these reports—one in 2007 and another in 2008—to cover RFO8, RF09, and the implementation of OLM at Sizewell in Cycles 8 and 9, thereby documenting the entire implementation process through its completion.

2 BACKGROUND

Nuclear power plants are typically required to calibrate their safety-related instruments once every fuel cycle. This requirement dates back nearly 40 years, when commercial nuclear power plants began operations. Based on calibration data accumulated over this period, it has been determined that the calibration of some instruments—such as pressure transmitters—do not drift enough to warrant calibration as often as once every fuel cycle [1, 2]. This fact, combined with safety concerns, availability of personnel, and tighter maintenance budgets, has motivated the nuclear industry, associated research organizations, and national and international laboratories to develop new technologies for identifying drifting instruments during plant operation. Implementing these technologies allows calibration efforts to be focused on the instruments that have drifted out of tolerance; current practice, by contrast, calls for calibration of almost all instruments in every fuel cycle.

An array of technologies has been developed to meet this objective. These technologies identify drifting sensors using techniques that compare a particular sensor's measured output to a calculated estimate of the sensor's output or to a calculated estimate of the actual process measured by the sensor. All of these methods are used while the plant is operating or *on-line*; hence, they are collectively referred to as *OLM techniques*. OLM techniques estimate process parameters or sensor outputs using a variety of mathematical models and algorithms, such as neural networks, fuzzy logic, simple statistics (as examples, averaging and regression), advanced statistics (such as nonlinear regression and nonparametric regression), first principles modeling, data reconciliation, and noise analysis.

This section presents a summary of the history of OLM implementation in nuclear power plants. Although there is a long history of R&D in the OLM area, little implementation has occurred in nuclear power plants. This is consistent with the nuclear industry's approach to implementation of new technologies: typically, the industry is very slow to implement new technologies, particularly those that involve software algorithms and require computers or digital systems. Concerns such as common mode failure (CMF), reliability issues, and difficulties in securing regulatory approval are among the reasons the nuclear industry has cited for its slow implementation of digital systems.

The wait, however, is almost over: digital systems have proven themselves in other industries and are now being used more often and more extensively in nuclear power plants in the form of smart sensors and transmitters, digital control systems, and automated test equipment. EPRI has been very active in the area of OLM research and has produced numerous papers and reports, conducted a variety of workshops, and participated in discussions with regulatory authorities to help the nuclear industry implement digital technologies.

History of OLM Implementation at Sizewell B

The Sizewell B plant represents the first fully documented commercial implementation of OLM for calibration interval extension under a formal quality assurance (QA) program with regulatory oversight. The Sizewell project follows a number of demonstration projects carried out in nuclear power plants under utilities' own initiatives, often with the help of EPRI, the NRC, or other organizations. Furthermore, BE has invested substantial resources of its own to establish the basis for implementation of on-line calibration monitoring at its Sizewell B plant, secure NII approval, fund the development of data acquisition and data analysis algorithms and software packages, and train its own personnel to perform on-line calibration monitoring independently. These efforts are documented in the following BE reports:

- *Drift Report E/REP/SXB/0015/00, Sensor Single Calibration Regression Methodology – Drift Statistics*, April 2002
- CRS0201R1, *On-Line Monitoring to Extend Calibration Intervals of Pressure Transmitters at Sizewell B*, March 2003
- CRS0202R2, *Specifications for Development of Capability to Analyze On-Line Monitoring Data to Extend Calibration Intervals of Pressure Transmitters at Sizewell B*, March 2003
- SIZ0303R0, *On-Line Calibration Monitoring of Pressure Transmitters at Sizewell B*, October 2003
- SIZ0402R0, *Results of Mid-Cycle 7 Analysis of On-Line Calibration Monitoring Data for Pressure Transmitters at Sizewell B*, December 2004
- SZB Engineering Change 109087, *Calibration Period Extension of Safety Related Sensors*, Issue 3, January 2005
- SZB Engineering Change 111655 (NP/NSC 7277), *Paper of Principle, Calibration Period Extension of Safety Related Sensors*, March 2005
- SIZ0503R0, *On-Line Calibration Extension Results for Pressure Transmitters at Sizewell B*, April 2005
- SIZ0603R0, *Results of Mid-Cycle 8 Analysis of On-Line Calibration Monitoring Data for Pressure Transmitters at Sizewell B*, March 2006
- E/TSK/SXB/0684, *QA Review Report – Provision of On-Line Monitoring System for Transmitter Calibration Extension*, August 2006
- Station Report SZB/ESR/503, Issue 1, *Sensor Calibration Extension (EC 109087), Additional Work to Support Continued Implementation*, September 2006

These and other documents, together with numerous formal and informal discussions with NII, have helped BE to obtain regulatory approval to use OLM to extend the calibration intervals of pressure transmitters at Sizewell B. The plant, however, is required to satisfy a number of stipulations: Sizewell is expected to develop its own, and not rely on a contractor's, expertise; the decision-making process must involve human analysts and not rely solely on computers and automation; and periodic physical inspections and visual examinations must be performed to ensure the integrity of the pressure sensing systems, including the transmitters and associated sensing lines.

History of OLM Implementation in U.S. Plants

Over the last 10 or so years, many U.S. nuclear power stations have experimented with OLM technologies for a variety of applications, including equipment diagnostics, instrument calibration verification, and equipment and process condition monitoring. Two examples are the VC Summer Nuclear Station in South Carolina and the McGuire Nuclear Station in North Carolina. The VC Summer plant has been active for over a decade in promoting the use of OLM to extend the calibration intervals of its pressure, level, and flow transmitters. The implementation effort at the McGuire plant was performed in the mid-1990s and involved nearly 200 pressure, level, and flow transmitters. The work at McGuire took place under an R&D project sponsored by the NRC to provide independent insight into OLM technologies and their use in nuclear power plants for instrument calibration reduction and detection of instrument anomalies [1, 10].

Although the NRC has agreed to the use of OLM for reduction of unnecessary calibration of pressure transmitters in nuclear power plants, no implementation has occurred as of the end of 2006 in any U.S. plant for a variety of reasons. For one, nearly 15 years ago, many U.S. plants stopped performing calibration work on transmitters during refueling outages and began instead to do the work during plant operating cycles. As a result, many plants do not have a strong incentive to use OLM; the savings that they gain would be lower than those realized by BE, which defers all safety-related pressure transmitter calibrations to refueling outages.

Another reason OLM has not been implemented in any U.S. plant is that in spite of the NRC's approval of the OLM approach for extending the calibration intervals of pressure transmitters in nuclear power plants, each plant must still apply to the NRC individually and receive specific approval to switch from conventional, time-directed calibration to performance-based calibration using OLM. This undertaking and its potential costs have deterred the plants from implementing OLM. As of now, only one plant (VC Summer) has applied to the NRC for approval to switch to on-line calibration monitoring.

History of OLM Implementation in Other Countries

For more than a decade, Electricité de France (EDF) has been using techniques similar to those used by BE to optimize the calibration intervals of nuclear power plant pressure transmitters. EDF has cited reduction in human errors and potential damage to plant equipment as key incentives for its move to OLM [11].

In other countries, utilities are considering OLM for condition monitoring applications, but there is no known instance outside of the United States, UK, and France in which OLM has been implemented to extend instrument calibration intervals in nuclear power plants. Predominantly, the applications in other countries use noise analysis techniques and first principles models to assess equipment condition, sensor health, and process diagnostics. For example, noise analysis techniques are commonly applied to verify equipment performance, detect process anomalies, and to get to the root cause of equipment and process mishaps. Noise analysis techniques are recognized as an OLM tool for verifying the dynamic performance of equipment and processes.

EPRI's Role in OLM Development and Implementation

EPRI's strategic role has been to facilitate the implementation and cost-effective use of OLM in numerous applications at power plants. To this end, EPRI sponsored an OLM implementation project to install and evaluate OLM technology at multiple nuclear plants. The dual purposes of the EPRI OLM implementation project were to apply OLM to all types of power plant applications and to document all aspects of the implementation process in a series of deliverable reports. This report will add to the reports already published by providing an example of a commercial application of OLM technology for calibration interval extension. The primary reports published by EPRI on the topic of OLM are as follows:

- *On-Line Monitoring of Instrument Channel Performance: TR-104695-R1 NRC SER* [5]. This report presents the methodology of OLM for calibration interval extension and recommends that it be used to monitor and schedule the calibration of safety-related transmitters in nuclear power plants. This report updated an earlier interim report prepared in 1998 that was submitted to the NRC. The updated version contains discussion and responses related to the 14 requirements defined by the NRC following the NRC's review of the 1998 report.
- *On-Line Monitoring of Instrument Channel Performance, Volume 1: Guidelines for Model Development and Implementation* [6]. The report addresses all aspects of modeling for OLM applications and their implementation. This report describes model development, data quality issues, training requirements, retraining criteria, failure alarm responses, and the criteria applied to declare a model ready for use.
- *On-Line Monitoring of Instrument Channel Performance, Volume 2: Algorithm Descriptions, Model Examples, and Results* [7]. This report presents detailed examples of models, empirical algorithm details, and further evaluations of the software used in the project.
- *On-Line Monitoring of Instrument Channel Performance, Volume 3: Applications to Nuclear Power Plant Technical Specification Instrumentation* [8]. This report addresses OLM for safety-related applications and the NRC SER for OLM. Topics include technical specifications, uncertainty analysis, procedures and surveillances, application considerations for the Multivariate State Estimation Technique (MSET), and miscellaneous technical considerations. The U.S. Department of Energy's (DOE's) Nuclear Energy Plant Optimization (NEPO) Program projects related to software verification and validation and uncertainty analysis provided input to this report.

In addition, EPRI has worked with BE in recent years to facilitate OLM implementation at the Sizewell B plant. For example, EPRI prepared a report for BE to document the historical calibration behavior of pressure transmitters at Sizewell B and to compare these results with data from U.S. plants. The report, *Instrument Drift Study, Sizewell B Nuclear Generating Station* [12], presents the results of an instrument drift study conducted at Sizewell B. The study includes Barton 763, 764, and 752 pressure and differential pressure transmitters used for various safety-related applications in the reactor protection system.

EPRI has also been involved in the development of industry standards for OLM technology. For example, working with the Instrumentation, Systems, and Automation Society (ISA), EPRI contributed to a revised version of ISA-67.06-1984 Response Time Testing of Nuclear Safety-Related Instrument Channels in Nuclear Power Plants [13]. In the early 1990s, EPRI initiated a process to update this standard and expand its scope to include requirements for implementation of OLM technologies in nuclear power plants. This effort resulted in a new standard: ANSI/ISA 67.06-01-2002 Performance Monitoring for Nuclear Safety-Related Instrument Channels in Nuclear Power Plants [14]. (ANSI is the American National Standards Institute.) This standard was used as the basis for developing a new international standard under the auspices of the International Electrotechnical Commission (IEC). This standard, IEC 62385 ("Nuclear Power Plants – Instrumentation and Control Important to Safety – Methods for Assessing the Performance of Safety System Instrument Channels") is due for publication in 2007 or 2008. A related standard, IEC 62342 ("Nuclear Power Plants – Instrumentation and Control Important to Safety – Management of Aging") is also under development and will be completed in 2007 or 2008.

Finally, the International Atomic Energy Agency (IAEA) has become involved in the development of technical reports (referred to as *TECDOCs*) that provide OLM implementation guidelines to the international nuclear power industry. Two TECDOCs have been prepared (but not yet published) on the subject of OLM, one on instrument channel performance monitoring and another on on-line condition monitoring of nuclear power plant equipment and processes. EPRI participated in the development of both TECDOCs.

3
TECHNICAL, ECONOMIC, AND SAFETY-RELATED JUSTIFICATIONS

The Sizewell B plant has established a sound foundation from which it can extend the calibration intervals of its pressure, level, and flow transmitters. This section provides examples of technical, safety, and economic justifications for OLM implementation at Sizewell B and the benefits to the plant in terms of risk reduction and personnel's reduced exposure to radiation.

Description of the Sizewell B Plant

The Sizewell site has two nuclear power plants. Sizewell A, which has two gas-cooled reactors (Sizewell A1 and Sizewell A2), and Sizewell B, which is a PWR. In fact, Sizewell B is the only PWR plant in Great Britain; the other 16 nuclear units are all gas-cooled reactors. Sizewell B is a single-unit, 1200-MW, Westinghouse PWR that began commercial operation in May 1995. The plant is located in Suffolk, 120 miles (193 kilometers) northeast of London, and is operated and maintained by a staff of about 400 on-site personnel. The engineering support for the plant comes from BE headquarters in Barnwood, England.

The site engineers and headquarter engineers have been involved in the implementation of the on-line calibration monitoring program at the Sizewell B plant. The small number of personnel working at the plant and the plant's large number of instruments make the return on investment very high at the Sizewell B plant when it comes to implementation of new techniques for automated monitoring and maintenance of plant instrumentation and equipment. To date, Sizewell B has taken advantage of *in situ* testing and OLM for a number of applications, such as cross-calibration during cooldown and/or heating of resistance temperature detectors (RTDs), automated rod drop time measurements, noise analysis for response time of RTDs and pressure transmitters, and reduced frequency of the calibration of pressure transmitters. The last two applications are the subject of this report.

The Sizewell B plant is unique in being the world's first PWR with a digital plant primary protection system (PPS). In addition, this plant has a complete and independent analog backup protection system known as a s*econdary protection system* (SPS). Because the PPS and SPS each has its a set of process sensors for measuring temperature, pressure, level, and flow, Sizewell has more than twice as many process instruments as other PWRs (see Table 3-1). This redundancy makes the Sizewell B plant an ideal candidate for implementation of on-line calibration monitoring. More specifically, with four to eight sensors for each service (typically), averaging techniques can provide a good estimate of each process parameter as the reference for calibration monitoring. The advantage in averaging techniques is that they are simple and, as important, the uncertainty of their results is easily calculated. As such, the on-line calibration monitoring

program that has been implemented at the Sizewell B plant is based on averaging techniques and focuses on parameters for which redundant instrumentation is available. Averaging techniques are not suitable for monitoring parameters when there is no redundant instrumentation. Plans have been made to employ other modeling techniques suitable for non-redundant sensors for the secondary system sensors and non-safety-related measurement channels.

Table 3-1
Number of Important Sensors in Sizewell B Compared with Other PWR Plants

Service	Typical PWR Plants (Approximately)	Sizewell B Plant (Approximately)
Primary coolant RTDs	20	60
Transmitters in containment	50	100
Transmitters in reactor protection system	100	500
Transmitters throughout the plant	800	2500

The ultimate goal of OLM implementation at Sizewell B is to extend the calibration intervals of all pressure and differential pressure transmitters in the primary and secondary systems of the plant. This will involve nearly 1200 Category 1 and Category 2 transmitters and will be implemented in the following four stages:

1. PPS pressure and differential pressure transmitters
2. SPS pressure and differential pressure transmitters
3. Post-fault monitoring (PFM) pressure and differential pressure transmitters
4. Other reactor protection system and PFM transmitters

Technical Justifications

A number of technical factors justify extending calibration intervals of pressure transmitters at the Sizewell B plant. These justifications are as follows:

- A BE analysis of historical calibration data from Sizewell pressure transmitters has shown that these transmitters rarely drift out of tolerance in a single fuel cycle [3]. This analysis and one performed by EPRI for Sizewell B [12] have shown that typically, less than about 5% of transmitters of the types used in Sizewell lose their calibration in a single fuel cycle. Therefore, it is reasonable to extend the calibration interval of these transmitters in accordance with the plant technical requirements, risk considerations, and regulatory position.
- Sizewell performs response time testing on all its important pressure, level, and flow transmitters once every fuel cycle. These tests are performed while the plant is on-line using the noise analysis technique. The purpose of these tests is to ensure that the dynamic response of the transmitters is intact and, as important, to identify any blockages in the pressure sensing lines.

- The *in situ* response time measurements, together with on-line calibration monitoring, will reveal any significant problem with the performance of the transmitters and provide a complete assessment of both the static and dynamic characteristics of each pressure sensing system at the plant.
- Shiftly (every 12 hours) channel checks and monthly surveillances that are performed at Sizewell B will reveal any gross calibration problems that might not be detected by the on-line calibration monitoring system.
- The performance of field calibrations obviously provides an opportunity for plant technicians to conduct a physical inspection of the pressure sensing systems. With any extension in a calibration period, the number of opportunities is reduced. In response to this issue, Sizewell has generated two new plant maintenance instructions (PMIs) that will be mandatory inspection routines to be performed at each refueling outage. These are Plant Maintenance Instruction PMI-SZ020, Inspection of Reactor Protection System Sensors Inside Containment (June 2006), and Plant Maintenance Instruction PMI-SZ021, Inspection of Reactor Protection System Sensors Outside Containment (June 2006). These PMIs provide plant technicians with step-by-step procedures to perform a walk through and a careful visual inspection of pressure transmitters and their associated hardware installed in the plant. The results of this effort are documented, and any observed problems are reported and resolved.
- There is no evidence of systematic drifting of pressure transmitters in the same direction at Sizewell B. And because one channel of each redundant group of transmitters will continue to be calibrated, any common mode drift will be revealed.
- Because different channels will be calibrated at each outage, the change to a maximum of eight years between calibrations will be introduced on a staggered basis. Although the typical Sizewell fuel cycle is 18 months, the plant's safety case was made for 24 months to allow for extended running at 50% power and the event of the loss of a single turbine. Therefore, the worst case of four cycles at 24 months yields eight years between calibrations.

Table 3-2 summarizes the maintenance practice of the Sizewell B plant for pressure transmitters before and after implementation of on-line calibration monitoring.

Table 3-2
Sizewell Practice for Maintenance of Pressure Transmitters Before and After OLM Implementation

Maintenance Task	Frequency of Maintenance Task	Maintenance Task Performed	
		Before OLM Implementation	After OLM Implementation
Channel checks.	Twice per day at each shift.	Yes.	Yes.
Surveillances.	Monthly; excludes the transmitter.	Yes.	Yes.
Response time testing.	Once per fuel cycle (using the noise analysis technique).	Yes.	Yes.
Testing of sensing lines (for blockages, air, leaks, and so on).	Once per fuel cycle in conjunction with noise analysis testing of transmitters.	Yes.	Yes.
On-line calibration monitoring.	Once per cycle.	No.	Yes.
Manual calibrations.	Once per cycle.	Yes.	No, unless maintenance is determined to be necessary. If OLM finds one transmitter in a group of redundant transmitters to have exceeded its calibration limits, all of the transmitters in that group will be calibrated.
Visual inspection of transmitter installation using PMI-SZ020 and PMI-SZ021.	Once per cycle during plant refueling outage.	No, not needed; performed in conjunction with calibration.	Yes.

Benefits to Plant Safety and Transmitter Maintenance

Reviews of calibration procedures and calibration data from nuclear power plants have shown that mistakes can be made during manual calibrations—in some cases, errors have upset transmitters with good calibration and have negated any benefit of the calibration [9]. An analysis of the history of Sizewell transmitters revealed that about 5% of transmitters sustained operator-induced errors during an outage. The errors required that additional calibrations be made within a couple of months of a refueling outage.

There have been incidents in which pressure sensing lines were not properly restored after a calibration, causing problems such as dynamic delays in measurement of transient pressure signals. More specifically, isolation valves, equalizing valves, and other valves in pressure sensing lines have been left partially or totally closed, which has created blockages and affected the static and/or dynamic performance of pressure transmitters [15]. In some cases, redundant transmitters share a common sensing line. In such cases, if a root valve is left partially or totally closed, it can affect the performance of all redundant transmitters. These problems can affect the safety of the plant and could be significantly reduced when OLM is implemented to optimize the frequency of calibration of pressure transmitters.

Furthermore, the calibration of some transmitters is affected by the environmental temperature and static pressure that are taken into account by OLM but neglected in conventional calibrations. Therefore, OLM implementation increases safety in a number of ways—notably, OLM results in fewer human errors, less calibration-induced damage to transmitters and other plant equipment, traceability of the effects of environmental and process conditions on calibration, and timely detection of out-of-calibration transmitters. The key benefits of OLM implementation for calibration monitoring of pressure transmitters at the Sizewell B plant are as follows:

- Unnecessary intrusive maintenance is reduced.
- The reliability of transmitters will actually be improved by removal of erroneous measurements and test equipment, a source of CMFs.
- Calibration problems are identified as they occur.
- Calibration drift and other anomalies and related hardware problems are identified.
- Wear on transmitter components, such as calibration potentiometers and other components manipulated during calibrations, is reduced.
- Calibrations are verified at normal operating temperature and pressure. That is, any effect on calibration resulting from static pressure or environmental temperature is accounted for in monitoring the transmitter drift during plant operation.
- Calibration work for safety-related transmitters in the reactor containment typically requires control room supervisor permission and appropriate equipment inoperability tagging and tracking. These efforts take valuable time away from control room operators during outages, when operators are very busy. With OLM, this burden can be reduced by 75%.

- Alarm traffic within the control room during calibration activities is reduced.
- The direct workload of plant technicians and others who must be involved in transmitter calibration is potentially reduced by as much as 75%.
- CMFs of the measurement and test equipment used for calibration will be revealed more quickly with OLM when only one of four channels is calibrated. (If four redundant transmitters are all calibrated with a faulty measurement and test equipment apparatus, it could take some time for this to be observed after startup because all sensors will be in agreement.)
- Maintenance-induced errors are reduced by as much as 75%. As previously mentioned, experience has shown that this is one of the most significant failure modes and is the result of miscalculation or failure to correctly return the transmitter to service. Figure 3-1 shows the results of a study of failures of pressure sensing systems in nuclear power plants and the causes of these failures [15]. The data for this study came from the NRC's Licensee Event Report (LER) Database and covered 12 years (1980–1992) of operation history for all U.S. nuclear power plants (nearly 100 plants). The study showed that human errors are a significant cause of reported failures of pressure sensing systems (made up of transmitters, sensing lines, and circuits) in nuclear power plants.

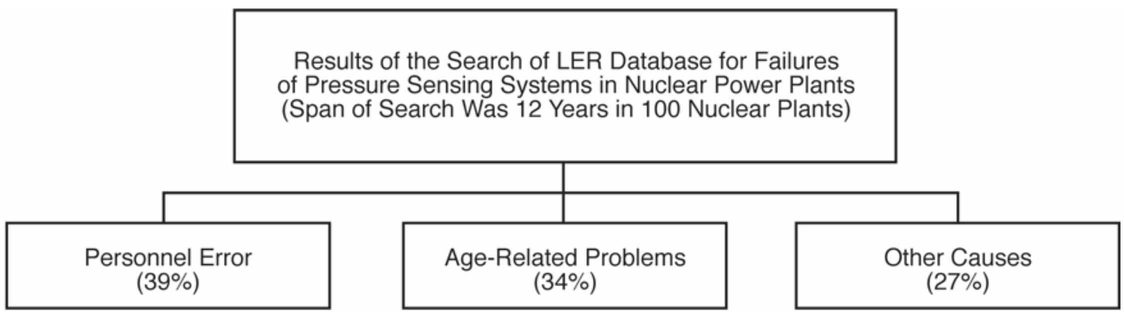


Figure 3-1
Failures of Pressure Sensing Systems and Their Potential Causes

Economic Justifications

The cost-benefit of OLM implementation will vary by site. There are initial cost considerations as well as recurring costs for OLM system maintenance and analysis. The economic benefits are primarily a result of outage time reduction, radiation exposure reduction, labor cost savings, and the reduced risk of plant trips and instrument damage incurred during manual calibrations. The discussions that follow are based primarily on the BE implementation at Sizewell.

Costs of Implementation

The Sizewell B plant computer contains all the data needed to verify the calibration of pressure transmitters. The data are easily retrieved from the plant computer and analyzed to identify calibration problems. Data from plant startup and shutdown periods are used to verify the calibration of instruments over their operating range. At Sizewell, the required data for OLM analyses are collected at a negligible cost because the data are already available. In plants that require a separate data acquisition system for OLM, this initial cost must be considered.

Other initial costs are acquisition of suitable software systems and engineering support, development of procedures, training, QA, verification and validation (V&V), and feasibility studies (and related documentation) required for regulatory approval. The primary recurring costs are the costs incurred by engineering staff to maintain the OLM system and perform data analysis. Continuous OLM system assessments, documentation of these assessments, and subsequent calibration activities will incur additional costs.

Economic Benefits of Implementation

A number of direct and indirect economic benefits result from the implementation of OLM for calibration interval extension. These benefits are described in the following sections, and a summary concludes Section 3.

Savings from Shortened Outages

At Sizewell, the primary benefit of OLM implementation stems from the reduction in the number of calibrations, which facilitates a reduction in the length of time required for a refueling outage. At the Sizewell B plant, it takes approximately 25 days to manually calibrate all of the in-containment transmitters—this time cannot be reduced by simply adding technicians to carry out the work. Thus, pressure transmitter calibration is the limiting factor in the plant's ability to reduce the plant outage time to less than 25 days. The OLM implementation removes this limitation. There are many other transmitters that are included in on-line calibration monitoring at Sizewell B, but only those in the reactor containment contribute directly to the length of the outage. Accordingly, the primary focus of Sizewell B in the first stage of this implementation project was to reduce the unnecessary calibration of the in-containment transmitters.

Currently, BE plans to reduce the plant outage duration to 20 days by 2008. This will be achievable only through implementation of OLM and subsequent transmitter calibration interval extensions, which are expected to save up to five days of outage time. Note that other modifications to the typical outage procedures will coincide with the OLM implementation to achieve a 20-day outage; however, without OLM and calibration interval extensions, the outage length could not be shortened to less than 25 days. If the savings are estimated to be $1 million per day, the total savings resulting from shortened outage time will be $5 million. This benefit alone justifies all the effort that BE has invested in OLM implementation and the cost of the work. Note that the reduction in outage time for other plants will vary according to a variety of factors, and in some cases, the result might be no reduction.

It should be pointed out that the 20- to 25-day outage duration for the Sizewell B plant would be enough time to calibrate all the in-containment transmitters were it not for other work that has to be performed in the containment at the same time. Also, some of the outage duration is taken up by plant cooling and heating periods at shutdown and startup, when calibration work is not performed, normally. The time that is available for in-containment work to calibrate pressure transmitters is typically much less than the 20- to 25-day duration of the outage. Furthermore, there are limitations on the number of personnel that can be working in the reactor containment at the same time during an outage.

Savings from Reduction in Required Calibrations

There are other direct benefits to a plant besides savings from outage duration. For example, the cost of calibration of an in-containment pressure transmitter is about $3,000. Therefore, if 50 transmitters are spared calibration, the savings will be $150,000 from labor cost savings alone.

Savings from Reduced Radiation Exposure

OLM implementation obviously contributes to the well-known dose reduction concept in the nuclear industry, a concept commonly referred to as *as low as reasonably achievable* (ALARA). The ALARA savings for Sizewell implementation of OLM are illustrated in the following three examples:

- Example 1: Dose savings realized in RFO7. During RFO7, 26 transmitters were not calibrated, of which 13 were in the reactor containment. This resulted in a direct dose savings of 320 man-micro Sieverts (man.µSv), as shown in the equation included in this example. Of the 13 in-containment transmitters, 12 were in a 5-micro-Sieverts (5-µSv)/hr area, and one was in a 20-µSv/hr area. Based on two personnel in containment for two hours, the total dose savings is calculated as follows:

  (2 x 2 x 12 x 5) + (2 x 2 x 1 x 20) = 320 man.µSv = 32 man-milliRem (man.mrem)

  The data for this calculation were obtained from BE's Health Physics Department for radiation doses that are currently experienced during power and refueling outage operations at Sizewell (see Table 3-3).

Table 3-3
Radiation Dose Rate Data for Sizewell

Radiation Dose During Sizewell B Plant Outages		
Location	**Gamma µSv/hr**	
Containment (average)	5	
Reactor coolant pump (RCP) seal injection (average)	20	
Volume control tank (VCT) level (average)	60	
Radiation Dose at Power		
Location	**Neutron µSv/hr**	**Gamma µSv/hr**
28 meter level	1	0.1
28 meter level	0.1	0.2
28 meter level	0.005	0.01
28 meter level	0.05	0.5
28 meter level	0.01	0.02
Average	**0.223**	**0.13**
Maximum	**1.0**	**0.5**

- Example 2: Dose savings when OLM is fully implemented. When OLM is fully implemented at Sizewell for the PPS transmitters in the containment, there will be 48 transmitters to include in OLM. Actually, there are 77 PPS transmitters in the containment, but of these, 64 are amenable to on-line calibration monitoring. Of the 64 PPS transmitters, 25% have to be calibrated every cycle, leaving 48 transmitters that are spared calibration. If no sensors are flagged for calibration by OLM, a total savings of 1800 man.µSv would be achieved for these 48 transmitters, as shown by the following calculation. The calculation is based on two personnel in containment for two hours on 42 transmitters in a 5-µSv/hr area, three in a 20-µSv/hr area, and three in a 60-µSv/hr area. The sample calculation for dose savings gained from full implementation of OLM is as follows:

  (2 x 2 x 42 x 5) + (2 x 2 x 3 x 20) + (2 x 2 x 3 x 60) = 1800 man.µSv = 180 man.mrem

- Example 3: Dose savings for reduction of post-outage recalibration. Sometimes transmitter calibrations that are performed during refueling outages are faulty and not discovered until after the plant returns to service. When the problem is discovered, plants often carry out the calibration at power. OLM will reduce this problem or enable the plant to avoid it altogether. More specifically, when fully implemented in a nuclear power plant, OLM is said to reduce technician-induced calibration errors by up to 75%. A single sensor subject to recalibration at power at Sizewell B would on

average attract a dose of 900 man.μSv and in some cases, more than 4000 man.μSv (both figures are based on Sizewell's current activity levels). There is a potential to reduce the number of in-containment recalibrations that result from operator error by three per cycle, which represents a dose savings of 2700 man.μSv or 270 man.mrem per cycle.

Note that these three examples assume two personnel for two hours in the reactor containment but do not make any allowance for Health Physics support or increased dose rates as the plant ages. Obviously, these additional factors would add to the ALARA benefits of OLM implementation.

Summary of Economic Justifications

Table 3-4 summarizes the cost elements discussed in the preceding section. The costs are very much dependent on the plant and whether OLM data can be retrieved from the plant computer.

Table 3-4
Potential Costs and Benefits of OLM

Cost Elements	
Initial Costs	**Recurring Costs**
Program development and feasibility demonstration	Operation and maintenance of the OLM system
Data acquisition	Person-hours to review results and identify drifted instruments
Data analysis	
Procedure preparation, training, QA, V&V, and commissioning	Documentation
Total initial costs: depends on the plant and whether data are readily available from the plant computer	**Total recurring costs per operating cycle: $45,000–$95,000**
Savings Elements	
OLM Benefits	**Savings from OLM Benefit**
Reduced outage time	$1,000,000 per day in avoided revenue loss
Labor cost savings (instrumentation and control [I&C] technicians, operations, utility support and supervisors, QA/quality control [QC] personnel, Health Physics personnel, administrative personnel, and so on)	$3,000 per transmitter
ALARA savings	$1,000 per transmitter
Trip reduction	$10,000 (based on a 1% chance of causing a plant trip that would cost $1,000,000 in lost revenue)
Reduced potential for damage to equipment	$500 per transmitter (based on a 1% chance of causing damage that would cost $50,000)

A simple calculation for the potential benefits of the OLM implementation at Sizewell B for RFO9, when the OLM system will be fully implemented, is as follows:

$$\text{Total potential benefit} = \left[5day \times \frac{\$1M}{day}\right] + \left[100transmitters \times \frac{(\$3000 + \$1000 + \$500)}{transmitter}\right] + \$10000$$

$$\text{Total potential benefit} = \$5,460,000$$

This is clearly a significant financial benefit—one that results mainly from the outage duration savings—and it justifies BE's motivation to implement the OLM system and extend the calibration intervals of Sizewell's transmitters.

Risk Analysis

The risks incurred as a result of the change in calibration strategy at the Sizewell B plant are discussed in this section. The benefits that offset these risks were presented previously. For calibration extension from two to eight years, the primary risks are the potential accumulation of drift and the increased probability of a dangerous failure that affects more than one safety channel. If totally ill conceived, calibration interval extension could increase the risk associated with transmitter reliability by a factor of four (for calibration period extension from two to eight years). To address this concern, an examination was performed by BE that concluded that risk, as measured by core melt frequency, is not directly related to the safety system's reliability. This is best illustrated in Table 3-5, which was extracted from the results of the Living Probability Safety Assessment (PSA) for Sizewell B.

Table 3-5
Sensitivity of PSA to PPS Reliabilities for Sizewell B

PPS Reliability Failures on Demand (F/D)	Living PSA Core Melt Frequency (per year)	Increase in Core Melt Frequency
1.0E-4	2.09E-5	--
1.0E-3	2.40E-5	0.15%
1.0E-2	3.78E-5	1.80%

The data in Table 3-5 show that even when the PPS reliability is reduced by two orders of magnitude from 10^{-4} to 10^{-2}, the increase in core melt frequency is less than 2% of a number less than $4E^{-5}$. Thus, under a worst-case scenario, the increase in core melt frequency would be $2\% \times 4E^{-5} = 8E^{-7}$.

4
OLM METHODOLGY

In a recent document, the NRC reviewed both redundant sensor monitoring techniques and techniques developed to model the relationships between non-redundant yet correlated sensors [16]. The focus application for this review was OLM for calibration interval extension of safety-related transmitters in nuclear power plants. The redundant techniques surveyed included the Instrumentation and Calibration Monitoring Program (ICMP) and Independent Component Analysis (ICA). The non-redundant methods presented in this report are the MSET, Auto Associative Neural Networks (AANN), and Nonlinear Partial Least Squares (NLPLS). The review presents the theory, general application, implementation, and uncertainty of these techniques. Interested readers should review this NRC reference for further information.

Although all of the OLM techniques previously mentioned are viable approaches to calibration monitoring, the methods that were applied at Sizewell and reported herein are strictly redundant sensor averaging techniques, very similar to the ICMP technique [17, 18].

Redundant Sensor Averaging Techniques

A variety of averaging techniques are available, including simple averaging, band averaging, weighted averaging, and parity space. These averaging techniques are illustrated in Figure 4-1. Simple averaging involves adding the values of the signals at each instant of time and dividing the sum by the number of signals. Band averaging uses a band to reject outliers and averages the values of the remaining signals at each instant of time. Weighted averaging applies a set of fixed multipliers to the signals prior to averaging. Typically, sensor weights are constant regardless of the agreement between the sensor measurements. In parity space, each signal is weighted according to the number of signals that share its parity space band. This weighted measure, commonly referred to as *consistency*, requires the determination of a consistency check value, which dictates the sensitivity of the parity space estimate to individual signal values that deviate from the simple average. The parity space averaging technique was specified by BE as the preferred method for OLM at Sizewell. The parity space average was used, except in cases in which it was not valid because of process noise, drifting sensors (when a sufficient number of sensors are not left in the average), or when there were only two sensors in the group. When parity space was not used, either the simple average or the band average was selected.

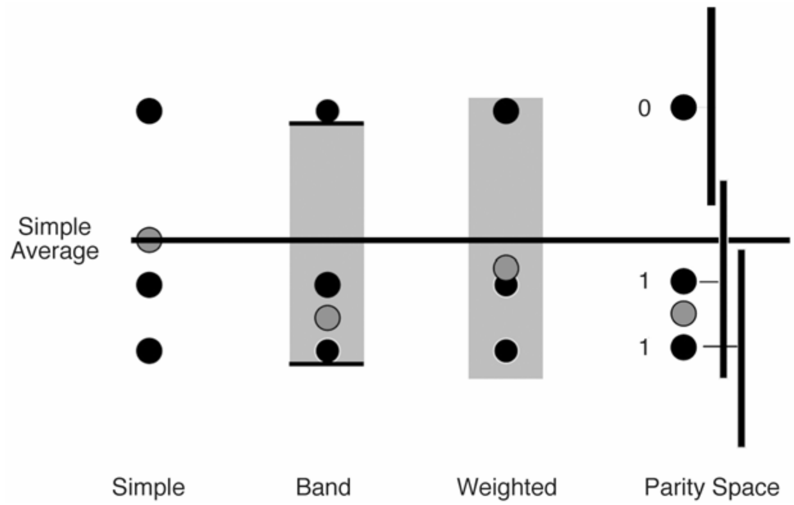


Figure 4-1
Typical Averaging Techniques

Parity Space Averaging

The parity space algorithm calculates a parameter estimate based on a weighted average of a set of redundant sensors. Weighting of individual sensors is based on their consistency with the other sensors in the group. Consistency is evaluated as the absolute difference between a given sensor and the other sensors in the group. The consistency value ranges from 0 to *n*–1, where *n* is the number of sensors in the group. Each sensor is assigned a consistency for each data sample evaluated. A sensor's consistency is calculated as follows for a set of *n* redundant sensors, $X_1, X_2, ..., X_n$:

$W_i = 0$

If $\left| X_i - X_j \right| \leq \delta$, then $W_i = W_i + 1$

where: $W_i =$ the consistency value of the i^{th} signal

$X_i =$ the output for signal i

$X_j =$ the output for signal j

$\delta =$ the consistency check allowance for the measured parameter

After the consistency values are calculated, the parity space average parameter estimate can be calculated as:

$$\overline{X}_{ParitySpace} = \frac{W_1 X_1 + W_2 X_2 + ... + W_n X_n}{W_1 + W_2 + ... + W_n}$$

Consistency controls the influence of an individual signal on the parameter estimate. If all sensors are considered equally consistent, the estimate is the simple average of the redundant sensors. If a sensor's consistency value is zero, the value will not influence the parameter estimate. For example, Figure 4-2 shows one time slice of three redundant pressure measurements.

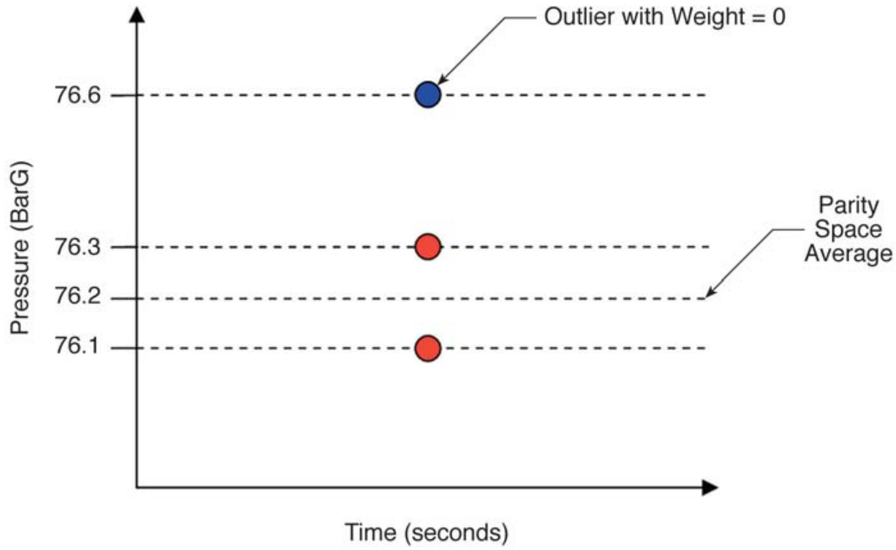


Figure 4-2
An Example of a Parity Space Average

Suppose that the consistency check limits for this group of transmitters is ±0.2 gauge pressure in units of Bar (BarG). The top signal in Figure 4-2 is not ±0.2 BarG from the other two measurements, so it is given a weight of 0. The other measurements are within ±0.2 BarG of each other, so they are both given a weight of 1. The parity space average is then calculated as follows:

$$\frac{(0*76.6)+(1*76.3)+(1*76.1)}{0+1+1}=76.2$$

Analysis of Deviation from the Parameter Estimate

Once the parameter estimate is calculated using the parity space averaging technique described, the deviations of each individual sensor in the redundant group from this estimate are computed, that is:

$$X_1-\overline{X}_{ParitySpace},\ X_2-\overline{X}_{ParitySpace},\ \ldots,\ X_n-\overline{X}_{ParitySpace}$$

These deviations are analyzed over an entire fuel cycle and checked against allowable calibration limits. The calibration limits are established in such a way that if the OLM system deviations reside within the allowable calibration limits, the sensor is determined to be within calibration.

Sensors are classified as being in need of calibration when their respective deviations exceed the allowable OLM calibration limits. Note that the allowable calibration limits referred to here must be derived specifically for the OLM application and differ from the manual as-found, as-left (AFAL) calibration limits. These limits are also commonly referred to as *acceptance criteria* for OLM and are discussed in detail in Section 6.

Figure 4-3 presents an illustration of a deviation analysis for four steam generator (SG) level transmitters. The y-axis in this figure is the difference between the reading of each transmitter from the parity space average estimate, and the x-axis represents time in months. The data shown are for the 30 months during which the plant operated. None of the four signals showed any significant drift during the 30-month period, and all remained within the allowable calibration limits. That is, these transmitters did not suffer any significant calibration change and did not need to be calibrated.

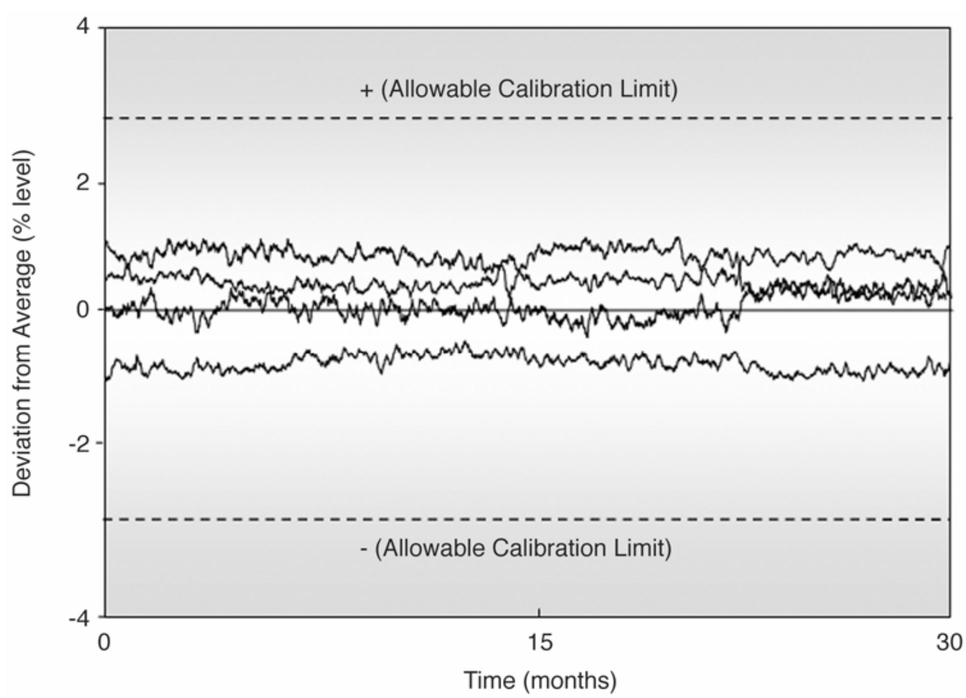


Figure 4-3
Deviation Analysis for Four SG Level Transmitters in a Nuclear Power Plant

OLM System Architecture

The architecture of the OLM software system implemented at Sizewell B is depicted in Figure 4-4. The raw data are first screened by a data qualification algorithm, and the signal statistics are analyzed. In the case of averaging analysis, consistency checking is also performed. Once the data are screened and qualified, they are passed to the appropriate software module to compute a parameter estimate for the monitored process. Figure 4-4 also shows a modeling block under data analysis that includes other possible OLM algorithms that can be applied to non-redundant

sensors to produce parameter estimates. In some cases in which the redundancy is too low to apply averaging techniques, the physical sensor measurements can be augmented with empirical estimates of the process based on related sensors in the plant. The augmented set of sensor readings can then be combined to produce the best estimate. During the implementation at Sizewell B, only redundant instrument sets were analyzed with the parity space technique. The best estimate is then subtracted from each individual sensor value, and the resultant deviation is compared to the allowable calibration limits. Finally, an engineering analyst reviews the results and prepares a list of instruments that require calibration.

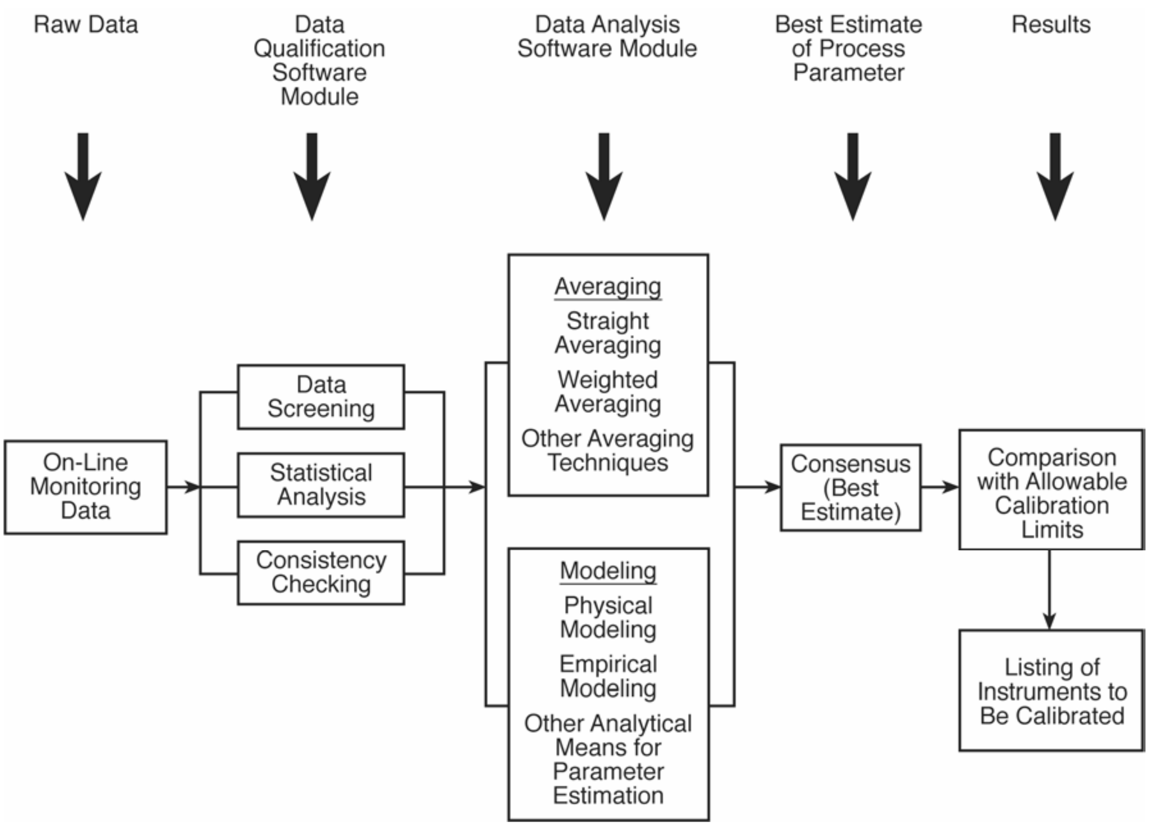


Figure 4-4
Components of Data Analysis Software for On-Line Calibration Monitoring

Types of Transmitter Drift

Pressure transmitter calibration can change as a result of a change in zero, a change in span, or a change in both zero and span. A change in zero is also referred to as a *bias error*, *offset*, or *zero shift*. A zero shift corresponds to a constant error in an instrument's reading (either positive or negative) at all points along the instrument's range. An example of high and low zero shift is shown in Figure 4-5. A zero shift can occur for a variety of reasons, such as environmental temperature changes, mechanical shock, and aging effects. For example, if an instrument is calibrated at room temperature and used at a different temperature, its output might include a bias error (or zero shift) because of the temperature difference.

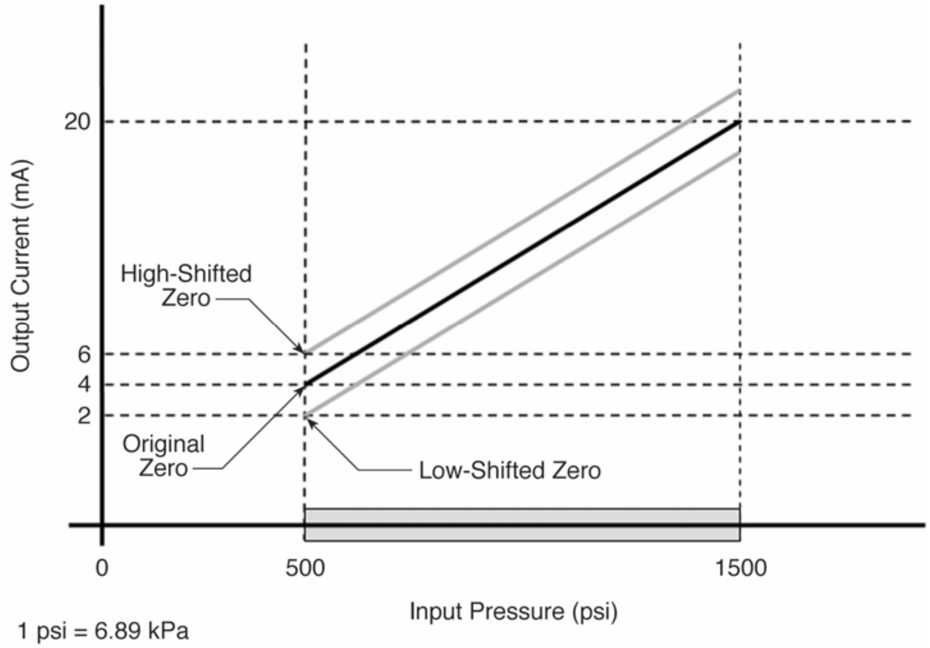
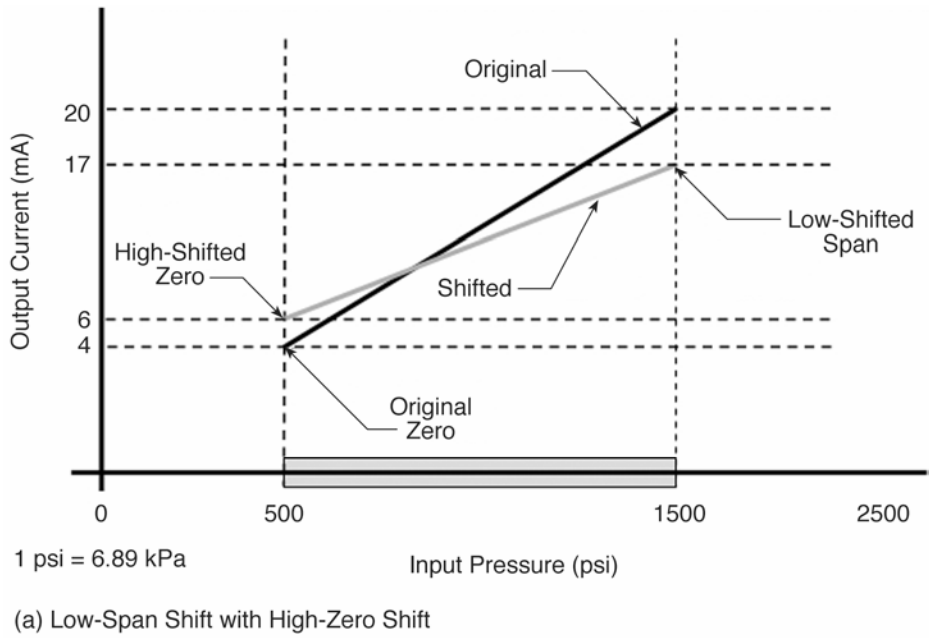


Figure 4-5
High and Low Zero Shift

A change in the slope of the input/output relationship is referred to as a *span shift*. A span shift might be accompanied by a zero shift. Figure 4-6 shows span shifts with and without zero shift. Typically, calibration errors involving only span shift are less common than calibration errors caused by both zero and span shifts.



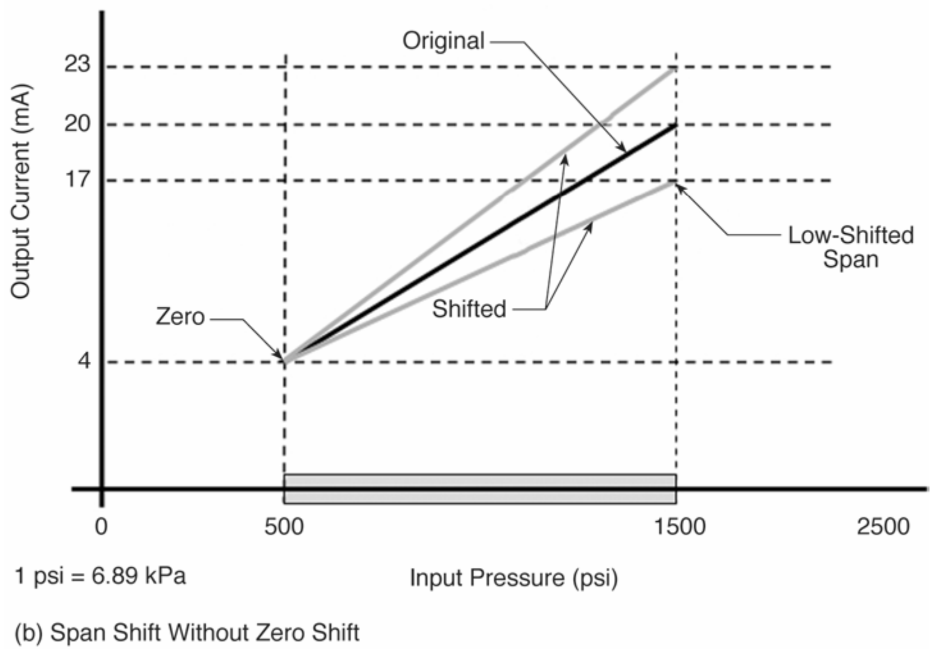


Figure 4-6
Span Shift With and Without Zero Shift

An EPRI study of transmitter calibrations [5] has shown that zero shift alone was the dominant type of drift, and it was also a contributor to drift in a significant portion of the span shift cases. The study evaluated the proportion of different drift types based on the magnitude of observed drift in the transmitter. Transmitters were initially grouped together based on the magnitude of observed drift—for example, 1–2% of span. For each of these defined groups, the proportion of

different types was then determined. An average representation of the cumulative results of the study is presented in Figure 4-7. Figure 4-7 indicates that calibration changes in pressure transmitters are caused solely by zero shift in 42% of cases, by zero and span shift in 33% of cases, and by span shift alone in 17% of cases. The remaining 8% of calibration changes are caused by other effects, such as nonlinearity.

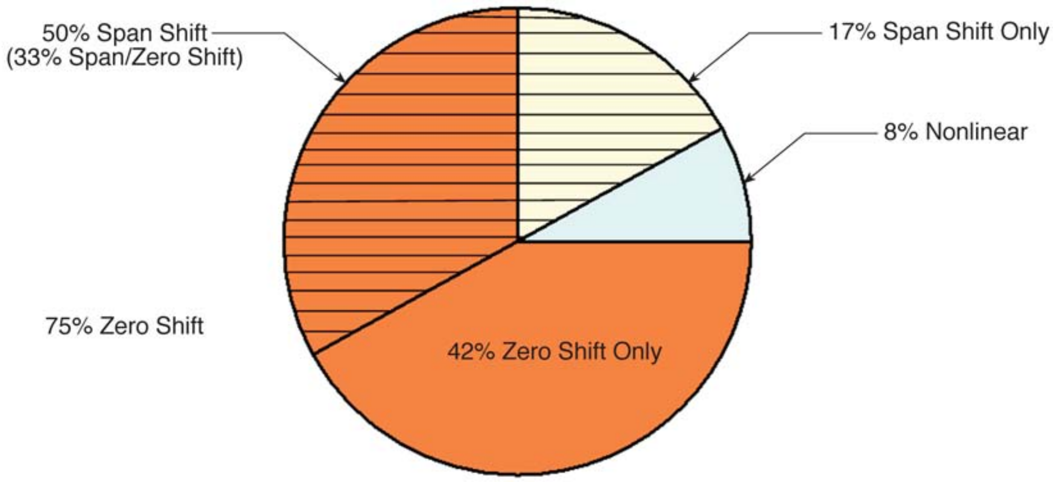


Figure 4-7
EPRI Drift Study Results

Technical Issues

Several technical issues described in this section are important considerations for OLM system implementations. Transmitter calibration must be verified over the entire operating range of the transmitter. Using parity space averaging, this can be achieved if data are available throughout the transmitter range. The next issue is common mode drift, for which concerns are addressed in this section. In addition, although OLM systems enable a degree of automation, there is still a significant role for a human analyst in reviewing the analysis results and making calibration recommendations.

Verifying Calibration over the Transmitter Operating Range

On-line calibration monitoring identifies calibration problems at the point at which the transmitter is currently operating. OLM can be viewed as a single-point calibration check, or what is commonly referred to as *single point monitoring* (SPM) and discussed in detail in Section 6. To verify the calibration of instruments over their entire range, OLM data should be collected during plant startup and/or shutdown periods. With data from these periods, the instrument calibration can be verified over a wide range.

Figure 4-8 shows startup and shutdown data retrieved from the Sizewell plant computer for nine transmitters. Figure 4-9 shows the deviation of one of the transmitters at seven points within the calibrated range of the transmitter. This result was obtained by determining the average deviation of each transmitter within a specified partition of the operating range from the parameter estimate. The dashed lines in Figure 4-9 represent the plant's acceptance criteria (its allowable calibration limits) for the deviation of these transmitters. How the acceptance criteria are established is discussed in Section 6.

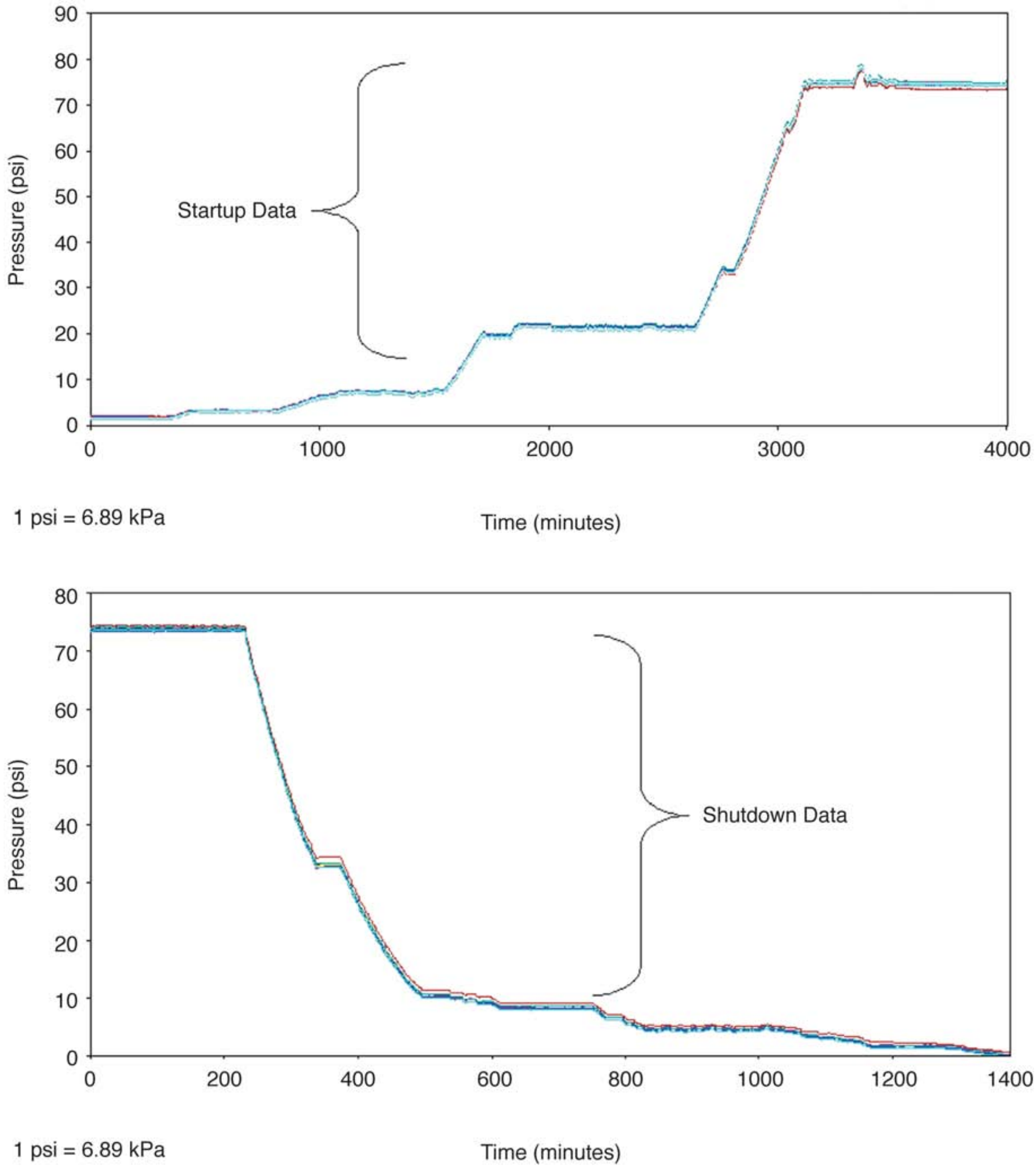


Figure 4-8
Plant Startup and Shutdown Data

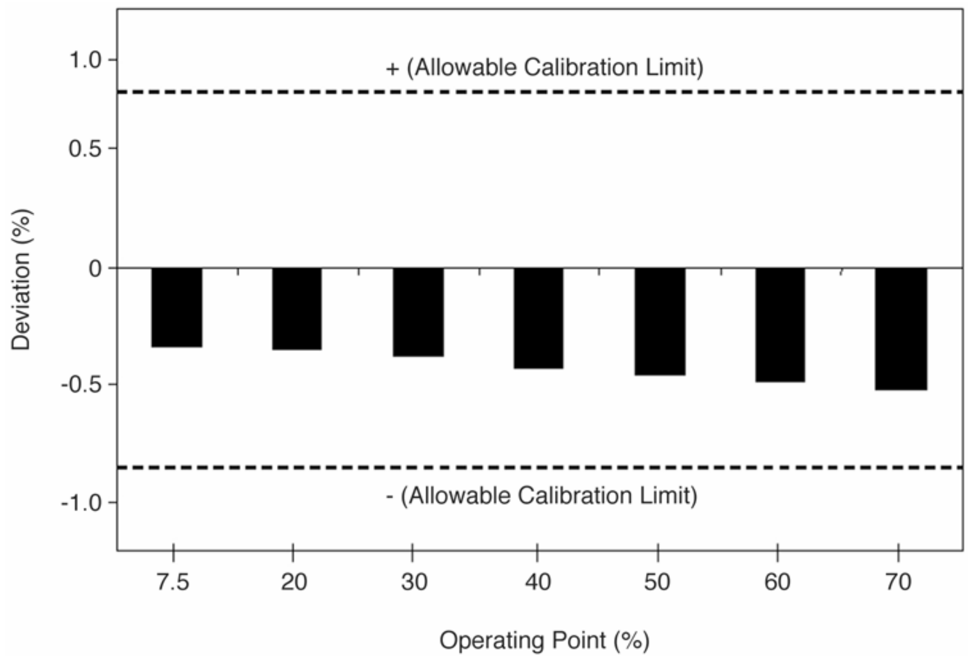


Figure 4-9
OLM Results for Assessment of Calibration of a Pressure Transmitter as a Function of Pressure Range

Availability of Data Covering the Transmitter Operating Ranges

Nearly all pressure transmitters are amenable to on-line calibration monitoring, some with stipulations and others without stipulations. For example, those transmitters for which OLM data are available during plant startup, shutdown, and normal operation are readily amenable to on-line calibration monitoring without stipulations. Some transmitters, such as water storage tank level transmitters that do not normally experience a wide range of input pressures, are amenable to on-line calibration monitoring if OLM data can be recorded from these transmitters when the tank is emptied or filled. This provides an opportunity to verify the calibration of the transmitter over a wide range.

Transmitters such as those that measure the containment pressure do not experience a wide range of input pressures. The exception is when the plant is going through an integrated leak rate test (ILRT), during which time the containment pressure changes significantly and BE can take advantage of the ILRT period to gather OLM data to verify the calibration of containment pressure transmitters. It should be pointed out, however, that ILRT is performed at Sizewell once every five years. Therefore, the adequacy of this period will have to be evaluated to determine whether containment pressure transmitters are amenable to on-line calibration monitoring without stipulations.

For pressure transmitters that normally operate at the bottom or at the top of their range, on-line calibration monitoring is subject to a strong stipulation because these transmitters can saturate low or high if they drift. For example, if a transmitter normally operates at 100%, its upward drift might not be observable if the transmitter output saturates high. Conversely, if a transmitter normally operates at 0%, its negative drift might not be detected. Thus, these transmitters are not included in on-line calibration monitoring or are handled on a case-by-case basis to determine if OLM can provide reliable results on their calibration drift and potential for calibration extension.

To determine the availability of data to cover the operating ranges of Sizewell transmitters, data for the PPS and SPS transmitters from Cycle 5 were evaluated based on the percent of the transmitters' span observed in the OLM data and the proximity of static data to the low end of the transmitters' ranges. Most of the Sizewell data examined transitioned through multiple points within the transmitter ranges. As long as each transmitter transitioned through at least 25% of its calibrated range, it was considered amenable to on-line calibration monitoring without stipulations. Sizewell transmitters that remained within 10% of the low end of their calibrated range must be reviewed on a case-by-case basis to evaluate the suitability of OLM for calibration verification.

Table 4-1 shows the transmitter groups that were reviewed. Most of the PPS groups were observed to transition through over 40% of their calibrated ranges, whereas six of the PPS groups were not observed to transition through over 25% of their ranges. In particular, the reactor building pressure A and the reactor building pressure B, both PPS groups, were observed at only 0 BarG and did not transition through any significant percentage of their ranges. Because they did not transition and they were observed close to the low end of their calibration ranges, they should be evaluated on a case-by-case basis for amenability to calibration extension.

Table 4-1
Sizewell B Transmitters Readily Amenable to Calibration Extension

Parameter	Full Range	Observed Range (Startup: Cycle 5)	Observed Range (Shutdown: Cycle 5)	Percent of Full Range Observed	Transmitter Type
Reactor coolant system (RCS) loop flow	0–120%	1: 100%, 107%, 117% 2: 100%, 107%, 117% 3: 100–110% 4: 100–110%	1: 100–110% 2: 100% 3: 100% 4: 100%, 110%	1: 17% 2: 17% 3: 10% 4: 10%	PPS
RCS narrow-range pressure	116–170 BarG	116–156 BarG	120–155 BarG	74%	PPS
RCS wide-range pressure	0–200 BarG	10–155 BarG	20–155 BarG	73%	PPS
Pressurizer narrow-range pressure	116–170 BarG	116–152 BarG	120–155 BarG	67%	PPS
Pressurizer level	0–100%	35–60%	10–90%	80%	PPS
SG outlet pressure	0–100 BarG	7–70 BarG	7–70 BarG	63%	PPS
Steam flow	0–600 kg/s	360–525 kg/s	30–520 kg/s	82%	PPS
SG narrow-range level	0–100% narrow range	A: 63–70% B: 63–70% C: 63–70% D: 64–70%	A: 10–90% B: 10–70% C: 10–70% D: 10–90%	A: 80% B: 60% C: 60% D: 80%	PPS
SG wide-range level	0–100% wide range	A: 76%, 86%, 96% B: 76%, 86%, 96% C: 76%, 86%, 96% D: 76%, 86%, 96%	A: 10–90% B: 10–90% C: 10–90% D: 10–90%	A: 80% B: 80% C: 80% D: 80%	PPS
Main feedwater flow	0–600 kg/s	A: 40–485 kg/s B: 50–475 kg/s C: 60–485 kg/s D: 50–470 kg/s	A: 70–440 kg/s B: 115–440 kg/s C: 105–445 kg/s D: 105–445 kg/s	A: 74% B: 71% C: 71% D: 70%	PPS
Volume control tank level	0–100%	35–65%	35–85%	50%	PPS
Refueling water storage tank (RWST) level	0–13.64 m	12.75 m	4–13 m	66%	PPS
Essential service water (ESW) flow to component cooling water (CCW) heat exchangers	0–7000 m^3/h	A: 1800–3300 m^3/h B: No data	A: 1600–2500 m^3/h B: 1800–2500 m^3/h	A: 21% B: 10%	PPS
CCW flow to low temperature loads	0–500 m^3/h	420–440 m^3/h	365–460 m^3/h	19%	PPS
CCW flow in RCP thermal barrier return	0–65 m^3/h	26–35 m^3/h	9–35 m^3/h	42%	PPS

Table 4-1 (continued)
Sizewell B Transmitters Readily Amenable to Calibration Extension

Parameter	Full Range	Observed Range (Startup: Cycle 5)	Observed Range (Shutdown: Cycle 5)	Percent of Full Range Observed	Transmitter Type
CCW surge tank level	0–100%	A: 37–42% B: 36–39%	A: 23–33% B: 36%	A: 10% B: 3%	PPS
RCS wide-range pressure	0–250 BarG	10–155 BarG	10–155 BarG	58%	SPS
RCS narrow-range pressure	100–200 BarG	100–155 BarG	110–155 BarG	45%	SPS
SG outlet pressure	0–100 BarG	7–70 BarG	7–70 BarG	63%	SPS
SG level	0–100%	A: 63–70% B: 63–70% C: 63–70% D: 63–70%	A: 10–90% B: 10–70% C: 10–70% D: 10–90%	A: 80% B: 60% C: 60% D: 80%	SPS
Reactor building pressure A	-0.3–5.0 BarG	0 BarG	0 BarG	-	PPS
Reactor building pressure B	-0.3–7.0 BarG	0 BarG	0 BarG	-	PPS
RCP seal injection flow	0–7 m^3/h	No grouping	No grouping	-	SPS

All SPS transmitters transitioned through >40% of their ranges. Note that data were not available to evaluate the RCP injection flow service. Although some transmitters were not observed to transition through a significant portion of their range and are thus not amenable to calibration interval extension, BE has requested that OLM results be provided anyway because the results can still show early indications of a transmitter problem.

The information presented in Table 4-1 was prepared to identify those transmitters that can easily be included in the calibration interval extension program and to identify transmitters for which more detailed analyses are required to set proper acceptance limits for OLM to account for the limited observable range of the data. BE carefully reviewed this information to determine which transmitters to include in the calibration interval extension program and to define the appropriate acceptance criteria.

Common Mode Drift

To rule out any systematic (common mode) drift in an OLM system implementation for calibration interval extension, one transmitter from every set of redundant transmitters is calibrated during each operating cycle, with cycles lasting 18–24 months depending on the plant. Systematic drift occurs if the transmitters drift together in one direction. In that case, the deviation from average would not reveal the common mode drift; thus, calibrating at least one transmitter from each set of redundant transmitters will prevent common mode drift from going undetected.

Another approach to account for common mode drift is to obtain an independent estimate of the monitored process and to track this estimate along with the indication of the instruments. A number of techniques are available to obtain an independent estimate of the value of the process parameter being monitored, as shown in the modeling block of Figure 4-4. Each technique can estimate the value of a process parameter based on other parameters that have a relationship to the monitored parameter. For example, in a boiling process, temperature and pressure are related by a simple model. Thus, if temperature in this process is measured, the corresponding pressure can be easily determined, tracked, and compared with the measured pressure as a reference to identify systematic drift. This approach can also be used to provide a reference for detecting drift if there is no redundancy or if there is a need to add to the redundancy. With this approach, the calibration drift of even a single instrument can be tracked and verified on-line. In essence, an analytical sensor can be created by modeling techniques and used as a reference for detecting drift or common mode drift or to serve as an analytically redundant sensor.

The modeling example involving a boiling process previously discussed is one of the simplest cases to consider. In practice, however, a process parameter cannot be identified from the measurement of another single parameter. For example, in physical modeling, complex relationships are often involved in relating one parameter to another. Furthermore, a fundamental knowledge of the process and material properties is often needed to provide reasonable estimates of a parameter using a physical model. As such, empirical models are often preferred for parameter estimation when additional analytical redundancy is required.

The Role of the Human Analyst

Although the screening, qualification, and analysis of on-line calibration monitoring data are largely automated, human expertise plays an important role in arriving at the final results—a plant should not depend solely on computer algorithms to identify the calibration status of instruments. The final decision as to whether a transmitter should be scheduled for calibration should be made by human experts after a careful review of all steps of the data processing sequence and the verification of the results. To this end, Sizewell B has been training its own personnel to analyze and interpret the data in addition to relying on AMS and its algorithms and software packages. During the implementation project performed at Sizewell B, BE personnel have remained engaged in all aspects of the project, from data acquisition to interpretation of results.

5
APPLICATION OF OLM AT SIZEWELL

In this section, the procedures that were followed for the implementation at Sizewell B are explained. Data processing and analysis are detailed, and the typical presentations of results from the OLM system are illustrated. The verification of the applied OLM procedure is briefly explained and followed by several examples of typical analysis results and a summary of interesting observations.

The application of OLM to extend the calibration intervals of pressure transmitters at Sizewell B involves data collection and data analysis performed under the following conditions:

- The transmitters being monitored are installed in the plant in the normal configuration for service.
- Transmitters are powered, active, and available.
- The plant is operating; operations include startup, normal operating conditions, and shutdowns. Periods of plant trips are also included.
- Data collection is passive and normally occurs at a remote location outside the reactor containment.
- Data analysis can be performed in real time or off-line (collected and stored, then analyzed at a later time).
- A dedicated data acquisition system (with proper isolation) is used to acquire the data independently, or data are retrieved from the plant computer.
- Data from redundant transmitters are collected simultaneously and synchronized so that there is no time lag between the signals that are averaged or modeled together.
- Data from diverse transmitters to be modeled together are sampled simultaneously and synchronized so that there is no time lag between the signals that are modeled together. When this is not possible, the effects of time difference between the signals are eliminated before analysis using techniques such as cross-correlation.

Data Collection and Processing

The OLM data can be obtained from the plant computer or a dedicated data acquisition system. Figure 5-1 shows the components of a dedicated data acquisition system for on-line calibration monitoring, including input test signals to verify the calibration and proper operation of the data acquisition system itself. This system should be designed to sample data from numerous instruments and store the data for subsequent analysis.

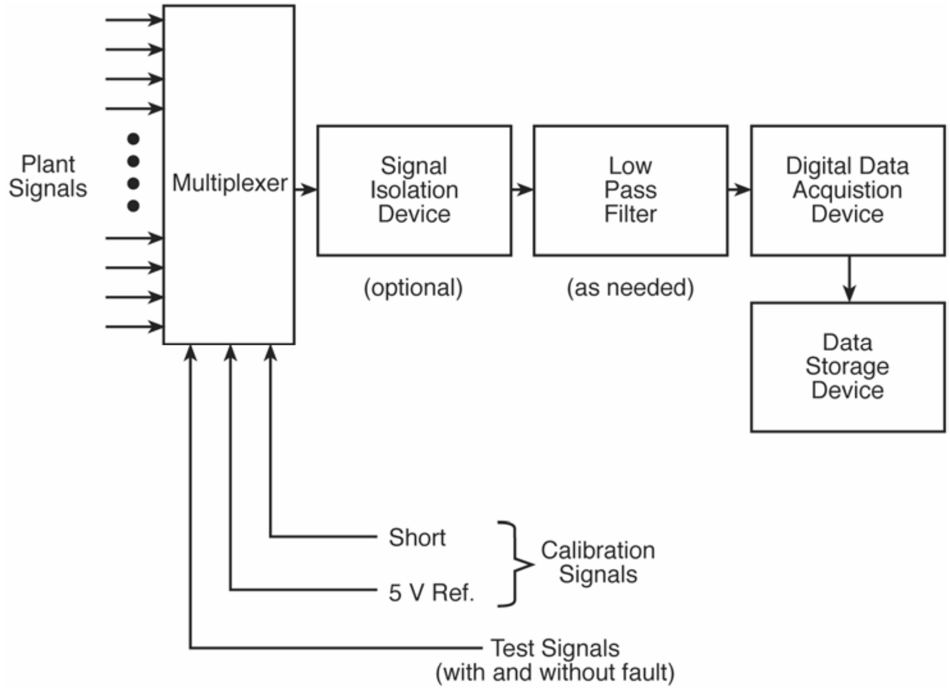


Figure 5-1
Dedicated Data Acquisition System for On-Line Calibration Monitoring

The Sizewell data were retrieved by BE and sent to AMS on CDs or through FTP. Figure 5-2 shows the data transfer chain from Sizewell. As shown in Figure 5-2, the data from the plant computer are stored on the Process Information (PI) System from OSIsoft, Inc., data management software that simplifies data storage and retrieval. The data are retrieved from the PI historian and then copied onto a CD and sent to AMS or uploaded to AMS directly through FTP. Upon receipt of data at AMS, a formal data transfer procedure is followed to document the receipt of the data and to back up the data.

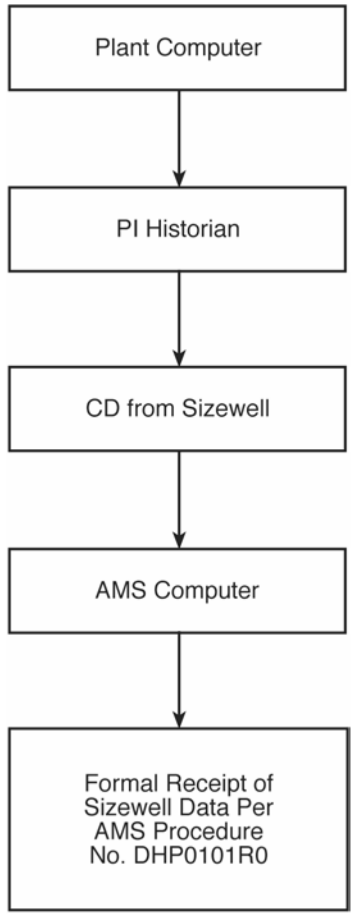


Figure 5-2
OLM Data Transfer Chain

AMS has received Sizewell OLM data from Cycles 1–7, the cycles covering the plant operating period September 1995–March 2005. Table 5-1 presents information regarding Sizewell data that were sent to AMS from Cycles 1–7. AMS continues to receive OLM data from Sizewell on a monthly basis. After the Cycle 6 startup, data were sent to AMS each month. This allowed AMS to monitor the calibrations of the transmitters each month and to trend the calibration status over the cycle.

Table 5-1
List of Sizewell B Data Files

Plant Condition	Start Time	End Time	Days
Cycle 1: startup	20-Sep-1995 23:23	17-Oct-1995 20:25	26.9
Cycle 1: mid-cycle	08-Feb-1996 11:56	26-Feb-1996 08:35	17.9
Cycle 1: shutdown	12-Jun-1996 00:00	03-Jul-1996 00:11	25.0
Cycle 2: startup	09-Aug-1996 00:01	21-Sep-1996 00:48	43.0
Cycle 2: mid-cycle	07-Apr-1997 03:03	26-Apr-1997 15:10	17.5
Cycle 2: shutdown	19-Aug-1997 11:39	15-Sep-1997 00:38	26.6
Cycle 3: startup	12-Dec-1997 10:52	14-Jan-1998 16:46	33.2
Cycle 3: mid-cycle	12-Jul-1998 21:39	29-Jul-1998 14:53	16.7
Cycle 3: shutdown	16-Feb-1999 19:42	15-Mar-1999 04:43	26.4
Cycle 4: startup	23-Apr-1999 23:50	25-May-1999 13:09	31.6
Cycle 4: mid-cycle	05-Jan-2000 13:06	22-Jan-2000 11:04	16.9
Cycle 4: shutdown	25-Aug-2000 10:02	13-Sep-2000 07:09	18.9
Cycle 5: startup	07-Oct-2000 13:00	14-Nov-2000 10:45	37.9
Cycle 5: mid-cycle	15-Nov-2001 18:25	01-Dec-2001 08:39	15.6
Cycle 5: near end	23-Feb-2002 00:00	11-Mar-2002 11:59	16.5
Cycle 5: shutdown	15-Apr-2002 00:00	06-May-2002 11:59	21.5
Cycle 6: startup	16-May-2002 15:03	12-Jun-2002 03:10	26.5
Cycle 6: mid-cycle	19-Jun-2002 03:20	24-Mar-2003 04:47	Seven days of data each month
Cycle 6: shutdown	16-Apr-2003 12:00	11-Sep-2003 23:59	One-half day of data each month

The Cycle 4 data were used to validate the OLM approach, and the data from Cycles 5–7 were used to prepare a list of transmitters that could have been excluded from manual calibrations during RF05, RF06, and RF07. When regulatory approval for this approach was given to BE in Cycle 7, the transmitters for which approval was granted were excluded from normal calibration practice. Data for Cycles 1–3 were not analyzed during this phase but might be used in a future phase of the project.

Data Preprocessing

Figure 5-3 shows the preprocessing steps: data conversion, data qualification, and data cleaning. The data from Sizewell are received in comma-separated text files. The data conversion process shown in Figure 5-3 converts the data into a binary format for analysis. During this process, data missing from the files are screened out, and based on the amount of missing data, the data quality is calculated for each transmitter in each input file. Also, there are typically seven input files for a specific period of time. Each of the seven files contains data from a portion of the transmitters. The data from the seven input files are combined into one binary data file that contains all the sensor data. Also, the data from different times are combined into one file. For example, 20 of the 12-hour format files covering a 10-day period for a particular sensor were combined into one binary data file so that the entire set of data for a specific period could be analyzed at once.

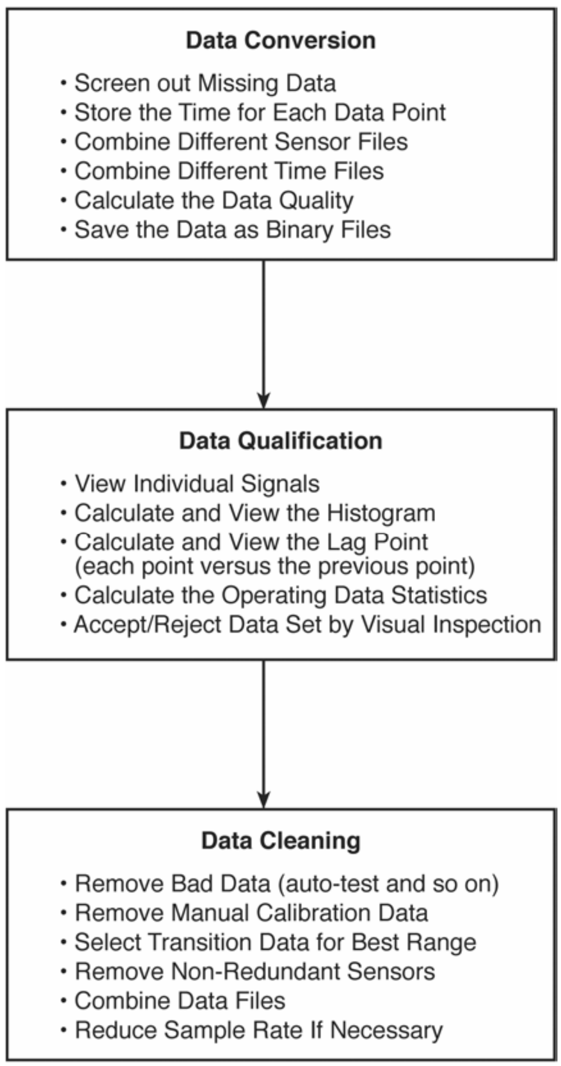


Figure 5-3
Data Preprocessing Block Diagram

After data conversion, a data qualification procedure is used to evaluate the information for each individual sensor. For each sensor, the data are viewed in a histogram and a lag plot. A lag plot shows each data point versus the previous data point; for data that follow a Gaussian distribution, this will form a filled circle. Also, statistical information, such as the mean and standard deviation of data, is calculated and evaluated for any sign of anomaly or abnormality. Any data that are anomalous or erratic are rejected based on a visual examination of data qualification information and statistical parameters. Next, a data cleaning procedure is followed. The data are reviewed in groups to identify and remove bad data, such as data that include portions for which work was performed on the channel. Examples of work that might have been performed are auto-tests, channel checks, and manual calibrations. All of the non-redundant signals are removed from the data using grouping information provided by Sizewell.

Data Analysis

Figure 5-4 shows the data analysis steps: plot the data, perform OLM analysis, review the results, produce a list of transmitters, and identify those that can be excluded from manual calibration. The data are plotted in raw format or as a deviation from the group average. The group average can be calculated using straight averaging, band averaging, weighted averaging, and/or parity space. Parity space was used by default unless spacing of the signals required another technique in order to obtain a valid estimate. When parity space was not used, either the simple average or the band average was selected. Using the group average, the deviations can then be obtained. To compensate for process noise, a median filter was used to smooth the results and to remove small spikes. Most often, a median filter of rank 20 was used. For the 10-second data, this creates a window of ±3 minutes on the data.

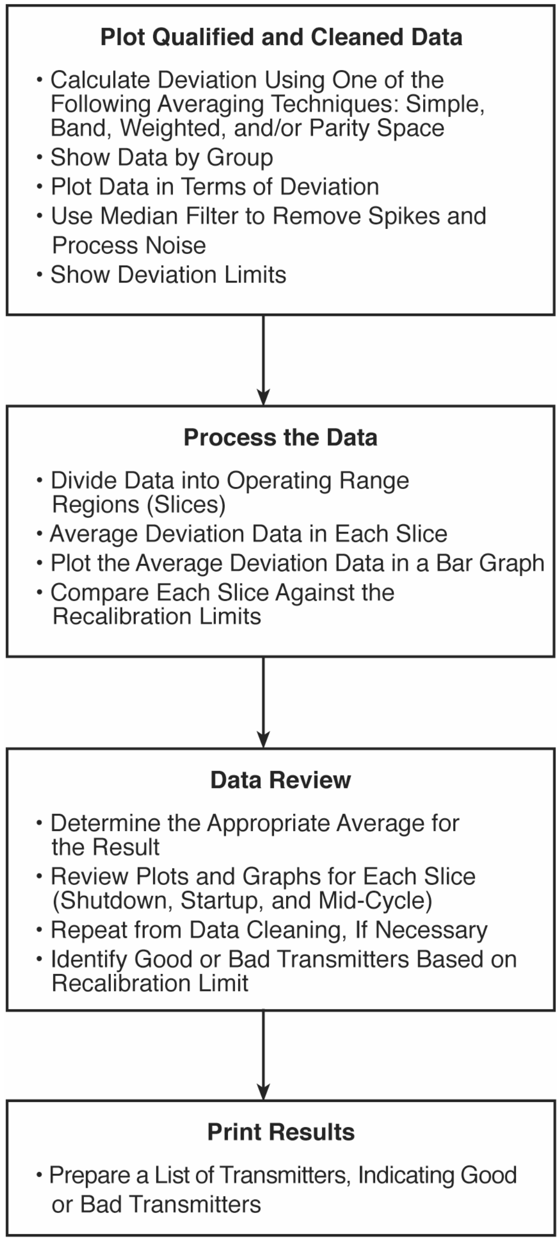


Figure 5-4
Data Analysis Block Diagram

The final step in data plotting is to show the allowable limits on the respective plots. Because some services contain both PPS and SPS sensors and because AMS had limits provided for PPS sensors only, the PPS limits are used for the SPS sensors whenever PPS and SPS sensors are combined. The parity space average and the band average both require a band limit or a consistency limit to remove outliers and determine the weighting factor for each sample of data. For these limits, AMS used the consistency check limit provided by Sizewell. The parity space average was used except in instances in which it was not valid because of process noise, drifting sensors (where a sufficient number of sensors are not left in the average), or when there are only two sensors in the group.

The next step is processing to perform the on-line calibration check. For each sensor, the same data that were plotted were divided into a specified region based on the calibration range of each transmitter. Then, each region or slice of data was averaged together to identify the transmitter's deviation for that slice or calibration point. These deviations were plotted over the calibration range of the transmitter on a graph. Each calibration point was then compared to the recalibration limit to identify whether the transmitter calibration was good or bad. Based on this information, a list of transmitters was created to indicate the good and the bad ones in terms of their need for a new calibration.

Data Analysis Procedure Simulation

To clarify the process of data analysis, a three-part simulation is presented in this section. First, a set of startup data was simulated for three redundant sensors. The startup occurred over 1000 equal but arbitrarily defined time samples. The startup occurs at a constant rate of +0.1% per sample. The simulated startup data are shown in the upper plot of Figure 5-5.

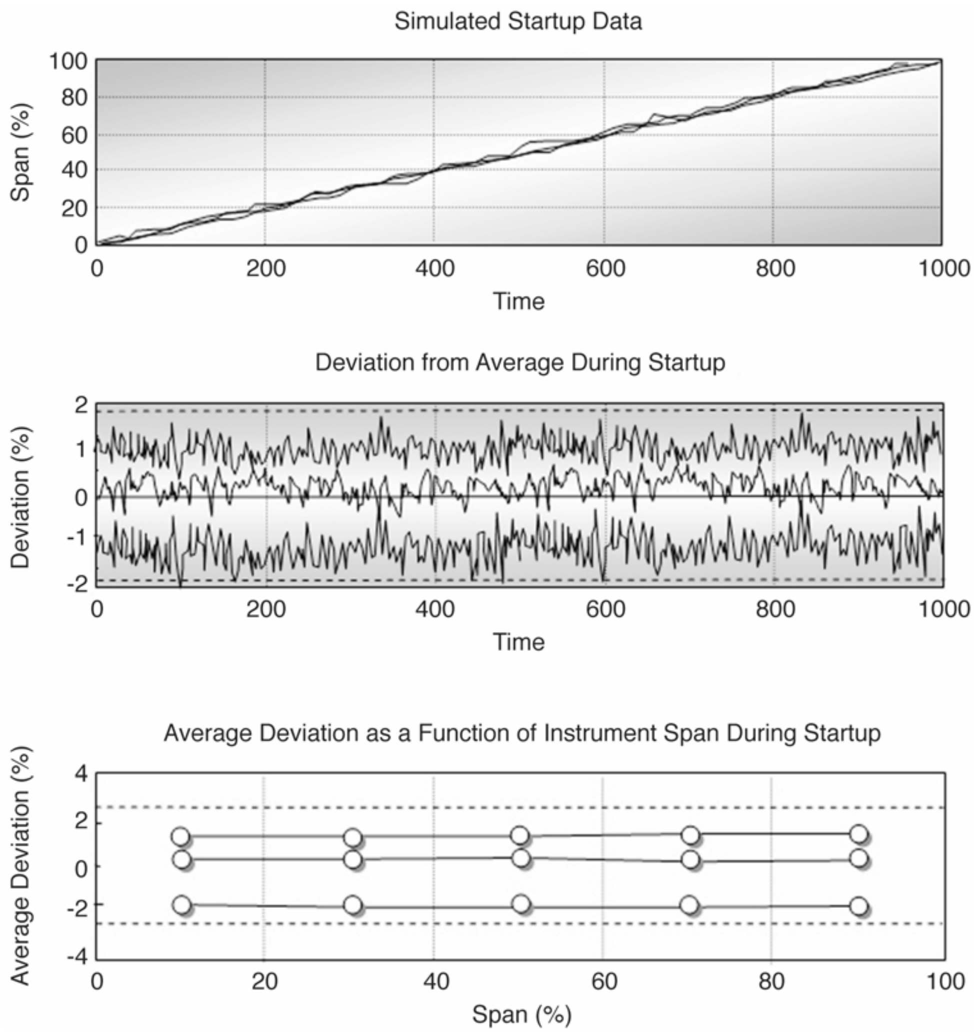


Figure 5-5
Simulated Data for a Startup Period

The middle plot of Figure 5-5 shows the deviation of each simulated instrument channel from the average value in each of the 1000 time samples. Note also that an arbitrary recalibration limit is shown at +2.5%. Finally, to create a plot of deviation as a function of instrument range, one must first specify a set of points along the range. In actual application, these points will correspond to the calibration check points defined for the instruments. For this simulation, the points were specified as 10%, 30%, 50%, 70%, and 90%. Referring to the upper plot in Figure 5-5 ("Simulated Startup Data"), note that the data from the time sample 0–200 vary from 0% to 20% of the instrument's range. Thus, to establish an average deviation at a 10% range, the deviation values (see the plot labeled "Deviation from Average During Startup" in Figure 5-5) from the first 200 points can be averaged to a single value. Similarly, the value at 30% can be obtained by averaging the deviation values from time sample 201–400, and so on. The end result is a set of five points of data for each instrument channel, as displayed in the plot "Average Deviation as a Function of Instrument Span During Startup" in Figure 5-5. Any point falling outside of the recalibration limit would be noted during the analysis.

Regarding the presentation of the overall OLM results at the end of a fuel cycle, there are several points of analysis at which an instrument's calibration is evaluated (see Figure 5-6). The results of the analysis described in this section will be null if the instrument's performance is within the deviation limits, or the result will be an X if the instrument's deviation exceeded the deviation limits at any point during the startup. The null or X result is denoted under the heading "Startup."

Item	Tag	Type	Start up (S1)	Month 1 (100)	Month 2 (200)	Month 3 (300)	Month 4 (400)	Month 5 (500)	Month 6 (600)	Month 7 (700)	Month 8 (800)	Month 9 (900)	Month 10 (1000)	Month 11 (1100)	Month 12 (1200)	Month 13 (1300)	Month 14 (1400)	Month 15 (1500)	Month 16 (1600)	Month 17 (1700)	Month 18 (1800)	Shutdown (S2)	Drift	Check Calibration

Figure 5-6
Format for Presentation of Results

The second part of this simulation was a review of the steady-state data, shown in Figure 5-7. The time scale was arbitrarily defined as 100 samples per month for an 18-month cycle. From the top down, the upper plot of Figure 5-7 shows the filtered data, the deviation of each point from the average, the average monthly deviation, and finally, in the bottom plot, the bias-corrected monthly average deviations. The average monthly deviations are obtained by averaging the deviations over the entire month. In the simulation, a month is represented by 100 time samples. The average of the first 100 time samples is plotted at time sample 100 in the steady-state deviation plot. The bias-corrected monthly average values are obtained by subtracting the zero offset from the first monthly average from the monthly averages for the remainder of the fuel cycle. These values are shown in the steady-state drift plot (the bottom plot of Figure 5-7). Note that the acceptance limits are different for the steady-state drift versus steady-state deviation because only the drift terms are included in the limit calculation. In some cases, the drift limit might be larger than the associated deviation limit because Sizewell used only one-half of the drift term in the OLM deviation limit to be conservative. The steady-state analysis shown in Figure 5-7 provides deviation and drift results for each of the 18 months of the fuel cycle (see Figure 5-6). Any monthly average exceeding the deviation limit is recorded under the appropriate month in Figure 5-6 based on

the steady-state deviation results. In addition, drifts over the fuel cycle are evaluated using the steady-state drift results (see the bottom plot in Figure 5-7) and noted in the "Drift" column in Figure 5-6.

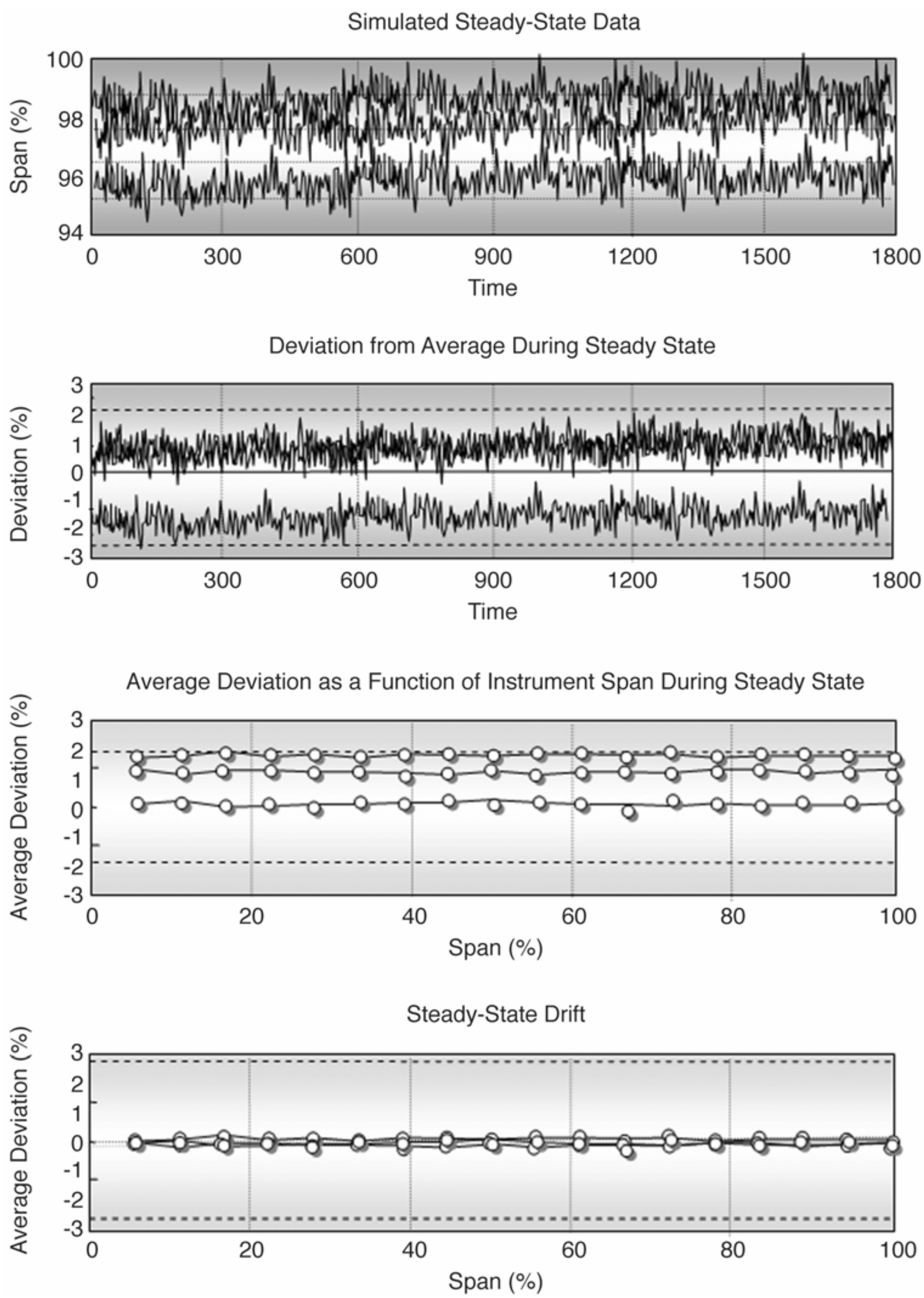


Figure 5-7
Simulated Data for a Steady-State Period

The final part of the simulation was the shutdown period. The simulation results are shown in Figure 5-8 and are presented in the same way as the startup data.

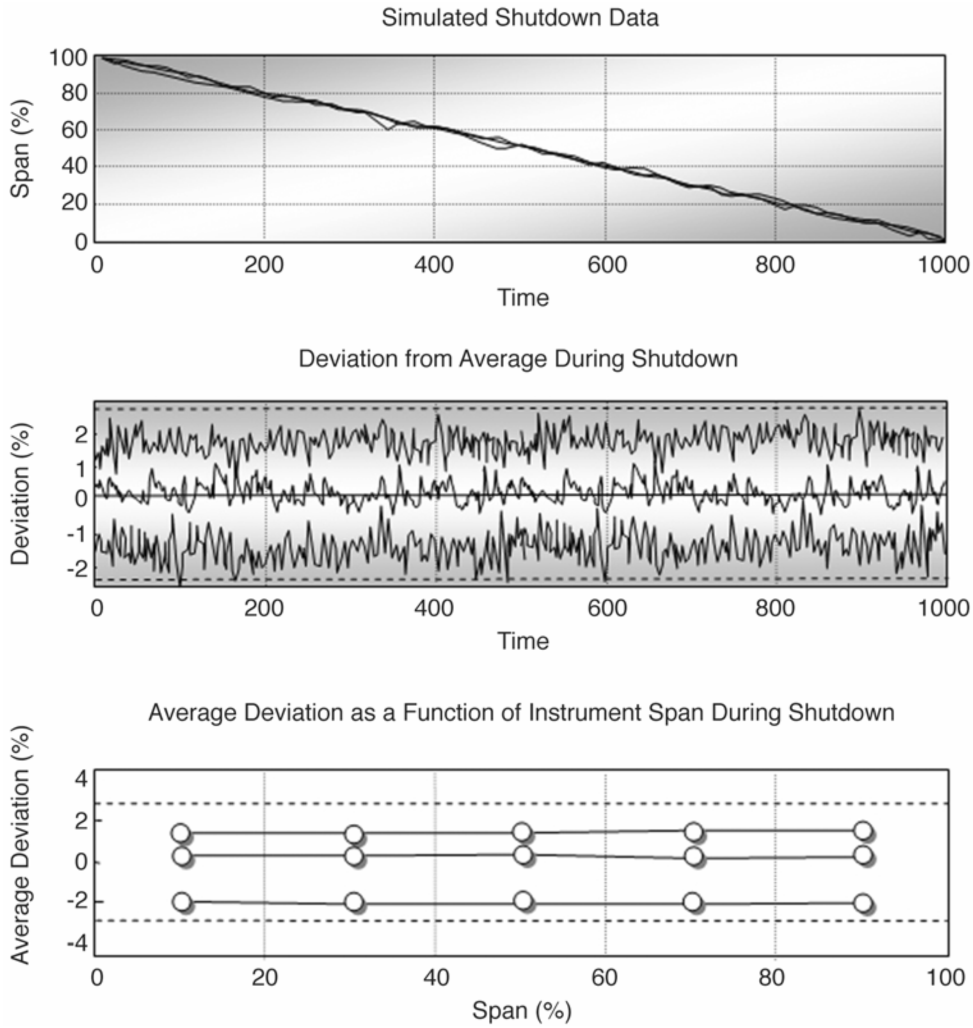


Figure 5-8
Simulated Data for a Shutdown Period

Evaluations of the individual deviation values and the average deviation values as a function of span are noted in the "Shutdown" column in Figure 5-6. When reporting the final calibration analysis at the end of a fuel cycle, if a deviation limit was exceeded at any of the 21 evaluation points (they consist of 18 monthly averages plus startup, shutdown, and drift), the offending instrument is scheduled for calibration during the refueling outage. This is reported under the "Check Calibration" heading at the end of the cycle summary table (see Figure 5-6). In some cases, there are exceptions to this rule if the behavior can be fully explained by an outside influence (such as mid-cycle recalibration or adjustment).

This three-part simulation illustrates the typical analysis process over an entire fuel cycle, from startup to shutdown. When deviations are found, a more thorough investigation of the data takes place to rule out causes other than instrument drift.

Single Calibration Regression Methodology

BE provided AMS with a report containing manual calibration data for Sizewell pressure transmitters [3]. The report contains transmitter drift statistics that were compiled from an analysis of work order cards from a period beginning January 1995, when Sizewell B began commercial operation. BE establishes transmitter drift characteristics by using the Single Calibration Regression Methodology (SCRM) on the historical AFAL data recorded on the work order cards. The AFAL data records are typically in the form of nine manual calibration points (five in the direction of increasing pressure [up] and four in the direction of decreasing pressure [down] from 0–100% span in increments or decrements of 25% span). The SCRM for a single transmitter proceeds as follows:

1. The AFAL data are normalized into percent span to facilitate a comparison of the results.
2. Regression lines are fit to the normalized ASAL data using a least squares method.
3. The slope of the as-left line is subtracted from the slope of the as-found line and multiplied by 100 to reveal any change in the transmitter span over the plant operation cycle being analyzed.
4. The intercept of the as-left line is subtracted from the intercept of the as-found line to reveal any change in the transmitter's zero that might have occurred over the plant operating cycle being analyzed.

The SCRM procedure provides a method for quantifying drift from manual calibration of Sizewell transmitters. As for on-line calibration monitoring, a similar method was needed to quantify transmitter drift from OLM data. This method was devised as described under "OLM Calibration Regression Methodology" and was used to compare drift information from manual calibrations with drift information from OLM monitoring.

OLM Calibration Regression Methodology

The methodology, which is used to calculate drift of a transmitter in a group of redundant transmitters, is as follows:

1. Using startup data, calculate the deviation of each transmitter from the group average. This is done for each plateau region of the transmitter calibration range (the result is referred to as the *as-left data*).
2. Using shutdown data, calculate the deviation of each transmitter from the group average. This is done for each plateau region of the calibration range (the result is referred to as the a*s-found data*).
3. Normalize the data from Steps 1 and 2 into percent span to make results comparable.

4. Calculate best-fit lines to the data from Step 3 using a least squares method.
5. Subtract the slope of the startup as-left line from the slope of the shutdown as-found line and multiply by 100 to give the drift of the transmitter span.
6. Subtract the intercept of the startup as-left line from the intercept of the shutdown as-found line to give the drift of the transmitter zero.

The typical results of this procedure are shown in Figure 5-9. Figure 5-9a shows the transmitter deviations during startup; Figure 5-9b shows the corresponding deviations for the same transmitter at shutdown. To show the drift characteristics, the startup best-fit line is subtracted from the shutdown best-fit line, as shown in Figure 5-9c.

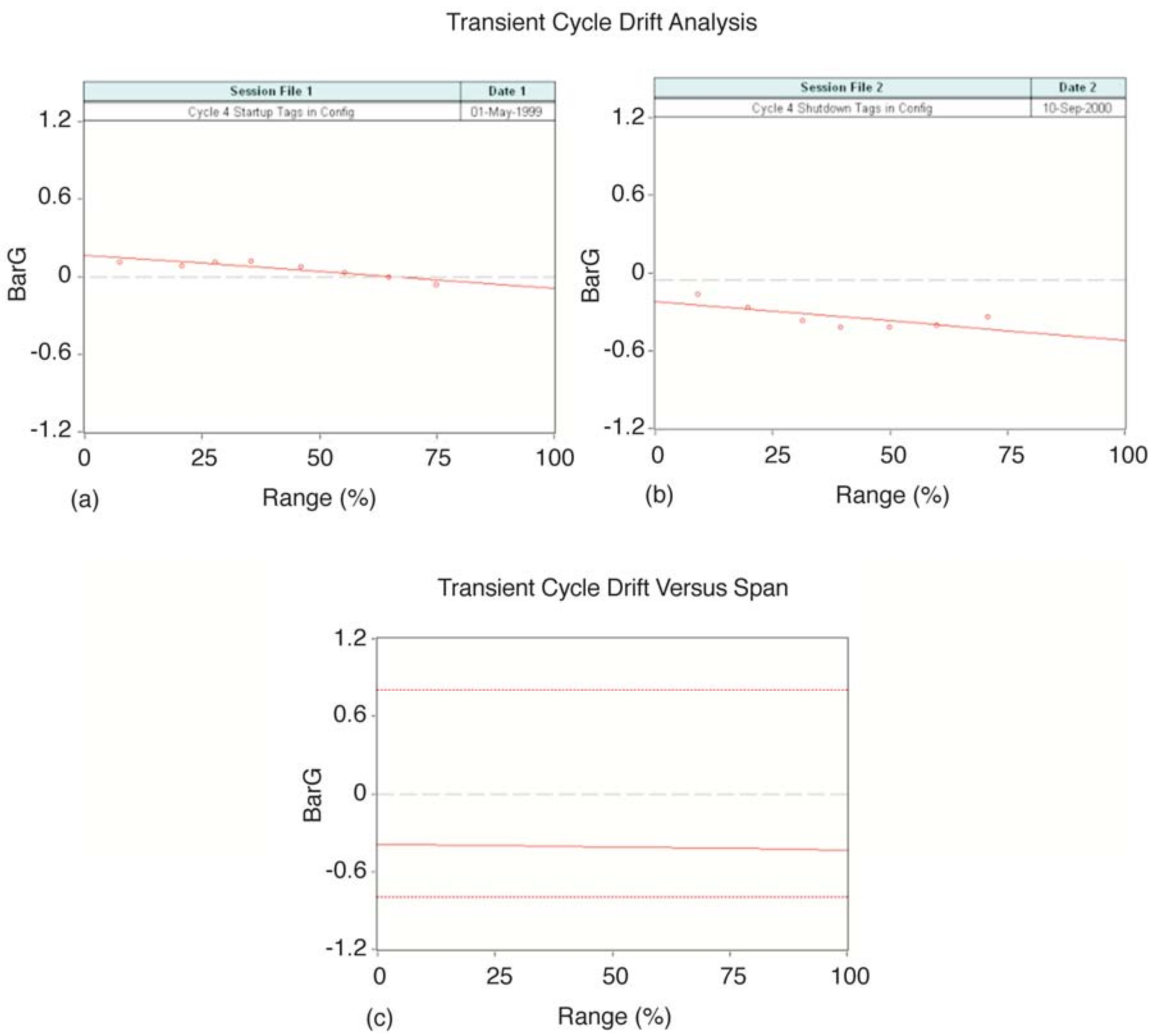


Figure 5-9
Zero and Span Shift Analysis

The analysis of zero and span shift presented in this section was completed as an additional feature of this project and is not required to make calibration decisions. Although this analysis can provide some additional insight into transmitter behavior over the fuel cycle, calibration interval extension decisions are made based solely on the deviation and drift analysis and not the zero and span shift analysis.

Description of the Methods Used to Present Analysis Results

The results of on-line calibration monitoring of pressure transmitters can be presented in a number of ways, as described in this section.

Deviation Versus Span

This presentation (an example of which is shown in Figure 5-10) consists of three plots: the raw data from the plant startup period, the deviation of each signal from the average of its peers (excluding any outliers), and the deviation of each transmitter from the average of its peers plotted as a function of the transmitter's operating range. In the last two plots, the allowable deviation limits are shown. Information on how these limits are established is presented in this report.

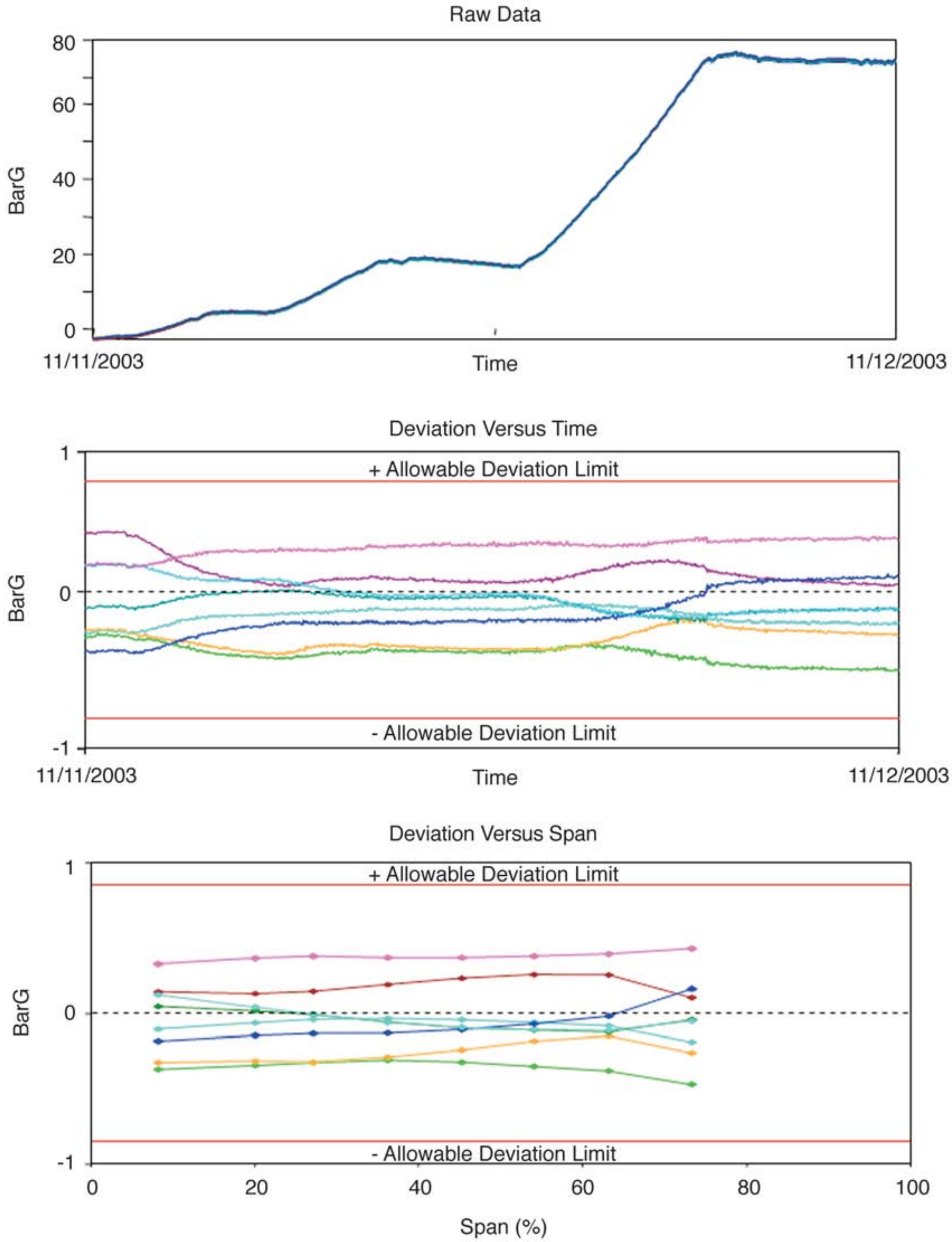


Figure 5-10
Deviation Versus Span Sample Analysis (Startup)

Deviation and Drift Versus Time Plots

Deviation and drift analysis plots provide monthly on-line calibration monitoring results during normal plant operation (see Figure 5-11). Two plots are shown in Figure 5-11; both represent the deviation of each transmitter from the average of its peers (less any outliers). The upper plot of Figure 5-11—the “Deviation Plot”—shows the deviation of the transmitters, including any bias that might come from the differences in the manual calibration of the transmitters, process effects such as temperature effect or static pressure effect, and so forth. In the lower plot of Figure 5-11—the “Drift Plot”—the bias is removed from the deviation data by subtracting the first data point, thereby showing only the drift of the transmitters during the analysis period. The allowable limits for the deviation and drift are also shown. The drift limits contain only the drift terms and not the total channel uncertainty that is common to redundant transmitters.

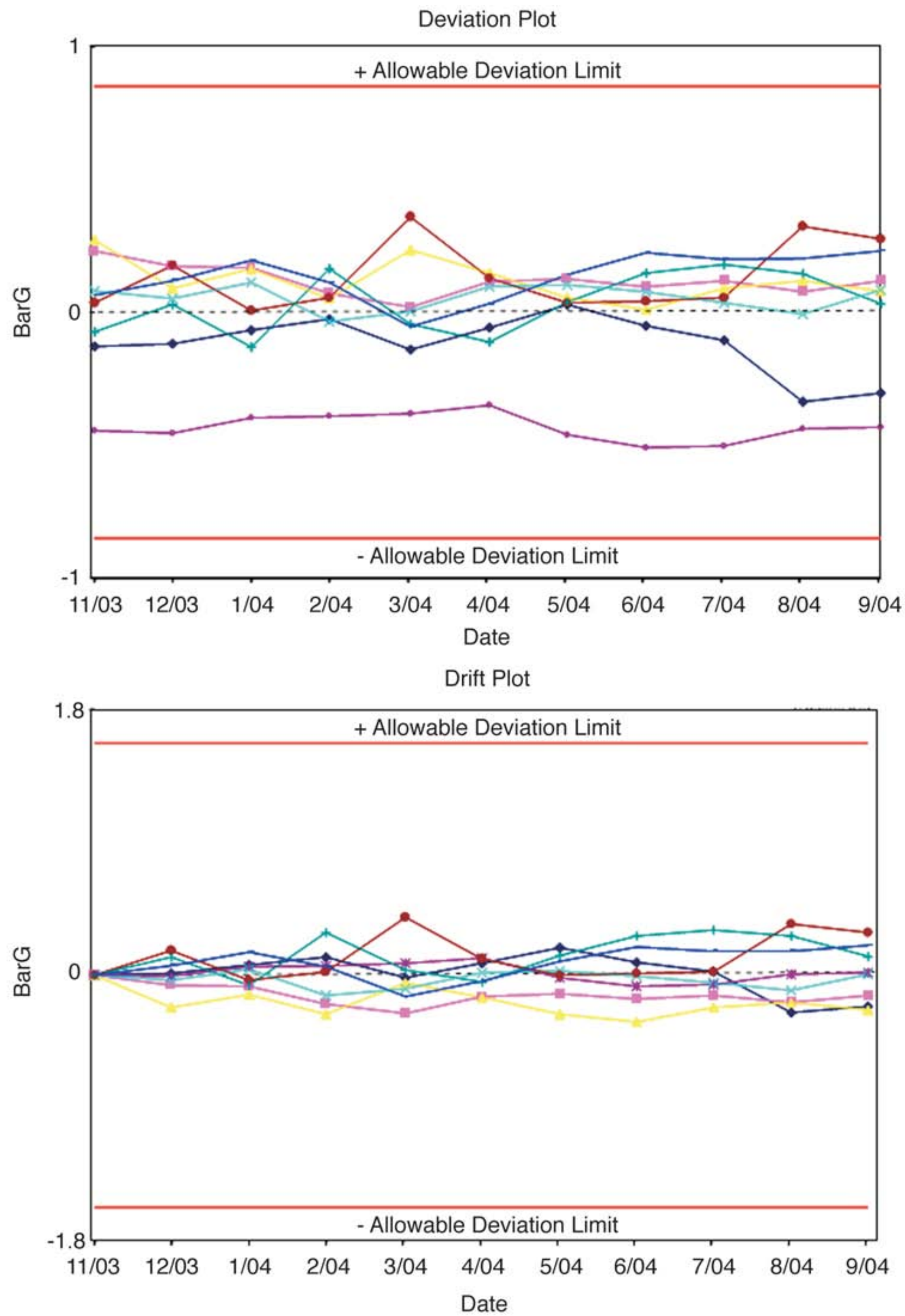


Figure 5-11
Deviation and Drift Analysis Plots

The plots in Figure 5-11 represent 11 months of data that were retrieved once a month during normal plant operation. Each month, 12 hours of data were retrieved from the plant computer and analyzed. Each point in the data represents the result for a transmitter extracted from the analysis of a 12-hour data record. This 12-hour duration for data was established in a feasibility study by comparing results from different sampling times.

Zero and Span Shift Analysis

In zero and span shift analysis presentations, the results of the SCRM zero and span shift analysis are provided. Data from startup and shutdown are compared to determine the change in a transmitter's calibration over the cycle between the plant's startup and shutdown dates (that is, 18 months later). To validate the OLM approach for calibration monitoring, this procedure was used at Sizewell to compare OLM results with the results from manual calibrations. This procedure is not used to identify a transmitter's calibration status.

The following three plots are shown in Figure 5-12:

1. The deviation of a transmitter from the average of its peers plotted against the transmitter's calibrated span over a startup period
2. The deviation of the same transmitter from the average of its peers plotted against the transmitter's calibrated span over the corresponding shutdown period
3. The difference between the shutdown and startup results (that is, startup plot minus shutdown plot)

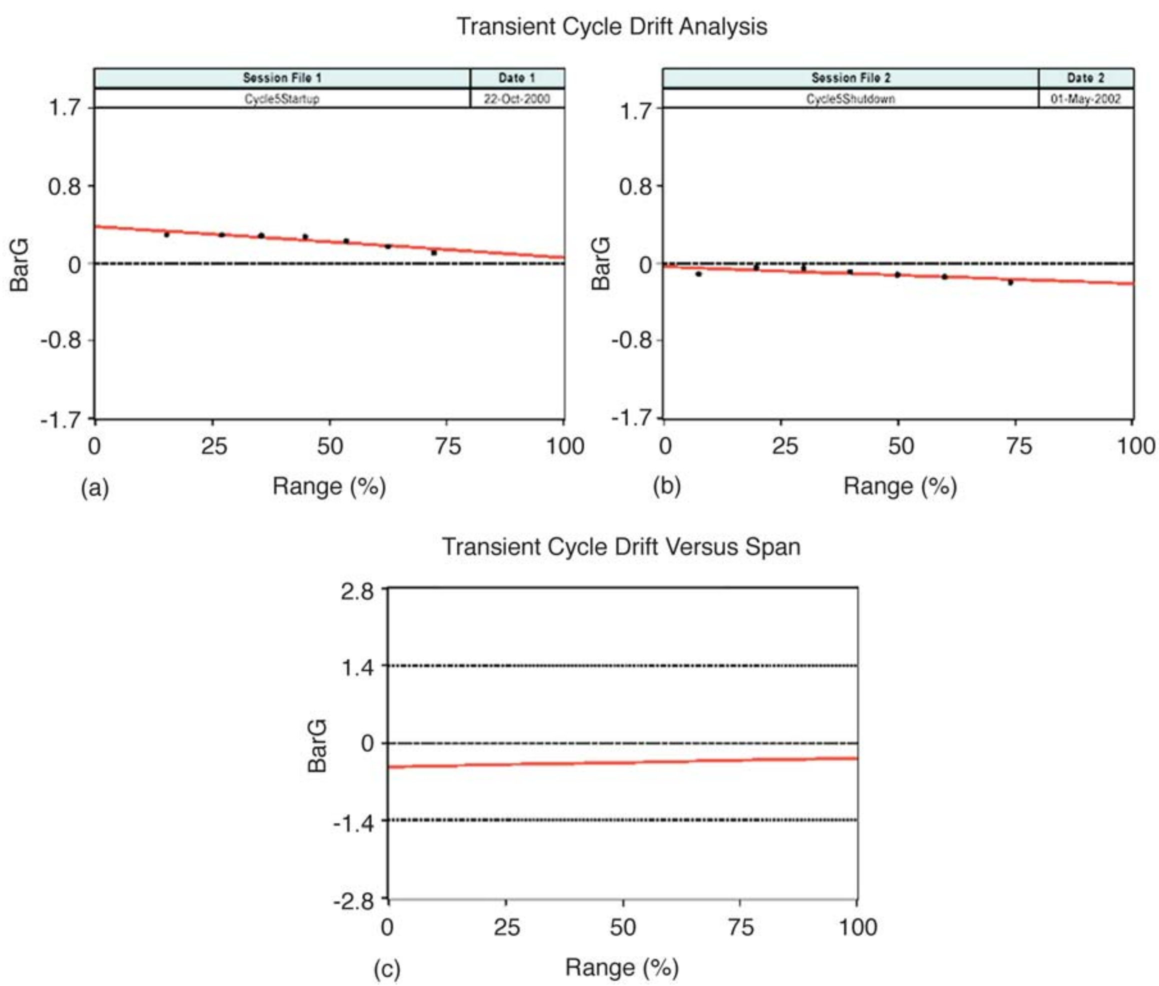


Figure 5-12
Zero and Span Shift Analysis Presentation

Typical Redundant Group Analysis

Figure 5-13 shows a typical screen of an on-line calibration monitoring system displaying data for nine transmitters. The top left plot in Figure 5-13 is a shutdown data plot for the transmitters. Moving counterclockwise, the next plot contains the deviations of each transmitter from the average of the nine transmitters (excluding one outlier). The next image plots the deviation of each transmitter as a function of operating range, and finally, the top right table contains the final results of on-line calibration monitoring. The faulty transmitter (the outlier) is identified in the results table as *bad* and the rest of the transmitters are marked as *good*, meaning that they remained within their allowable calibration limits throughout the monitored range of pressure.

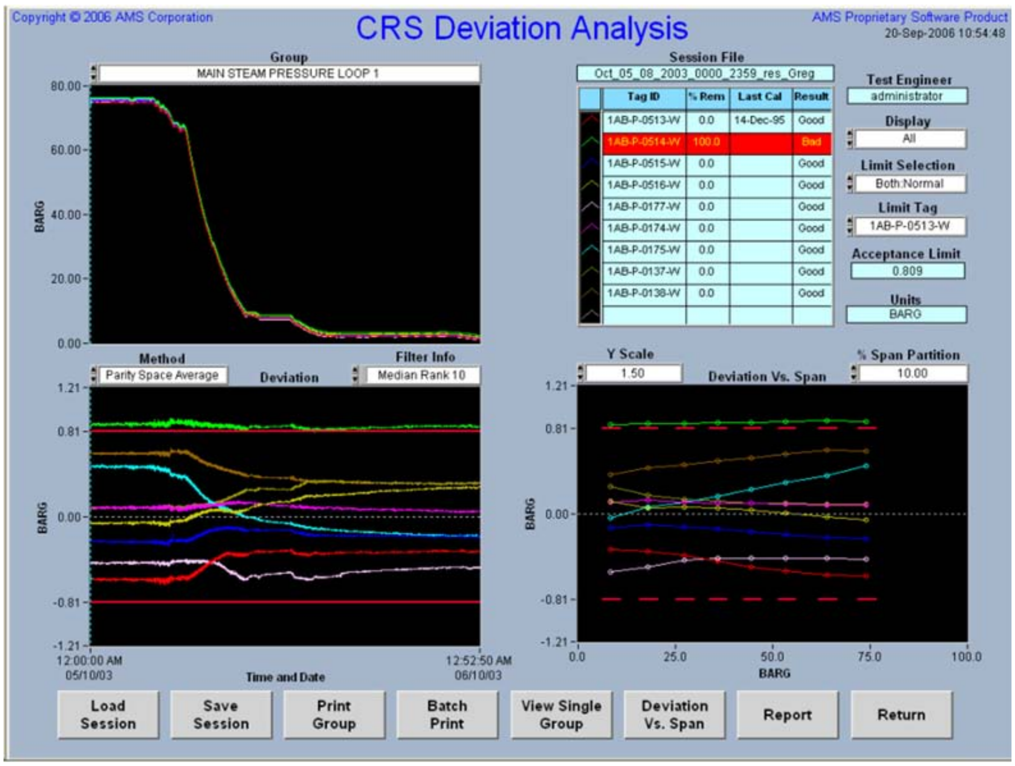


Figure 5-13
Software Screen with Sample Results of On-Line Calibration Monitoring

Cycle Summary

After the startup data, steady-state data, and shutdown data have been analyzed, the data are combined for each service in a cycle summary, shown in Figure 5-14. In Figure 5-14, directly below the table and in the left column, are the deviation versus span plots for the startup data at the beginning of the cycle and the shutdown data at the end of the cycle. In the right-hand column are the steady-state deviation and steady-state drift plots. Figure 5-14 has both PPS and SPS transmitters with different limits. When shown in a group, as in Figure 5-14, the limit for the

first sensor (a PPS sensor in this case) is displayed. Although the SPS sensors appear to pass the displayed PPS limits, the SPS limits are actually smaller. For example, if 1AB-P-0174-W were viewed alone, it would be evident that it exceeds its limits. The same is true for the deviation and drift plots.

Group: MAIN STEAM PRESSURE LOOP 1 Summary File: cycle 7 Test Engineer: AMS

Tag	Name	S1	20 Nov 2003	13 Dec 2003	12 Jan 2004	14 Feb 2004	13 Mar 2004	12 Apr 2004	10 May 2004	14 Jun 2004	17 Jul 2004	12 Aug 2004	11 Sep 2004	12 Oct 2004	13 Nov 2004	13 Dec 2004	12 Jan 2005	12 Feb 2005	12 Mar 2005	S2	Drift	Final
1AB-P-0513-W	PPS									X	X	X	X	X	X	X	X	X	X			X
1AB-P-0514-W	PPS	X																		X		X
1AB-P-0515-W	PPS																					
1AB-P-0516-W	PPS																					
1AB-P-0177-W	PFM						X		X	X											X	X
1AB-P-0174-W	SPS																			X	X	X
1AB-P-0175-W	SPS																				X	X
1AB-P-0137-W	SPS																				X	X
1AB-P-0138-W	SPS		X																		X	X

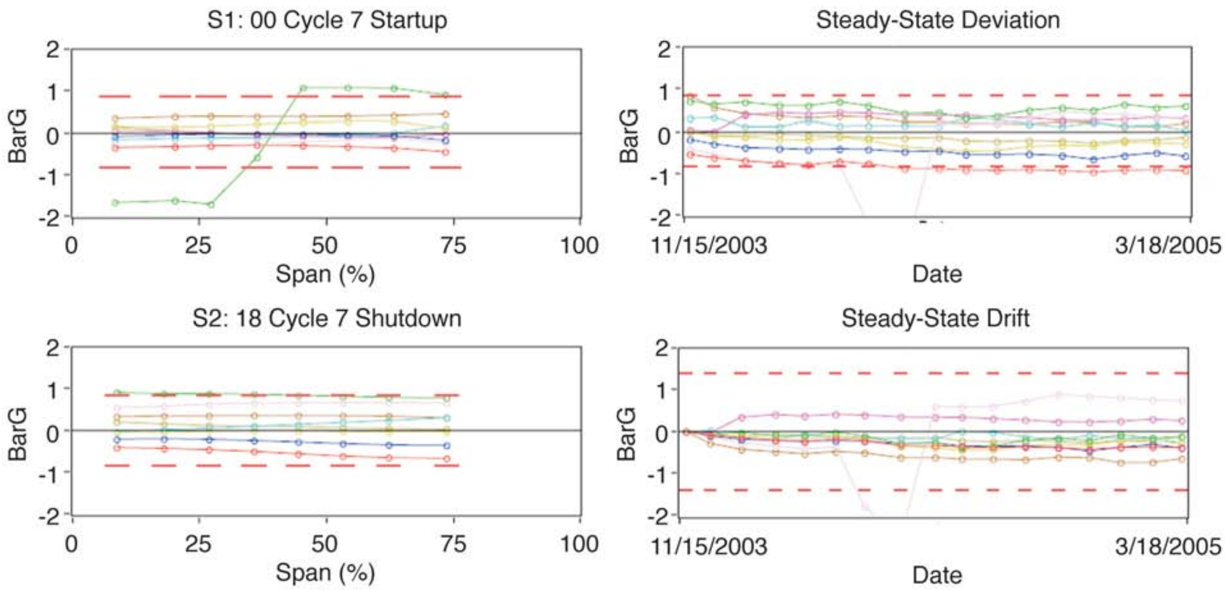


Figure 5-14
A Typical Cycle Summary for One Service

This information summarizes the state of the transmitter's calibration over the entire cycle. In some cases, a transmitter can be out during some months of the cycle but be within its acceptance limits toward the end of the cycle and during shutdown. In some cases, it can be determined that an adjustment was made to the transmitter or channel during the cycle, and this adjustment explains the months when the transmitter exceeded its limits. When this is the case, the good shutdown data will be used to verify that the transmitter is still within its calibration limits and does not need a calibration check. This would result in the "Final" column of the table in Figure 5-14 not containing an X, even though the transmitter might have an X in other columns.

Validation of OLM Application

The on-line calibration monitoring approach was validated for Sizewell B using the following three types of data:

1. Synthetic digital data generated by the computer
2. Data from manual calibrations of pressure transmitters as performed by the plant technicians
3. OLM data from Cycle 4

Synthetic Data Analysis

Synthetic data with and without drift were generated and analyzed to verify that the OLM approach correctly identifies the magnitude and direction of the drift. Synthetic data were produced in redundant groups of four and eight transmitters to simulate the most common configurations that correspond to actual Sizewell B data. In each validation test, one or more of the synthetic transmitters was given a known amount of drift. The OLM analysis was then performed on the data. The results of the OLM approach were analyzed to determine whether the drifting synthetic transmitter was detected and whether the magnitude and direction of drift were correctly quantified. The synthetic data groups were subjected to the following four episodes:

1. No drift
2. Zero shift
3. Span shift
4. Zero shift and span shift

Validation of OLM Calibration Regression Methodology

The method devised to identify changes in zero and span over a fuel cycle was validated using data from Cycle 4. In this section, the results from the SCRM carried out by BE are compared to the results obtained from the OLM calibration regression methodology. Note that this analysis is also referred to as a *transient cycle drift analysis*. On-line transmitter data from Cycle 4 startup and Cycle 4 shutdown were selected because these data contained a number of transmitters that transitioned through more than half of their calibration ranges. Also, AFAL drift characteristics were available in the BE report for data collected just before Cycle 4 startup and just after Cycle 4 shutdown.

Table 5-2 shows the drift characteristics calculated by OLM and manual calibration and the differences between the two methods for each of the 30 transmitters that met the previously specified criteria (that is, they transitioned through a large portion of their operating ranges). As shown in Table 5-2, the span and zero drift characteristics computed using the two different approaches agree within 0.75% of span for over 70% of the transmitters examined. In light of the fact that OLM and manual calibration regression methodologies are not performed under the same conditions, the 70% agreement is excellent.

Table 5-2
Cycle 4 Validation Results for the Transient Cycle Drift Analysis

Item	Tag	On-Line Span	On-Line Zero	Manual Span	Manual Zero	ΔZero	ΔSpan
1	1AB-P-0513-W	-0.025	-0.395	-0.095	-0.414	0.070	0.019
2	1AB-P-0525-W	-0.031	-0.379	0.055	-0.037	-0.086	-0.342
3	1AB-P-0536-W	-0.242	0.162	-0.042	0.636	-0.200	-0.474
4	1AB-P-0544-W	0.024	0.036	0.173	-0.330	-0.149	0.366
5	1BB-P-0401-W	0.285	-0.385	-0.006	-0.225	0.291	-0.160
6	1BB-P-0402-W	-0.264	0.227	0.247	0.000	-0.511	0.227
7	1BB-P-0403-W	-0.142	0.175	0.143	0.001	-0.285	0.174
8	1BB-P-0404-W	0.103	-0.011	-0.014	-0.090	0.117	0.079
9	1BB-P-0406-W	-2.265	0.345	-2.816	-0.447	0.551	0.792
10	1BB-P-0407-W	1.803	-0.349	0.108	0.126	1.695	-0.475
11	1BB-P-0409-W	1.283	1.049	1.134	-0.430	0.149	1.479
12	1BB-P-0411-W	0.138	-0.169	0.005	0.002	0.134	-0.171
13	1BB-P-0421-W	-0.181	0.142	0.007	-0.005	-0.188	0.147
14	1BB-P-0431-W	-0.096	0.065	-0.057	0.023	-0.039	0.042
15	1BB-P-0441-W	0.412	-0.185	0.005	0.003	0.407	-0.188
16	1BB-P-0412-W	-0.399	-0.001	-0.010	0.035	-0.389	-0.036
17	1BB-P-0422-W	-0.400	0.048	0.066	-0.086	-0.466	0.134
18	1BB-P-0432-W	-1.484	0.020	-0.069	0.022	-1.415	-0.002
19	1BB-P-0442-W	-0.592	0.279	0.001	0.002	-0.593	0.277
20	1BB-P-0455-W	0.011	-0.087	-0.728	1.213	0.739	-1.300
21	1BB-P-0457-W	0.046	-0.307	-1.001	0.308	1.047	-0.615
22	1BB-P-0458-W	-0.066	-1.175	-0.283	-1.225	0.217	0.050
23	1BB-L-0467-W	0.224	-0.719	0.590	-0.211	-0.366	-0.508
24	1BB-L-0468-W	0.973	-0.893	-1.607	1.483	2.580	-2.376
25	1BG-L-0142-W	-1.583	1.126	0.136	0.598	-1.719	0.528
26	1BG-L-0144-W	-0.783	0.038	-0.351	-0.077	-0.432	0.115
27	1BG-L-0145-W	-0.127	-0.342	0.647	-0.557	-0.774	0.215
28	1AE-F-0515B-W	1.814	-1.076	-0.630	-0.118	2.444	-0.958
29	1AE-F-0525B-W	-2.559	0.974	-0.044	-0.126	-2.515	1.100
30	1AE-F-0545B-W	-0.176	-0.058	0.188	0.236	-0.364	-0.294

Figure 5-15 summarizes the results of Table 5-2. Figure 5-15 shows that the difference between OLM and manual calibration regression methodologies is random and not biased for either zero or span error. The top bar plot shows the slope percent difference sorted in ascending order, which indicates a random distribution with many small differences and a few outliers at each end. The same is true for the zero percent difference plot in the center of Figure 5-15. The bottom plot shows how wide the acceptance limit can be between the methods for various percent agreements. This type of comparison between the OLM and manual calibration results was also performed for data from Cycles 5–7.

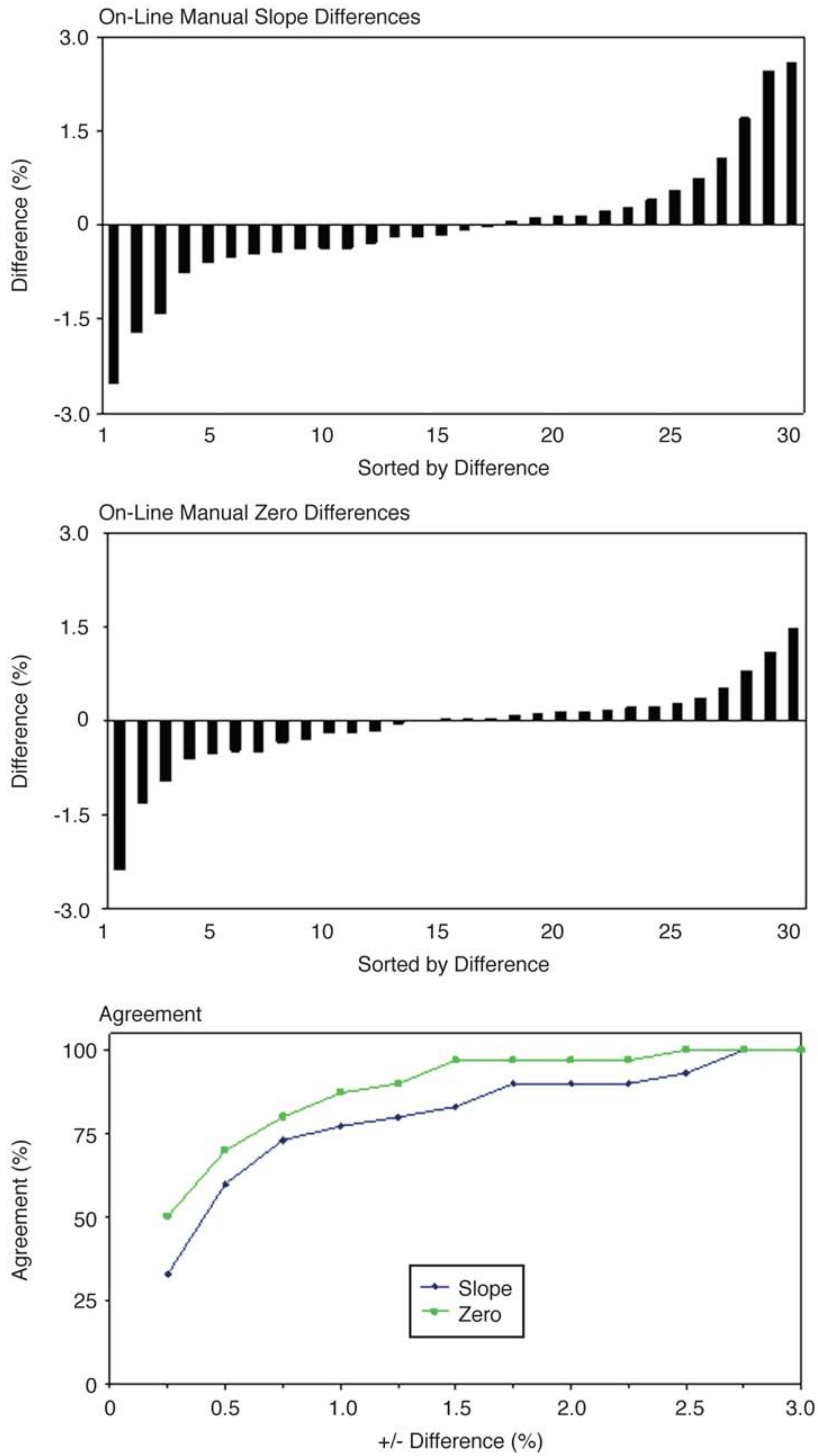


Figure 5-15
Agreement Between On-Line and Manual Drift Characteristics

Actual Data Analysis Examples

This section presents several examples of different types of available results and information. The full set of results is provided in Volume 2 of this report.

Raw Data Plots

The Sizewell data received on CDs were sampled by the plant computer at sampling rates of 1 to 30 seconds depending on the transmitter services. Figure 5-16 shows a plot of the raw data from the Cycle 5 shutdown. The plot includes four reactor coolant flow transmitters in Loop 1. First, the extraneous spikes and artifacts are removed, as shown in Figure 5-17. Next, an appropriate filter is selected to remove the process noise and any spikes. Typically, a median filter with a window size of 20 is used to filter the data. The filter replaces a data point with the median data value within the window. This filtering reduces the effect of the process variance, making it easier to view the deviations among the signals. Figure 5-18 shows the filtered data.

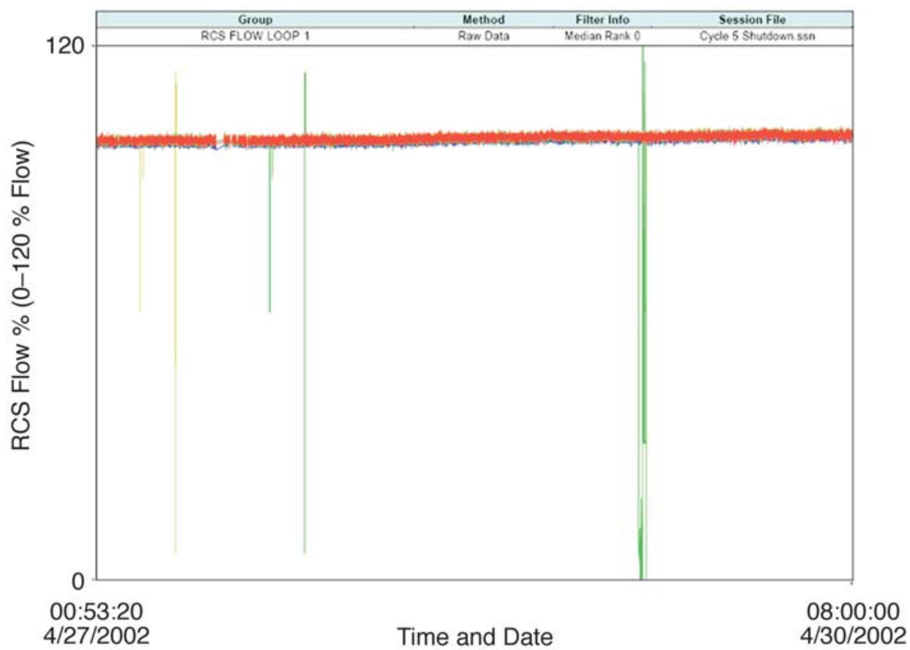


Figure 5-16
Plot of Raw Data as Received from Sizewell B

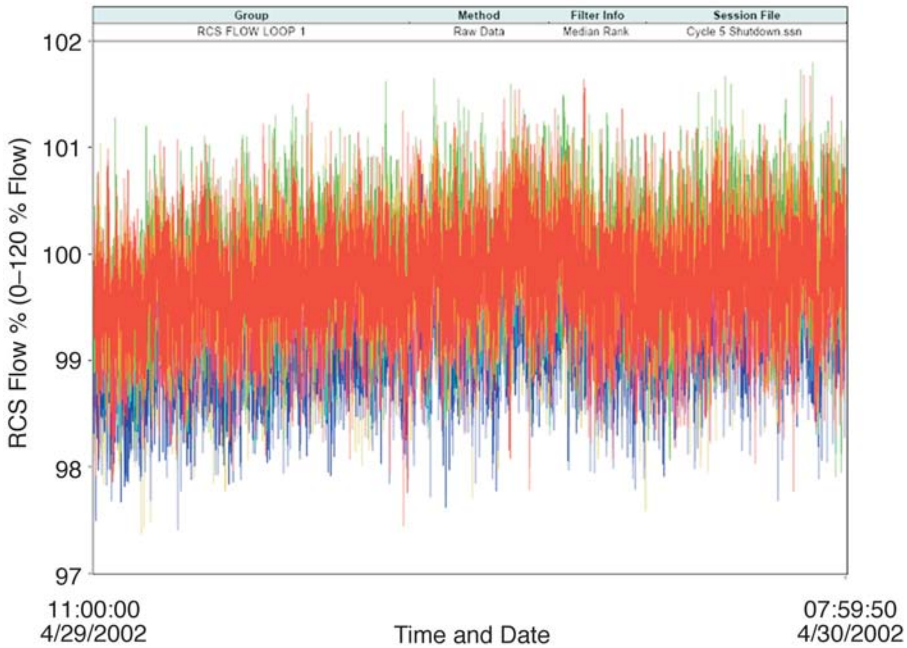


Figure 5-17
Data for Four Sizewell Transmitters Once the Spikes Are Removed

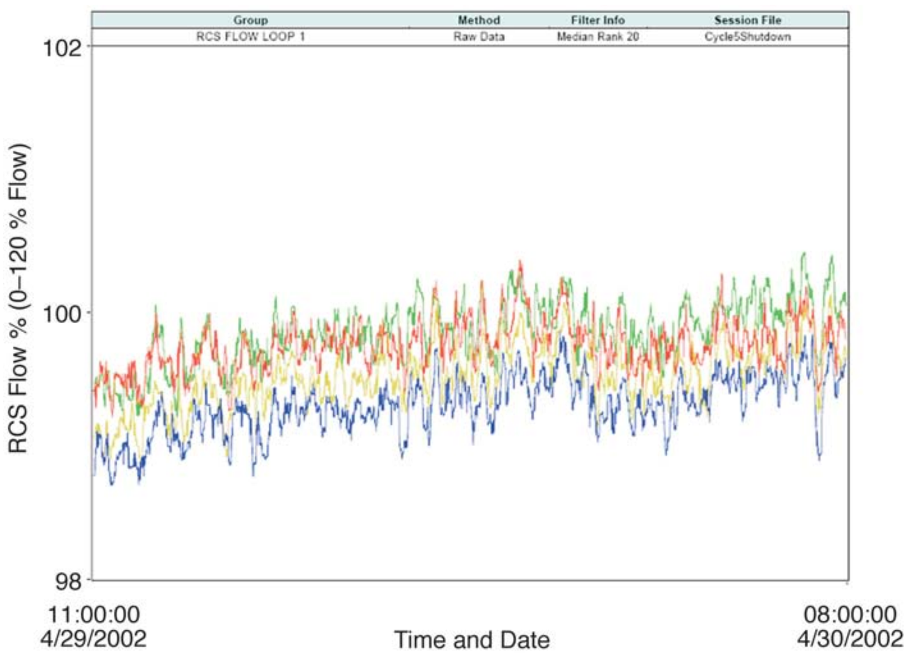


Figure 5-18
Data for Four Sizewell Transmitters Once the Spikes Are Removed and a Filter Is Applied

Deviation Plots

After OLM data are cleaned and filtered as necessary, they are analyzed to determine the calibration status of the transmitters. The analysis begins with a calculation of the deviation of each transmitter from the average of all transmitters in a redundant group (less any outliers). The deviations are then reviewed against the allowable calibration limits that are arrived at based on the process parameter that the transmitters measure. Figure 5-19 shows deviations from the parity space average for nine transmitters at Sizewell B, all of which lie within the allowable calibration bands. The data for this plot came from a shutdown period. Note that there are transients toward the end of the data: this is normal and occurs as a result of the process transition during shutdown. These data are typical for most of the transmitters that AMS analyzed for Sizewell, but there were a number of cases in which transmitters behaved differently. For example, Figure 5-20 shows four RCS flow transmitters, three of which fall well within the calibration band and one of which has a significant deviation. Another example is presented in Figure 5-21, in which one pair of signals is shown with their deviations exceeding the positive (+) band and the other pair near the negative (-) band, causing all four to fall out of tolerance.

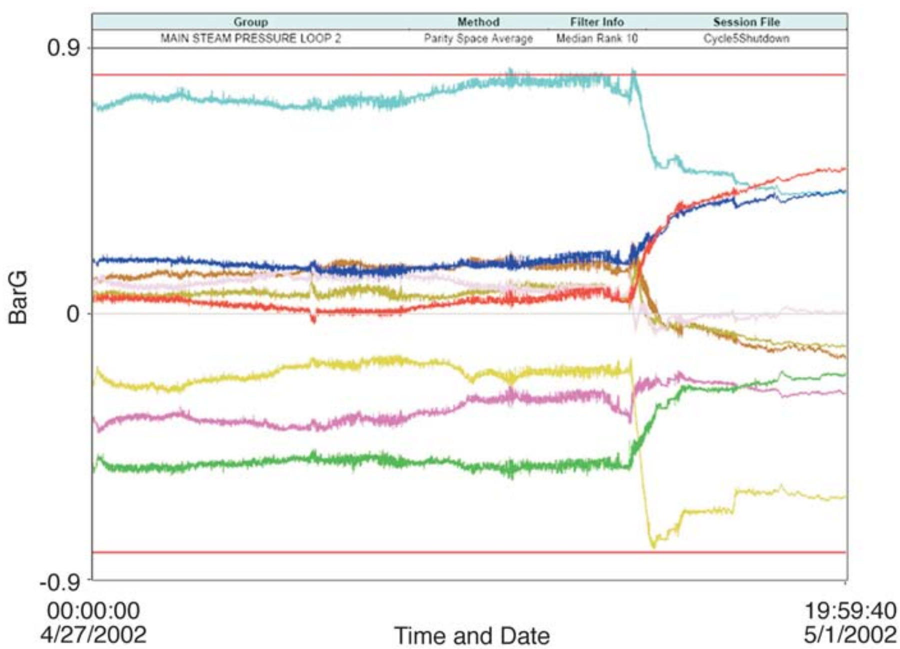


Figure 5-19
Typical Deviation Plot for a Group of Nine Sizewell Transmitters

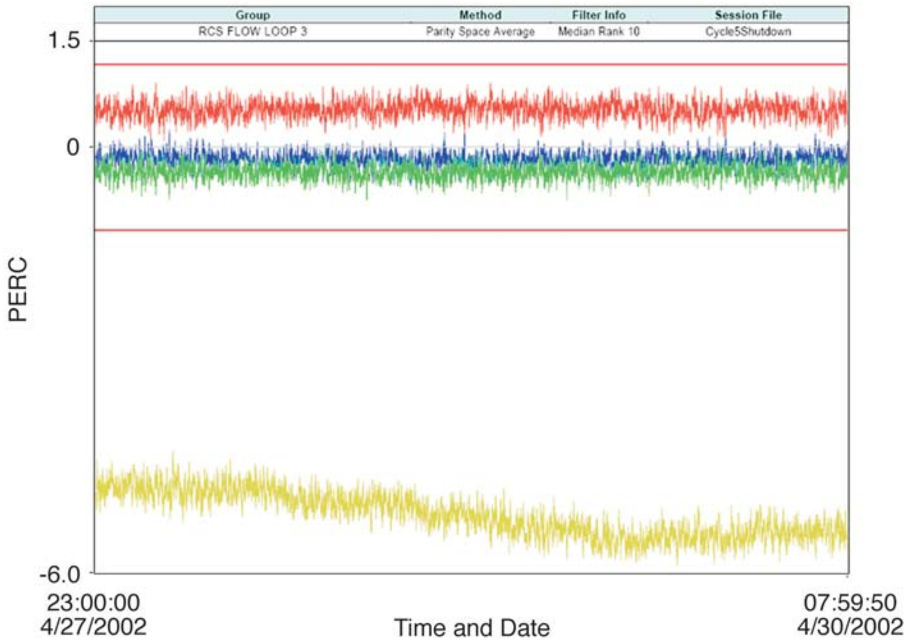


Figure 5-20
Sizewell RCS Flow Signals with One Falling out of Limit

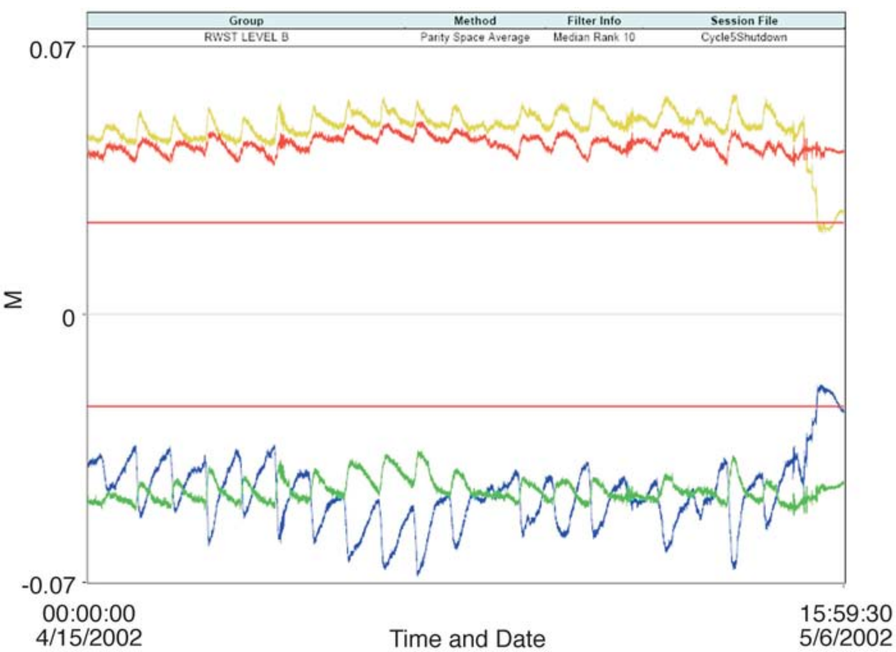


Figure 5-21
Sizewell RWST Level Signals with Pairs Exceeding the Allowable Limits

Deviations Versus Calibration Range

At Sizewell B, the plant computer samples data during plant startup and shutdown as well as during operating conditions. This provides the opportunity to verify the calibration of the transmitters throughout their operating range. Figure 5-22 shows the deviation of a feed flow transmitter as a function of operating points. This plot is based on data collected at Sizewell during the Cycle 5 shutdown. The allowable calibration bands are also shown. Note that the calibration of this transmitter falls well within the calibration tolerance throughout the transmitter operating range.

Figure 5-22
Feedwater Flow Transmitter Calibration Deviations as a Function of Operating Range

Furthermore, the deviations are random (some are positive and some are negative) as opposed to representing a bias or a span problem. In Figure 5-23, the same type of information is shown for a main steam pressure transmitter. This result shows that although the transmitter is within its calibration tolerance, it has a positive bias error (or zero shift). These data are from the Cycle 5 shutdown period at Sizewell B. Similarly, results are shown in Figure 5-24 for a main steam pressure transmitter with a negative bias.

Figure 5-23
Calibration Deviation as a Function of Range for a Main Steam Pressure Transmitter with a Positive Bias

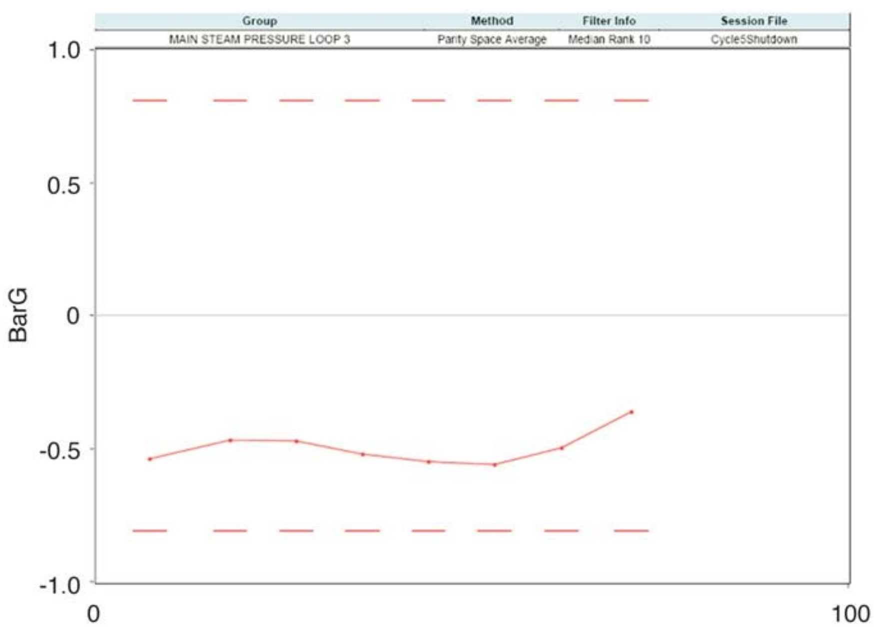


Figure 5-24
Calibration Deviation as a Function of Range for a Main Steam Pressure Transmitter with a Negative Bias

Because the feedwater flow is calculated from the square root of a differential pressure measurement, a simple bias or zero shift in the differential pressure often results in fan-out at the low end of the flow measurement, thus appearing as a span problem. This is shown in Figure 5-25, which is followed by Figure 5-26, an example of results that bear both a zero and span shift.

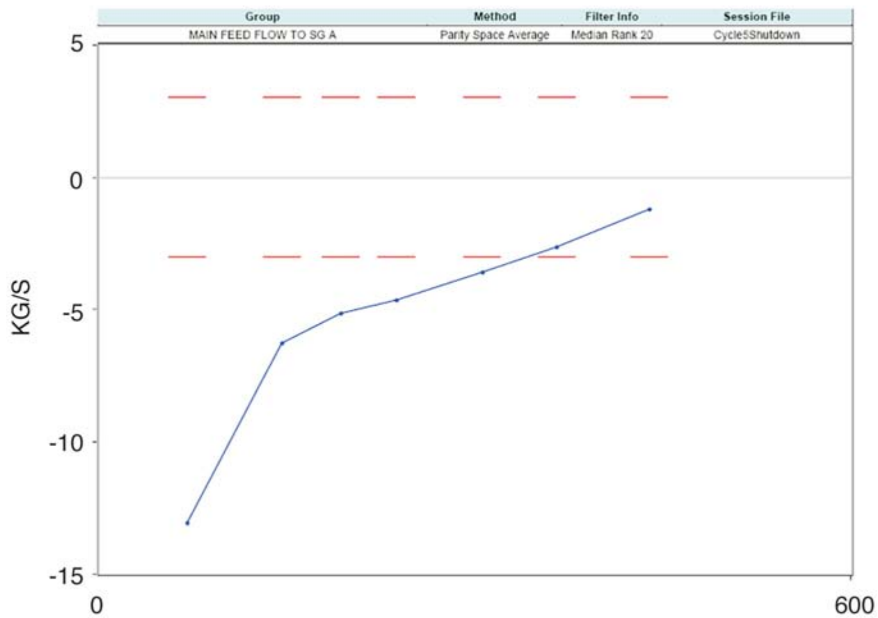


Figure 5-25
Calibration Deviation as a Function of Range for a Feedwater Flow Transmitter

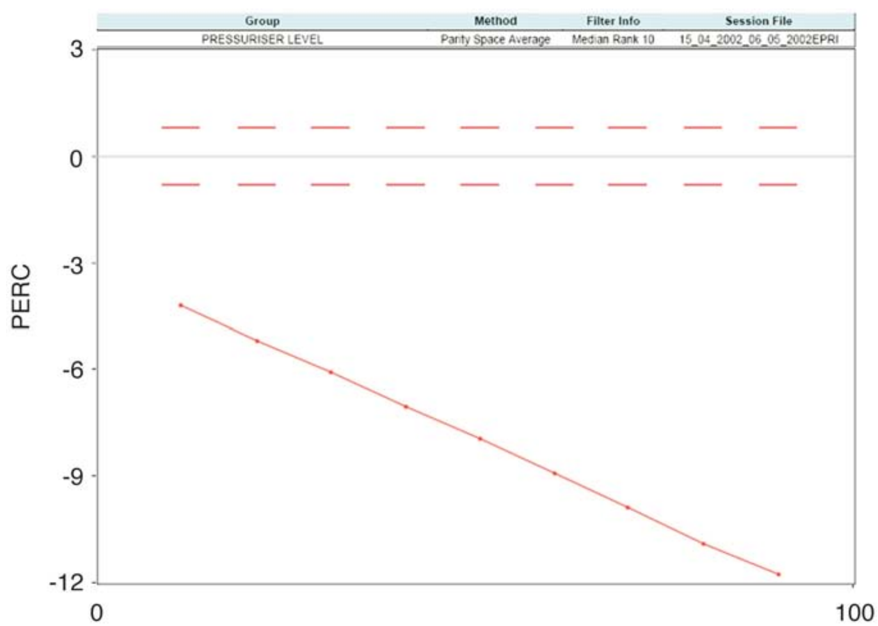
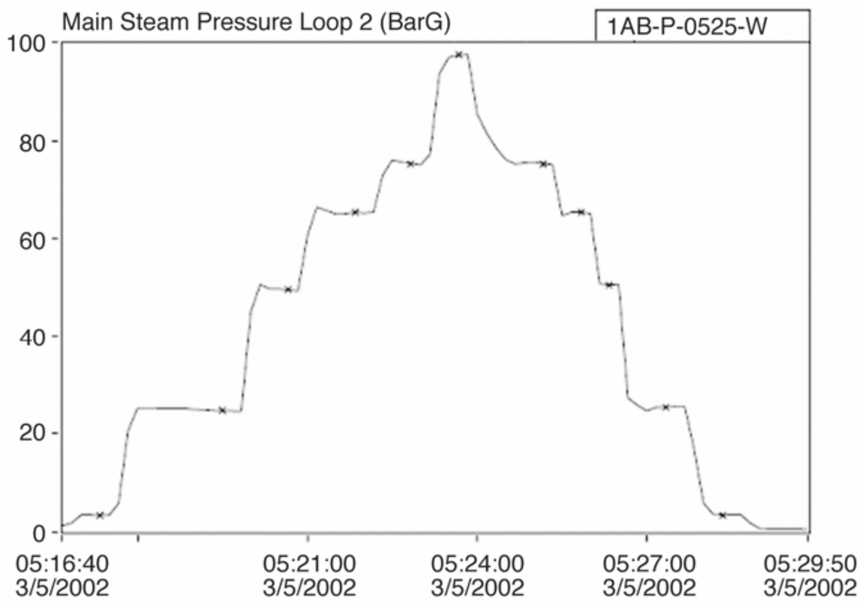


Figure 5-26
Calibration Deviation as a Function of Range for a Pressurizer Level Transmitter

Interesting Observations from the Analysis of Cycles 4 and 5

During the analysis of the data from Cycles 4 and 5 at Sizewell, a number of interesting and important observations were made. A few of these are described in this section.

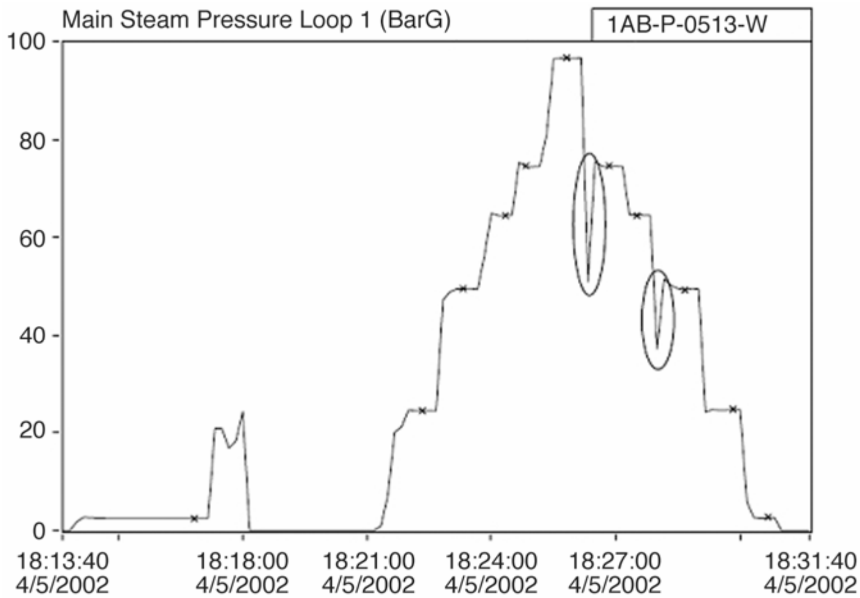
Figure 5-27 shows data resulting from a calibration check of a main steam pressure transmitter. Figure 5-28 shows a similar plot with a different transmitter. In this plot, calibration setpoints were missed at several points on the decreasing portion of the calibration, and these setpoints had to be reset. This might or might not be a problem, but it shows that in the first case, the calibration was performed more carefully in order to avoid the overshoots.



Calibration Table

Calibration Step	Measured	Actual	Error
1	3.316		
2	24.712		
3	49.493		
4	65.388		
5	75.364		
6	97.527		
7	75.357		
8	65.385		
9	50.510		
10	25.449		
11	3.318		

Figure 5-27
Main Steam Pressure Transmitter Calibration Check



Calibration Table

Calibration Step	Measured	Actual	Error
1	2.524		
2	24.512		
3	49.500		
4	64.492		
5	74.478		
6	96.663		
7	74.529		
8	64.588		
9	49.296		
10	24.788		
11	2.602		

Figure 5-28
Main Steam Pressure Calibration Check with Overshoot

Other important observations based on Cycle 5 data follow:

- The main feed flow to SGs A, B, C, and D all had large zero and span errors for the low end of the calibration range, causing many of these transmitters to fail OLM.
- The reactor building pressure does not vary and is very close to the low end of its calibrated range, resulting in a lower confidence than would be obtained if the pressure transitioned through its range.
- SG level narrow-range transmitters have larger deviations during plant operation because of the process noise. These deviations make some of the properly calibrated transmitters fail during the cycle. (Shutdown transients clearly indicate that the transmitters are in calibration.)

- It was difficult to obtain good calibration transients for some transmitters during shutdown as a result of manual calibrations that were performed as the process transitioned through the transmitters' calibration range.
- It would be best for OLM if manual calibrations were performed after the transmitters have gone off scale.
- Reactor coolant flow transmitters transition through a limited portion of their range, which could allow these transmitters to be monitored at a single point.

6
ACCEPTANCE CRITERIA FOR ON-LINE CALIBRATION MONITORING

The acceptance criteria for the results of on-line calibration monitoring are derived from the uncertainties used in plant setpoint methodology. The procedure is similar to the one that is used to arrive at the acceptance criteria for manual calibrations. To provide a good understanding of how the acceptance criteria are developed for on-line calibration monitoring, this section begins with an explanation of how the acceptance criteria for manual calibrations are typically established. Once the calculation of acceptance criteria for manual calibrations is understood, one can better understand the differences between the acceptance criteria for manual calibrations and on-line calibration monitoring methods.

There are a number of differences between acceptance criteria for manual calibrations and acceptance criteria for on-line calibration monitoring results. For example, one difference is in the conditions that exist during the two calibrations. Manual calibrations are often performed when the plant is at cold shutdown, particularly on transmitters that are in inaccessible locations, such as the reactor containment. Thus, the effect of temperature and static pressure on calibration must be accounted for in arriving at acceptance criteria for manual calibrations.

Another difference is in the number of components that are included in the acceptance criteria calculation. In a manual calibration, only the uncertainties related to calibrating the sensor/transmitter are usually included; in on-line calibration monitoring, by contrast, other uncertainties are involved. The following sections describe the typical components used to calculate the acceptance criteria for both the manual and OLM methods. A description of the methodology used by BE to calculate the OLM acceptance criteria for their pressure transmitters is presented. Note that in this report, the terms *manual calibration* and *conventional calibration* are used interchangeably. This section concludes with a discussion of the impact of the ISA standard Setpoints for Nuclear Safety-Related Instrumentation [19] on OLM acceptance criteria.

Typical Acceptance Criteria for Manual Calibrations

The acceptance criteria for manual calibrations—the AFAL limits—can be viewed as uncertainty bands around a measured point. To be considered in-calibration, an instrument's indication must lie within these uncertainty bands. For an instrument to be acceptable, its as-found value around all measured points must be within the as-found limit for those points. For the same instrument to not require a calibration, its as-found limit must be within the as-left tolerance at all

measurement points. Figure 6-1 illustrates the concepts of AFAL limits for a typical pressure transmitter around a measurement point. The five typical uncertainties included in calculating the AFAL limits are listed in Table 6-1.

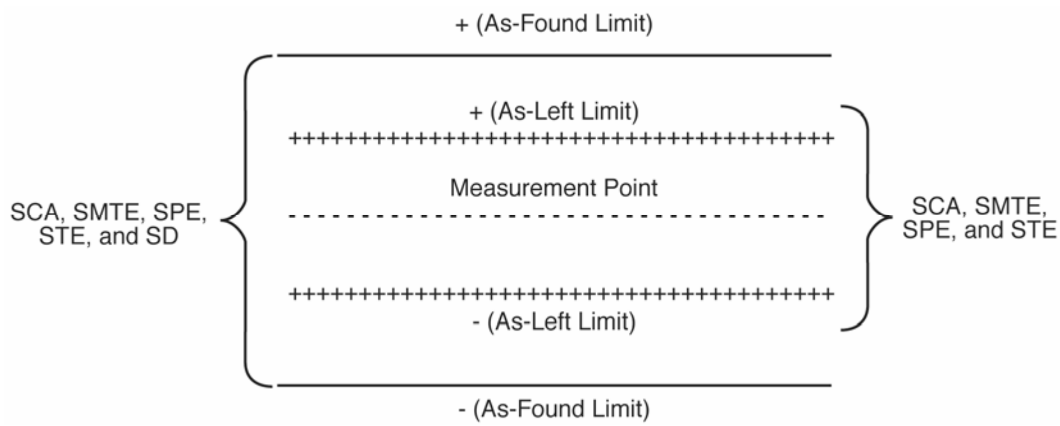


Figure 6-1
AFAL Calibration Limits for a Typical Pressure Transmitter

Table 6-1
A Typical Example of Potential Sources of Uncertainty in Manual Calibrations

Acronym	Definition
SCA	Sensor calibration accuracy. The inherent accuracy of the sensor at reference conditions; it is typically vendor-supplied.
SMTE	Sensor measurement and test equipment. The uncertainties associated with the equipment used to calibrate the sensor. Some plants assume 0.0 for SMTE if the calibration standards and the equipment used for the calibration meet the 4:1 accuracy ratio.
SD	Sensor drift. The observed change in sensor accuracy as a function of time; it is typically supplied by the vendor.
SPE	Sensor pressure effect. The potential effect of static pressure on transmitter calibration.
STE	Sensor temperature effect. The potential effect of environmental temperature on transmitter calibration.

As shown in Figure 6-1, the uncertainties associated with the as-found limit are SCA, SMTE, STE, SPE, and SD. These terms represent the uncertainties that will affect the measurement of the transmitter when the calibration technician first takes a reading. If the technician finds the transmitter to be within the as-found limits but beyond the as-left limits, he or she must calibrate the transmitter to within the as-left limits. Note that the as-left limits are the same as the as-found limits without the SD term. The SD term is included in the as-found limits to give the instrument some allowance for drift between calibrations. The value of the SD term is typically supplied by

the vendor and is time-dependent—it increases with the time between calibrations. For a typical pressure transmitter in a nuclear plant, the time between calibrations is 18–24 months. For more details on the types of uncertainties included in manual calibrations, see the ISA standard Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation [20].

Typical Acceptance Criteria for OLM

An instrument channel is said to be *in calibration* if the difference between a known value and its measured value is within the acceptance limits. For on-line calibration monitoring, the channel output is subtracted from the best estimate of the process, and the results are plotted to check for drift and other problems. If there are redundant instruments, the average of the redundant readings is used as the best estimate of the process. By doing so, the redundant readings can be averaged using a variety of methods (such as the parity space method) to ensure that outliers are minimized in the averaging process. When there is little or no redundancy, modeling techniques can be used to arrive at a best estimate for the process.

Figure 6-2 shows OLM data for nine redundant transmitters at Sizewell B. The traces in Figure 6-2 represent the unfiltered deviation of each signal from the average of the redundant signals, which is assumed to be the best estimate of the actual process. Also shown in Figure 6-2 are the acceptance limits (acceptance criteria)—they are the lines above and below the transmitter data. The acceptance limits for Sizewell transmitters were calculated by BE using a proprietary methodology and made available to AMS.

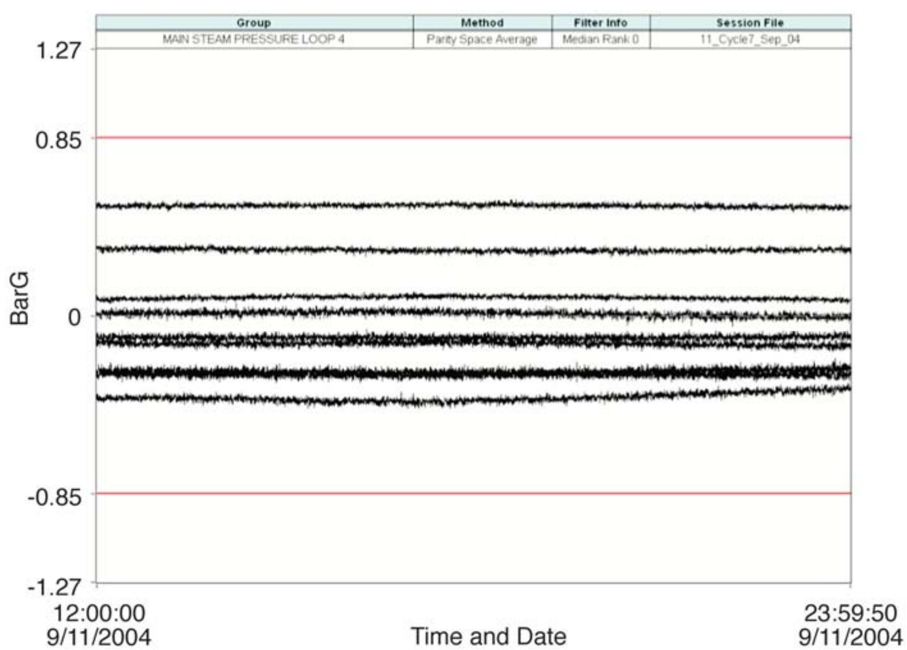


Figure 6-2
Unfiltered Deviation Plot of Nine Main Steam Pressure Transmitters at Sizewell B

The acceptance criteria for on-line calibration monitoring include the same uncertainty terms as the manual calibration limits but also include uncertainties in parts of the channel unique to the OLM process measurement. The uncertainties involved in OLM are combined to form the channel statistical accuracy or channel statistical allowance (CSA) band that is used as the acceptance criteria or allowable band for the results of on-line calibration monitoring. Note that *allowable limit*, *acceptance criteria*, and *CSA* all refer to the deviation limits for OLM.

CSA Band

This section describes how the CSA band can be determined. It should be pointed out that the CSA band as described here is simply an example of a method for determining the acceptability of a transmitter calibration: there are other methods that one can use to determine if and when a transmitter must be calibrated. For example, in performing the work for Sizewell B, the acceptance criteria for OLM results were provided by BE based on calculations similar to the CSA band. The acceptance criteria, however, were customized by BE to include the uncertainties that are unique to the Sizewell B plant. The calculation of the acceptance criteria is described in more detail under “Acceptance Criteria for Sizewell B Transmitters.”

Table 6-2 provides an example of potential sources of uncertainty in making a process measurement in a nuclear power plant. To establish the CSA band, these uncertainties are combined in a way that depends on whether they are random or systematic, dependent or independent. Random uncertainties are also referred to as *experimental errors*, and systematic uncertainties are also referred to as *bias errors*.

Table 6-2
Potential Sources of Instrument Channel Uncertainty

Acronym or Term	Definition
PMA	Process measurement accuracy. Inherent noise in the process. PMA sources are listed as water leg correction, elbow tap error, streaming, and thermal mismatch (power range detectors). As an example, for the reactor coolant flow channel, PMA is a root sum square (RSS) combination of 0.33 for density, 0.30 for noise, and 1.33 for calorimetric uncertainties. This RSS combination equals 1.4%.
PEA	Primary element accuracy. Represents the error resulting from the use of a metering device, such as a flow orifice.
SCA	Sensor calibration accuracy. The inherent accuracy of the sensor at reference conditions; it is typically vendor-supplied.
SMTE	Sensor measurement and test equipment. The uncertainties associated with the equipment used to calibrate the sensor. Some plants assume 0.0 for SMTE if the calibration standards and the equipment used for the calibration meet the 4:1 accuracy ratio.
SD	Sensor drift. The observed change in sensor accuracy as a function of time; it is typically supplied by the vendor.
SPE	Sensor pressure effect. The potential effect of static pressure on transmitter calibration.
STE	Sensor temperature effect. The potential effect of environmental temperature on transmitter calibration.
RCA	Rack calibration accuracy.
RMTE	Rack measurement and test equipment. Some plants assume 0.0 for RMTE because the equipment used meets the 4:1 accuracy ratio.
RCSA	Rack comparator setting accuracy.
RD	Rack drift.
RTE	Rack temperature effects.
EA	Environmental allowance. Represents the change in the instrument channel's response as a result of accident environmental conditions. Some plants use 0.0 for EA for normal CSAs as opposed to accident CSAs.
Bias	For the reactor coolant flow channel, for example, bias represents the flow measurement error for the elbow taps.

If the uncertainties are random, they are considered as independent errors and therefore squared, added together, and the RSS calculated. This RSS is then added to the sum of the biases to yield the total uncertainty. The following equation is an example of how the total uncertainty (± CSA band) can be calculated. Note that in the equation, the terms that are dependent are first added together and then squared to calculate the RSS error.

$$CSA = \sqrt{PMA^2 + PEA^2 + (SCA + SMTE + SD)^2 + SPE^2 + STE^2 + (RCA + RMTE + RCSA + RD)^2 + RTE^2} + EA + BIAS$$

ISA Standards 67.04.01 [19] and 67.04.02 [20] provide detailed descriptions of the terms to include in the CSA as well as recommendations for combining dependent and independent terms.

The uncertainties included in the calculation of the CSA depend on the location in the instrument channel at which the OLM data are measured. Figure 6-3 shows a simplified layout of a safety-related instrument loop for both analog and digital protection systems.

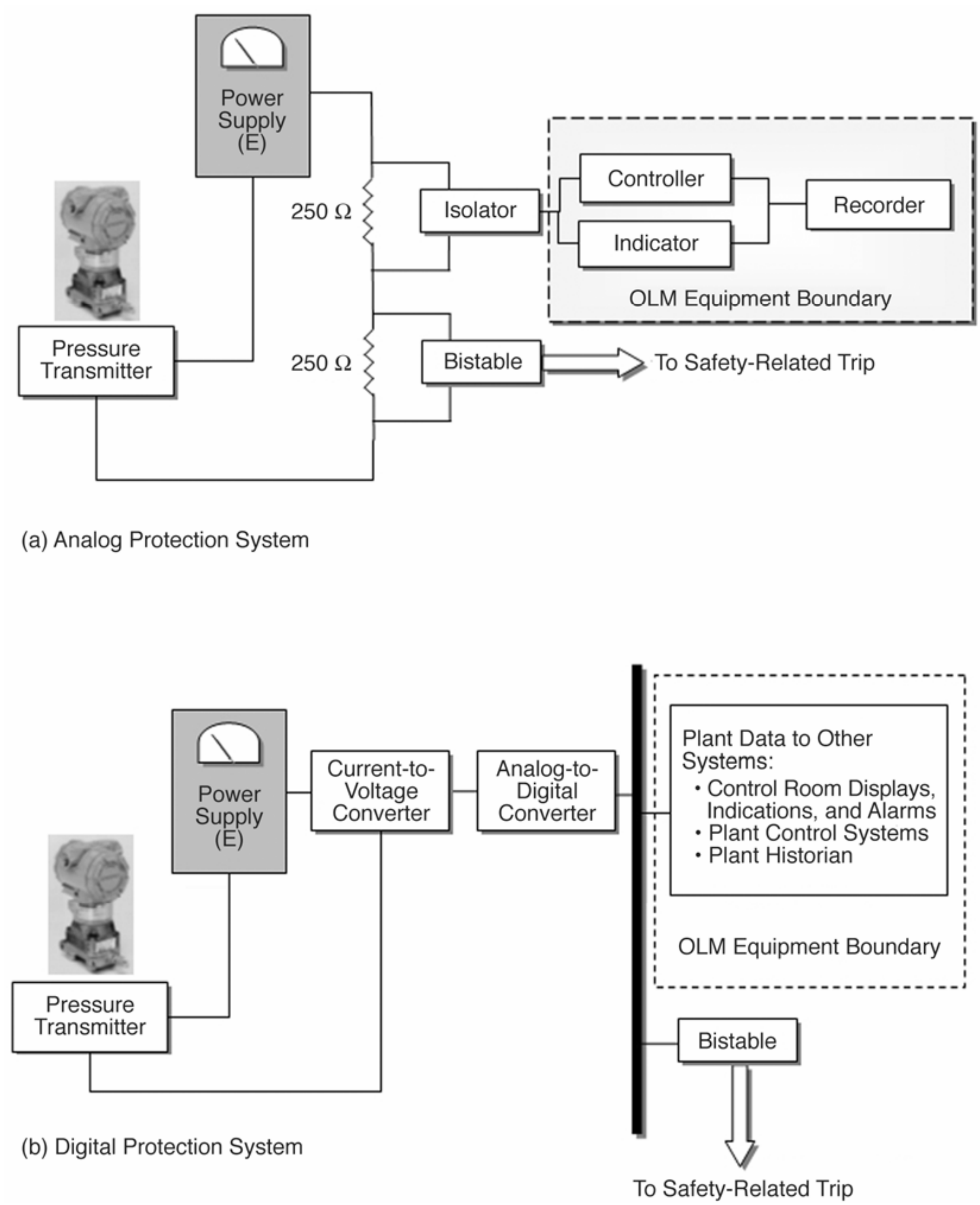


Figure 6-3
Data Acquisition Setup for OLM

Notice that in Figure 6-3, the safety-related actuation function performed by the bistable is not a part of the OLM circuit. Also, notice that the OLM circuit contains additional instrumentation that is not a part of the safety-related function. The principal overlap between the safety-related and the non-safety-related portions of the instrument channel occurs at the sensor. Table 6-3 summarizes the traditional contributors to measurement uncertainty in each signal path. It is clear that the OLM circuit does not monitor the entire trip circuit portion of the instrument loop; the bistable's uncertainty elements are not included in the monitored path.

Table 6-3
Sources of Uncertainty in a Traditional Process Instrument Circuit

Uncertainty Term	Present in OLM Path?	Present in Safety-Related Trip Path?	Included in Sensor Calibration?
PMA	X	X	
PEA	X	X	
Sensor reference accuracy	X	X	X
SD	X	X	X
STE	X	X	X (partial)
SPE	X	X	
Sensor vibration	X	X	
Sensor calibration tolerance	X	X	X
Sensor measuring and test equipment (M&TE) accuracy	X	X	X
Isolator reference accuracy	X		
Isolator drift	X		
Isolate temperature effect	X		
Isolator calibration tolerance	X		
Isolator M&TE accuracy	X		
Computer input analog-to-digital (A/D) accuracy	X		
Bistable reference accuracy		X	
Bistable drift		X	
Bistable temperature effect		X	
Bistable calibration tolerance		X	
Bistable M&TE accuracy		X	

SPM

On-line calibration monitoring data should be collected not only during normal plant operation, but also during startup and/or shutdown periods to provide the information that is needed to verify the calibration of transmitters over their operating range. When data are not available from startup and/or shutdown periods, the acceptance band for on-line calibration monitoring should be tightened to compensate for lack of these data. That is, if OLM data are available only from normal plant operation (primarily steady-state), the OLM approach is still valid for determining the calibration status of transmitters. However, it might be necessary to reduce the OLM

acceptance criteria. This is a more significant issue for non-redundant modeling techniques because they typically require more data than is available during plant startup and shutdown to maintain accuracy during these transients.

Figure 6-4 presents the results of a comprehensive study performed by EPRI [5]. This work facilitates the use of OLM for calibration monitoring based on data from a single point within the operating range of the transmitter if the uncertainty related to SPM is factored into the OLM acceptance criteria.

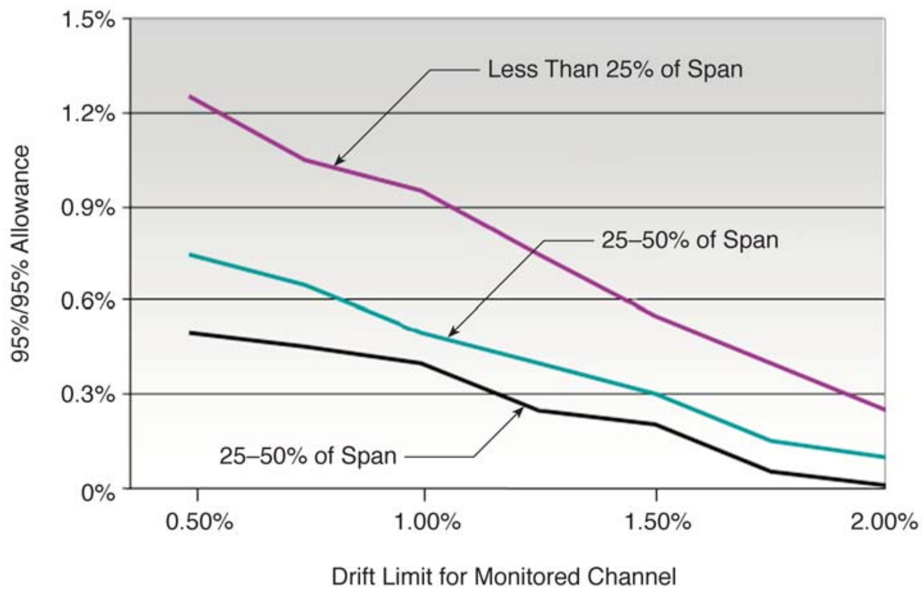


Figure 6-4
SPM Penalty Curve

For most transmitters, plants should easily be able to obtain startup, shutdown, or trip data to avoid the use of an SPM penalty. If a suitable volume of data covering the entire operating ranges of the transmitters is available, an averaging technique can be applied as described in this report without the need to enforce an SPM penalty. There are, however, services for which transmitter output data are not available because the transmitters might not come on scale until normal operating conditions prevail. For these transmitters, the SPM penalty can be used to compensate for the lack of data over the transmitter range. Alternatively, plants might be able to develop their own SPM penalty curves based on historical transmitter performance to obtain results more specific to their site. There are no requirements or standards for SPM that dictate when SPM should be applied. The NRC has raised this issue in its SER [4]. BE reviews the operational history of Sizewell's transmitters before applying OLM and has factored in all necessary uncertainties into the OLM allowance limits, including SPM issues where applicable.

Procedure for Determining the CSA Band

The CSA band for on-line calibration monitoring is typically established as follows:

1. Combine the uncertainties of the components that are included in the OLM of an instrument or an instrument channel.
2. Calculate the uncertainty of the process estimation. The calculation for the simple averaging technique is illustrated in Figure 6-5. In this illustration, the individual uncertainties (σ_i) are arrived at based on the accuracy of the pressure transmitter, process noise level that is characterized by the standard deviation of the noise, process temperature and pressure effects on transmitter calibrations, pressure transmitter resolution, and transmitter drift. These terms are combined in an RSS formula for each transmitter to arrive at the individual uncertainties. Assuming that individual uncertainties are normally distributed (that is, are Gaussian) and are independent, the uncertainty of the average (σ) is then calculated as shown in Figure 6-5.
3. Subtract the uncertainty of the process estimation from the CSA band calculated in Step 1.
4. Subtract the SPM penalty where appropriate. This provides the final acceptance limit for OLM over an entire fuel cycle of 18–24 months. If the transmitter drift is to be monitored for a shorter period, the allowable limits should be reduced accordingly.

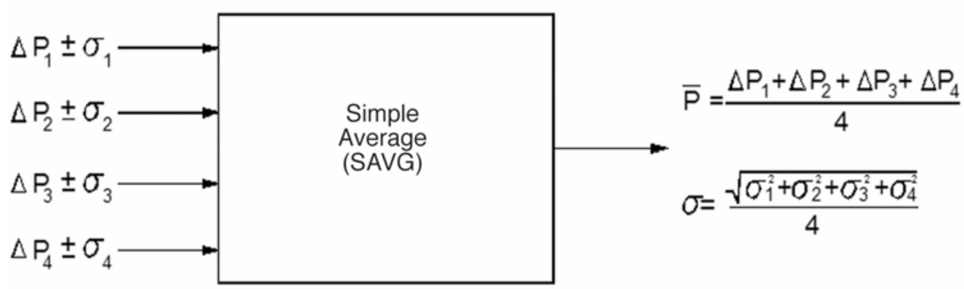


Figure 6-5
Calculating the Uncertainty of Simple Averaging for Process Estimation

The formula for calculating the CSA band will most likely be different for each plant and should be derived from the uncertainties used to calculate the plant trip setpoints. In this way, the on-line calibration monitoring limits can be linked to the plant's technical specifications. Calculation of the process estimation uncertainty can be difficult for modeling techniques and might need to be estimated on a case-by-case basis. For Sizewell, averaging was used to calculate the process estimate, and the uncertainty of this estimate was calculated using the procedure shown in Figure 6-5.

Acceptance Criteria for Sizewell B Transmitters

This section describes the method used by BE engineers to calculate the OLM acceptance criteria. The acceptance criteria calculations are provided in detail in the BE report *Acceptance Criteria for Use in OLM of Protection System Transmitters* [21]. The methodology for calculation of Sizewell acceptance limits is proprietary; accordingly, no details are provided herein regarding the precise methodology.

The OLM acceptance criteria for Sizewell B were calculated with a procedure similar to the one previously discussed. First, all of the appropriate uncertainties in the OLM channel except the drift term were combined. This defined a normal band within which all transmitters would be expected to lie if there were no transmitter drift (see Figure 6-6). Further, a drift band was added to the normal band in order to give the transmitter a drift allowance between refueling outages. Next, it was necessary to tighten the allowable limits to account for the uncertainty in determining the value of the process parameter being monitored. This uncertainty is called the *process estimate uncertainty*. In some cases, instrument channels had additional components in the monitoring channel that were not included in the normal band. In these instances, it was necessary to tighten the limits further to account for the additional uncertainty. This is called the *monitoring channel uncertainty*.

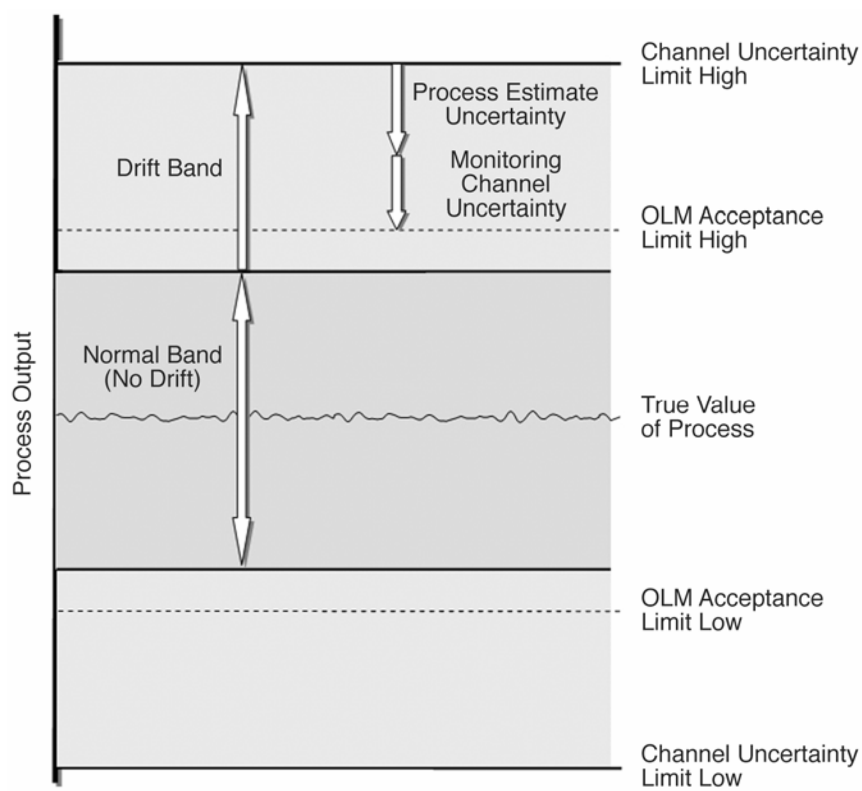


Figure 6-6
Illustration of OLM Acceptance Limits

The general formula for calculation of OLM acceptance limits at Sizewell B was:

OLM acceptance limit = normal band + drift band – process estimate uncertainty – monitoring channel uncertainty

As mentioned, the acceptance criteria for on-line calibration monitoring results for Sizewell transmitters were provided by BE. The criteria are provided in Table 6-4. The columns shown in Table 6-4 are the following:

1. The transmitter service or the parameter that the transmitters measure
2. OLM acceptance limits that are used with deviation plots
3. Consistency limits that are used in the parity space technique (or band average)
4. Manufacturer-supplied transmitter drift limits that are used with drift plots
5. Units for the parameter that the transmitter is measuring

Table 6-4
Acceptance Criteria for OLM at Sizewell B

Transmitter Service	Recalibration Limits	Consistency Limits	Drift Limits	Units
PPS Transmitters				
Main steam pressure	0.849	0.707	1.414	BarG
SG narrow-range level	0.871	0.707	1.414	%
SG wide-range level*	0.805	0.707	1.414	%
Pressurizer level	0.799	0.707	1.414	%
RCS wide-range pressure	1.579	1.414	2.830	BarG
RCS narrow-range pressure	0.530	0.382	0.764	BarG
Pressurizer pressure	0.439	0.382	0.764	BarG
Feed flow	2.981	2.677	5.355	kg/s
RCS loop flow	1.172	2.121	1.018	%
Reactor building pressure A	0.038	0.037	0.075	BarG
Reactor building pressure B	0.056	0.037	0.0212	BarG
RWST level for A	0.125	0.096	0.1918	m
RWST level for B	0.020	0.039	0.0235	m
Volume control tank level	0.925	0.707	1.414	%
ESW flow train for A and B	133.185	101.781	203.54	m^3/hr
CCW flow train for A and B	2.578	1.966	3.930	m^3/hr
CCW flow in RCP thermal barrier	0.537	0.410	0.820	m^3/hr
Surge tank level	0.964	0.707	1.414	%
Main steam flow*	2.778	2.677	2.981	kg/s

Table 6-4 (continued)
Acceptance Criteria for OLM at Sizewell B

Transmitter Service	Recalibration Limits	Consistency Limits	Drift Limits	Units
SPS Transmitters				
Main steam pressure*	0.604	0.707	0.200	BarG
SG narrow-range level*	0.613	0.707	0.252	%
RCS wide-range pressure	0.984	0.707	0.400	BarG
RCS narrow-range pressure	0.436	0.283	0.400	BarG
RCP seal injection flow	0.058	0.038	0.0385	m^3/hr
PFM Transmitters				
Main steam pressure*	0.849	0.000	1.414	BarG
Volume control tank level*	0.925	0.000	1.414	%

* Limits were not provided by BE; this was beyond the scope of BE's Phase 1 implementation project.

For the transmitters marked with an asterisk in Table 6-4, limits were inferred. The process of inference is described as follows:

1. PPS SG wide-range level limits were taken from the SG narrow-range level limits.
2. Tentative PPS main steam flow limits were provided by BE in an e-mail correspondence in August 2004 and are similar to the feed flow limits.
3. Parity space consistency check limits were not provided for a combination of PPSs and SPSs. For main steam pressure and SG narrow-range level transmitters, the consistency check limits were taken from the PPS consistency check limits.
4. Parity space consistency check limits were not provided for a combination of reactor building A and reactor building B transmitters. Therefore, the reactor building pressure consistency check limits were taken from the reactor building A consistency check limits.
5. No limits were provided for the PFM transmitters. Accordingly, for the PFM main steam pressure and the PFM chemical volume control system (CVCS) control volume tank level transmitters, the limits were taken from the corresponding PPS limits. The consistency limits for the PFM main steam pressure and PFM CVCS control volume tank level were set to 0 so that these transmitters would not be included in the average.

Acceptance Criteria at the McGuire Nuclear Station

To provide a point of reference for the OLM acceptance limits provided by BE, a similar set of limits was constructed for Duke Power's McGuire Nuclear Station during an NRC-funded project [1]. The estimated CSA bands are provided in Table 6-5, and the values for the uncertainty terms used to compute these CSA bands are provided in Table 6-6.

Table 6-5
Estimated CSA Bands for Representative McGuire Transmitters

Channel	Number of Signals	CSA Band (% of Span)
Feedwater flow	2	1.33
SG level	4	2.26
Reactor coolant flow	3	1.23
Pressurizer level	3	2.03
Wide-range pressure	2	1.30
Pressurizer pressure	4	2.81
Containment pressure	3	1.55
Steam pressure	3	2.16
Turbine impulse pressure	2	1.04

Table 6-6
Typical Uncertainty Values for Process Instrumentation Channels at McGuire (Percent of Span)

Service	PMA	PEA	SCA	SMTE	SD	SPE	STE	RCA	RMTE	RCSA	RD	RTE	EA	Bias
Feedwater flow	0.00	0.25[1]	0.10		0.30	0.56	0.10	1.50		0.00	1.00	0.50		0.00
SG level	2.00[2]		0.50		1.00	0.30	0.50	0.50		0.48	1.00	0.50		0.00
Reactor coolant flow	1.40[3]		0.00		0.60	0.00	0.00	0.30		0.17	0.60	0.30		0.05[4]
Pressurizer level	2.00[2]		0.50		1.00	0.50	0.50	0.50		0.35	1.00	0.50		0.00
Wide-range pressure	0.00		0.50		1.50	0.00	0.50	0.50		0.35	1.00	0.50		0.00
Pressurizer pressure	0.00		0.50		1.00	0.00	0.50	0.50		0.35	1.00	0.50		1.50[5]
Containment pressure	0.00		0.50		1.00	0.00	0.80	0.50		0.35	1.00	0.50		0.00
Steam pressure	0.20[6]		0.50		1.73	0.00	1.12	0.50		0.35	1.50	0.50		0.00
Turbine impulse pressure	0.00		0.50		0.63	0.00	0.72	0.50		0.00	1.00	0.50		0.00
Power range	4.17		4.17		0.00	0.00	0.00	0.50		0.25	1.00	0.50		0.00
In-core thermocouples	0.00		7.20		10.00	0.00	2.30	6.90		0.00	2.30	11.50		0.00

Notes:
1 0.25% represents uncertainty in flow measurements resulting from flow orifice.
2 2.00% represents uncertainty in level measurements resulting from the density of water.
3 0.33 of this 1.4 is uncertainty in flow measurements resulting from the density of water.
4 0.05% is bias resulting from tap location.
5 1.50% bias represents thermal non-repeatability.
6 0.20% is from water leg compensation.

The bias terms in Table 6-6 are common to redundant sensors; thus, they were not included in calculating the process estimation uncertainties presented in this section for the McGuire instruments.

Procedure for Determining the Acceptability of a Calibration and Required Actions

A transmitter is declared *good* if its deviation remains within the OLM acceptance limits at all times during the OLM process, including during startup and shutdown periods. (The exception to this is when a transmitter output exceeds the acceptance band as a result of process noise or anomalies not attributed to the calibration.) If the transmitter deviation exceeds the acceptance limit at any time and the transmitter is determined to have drifted out of tolerance, it will be deemed one that must be calibrated during the next outage.

One of the advantages of OLM is that it identifies calibration problems as they occur, as opposed to conventional calibrations that reveal many calibration problems during the periodically scheduled calibrations (typically, refueling outages) only. On the other hand, one might be faced with a transmitter that exceeds its calibration limits while the plant is at power. Of course, this cannot be ignored—it would negate one of the important benefits of OLM. Because OLM implementation for calibration monitoring is still new in the nuclear power industry, there is no consensus as to what must be done when a transmitter is found to exceed its OLM allowable drift limits during plant operation. One approach is as follows: if a transmitter consistently exceeds its OLM allowable drift limit (but not operability limit as defined by plant technical specifications), it must be tagged for closer observation. Sometimes, a transmitter exceeds its drift limits for a period and later returns to within limit. Therefore, it is important to closely monitor the transmitter to determine whether its deviation is consistently outside allowable limits.

It should be emphasized here that drift at the output of a pressure sensing channel can originate in any of the components in the path of the signal from the process to the plant computer or the data acquisition point. Further, any leakage in the pressure sensing line can cause drift at the output of a pressure transmitter. Therefore, it is important not to rush out to the field and calibrate a transmitter upon detection of drift; rather, all the components of the pressure sensing system should be evaluated to pinpoint the origin of a drift.

The daily/per-shift channel checks and monthly surveillances are additional measures to ensure that gross calibration problems are detected. Furthermore, at Sizewell B, response time measurements are performed on pressure transmitters once every cycle to verify proper dynamic performance. (OLM, in other words, is not the sole means of testing the Sizewell transmitters.) In the unlikely case that OLM is flawed, there are additional measures to protect the plant's safety. Eventually, daily/per-shift channel checks and monthly or quarterly surveillances might also turn out to be unnecessary once an OLM system is implemented and adequate experience using it is accumulated.

Role of ISA Standards in OLM Acceptance Criteria

ANSI/ISA Standard 67.04.01-2006 Setpoints for Nuclear Safety-Related Instrumentation Used in Nuclear Power Plants [22] provides guidelines on establishing setpoint values for safety-related parameters in nuclear power plants. The original version of this standard published in 2000 [19] was endorsed by the NRC in Regulatory Guide 1.105, *Setpoints for Safety-Related*

Instrumentation [23]. The 2006 revision of the ISA 67.04 standard addresses concerns related to the use of a single allowable value as an acceptance criterion for testing setpoints and the appropriateness of some of the methodologies used to calculate allowable values.

Using the nomenclature of ISA 67.04, this section explains how OLM acceptance criteria and the trip setpoint calculations are related. It is important to note that this section is intended to give the reader only a general understanding of the relationship between OLM acceptance criteria and the plant trip setpoints. Because setpoint calculations for each plant are unique, there is no single correct way to calculate them, and the calculations in this section should be viewed only as illustrative examples.

The methodology for calculation of OLM acceptance criteria for each plant will be unique but must be traceable to the setpoint uncertainty calculations to ensure that OLM results do not impair the safety of the plant. For more information on the terms included in the setpoint and OLM calculations and how to combine them, see ISA's recommended practice for setpoint calculations [20].

Relationship Between ISA 67.04 and NRC Requirements

ISA 67.04 plays a role in one of the NRC requirements given in the SER that approved the OLM methodology for extending the calibration interval of pressure transmitters in nuclear power plants. In particular, the first requirement stated in the SER is as follows:

> The submittal for implementation of the on-line monitoring technique shall confirm that the impact on plant safety of the deficiencies inherent in the on-line monitoring technique (inaccuracy in process parameter estimate, single-point monitoring, and untraceability of accuracy to standards) on plant safety will be insignificant, and that all uncertainties associated with the process parameter estimate have been quantitatively bounded and accounted for either in the online monitoring acceptance criteria or in the applicable setpoint and uncertainty calculations. [4]

This requirement emphasizes that the new uncertainties introduced by OLM must be addressed in either the OLM acceptance criteria or the plant's setpoint calculations (that is, by recalculating the plant's trip setpoints to include the new uncertainties). Either way, this requirement is meant to ensure that the effect of OLM on plant safety is insignificant. Obviously, most plants would not normally change their trip setpoints to implement OLM; they would typically account for OLM uncertainties in the OLM acceptance criteria while ensuring that the OLM acceptance criteria are calculated in a way that does not violate the assumptions made in the plant's trip setpoint calculations.

Setpoint Definitions and Related Terminology

Figure 6-7 shows the limits related to nuclear safety for important process parameter measurements [19]. These limits are defined as follows:

- Safety limit. This is the point at which actual damage to the plant can occur if an important process parameter exceeds it. If the limit is exceeded, the integrity of physical barriers that guard against the uncontrolled release of radiation might be challenged. To ensure that the safety limit is not violated, constraints are imposed in the plant safety analysis on process measurements and their uncertainties.
- Analytical limit. This is the limit of a measured or calculated variable established by the safety analysis to ensure that the safety limit is not exceeded. The calculation of the analytical limit also takes into account design basis events. The analytical limit is specified in the plant safety analysis and is the starting point for the calculation of the trip setpoint.
- Trip setpoint. To ensure that the analytical limit is not exceeded, a trip is set to occur when an important process parameter reaches a point referred to as a *trip setpoint*. That is, the trip setpoint is the value at which the final setpoint device is set to actuate a trip.
- Allowable value. Ideally, the trip setpoint should remain at its intended value, but drift and other factors can cause it to change. Therefore, a limit—called the *allowable value*—is set in order to bound the setpoint. During periodic calibrations of instrumentation in nuclear power plants, plant technicians follow a procedure to verify that the trip setpoint has not exceeded the allowable value.
- Normal. The normal operating point is not a limit but is included in the diagram to show the normal operating point relative to the trip setpoint.

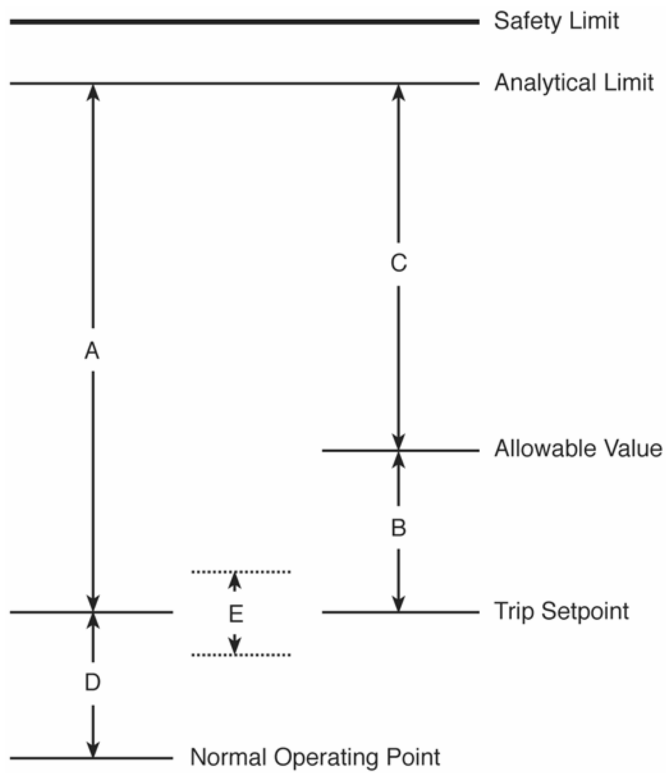


Figure 6-7
Nuclear-Safety-Related Setpoint Relationships

In Figure 6-7, five bands, A–E, are shown. Descriptions of these bands follow:

A. An allowance is provided between the trip setpoint and the analytical limit to ensure that a trip occurs well before the analytical limit is reached. This allowance is made up of the total loop uncertainty (TLU) and an additional margin that the plant might include to be conservative. The TLU represents the expected performance of the instrumentation under any applicable process and environmental conditions and includes uncertainties associated with the following:

- Instrument calibration
- Normal operation uncertainties (for example, temperature and pressure effects)
- Instrument drift
- Design basis events (if not accounted for in the analytical limit calculation)
- Process-dependent effects (for example, fluid stratification on temperature measurements)
- Calculation effects (for example, uncertainties from calculating primary side power through the secondary side power calorimetric)

- Dynamic effects (behavior of the channel's output as a function of input with respect to time; that is, the effect of response time)
- Calibration and installation bias (any bias of fixed magnitude and known direction) resulting from equipment installation

B. An allowance between the trip setpoint and the allowable value to give some margin when the trip setpoints are tested.

C. The region higher than the allowable value and lower than the analytical limit. If the channel is not tripped before this region is reached, the assumptions that were used to calculate the allowable value were not correct or the instrument has failed. The responsible instrument must be declared inoperable if it reaches Band C and no trip results.

D. The region lower than the trip setpoint and higher than normal operation. This band accounts for normal plant transients.

E. The region of trip setpoint calibration tolerance (calibration as-left limits).

Formula for Calculation of Setpoint

The trip setpoint for an important process measurement channel is typically calculated as follows:

$$TS = AL - TLU - margin$$

where TS is the trip setpoint, AL is the analytical limit, TLU is the total loop uncertainty, and margin is often included to add an extra level of conservatism. Because the preceding equation assumes a process that goes upward and approaches the analytical limit, the TLU and margin are **subtracted** from the AL. The TLU is made up of all the uncertainties previously mentioned in this section.

Relationship Between Setpoint Values and OLM Acceptance Criteria

OLM acceptance criteria relate to the setpoint calculations through inclusion of terms from the TLU calculation in the OLM acceptance limits. Therefore, if the OLM acceptance criteria have not been violated, the plant will have confidence that its setpoint uncertainty assumptions as calculated in the TLU have also not been violated. The terms that are included in the OLM acceptance criteria and how they are combined are normally plant-specific, but they must always be consistent with the calculation of the TLU. The OLM acceptance criteria must also include a term for the uncertainty of the process estimate.

The way the process estimate is calculated can also affect which terms are included or excluded. For example, if averaging of redundant sensors is used to calculate the process estimate, instrument bias effects would apply equally to all sensors and would not need to be included in

the limits, which are based on comparison with an average. Also, some terms that were calculated in the TLU and based on the setpoint might need to be recalculated to take into account the fact that the OLM measurements are made at the operating point. Drift terms might also need to be recalculated because they are often time-dependent. Therefore, if in the setpoint calculation the drift term was calculated based on an 18-month frequency, it might need to be reduced in order to reflect the shorter OLM frequency.

The main point is that plant engineers will have to decide on a case-by-case basis which terms to include or exclude in the calculation of the OLM acceptance criteria and whether some terms need to be recalculated based on where or when they are measured. However, the terms used in the calculation of the OLM acceptance criteria must have a clear link to the calculation of the TLU in order to not violate the setpoint calculation assumptions.

An Example of a Calculation of OLM Limits

The following is a simple example to demonstrate the concepts in the preceding sections. Suppose a plant has decided to monitor the calibration of a group of redundant steam pressure transmitters once every nine months, and it uses an averaging technique to do so. From its setpoint uncertainty analysis, the plant has determined that its TLU for a steam line pressure transmitter is ±2.0 Bar. The terms that went into the calculation of the TLU are shown in Table 6-7.

Table 6-7
Uncertainty Terms Used in the Steam Pressure Transmitter Monitoring Example

Uncertainty Term	Acronym or Term	Value (Bar)
Sensor calibration accuracy	SCA	0.20
Sensor measurement and test equipment	SMTE	0.10
Sensor drift (over 18 months)	SD	0.40
Sensor temperature effects	STE	1.0
Sensor bias	Bias	0.78
On-line monitoring process estimate	OPE	0.5

The TLU was calculated in the setpoint calculations using the following formula:

$$TLU = \pm\sqrt{(SCA + SMTE + SD)^2 + STE^2} + BIAS$$

Using the values from Table 6-7 gives the following equation:

$$TLU = \pm\sqrt{(0.20 + 0.10 + 0.40)^2 + 1.0^2} + 0.78 = \pm\ 2.0\ \text{Bar}$$

To calculate the OLM acceptance limits, the plant adjusts the values of the terms to account for differences in the OLM measurement and the setpoint calculation. For example, the SD value in Table 6-7 assumes drift over 18 months. Because OLM will be evaluating the transmitter every nine months, this value is reduced by half (assuming a linear drift rate) to 0.40 x 0.5 = 0.20 Bar. Likewise, the temperature effect term (STE) is reduced to reflect the fact that the OLM data will be taken from the operating point that is 20% of the transmitter's range below the setpoint. Assuming a linear decrease in the temperature effect, this will give STE = 1.0 – (20/100) = 0.80 Bar. Because the plant is using the average of redundant transmitters to determine the process estimate and the bias term is assumed to affect all of the redundant transmitters equally, it will not need to be included in the OLM acceptance criteria. The plant has determined that the average of four redundant sensors will give a process estimate uncertainty (OPE) of 0.5 Bar, which must also be included in the OLM limits. The plant engineers have decided to treat the OPE uncertainty as a bias and subtract it from the other uncertainty terms. The following formulas account for OPE bias:

$$OLM = \pm\sqrt{(SCA + SMTE + SD)^2 + STE^2} - OPE$$

$$OLM = \pm\sqrt{(0.20 + 0.10 + 0.20)^2 + 0.80^2} - 0.50 = \pm\ 0.44 \text{ Bar}$$

Figure 6-8 shows the OLM limits relative to the TLU used to calculate the setpoint limits. If the deviation of each transmitter does not exceed the high or low OLM limits, the plant setpoint uncertainty calculations have not been violated because the same terms were used in each calculation. This region is labeled as the "Acceptable Region" band in Figure 6-8. If the deviation of a transmitter exceeds the high or low OLM limit but remains within the high or low TLU limits, the transmitter should be scheduled for routine calibration. This region is labeled as the "Schedule Routine Calibration" band in Figure 6-8. If the transmitter deviation is in this region, the transmitter has exceeded the assumptions used to calculate the OLM limits and must be checked. If the transmitter deviation exceeds the high or low TLU limits, the assumptions used to calculate the TLU have been violated, and the transmitter must be either immediately calibrated or classified as inoperable. If the TLU limits are exceeded, the assumptions used to calculate the plant's trip setpoint no longer hold, and immediate action is required.

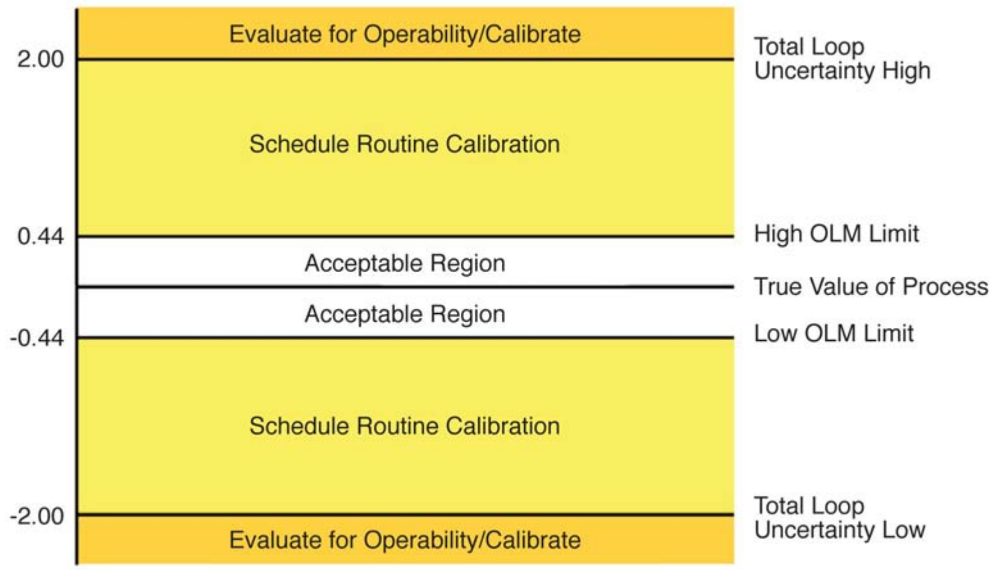


Figure 6-8
TLU and OLM Limits for the Steam Line Pressure Transmitter Example

Note: when a bad transmitter is found during the mid-cycle analysis (that is, nine months into the cycle), Sizewell schedules the transmitter for calibration during the next outage but does not consider the transmitter inoperable.

7 COMPARISON OF RESULTS OF OLM AND MANUAL CALIBRATIONS FOR SIZEWELL TRANSMITTERS

This section presents a comparison of the results of OLM and manual calibration methodologies for pressure, level, and flow transmitters installed at the Sizewell B plant. These results are based on data from 64 PPS transmitters at Sizewell B. The data were retrieved from the Sizewell plant computer for operating Cycles 5–7 that cover plant operations from October 2000 to April 2005.

The OLM results for Cycle 5 come from data taken at startup in October 2000, normal operation conditions from November 2001 and March 2002, and shutdown data from April 2002. The OLM results for Cycle 6 come from data taken at startup in May 2002, 17 months of normal operation from May 2002 to September 2003, and shutdown data in October 2003. The OLM results for Cycle 7 come from data taken at startup in November 2003, 17 months of normal operation data from November 2003 to March 2005, and shutdown data from March 2005.

Summary of OLM Validation Results

Comparisons of cumulative calibration results for three operating cycles for 64 PPS transmitters are presented in Tables 7-1 and 7-2. Tables 7-1 and 7-2 show the agreement between the results of OLM and manual calibrations. The terminology that is used to present these results is defined as follows: *good* means that the method identified the transmitter as being in calibration, and *bad* means that the method identified the transmitter as being out of calibration. The good/bad classification was obtained independently for the manual calibrations performed by BE and the OLM analysis performed by AMS. These assessments were made based on the OLM acceptance limits established by BE and provided to AMS for use in this project.

Table 7-1
Summary of Results of OLM Validation for Sizewell B

OLM	Manual	Number of Calibration Checks	Assessment
Good	Good	133	Exact match
Bad	Bad	8	Exact match
Bad	Good	22	Conservative mismatch
Good	Bad	12	Non-conservative mismatch

Table 7-2
Classification of Transmitters Found to Be Bad by the OLM System

Reason That Transmitter Was Found to Be Bad	Number of Instances
Low or high bias	18
Bias plus span shift	3
High or low at 10% range	4
High or low at 75% range	3
Other reasons	2

The results discussed in this report for the 64 PPS transmitters over three operating cycles add up to 175 cases. (A total of 17 cases were not included for Cycle 7 because calibration period extension received regulatory approval in this cycle for one of the four redundant groups of transmitters. Of these 17 cases, one case was omitted because the data were insufficient, and the other 16 were omitted because their calibration intervals were extended.) Of the total 175 cases, the results of manual calibrations and OLM agreed or were conservative for all but 12 cases—that is, when OLM found the calibration of a transmitter to be good or bad, the manual calibration yielded the same evaluation.

OLM found a few transmitters to be bad that turned out to be good in manual calibrations. Although this outcome is not ideal, it is acceptable because it is conservative. On the other hand, for 12 cases, OLM determined good calibrations, but manual calibrations identified the same transmitters as bad. This is not conservative, and an investigation was performed to determine why OLM produced non-conservative results for these 12 transmitters. In Section 8, each of the non-conservative results is explained in detail.

As indicated in Table 7-2, the majority of transmitters that OLM found to be bad suffered from a bias error. This is consistent with the nuclear industry's experience with calibration drift of pressure transmitters. More specifically, EPRI and others have shown that a majority of calibration losses in nuclear power plant transmitters result from a change in offset (bias error) rather than drift [5].

Table 7-3 compares the outcome of OLM and manual calibration methodologies for the 64 PPS transmitters included in this project. The results are given for data retrieved from the plant computer for Cycles 5–7. The OLM and manual calibration results agree well with each other, except for the few cases that are shaded in Table 7-3 (light shading indicates conservative agreement; dark shading indicates non-conservative agreement). Table 7-3 will be updated with future results to document the history of the OLM program at Sizewell B.

Table 7-3
Aggregate Results of OLM Analysis and Manual Calibrations

Item #	Tag	Group	Result of OLM			Result of Manual Calibration		
			Cycle 5	Cycle 6	Cycle 7	Cycle 5	Cycle 6	Cycle 7
1	AB-P-0513-W	Main Steam Pressure Loop 1	Good	Good	Bad	Good	Good	Good
2	AB-P-0525-W	Main Steam Pressure Loop 2	Good	Good	Good	Good	Good	Good
3	AB-P-0536-W	Main Steam Pressure Loop 3	Good	Good	Good	Good	Good	Good
4	AB-P-0544-W	Main Steam Pressure Loop 4	Good	Good	Good	Good	Good	N/A
5	AE-L-0501-W	SG A Level WR	Good	Good	Good	Good	Good	Good
6	AE-L-0505-W	SG A Level WR	Good	Good	Good	Good	Good	Good
7	AE-L-0502-W	SG B Level WR	Good	Good	Bad	Good	Good	Bad
8	AE-L-0506-W	SG B Level WR	Good	Good	Bad	Good	Good	Good
9	AE-L-0503-W	SG C Level WR	Good	Good	Good	Good	Good	Bad
10	AE-L-0507-W	SG C Level WR	Good	Good	Good	Good	Good	N/A
11	AE-L-0504-W	SG D Level WR	Good	Good	Good	Good	Good	Bad
12	AE-L-0508-W	SG D Level WR	Good	Good	Good	Good	Good	Good
13	AE-L-0517-W	SG A Level Narrow-Range	Good	Good	Good	Good	Good	Good
14	AE-L-0518-W	SG A Level Narrow-Range	Good	Good	Good	Good	Good	N/A
15	AE-L-0519-W	SG A Level Narrow-Range	Good	Good	Good	Good	Good	Good
16	AE-L-0551-W	SG A Level Narrow-Range	Good	Good	Good	Good	Good	Good
17	AE-L-0527-W	SG B Level Narrow-Range	Good	Good	Good	Good	Good	Good
18	AE-L-0528-W	SG B Level Narrow-Range	Good	Good	Good	Good	Good	N/A
19	AE-L-0529-W	SG B Level Narrow-Range	Good	Good	Good	Good	Good	Good
20	AE-L-0552-W	SG B Level Narrow-Range	Good	Good	Bad	Good	Good	Good
21	AE-L-0537-W	SG C Level Narrow-Range	Good	Good	Good	Good	Good	Good
22	AE-L-0538-W	SG C Level Narrow-Range	Good	Good	Good	Good	Good	N/A
23	AE-L-0539-W	SG C Level Narrow-Range	Good	Good	Good	Good	Good	Good
24	AE-L-0553-W	SG C Level Narrow-Range	Good	Good	Good	Good	Good	Good
25	AE-L-0547-W	SG D Level Narrow-Range	Good	Good	Good	Good	Good	Good
26	AE-L-0548-W	SG D Level Narrow-Range	Good	Good	Good	Good	Good	N/A
27	AE-L-0549-W	SG D Level Narrow-Range	Good	Good	Good	Good	Good	Good
28	AE-L-0554-W	SG D Level Narrow-Range	Good	Good	Good	Good	Good	Good
29	AE-F-0515B-W	Main Feed Flow to SG A	Bad	Bad	Good	Good	Good	N/A
30	AE-F-0525B-W	Main Feed Flow to SG B	Bad	Bad	N/A	Good	Bad	Good
31	AE-F-0535B-W	Main Feed Flow to SG C	Good	Bad	Good	Good	Good	N/A
32	AE-F-0545B-W	Main Feed Flow to SG D	Good	Bad	Bad	Good	Good	Good

Legend	
(yellow)	Conservative
(orange)	Non-Conservative

Table 7-3 (continued)
Aggregate Results of OLM Analysis and Manual Calibrations

Item #	Tag	Group	Result of OLM			Result of Manual Calibration		
			Cycle 5	Cycle 6	Cycle 7	Cycle 5	Cycle 6	Cycle 7
33	BB-P-0455-W	Pressurizer Pressure	Good	Good	Good	Good	Good	Good
34	BB-P-0456-W	Pressurizer Pressure	Bad	Bad	Good	Good	Bad	N/A
35	BB-P-0457-W	Pressurizer Pressure	Good	Good	Good	Good	Good	Good
36	BB-P-0458-W	Pressurizer Pressure	Bad	Good	Good	Bad	Good	Good
37	BB-L-0465-W	Pressurizer Level	Bad	Bad	Bad	Bad	Good	Good
38	BB-L-0466-W	Pressurizer Level	Bad	Good	Good	Bad	Good	N/A
39	BB-L-0467-W	Pressurizer Level	Good	Good	Good	Good	Good	Good
40	BB-L-0468-W	Pressurizer Level	Good	Good	Good	Good	Good	Bad
41	BB-P-0406-W	RCS Pressure Narrow-Range PPS	Good	Good	Good	Good	Bad	Good
42	BB-P-0407-W	RCS Pressure Narrow-Range PPS	Bad	Bad	Good	Bad	Good	N/A
43	BB-P-0408-W	RCS Pressure Narrow-Range PPS	Bad	Bad	Good	Good	Good	Good
44	BB-P-0409-W	RCS Pressure Narrow-Range PPS	Good	Good	Good	Good	Bad	Good
45	BB-P-0401-W	RCS Pressure Wide-Range PPS	Good	Good	Good	Good	Good	Good
46	BB-P-0402-W	RCS Pressure Wide-Range PPS	Good	Good	Good	Good	Good	N/A
47	BB-P-0403-W	RCS Pressure Wide-Range PPS	Good	Bad	Good	Good	Good	Bad
48	BB-P-0404-W	RCS Pressure Wide-Range PPS	Bad	Good	Good	Good	Good	Good
49	BB-F-0416-W	RCS Flow Loop 1	Good	Bad	Good	Bad	Good	Good
50	BB-F-0417-W	RCS Flow Loop 1	Good	Bad	Good	Good	Good	N/A
51	BB-F-0418-W	RCS Flow Loop 1	Good	Good	Good	Good	Good	Good
52	BB-F-0419-W	RCS Flow Loop 1	Good	Bad	Good	Good	Good	Good
53	BB-F-0426-W	RCS Flow Loop 2	Good	Bad	Good	Good	Good	Good
54	BB-F-0427-W	RCS Flow Loop 2	Good	Good	Good	Good	Bad	N/A
55	BB-F-0428-W	RCS Flow Loop 2	Good	Good	Good	Good	Good	Good
56	BB-F-0429-W	RCS Flow Loop 2	Good	Bad	Good	Good	Good	Good
57	BB-F-0436-W	RCS Flow Loop 3	Good	Good	Good	Good	Good	Good
58	BB-F-0437-W	RCS Flow Loop 3	Good	Good	Good	Good	Good	N/A
59	BB-F-0438-W	RCS Flow Loop 3	Good	Good	Good	Good	Good	Good
60	BB-F-0439-W	RCS Flow Loop 3	Bad	Good	Good	Bad	Bad	Good
61	BB-F-0446-W	RCS Flow Loop 4	Good	Good	Good	Good	Bad	Bad
62	BB-F-0447-W	RCS Flow Loop 4	Good	Good	Good	Good	Bad	N/A
63	BB-F-0448-W	RCS Flow Loop 4	Good	Good	Good	Good	Good	Good
64	BB-F-0449-W	RCS Flow Loop 4	Good	Good	Good	Good	Good	Good

Legend	
(yellow)	Conservative
(orange)	Non-Conservative

Details of Qualitative Analysis of OLM Data

In this qualitative comparison, the terms *good* and *bad* are used as previously described to refer to transmitters that have exceeded their allowable limits during manual calibrations or OLM. The OLM analysis for each transmitter involved data from three periods: startup, normal operation, and shutdown. Each transmitter was evaluated against its OLM drift allowance over the duration of each operating cycle. The details of the methodology are presented in Section 4 of this report, and Sizewell B's application of the methodology is described in Section 5. The following summaries can be established for the OLM results based on the data in Table 7-3:

- Cycle 5: 54 good, 10 bad, with ~15% identified as out-of-calibration
- Cycle 6: 50 good, 14 bad, with ~21% identified as out-of-calibration
- Cycle 7: 57 good, 6 bad, 1 N/A, with ~10% identified as out-of-calibration

Generally, the number of transmitters that indicate calibration problems over a single fuel cycle is very small. Thus, the 15% and 21% observed for Cycles 5 and 6, respectively, are larger percentages than expected. A reason for this might be the high degree of conservatism that AMS has adopted in assessing the OLM results for these PPS transmitters. Note that for Cycle 7, the result for one of the transmitters was classified as N/A: the OLM data for this particular transmitter did not meet the quality criteria established by AMS for on-line calibration monitoring of the Sizewell B transmitters.

Table 7-4 lists the transmitters that were found to be bad and a brief description of the reason for this assessment. It is apparent from the information in Table 7-4 that bias is the dominant cause of bad transmitter calibrations. Furthermore, it should be pointed out that the indication for one flow transmitter—1AE-F-0545B-W—was found to be low at 40% of the transmitter's range.

Table 7-4
Classification for Transmitters Identified as Bad Through OLM

Item #	Tag	Group	Reason for Calibration
Cycle 5			
Item #	**Tag**	**Group**	**Reason for Calibration**
1	1AE-F-0515B-W	Main Feed Flow to SG A	High at low flow
2	1AE-F-0525B-W	Main Feed Flow to SG B	Low bias
3	1BB-P-0456-W	Pressurizer Pressure	High bias
4	1BB-P-0458-W	Pressurizer Pressure	Low bias
5	1BB-L-0465-W	Pressurizer Level	Low bias and span shift
6	1BB-L-0466-W	Pressurizer Level	Low bias
7	1BB-P-0407-W	RCS Pressure Narrow-Range PPS	High bias
8	1BB-P-0408-W	RCS Pressure Narrow-Range PPS	Low bias
9	1BB-P-0404-W	RCS Pressure Wide-Range PPS	Low bias
10	1BB-F-0439-W	RCS Flow Loop 3	Low bias
Cycle 6			
Item #	**Tag**	**Group**	**Reason for Calibration**
1	1AE-F-0515B-W	Main Feed Flow to SG A	High bias
2	1AE-F-0525B-W	Main Feed Flow to SG B	Low bias
3	1AE-F-0535B-W	Main Feed Flow to SG C	High at 10% range
4	1AE-F-0545B-W	Main Feed Flow to SG D	Low at 10% range
5	1BB-P-0456-W	Pressurizer Pressure	High bias and span shift
6	1BB-L-0465-W	Pressurizer Level	Low bias and span shift
7	1BB-P-0407-W	RCS Pressure Narrow-Range PPS	High bias
8	1BB-P-0408-W	RCS Pressure Narrow-Range PPS	High bias
9	1BB-P-0403-W	RCS Pressure Wide-Range PPS	High bias
10	1BB-F-0416-W	RCS Flow Loop 1	Low at 10% range
11	1BB-F-0417-W	RCS Flow Loop 1	High at 10% range
12	1BB-F-0419-W	RCS Flow Loop 1	Low at 75% range
13	1BB-F-0426-W	RCS Flow Loop 2	Low at 75% range
14	1BB-F-0429-W	RCS Flow Loop 2	High at 75% range
Cycle 7			
Item #	**Tag**	**Group**	**Reason for Calibration**
1	1AB-P-0513-W	Main Steam Pressure Loop 1	Low bias
2	1AE-L-0502-W	SG B Level Wide-Range	High bias
3	1AE-L-0506-W	SG B Level Wide-Range	Low bias
4	1AE-L-0552-W	SG B Level Narrow-Range	High bias
5	1AE-F-0545B-W	Main Feed Flow to SG D	Low at 40% range
6	1BB-L-0465-W	Pressurizer Level	Low bias

Details of Qualitative Analysis of Manual Calibration Data

This section presents the results of manual calibrations performed by Sizewell technicians on the same 64 PPS transmitters that were involved in OLM. The results of the manual calibrations performed by Sizewell are documented in the plant's AFAL calibration records. These records generally contain nine calibration points—five in the up direction and four in the down direction. Typically, the nine calibration points are at 3%, 25%, 50%, 75%, 97%, 75%, 50%, 25%, and 3% of span.

The results of the manual calibrations of the 64 transmitters for Cycles 5–7 were presented in Table 7-3. In Table 7-3, a transmitter is classified as good if no calibration adjustment was made by the calibrating technician and bad if the transmitter was adjusted to improve calibration. The following summaries can be established for the manual calibration results based on the data in Table 7-3:

- Cycle 5: 58 good, 6 bad, with ~20% identified as out-of-calibration.
- Cycle 6: 56 good, 8 bad, with ~12% identified as out-of-calibration.
- Cycle 7: 42 good, 6 bad, with ~12% identified as out-of-calibration. (The Cycle 7 manual calibrations included only 48 of the 64 transmitters because 16 qualified for calibration interval extension and were not manually calibrated during RFO7.)

Table 7-5 lists the transmitters that were identified as bad through the manual calibrations along with a brief description of the reason for this assessment. Again, most of the problems found during manual calibrations were the result of a bias error. This is consistent with the conclusions drawn from the OLM results and also with what the nuclear power industry has learned from experience—namely, that most calibration changes are a consequence of bias errors.

Table 7-5
Transmitters Requiring Manual Adjustment

Item #	Tag	Group	Reason for Adjustment
Cycle 5			
1	BB-P-0458-W	Pressurizer Pressure	Low bias
2	BB-L-0465-W	Pressurizer Level	Defective transmitter; replaced
3	BB-L-0466-W	Pressurizer Level	Low bias
4	BB-P-0407-W	RCS Pressure Narrow-Range PPS	Low bias
5	BB-F-0416-W	RCS Flow Loop 1	Failed an at-power span check
6	BB-F-0439-W	RCS Flow Loop 3	Defective transmitter; replaced
Cycle 6			
Item #	**Tag**	**Group**	**Reason for Adjustment**
1	AE-F-0525B-W	Main Feed Flow to SG B	Low at 5.8% point
2	BB-P-0456-W	Pressurizer Pressure	High at 3% and 50% (down) points
3	BB-P-0406-W	RCS Pressure Narrow-Range PPS	High at 97% (up), 25%, and 50% (down) points
4	BB-P-0409-W	RCS Pressure Narrow-Range PPS	High at 97% (up) to 50% (down) points
5	BB-F-0427-W	RCS Flow Loop 2	High at 94% point
6	BB-F-0439-W	RCS Flow Loop 3	High at 75% and 94% points
7	BB-F-0446-W	RCS Flow Loop 4	High at 3% point
8	BB-F-0447-W	RCS Flow Loop 4	High at 50% (up) and 25% to 75% (down) points
Cycle 7			
Item #	**Tag**	**Group**	**Reason for Adjustment**
1	AE-L-0502-W	SG B Level Wide-Range	High at 3% to 75% (up) and 3% (down) points
2	AE-L-0503-W	SG C Level Wide-Range	High at 75%, 97% (up) and 75%, 50% (down) points
3	AE-L-0504-W	SG D Level Wide-Range	High at 75% (up) point
4	BB-L-0468-W	Pressurizer Level	High at 75% (up) and 75% and 50% (down) points
5	BB-P-0403-W	RCS Pressure Wide-Range PPS	High at 97% point
6	BB-F-0446-W	RCS Flow Loop 4	Marginally high at all points

Summary of Qualitative Results

Table 7-6 presents a summary of the qualitative comparisons for Cycles 5–7. Additional information about the non-conservative results—those shown in the fourth row of Table 7-6—is given in Section 8.

Table 7-6
Summary of OLM and Manual Calibration Comparison for Cycles 5–7

OLM Result	Manual Result	Assessment	Cycle 5	Cycle 6	Cycle 7
Good	Good	Exact match	53	44	36
Bad	Bad	Exact match	5	2	1
Bad	Good	Conservative mismatch	5	12	5
Good	Bad	Non-conservative mismatch	1	6	5

Quantitative Comparisons

In quantitative comparisons, the changes in transmitters' zero and span that occurred during the cycle are determined by comparing the results of BE's SCRM methodology with the OLM regression methodology as defined in Section 5.

To compare the results of the OLM with the manual calibrations (SCRM), the change in each transmitter's span drift as calculated based on the manual calibrations is subtracted from the corresponding span drift that is calculated based on OLM data. Likewise, the intercept based on the manual calibrations is subtracted from the intercept that is calculated based on the OLM data. Table 7-7 shows the AFAL results of these calculations for a selected group of 44 transmitters in Cycles 5–7. In Table 7-7, the difference between the value of the transmitter zero change is displayed in the ΔZero column, and the difference between the span change calculated for OLM and manual calibration is displayed in the ΔSpan column. These 44 transmitters were selected because they transitioned through more than 60% of their calibrated ranges in both the startup and shutdown OLM data for Cycles 5–7. The paragraph that follows Table 7-7 discusses the outcome of each of the three refueling outages.

Table 7-7
Comparison of OLM and Manual AFAL Results for Cycles 5–7

		Cycle 5		Cycle 6		Cycle 7	
Item	Tag	ΔZero	ΔSpan	ΔZero	ΔSpan	ΔZero	ΔSpan
Main Steam Pressure							
1	1AB-P-0513-W	-0.29	0.06	0.00	-0.74	0.14	0.01
2	1AB-P-0514-W	-0.19	0.11	-0.56	-0.16	N/A	N/A
3	1AB-P-0515-W	0.42	-0.89	-0.24	0.27	-0.18	-0.29
4	1AB-P-0516-W	0.64	-0.49	0.02	-0.32	-0.27	-0.18
5	1AB-P-0177-W	-0.28	-0.02	-0.55	0.30	0.47	-1.00
6	1AB-P-0174-W	0.01	0.23	0.20	0.26	N/A	N/A
7	1AB-P-0175-W	0.01	-0.29	0.09	0.39	0.11	0.05
8	1AB-P-0137-W	-0.06	0.03	0.44	0.31	-0.27	0.05
9	1AB-P-0138-W	0.29	-0.45	0.18	0.17	-0.04	0.13
10	1AB-P-0523-W	-0.08	-0.22	0.14	-0.11	0.19	-0.36
11	1AB-P-0524-W	N/A	N/A	N/A	N/A	N/A	N/A
12	1AB-P-0525-W	-0.04	-0.18	-0.01	-0.37	0.55	-0.64
13	1AB-P-0526-W	0.35	-0.16	-0.41	0.29	0.10	0.46
14	1AB-P-0277-W	-0.17	-0.08	-1.06	-0.49	0.62	0.08
15	1AB-P-0275-W	0.19	0.11	-0.16	0.39	0.19	-0.09
16	1AB-P-0274-W	0.40	1.88	-0.12	0.41	-0.07	0.31
17	1AB-P-0237-W	-0.14	0.21	0.11	0.23	0.02	-0.20
18	1AB-P-0238-W	-0.20	-0.22	0.45	0.42	0.12	-0.18
19	1AB-P-0533-W	0.06	-0.73	-0.17	-0.39	0.12	0.01
20	1AB-P-0534-W	-0.81	0.14	-0.56	0.38	N/A	N/A
21	1AB-P-0535-W	-0.15	-0.43	-0.47	-0.19	-0.23	-0.25
22	1AB-P-0536-W	0.30	-0.18	-0.27	0.15	-0.24	0.36
23	1AB-P-0377-W	0.08	-0.63	0.06	-0.29	-0.33	-0.14
24	1AB-P-0337-W	-0.12	-0.13	-0.15	0.10	0.27	-0.13
25	1AB-P-0338-W	-0.32	-0.28	0.02	0.14	0.27	0.16
26	1AB-P-0375-W	-0.23	0.15	0.00	0.21	0.01	0.06
27	1AB-P-0374-W	-0.31	-0.41	0.47	0.35	-0.09	-0.15
28	1AB-P-0543-W	-0.67	-0.34	0.86	-1.29	-0.53	0.12
29	1AB-P-0544-W	-0.50	0.20	0.29	-0.37	N/A	N/A
30	1AB-P-0545-W	-0.08	-0.21	0.43	-0.54	-0.42	-0.14
31	1AB-P-0546-W	-0.02	0.38	0.13	-0.23	0.28	-0.24
32	1AB-P-0477-W	-0.49	0.53	0.00	0.17	-0.43	0.78
33	1AB-P-0437-W	-0.10	-0.08	0.19	0.30	0.04	0.04
34	1AB-P-0438-W	-0.27	0.02	0.29	-0.29	0.61	0.10
35	1AB-P-0474-W	-0.17	0.28	0.19	0.10	0.03	-0.10
36	1AB-P-0475-W	-0.26	0.06	-0.04	-0.12	-0.03	0.13
Pressurizer Pressure							
37	1BB-P-0455-W	-0.21	-0.24	0.34	0.23	0.18	-0.06
38	1BB-P-0456-W	3.02	-1.77	1.90	-2.43	N/A	N/A
39	1BB-P-0457-W	0.71	-1.49	-0.68	0.43	-0.02	-0.22
40	1BB-P-0458-W	-0.10	0.06	0.33	0.01	-0.18	0.13
Pressurizer Level							
41	1BB-L-0465-W	N/A	N/A	N/A	N/A	0.52	1.07
42	1BB-L-0466-W	-0.12	-0.38	-0.54	-0.10	N/A	N/A
43	1BB-L-0467-W	-0.42	0.16	0.68	-0.06	0.06	-0.61
44	1BB-L-0468-W	0.29	-0.46	-0.30	0.03	-0.17	-0.24

Comparison data for transmitter 1AB-P-0524-W were not available for any of the three cycles. Comparison data for transmitter 1BB-L-0465-W were not available for Cycles 5 and 6. OLM shutdown data were not received for transmitter 1AB-P-0174-W during Cycle 7, so the field is marked as “N/A.” The Main Steam Pressure Loop 1 transmitter (1AB-P-0514-W) showed erratic behavior in the OLM startup data for Cycle 7 and was thus also marked as “N/A.” Several additional transmitters are marked as “N/A” for Cycle 7 because they were excluded from calibration during RFO7.

For Pressurizer Pressure transmitter 1BB-P-0456-W, there were large differences in the zero and span between the two methods. During startup or shutdown transitions, this transmitter tends to exhibit large deviations in OLM data, but it does not exceed its manual calibration limits.

As shown in Table 7-7, the span and zero drift characteristics in OLM and manual calibrations agree within 0.75% of span for over 90% of the transmitters examined during Cycles 5–7. Figures 7-1 through 7-3 present the information in Table 7-7 for each fuel cycle of Cycles 5–7. These figures show that for Cycles 5–7, the differences between OLM and manual calibrations are random and not biased for either zero or span changes.

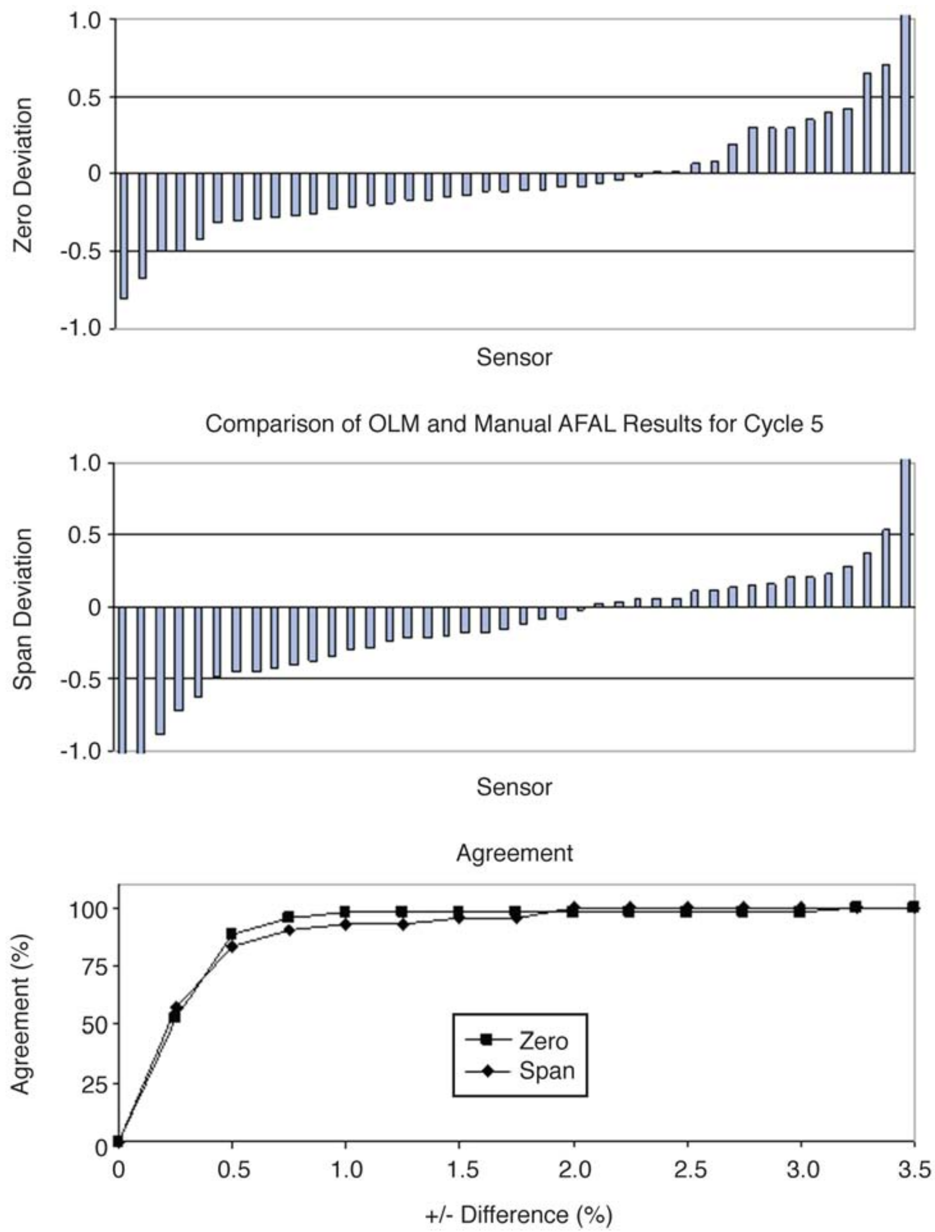


Figure 7-1
Comparison of OLM and Manual AFAL Results for Cycle 5

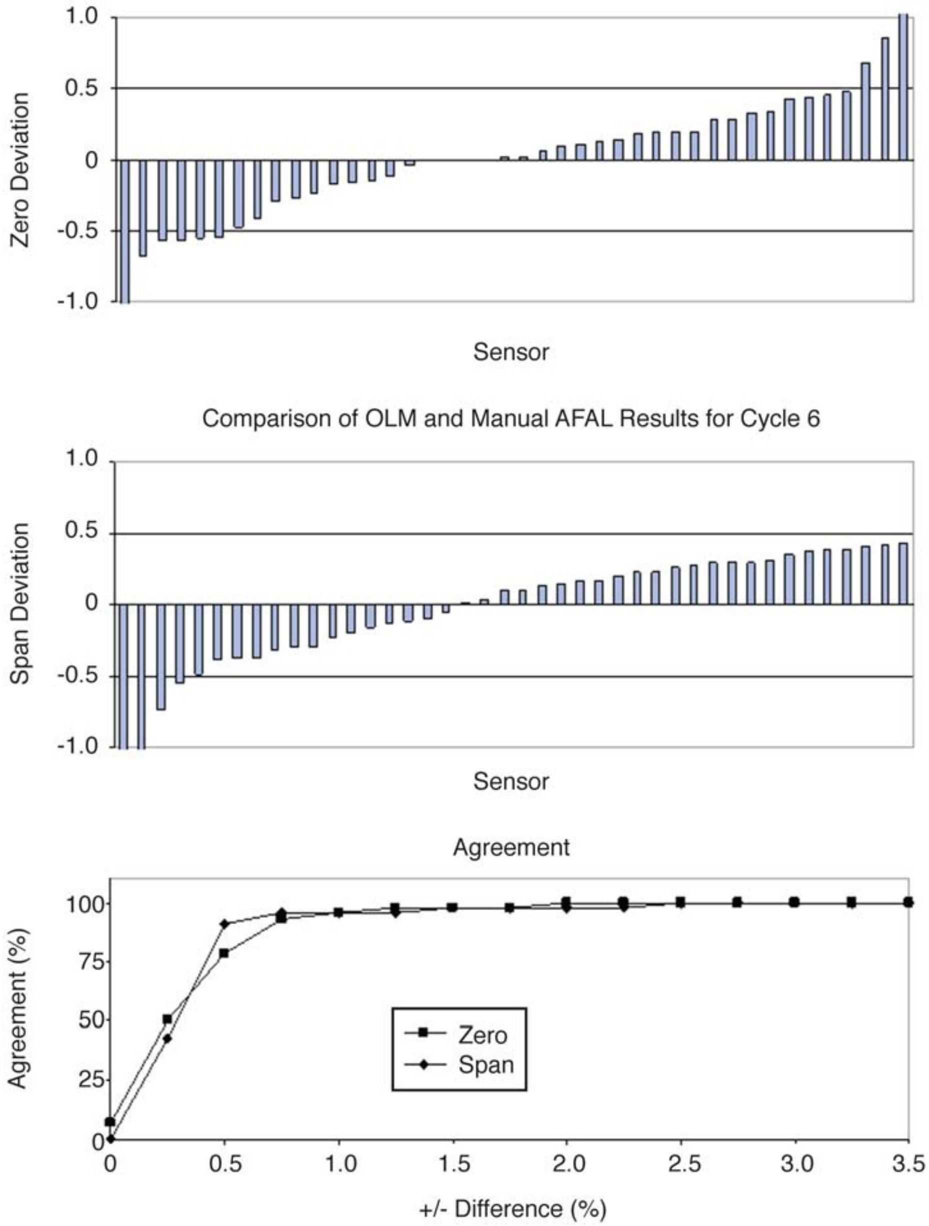


Figure 7-2
Comparison of OLM and Manual AFAL Results for Cycle 6

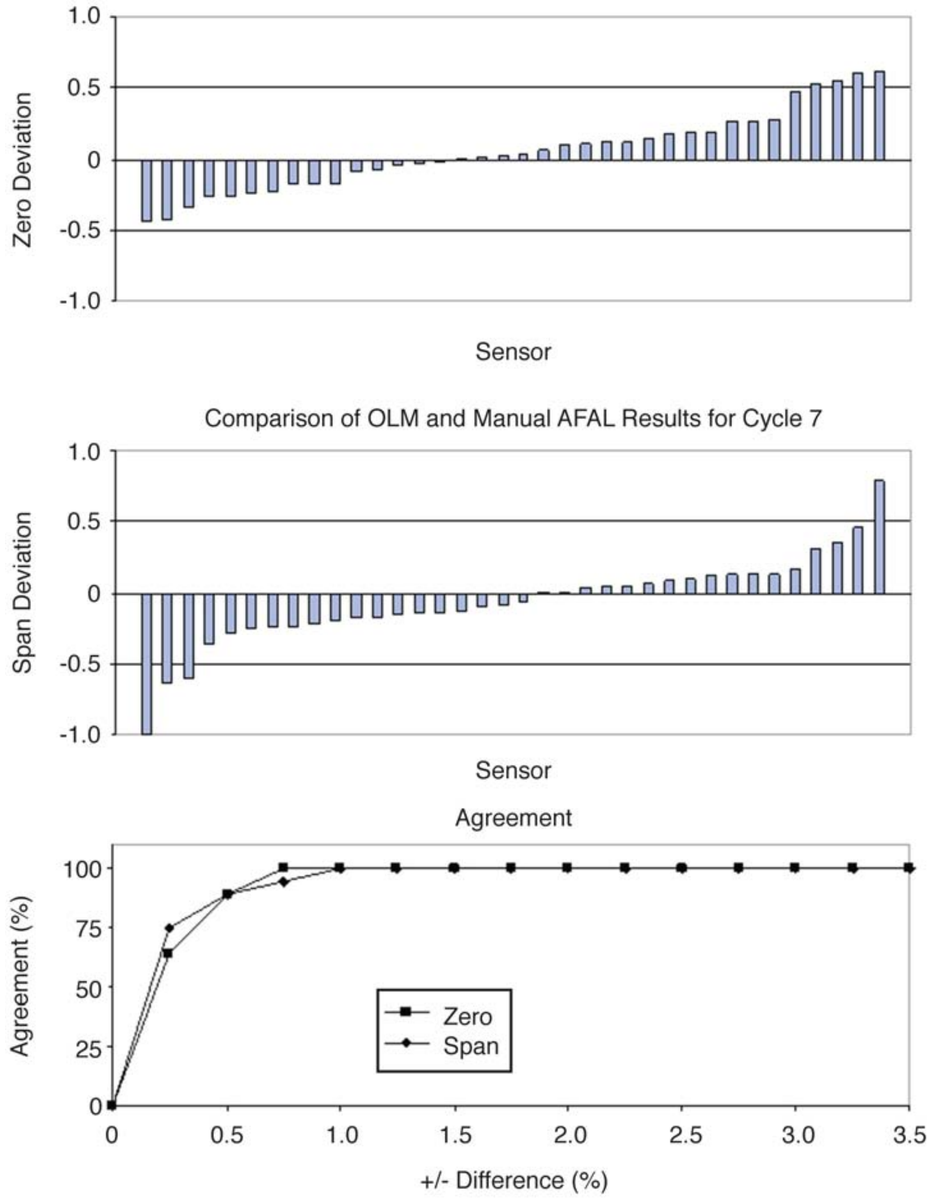


Figure 7-3
Comparison of OLM and Manual AFAL Results for Cycle 7

Summary of Results

Overall, the results of manual calibrations and OLM methodologies agree well. This is especially true when the differences between the two methodologies and acceptance criteria are considered. The results discussed for the 64 PPS transmitters over three operating cycles add up to 175 cases (excluding 17 cases that were not included in Cycle 7). Of these 175 cases, the results of manual calibrations and OLM agreed well or were conservative in all but 12 cases. These 12 non-conservative results are discussed in detail in the next section.

8
RESOLVING NON-CONSERVATIVE RESULTS

In the comparison of Sizewell OLM results for Cycles 5–7, there were 12 cases in which transmitters were classified as good by OLM that were subsequently found by traditional calibrations to be bad. This is significant not only because of the disagreement between the two methods, but also and more importantly, because the disagreement is non-conservative. The term *non-conservative* is used to describe a situation in which OLM identifies a transmitter as good but manual calibration identifies the same transmitter as bad. The term *conservative* is used to describe a situation in which OLM identifies a transmitter as bad when it is actually good.

Table 8-1 shows the 12 transmitters in question and explains the reasons for the discrepant results. These reasons were arrived at in consultation with BE personnel. Overall, 11 of the 12 discrepancies were resolved, as explained in the following sections.

Table 8-1
Summary of Non-Conservative Results for Sizewell Transmitters

Item #	Tag	Group	Reason for Discrepancy
Cycle 5			
1	BB-F-0416	RCS Flow Loop 1	Adjusted by operators to read 100% flow.
Cycle 6			
2	BB-P-0406	RCS Narrow-Range Pressure PPS	1) Non-redundant process due to pumps being shut off. 2) Two of four out-of-calibration transmitters biased the estimate.
3	BB-P-0409	RCS Narrow-Range Pressure PPS	
4	BB-F-0427	RCS Flow Loop 2	Adjusted by operators to read 100% flow.
5	BB-F-0439	RCS Flow Loop 3	Adjusted by operators to read 100% flow.
6	BB-F-0446	RCS Flow Loop 4	Adjusted by operators to read 100% flow.
7	BB-F-0447	RCS Flow Loop 4	Adjusted by operators to read 100% flow.
Cycle 7			
8	AE-L-0503	SG C Level Wide-Range	1) Only two redundant sensors. 2) Appears borderline low after calibration.
9	AE-L-0504	SG D Level Wide-Range	1) Only two redundant sensors. 2) OLM borderline high. Improved after calibration.
10	BB-L-0468	Pressurizer Level	OLM well within limits. No explanation.
11	BB-P-0403	RCS Wide-Range Pressure PPS	OLM borderline high. Improved after calibration.
12	BB-F-0446	RCS Flow Loop 4	Might be a change in calibration limits.

Results for Flow Transmitters in Cycles 5 and 6

Five of the 12 discrepant results are related to RCS flow transmitters BB-F-0416, BB-F-0427, BB-F-0439, BB-F-0446, and BB-F-0447. The discrepancy resulted when OLM declared these transmitters to be good, but plant records showed that the technicians had adjusted them. Upon consultation with BE, AMS learned that these transmitters might have been adjusted by an operational procedure to read 100% at full flow regardless of their calibration. Figure 8-1 shows OLM raw data for one of the RCS flow transmitters (BB-F-0416). It is apparent that this transmitter has suffered no drift and that it is well within its OLM limits.

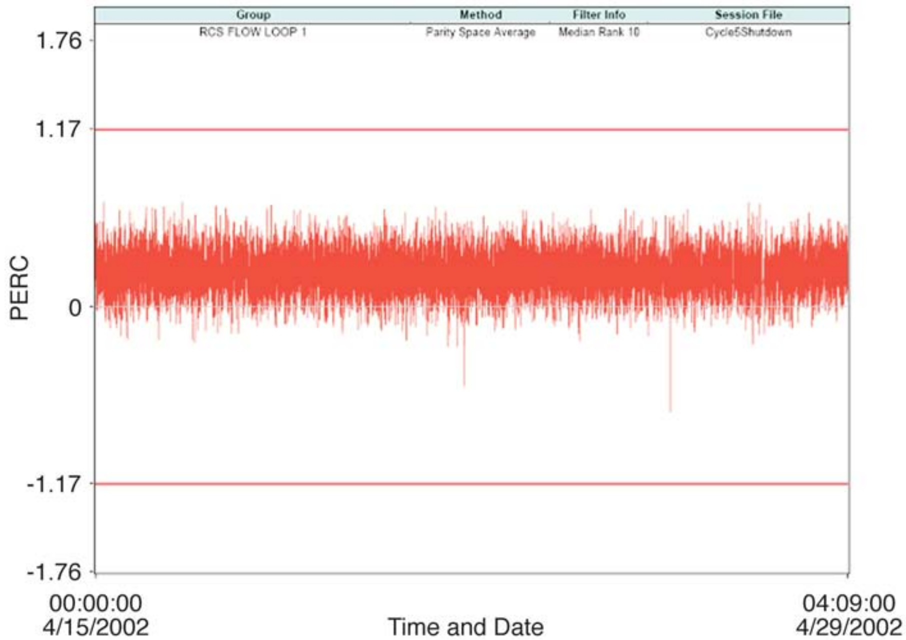


Figure 8-1
RCS Flow Loop 1 Transmitter BB-F-0416 Cycle 5 Data

During manual calibration checks, the following results and consequent actions occurred:

- 1BB-F-0416-W failed its at-power span check and was calibrated during RFO5.
- 1BB-F-0427-W read marginally high at its 94% checkpoint during RFO6 and was calibrated.
- Transmitters 1BB-F-0427-W, 1BB-F-0439-W, 1BB-F-0446-W, and 1BB-F-0447-W were found to exceed their as-left tolerance values during RFO6 in those ranges of their spans that were not observed in OLM data.

Results for Narrow-Range Pressure PPS Transmitters in Cycle 6

There are four transmitters in the RCS narrow-range pressure PPS service: BB-P-0406, BB-P-0407, BB-P-0408, and BB-P-0409. Manual calibration records show that transmitters BB-P-0406 and BB-P-0409 were adjusted on October 5, 2003 and October 9, 2003, respectively. The reason for the adjustment was that both transmitters exceeded the upper manual calibration limit at 25%, 50%, and 97% of their ranges. The OLM data at Cycle 6 shutdown, shown in Figure 8-2, show a step change in pressure just before the RCS is depressurized for transmitters BB-P-0407 and BB-P-0408. Because the step change caused these transmitters to exceed their OLM limits, the transmitters were removed from the calculation of the average. Removing them resulted in BB-P-0406 and BB-P-0409 appearing to be within the OLM limits when they were actually in need of a calibration.

Most services have redundant transmitters that all have the same calibration range. However, for the RCS pressure transmitter, this is not the case. Each loop of the four-loop plant has one narrow-range PPS pressure transmitter. During normal operation, the four transmitters are essentially redundant; however, when a pump is turned off and the flow is stopped in a loop, its transmitter is no longer redundant with the other transmitters in the loops that still have flow. This no-flow condition results in a pressure bias in that loop relative to the loops with flow. Immediately prior to Cycle 6's shutdown, the pumps were turned off in Loops 2 and 3. This caused a step change in RCS narrow-range pressure transmitters in Loops 2 and 3, as shown in Figure 8-2. The OLM analyst originally attributed this to a calibration problem when it was in fact caused by the process conditions. Because these transmitters measure pressure in different loops, they are not truly redundant, which makes the comparison difficult in periods such as shutdown, when the pressures in different loops can be different from each other.

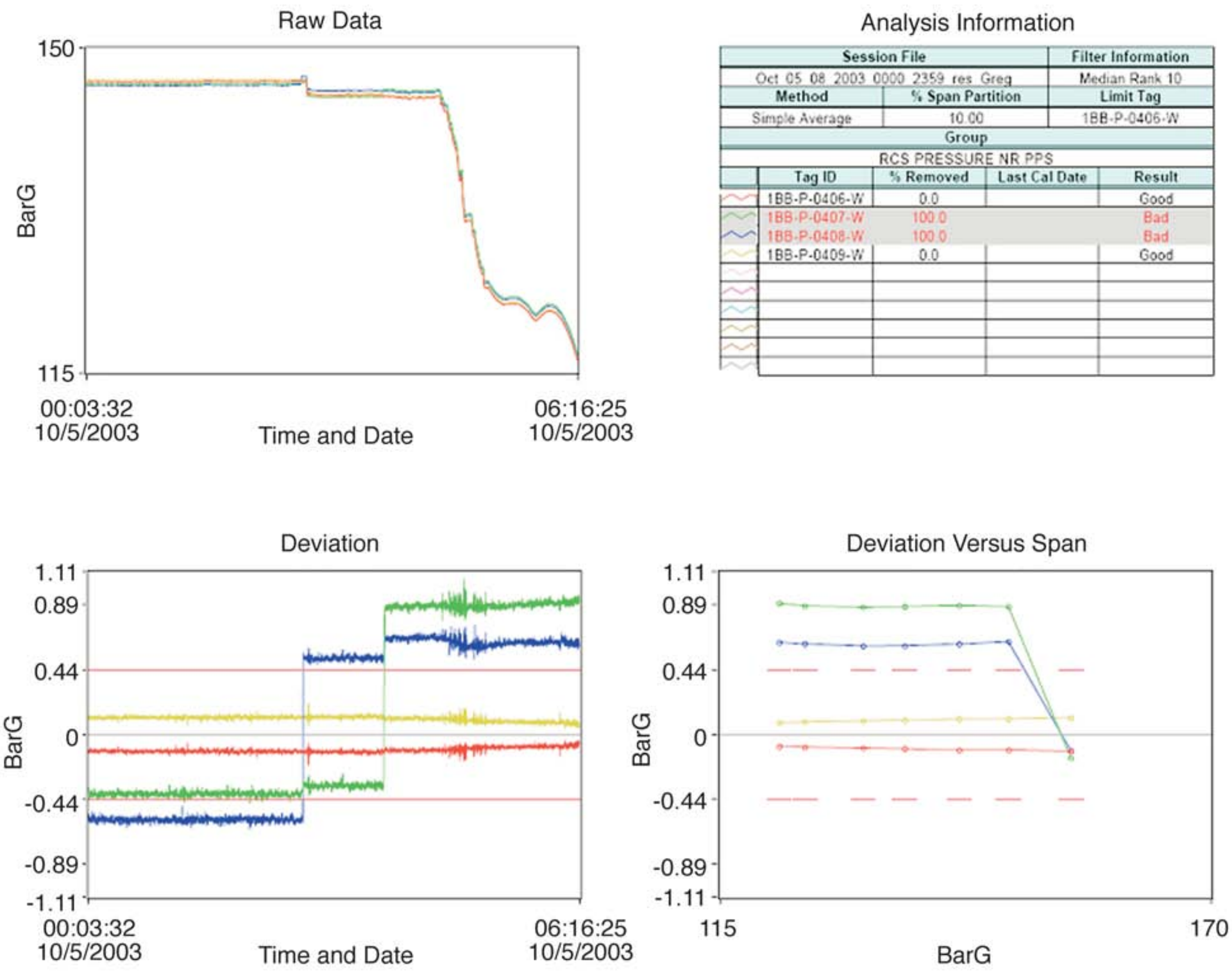


Figure 8-2
Cycle 6 Shutdown Data for the RCS Narrow-Range Pressure Transmitter

Cycle 6 startup data for RCS narrow-range PPS pressure transmitters are shown in Figure 8-3. All the transmitters appear to be in calibration over the observed range of about 0–73% of their ranges. Steady-state data immediately prior to Cycle 6's shutdown are presented in Figure 8-4. The RCS steady-state pressure is about 155.4 BarG (which is 73% of the transmitter's range). Figure 8-4 shows the top two plots—BB-P-0406 (red) and BB-P-0409 (yellow)—within the acceptance limits. The deviations of the transmitters do not appear to have changed from startup to just before shutdown.

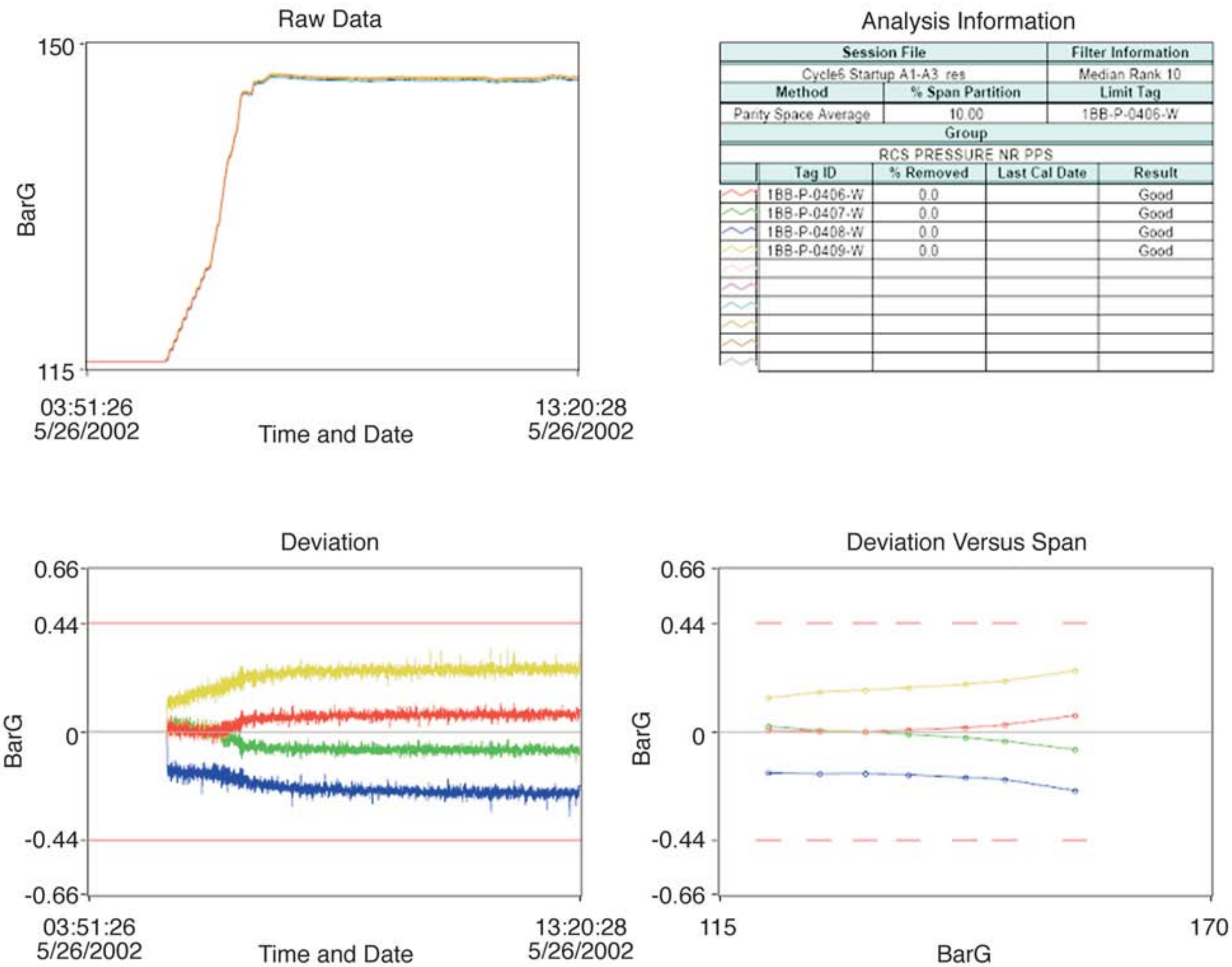


Figure 8-3
Cycle 6 Startup Data for the RCS Narrow-Range Pressure Transmitter

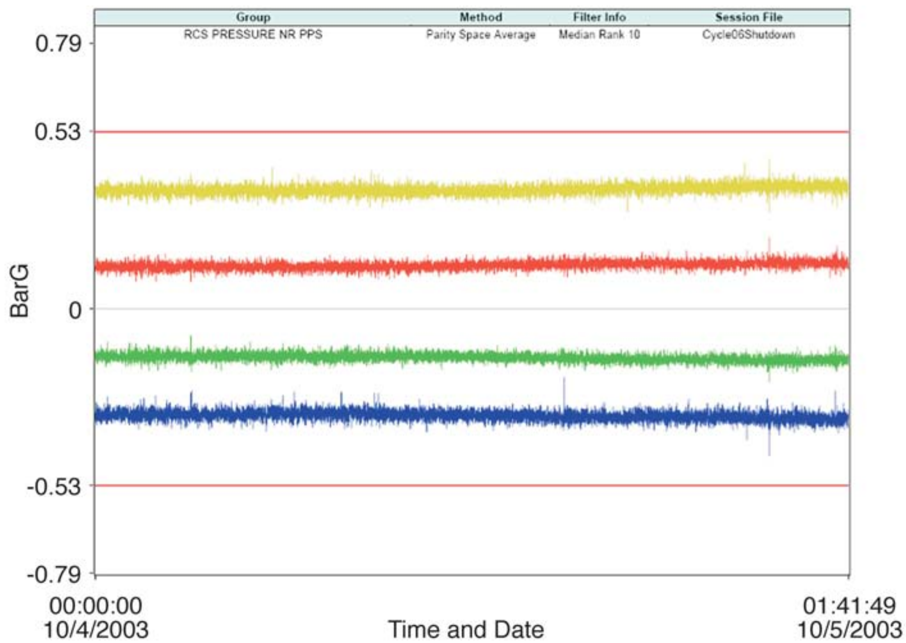


Figure 8-4
RCS Narrow-Range Pressure Data Immediately Prior to Cycle 6 Shutdown

Overall, the OLM Cycle 6 data for RCS narrow-range PPS pressure transmitters do not indicate a problem with BB-P-0406 and BB-P-0409. Assuming that the manual calibrations correctly identified these two transmitters as requiring calibration, two of the four signals that were averaged to produce the process estimate were both significantly higher than the manual calibration limit. These high signals caused a bias in the process estimate known as *spillover*, which prevented the signals from exceeding the OLM limits.

Results for SG Wide-Range Level Transmitters in Cycle 7

Wide-Range SG Level C Transmitter AE-L-0503 was manually adjusted on August 23, 2005 after it exceeded its upper manual calibration limit at 75% and 97% of its range in the up direction. The same transmitter also read high at 75% and 50% in the down direction. Although there were no OLM data at 50% range, the OLM results at 75% and 97% of span showed the transmitter to be well within its acceptance limits. Figure 8-5 shows Cycle 7 shutdown data for this transmitter on the left and Cycle 8 data after startup on the right along with the transmitter's redundant counterparts. At first (refer to the left-bottom data), the two signals agreed well, but after adjustment (refer to the right bottom), the two redundant signals are only marginally within their acceptance limits. Also, AE-L-0507, the higher of the two signals in the figure, was excluded from calibration in Cycle 7 and was not adjusted. Because this service has only two redundant sensors, if they are both in calibration by OLM but one is found to exceed the manual calibration limit, the other sensor should also be manually calibrated; this explains the discrepancy with OLM. This is a good example of situations in which modeling can supplement the averaging and determine whether one or both of the signals are out of calibration.

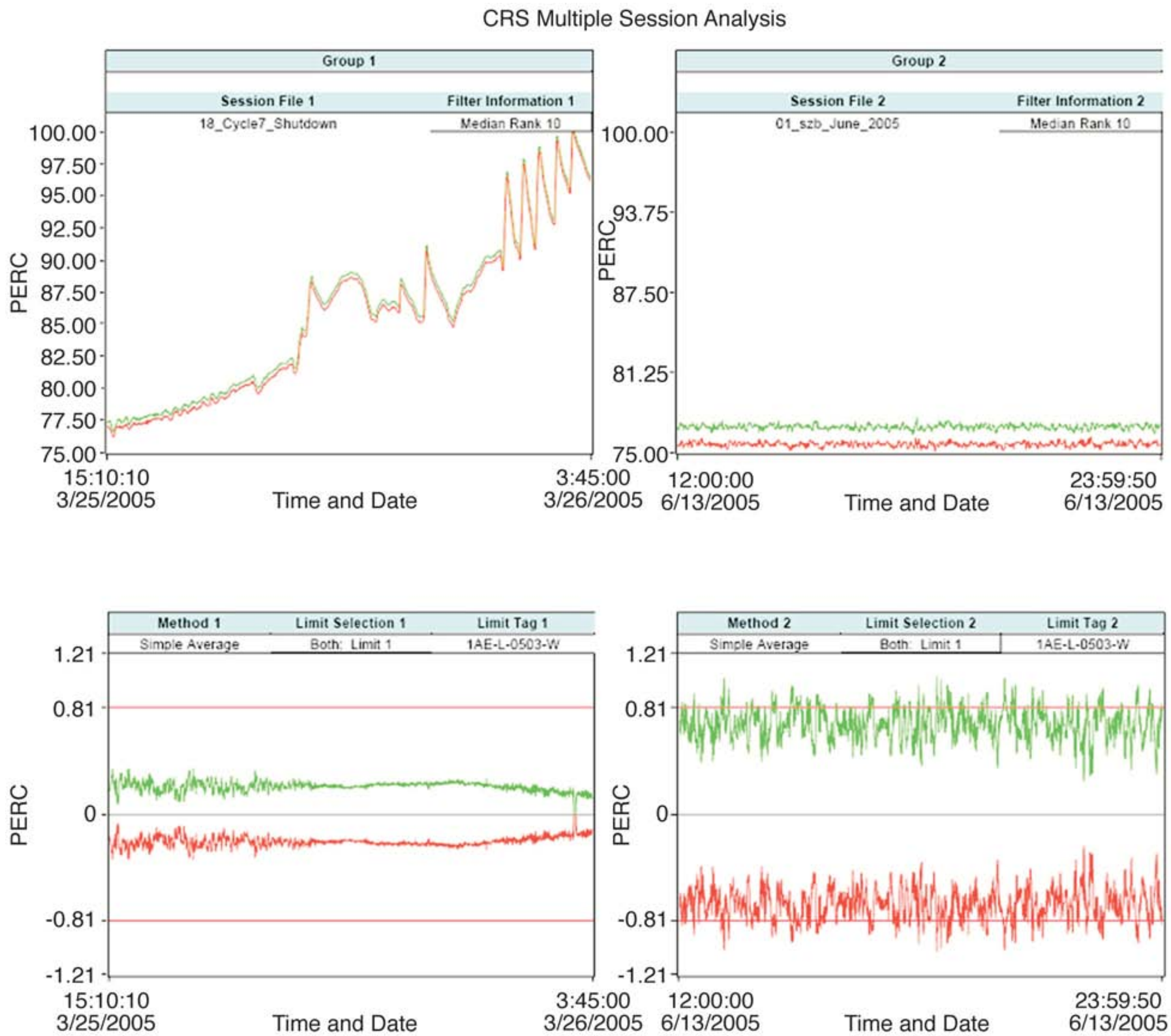


Figure 8-5
Wide-Range SG Level C Transmitters for Cycle 7 Shutdown (left) and Cycle 8 Startup (right)

Wide-Range SG Level D Transmitter AE-L-0504 was manually adjusted on March 28, 2005 after it exceeded its upper manual calibration limit by 0.05 Bar at 75% of its range in the down direction. The OLM data for this transmitter showed that it read marginally high at the 75% point but remained within its acceptance limits. Figure 8-6 shows Cycle 7 shutdown data for this transmitter on the left and Cycle 8 data after startup on the right together with its redundant counterpart. Before the adjustment (refer to the left bottom of Figure 8-6), the two signals were marginally within the acceptance limits. After the adjustment (the right bottom), transmitter AE-L-0504 (the upper signal) appears closer to AE-L-0508 (the lower signal), which was found to be within its calibration limits after shutdown in Cycle 7. Because this service has only two redundant sensors, if they are both in calibration by OLM but one is found to exceed the manual calibration limit, the other sensor should also be calibrated. Whenever signals are marginally

within their limits with one high and the other low, it is reasonable to assume that some spillover into the process estimate is allowing one of the signals to pass OLM. Here, again, modeling can be used to supplement the averaging.

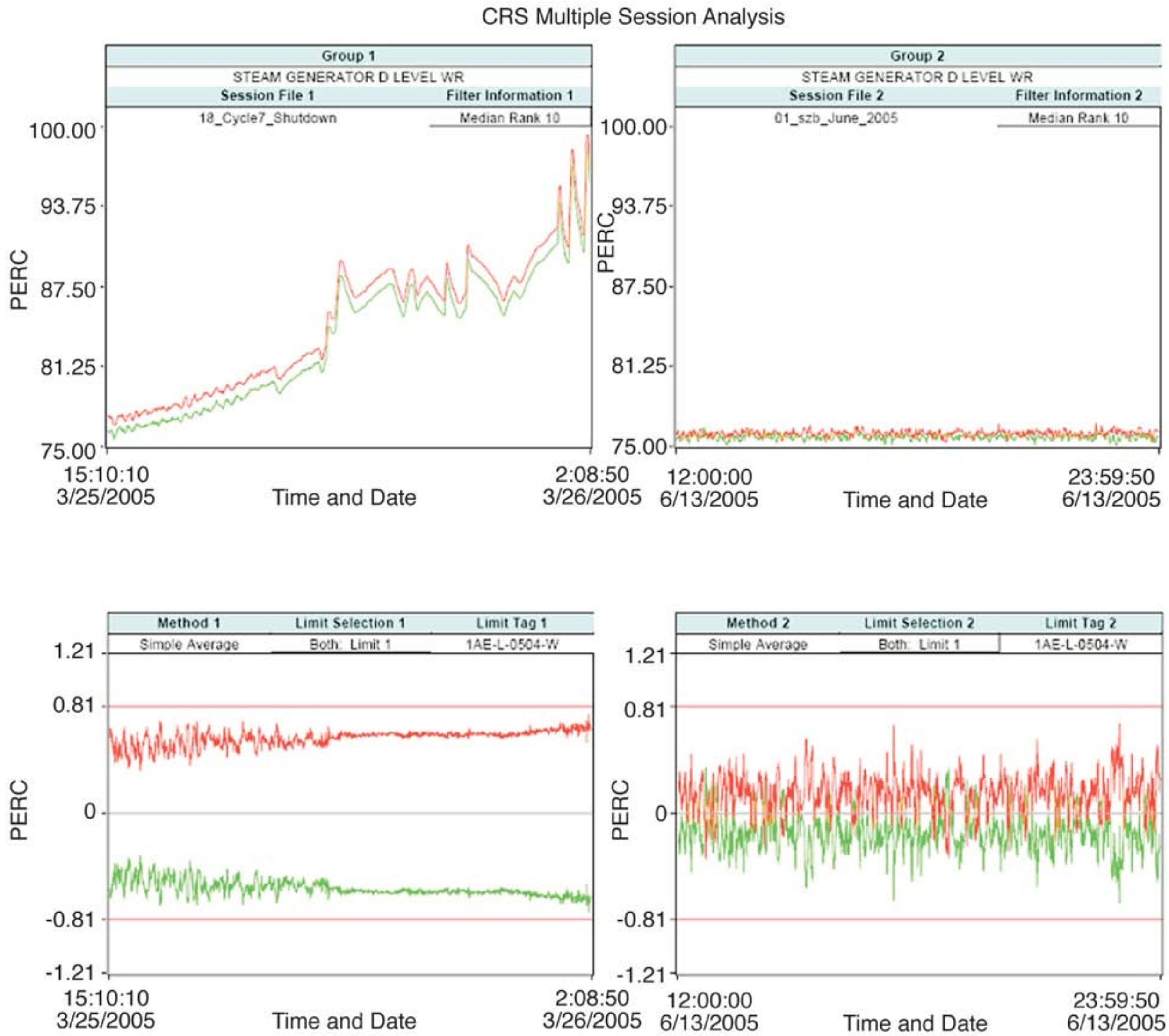


Figure 8-6
Wide-Range SG Level D Transmitters for Cycle 7 Shutdown (left) and Cycle 8 Startup (right)

The wide-range level transmitters are in redundant pairs, making the analysis difficult. One solution might be to mandate that both transmitters be calibrated if one of them is identified as bad through OLM (unless the first calibration makes it obvious which of the two transmitters was out of calibration). In addition, if both transmitters pass OLM but manual calibration reveals results beyond the as-left limits for one transmitter, calibrate both transmitters (unless additional knowledge deems this unnecessary).

Results for the Pressurizer Level Transmitters in Cycle 7

Pressurizer Level Transmitter BB-L-0468 was manually adjusted on March 27, 2005 after it exceeded its upper manual calibration limit at 75% and 50% of its range. Figure 8-7 presents data for Cycle 7's shutdown that show that BB-L-0468 (yellow) is within its acceptance limits over nearly 70% of its range, including the ranges in which the manual calibrations showed that it was reading high. Transmitters BB-L-0465 (red) and BB-L-0467 (blue) were manually checked but found to have no calibration problem. Transmitter BB-L-0466 (green) was excluded from manual calibrations in Cycle 7. Figure 8-8 shows pressurizer level data for Cycle 7 shutdown on the left and Cycle 8 steady-state data on the right. Here, BB-L-0468 (yellow) appears to have shifted down as expected because of its calibration adjustment between Cycle 7 and Cycle 8. Because BB-L-0468 is still within the OLM acceptance limits both before and after the calibration, it does not appear that a calibration was necessary. There is no discernable explanation as to why this transmitter was calibrated.

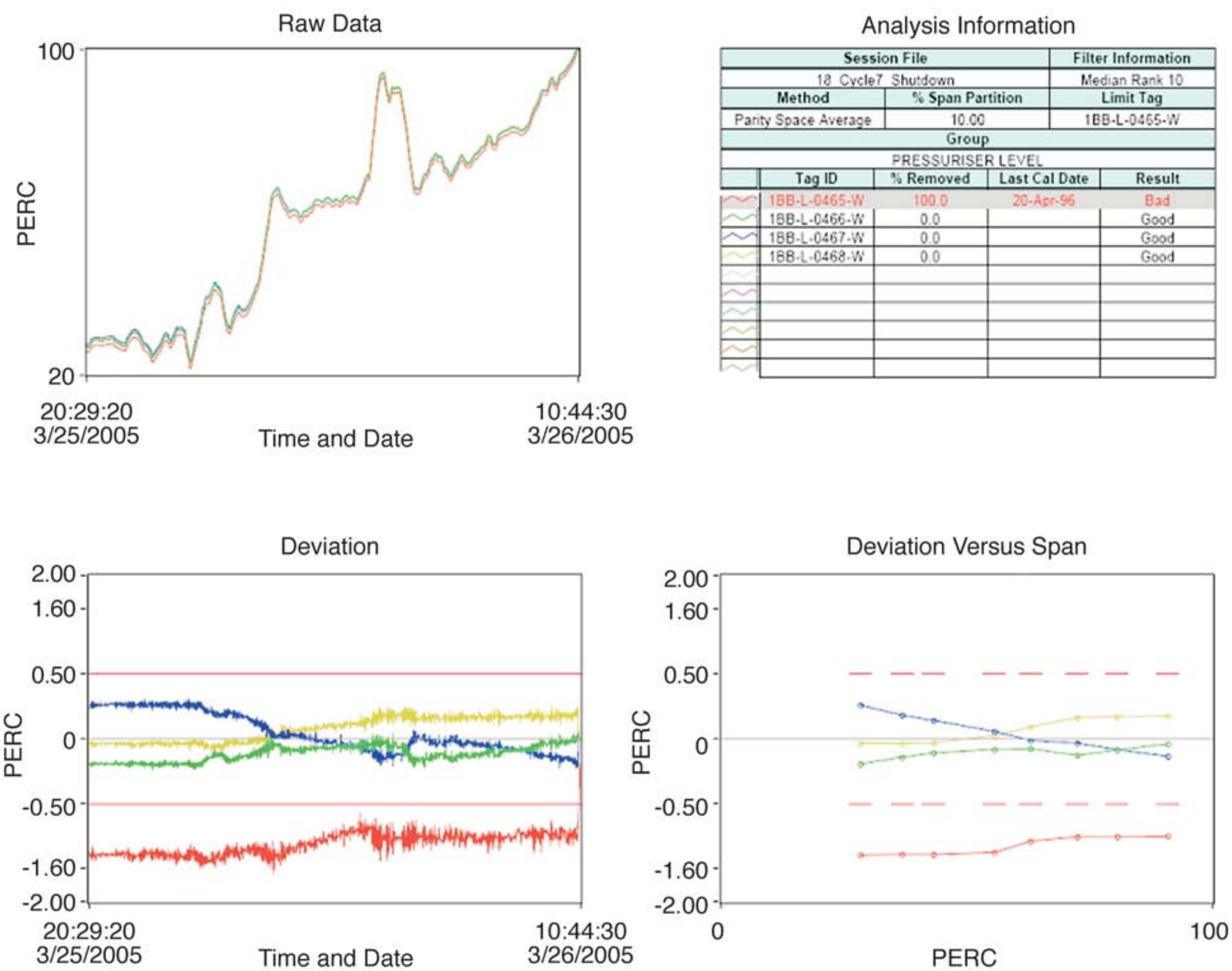


Figure 8-7
Pressurizer Level Data for Cycle 7 Shutdown

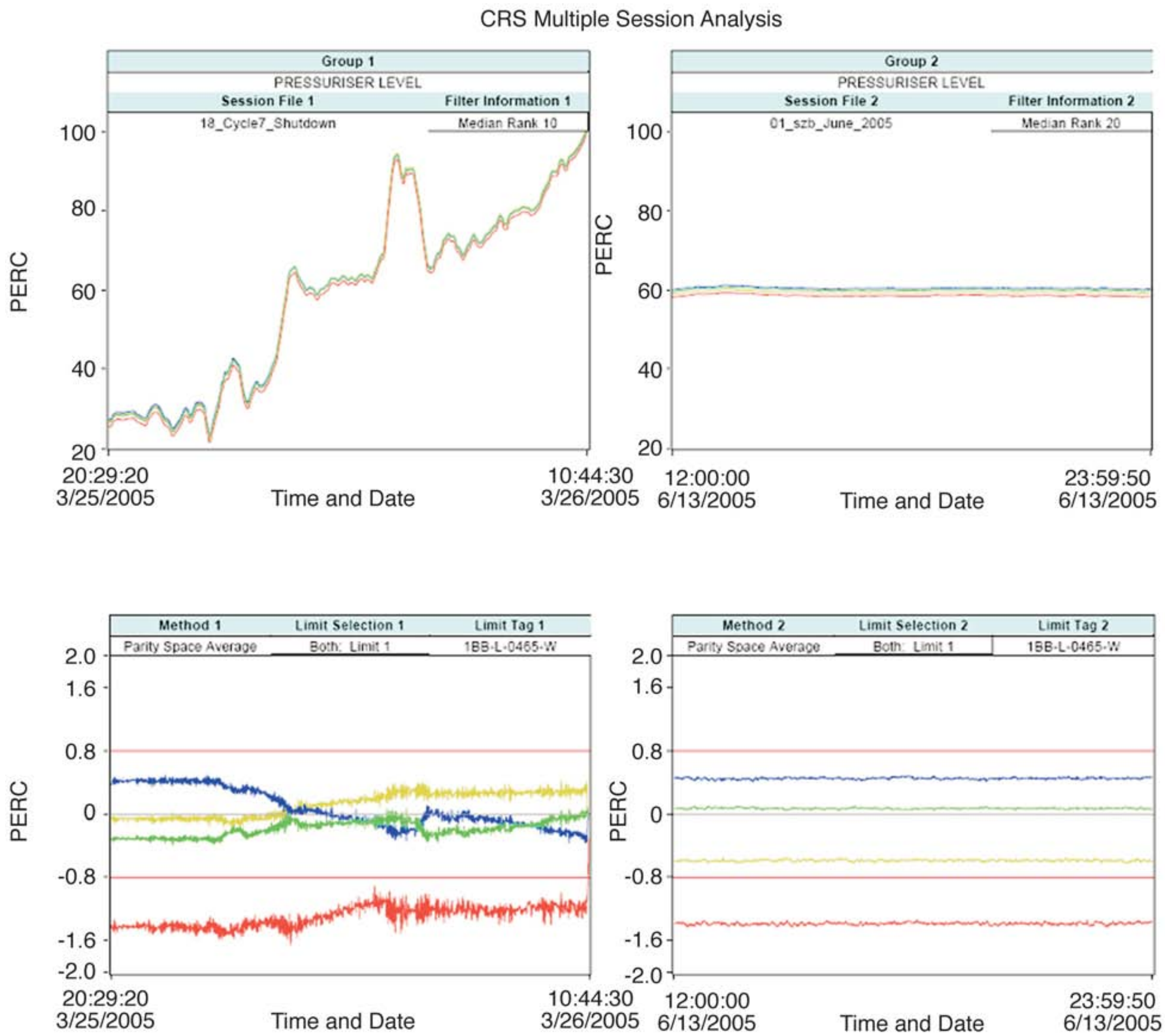


Figure 8-8
Pressurizer Level Data for Cycle 7 Shutdown (left) and Cycle 8 Steady State (right)

Results for Wide-Range Pressure PPS Transmitter in Cycle 7

RCS Wide-Range Pressure PPS transmitter BB-P-0403 was manually adjusted on March 29, 2005 after it exceeded its upper manual calibration limit by 0.1 BarG at 97% of its range. Figure 8-9 shows Cycle 7 shutdown data for this transmitter. The transmitter (shown in blue) is within its acceptance limits up to about 77% of range, although it appears to have a higher bias than the other transmitters. Transmitters BB-P-0401 (red) and BB-P-0404 (yellow) did not show any calibration problems. Transmitter BB-P-0402 (green) was excluded from manual calibrations in Cycle 7. Likewise, Figure 8-10 shows that for the Cycle 7 data before shutdown, BB-P-0403 appears to have a higher bias than the other transmitters in the group but is within its acceptance limits. Figure 8-11 shows the RCS Wide-Range PPS transmitters for Cycle 7 steady state on the left and Cycle 8 steady state on the right. Transmitter BB-P-0403 appears to have been brought

closer to the other transmitters as a result of the calibration between Cycle 7 and Cycle 8. This example raises the question of whether the limits should be tightened, because the transmitter in question had a high bias in Cycle 7 but remained within the OLM limits. Alternatively, the other three transmitters in this service could be slightly high within their calibration limits, which would result in a spillover effect in the process estimate and would make the highest transmitter data appear to be within the OLM acceptance limits. Whatever the case, both methods showed that this transmitter was high, although it did not exceed the OLM limits.

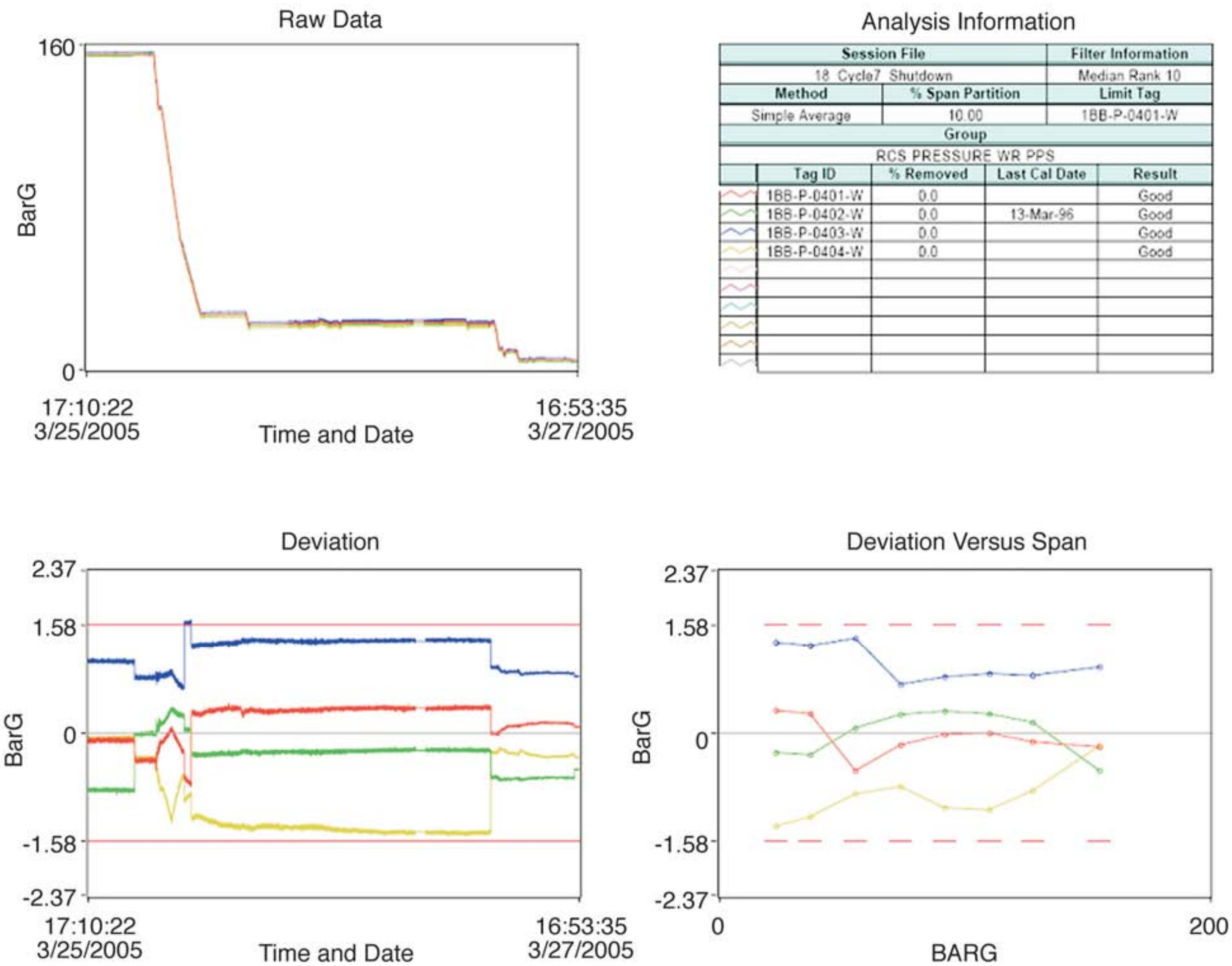


Figure 8-9
RCS Wide-Range Pressure PPS Transmitter Data for a Cycle 7 Shutdown

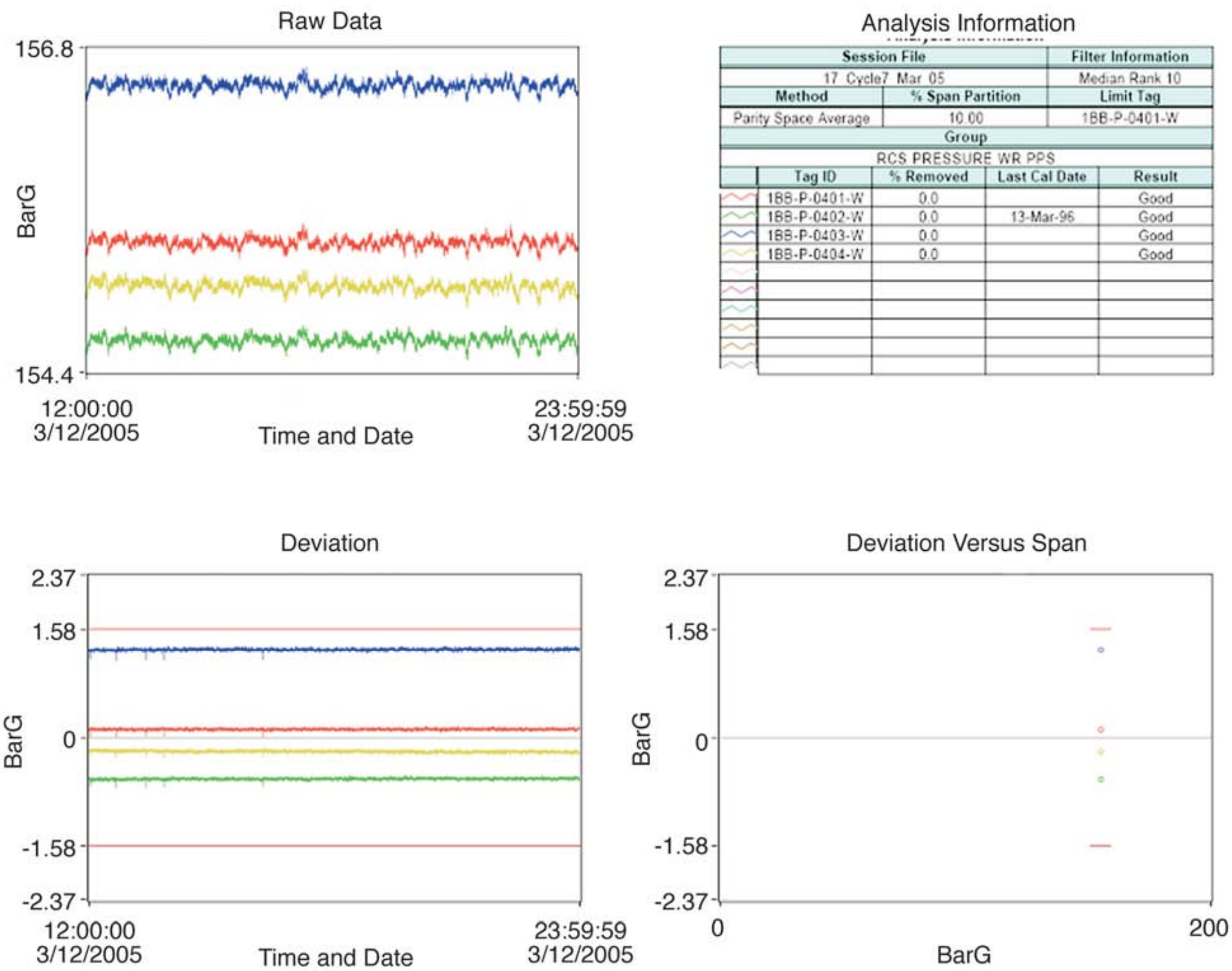


Figure 8-10
RCS Wide-Range Pressure PPS Data Immediately Prior to a Cycle 7 Shutdown

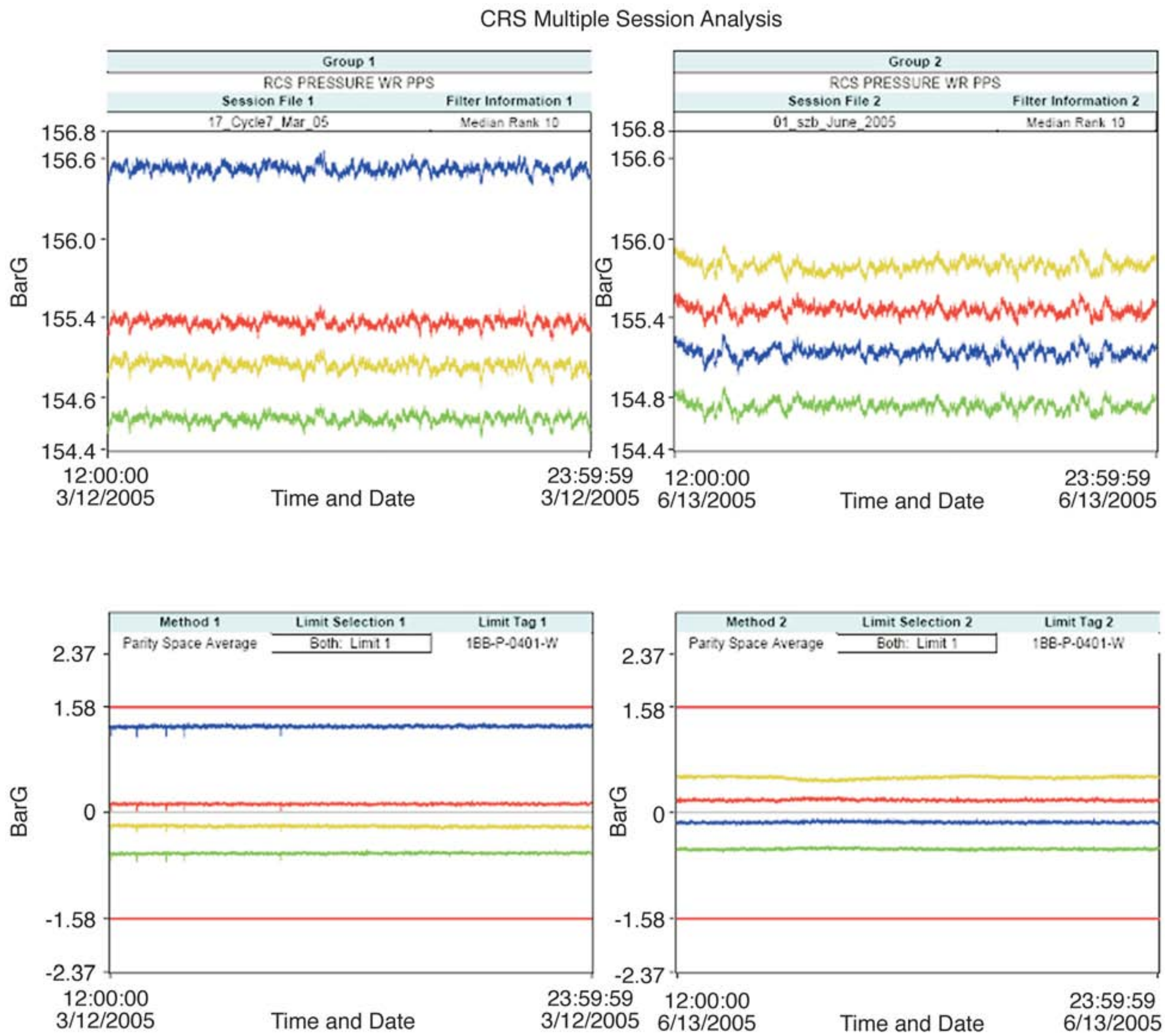


Figure 8-11
RCS Wide-Range Pressure PPS from Cycle 7 Steady State (left) and Cycle 8 Steady State (right)

Results for the Loop 4 Flow Transmitter in Cycle 7

RCS Flow Loop 4 transmitter BB-F-0446 was manually adjusted on March 30, 2005 after it marginally exceeded its upper manual calibration limit throughout its range. Figure 8-12 presents data for Cycle 7's shutdown. In this figure, BB-F-0446 (red) is within its calibration limits at the upper portion of its range and is tracking closely with BB-F-0448 (blue), which did not show any calibration problems between Cycle 7 and Cycle 8. Also, BB-F-0449 (yellow) did not show any calibration problems. Transmitter BB-F-0447 (green) was excluded from manual calibrations in Cycle 7. Figure 8-13 shows RCS Flow Loop 4 data for Cycle 7 steady state on the left and Cycle 8 steady state on the right. In this case, BB-F-0446 (red) appears to be deviating more significantly from the other transmitters at steady state after the calibration between Cycles 7 and

8. Because the calibration procedure was changed for the flow transmitters between Cycles 6 and 7, there was some question as to whether the calibration limits in the procedure were correct. In any event, this manual calibration was marginal, and the result of the calibration still has the OLM data within its calibration limit for Cycle 8.

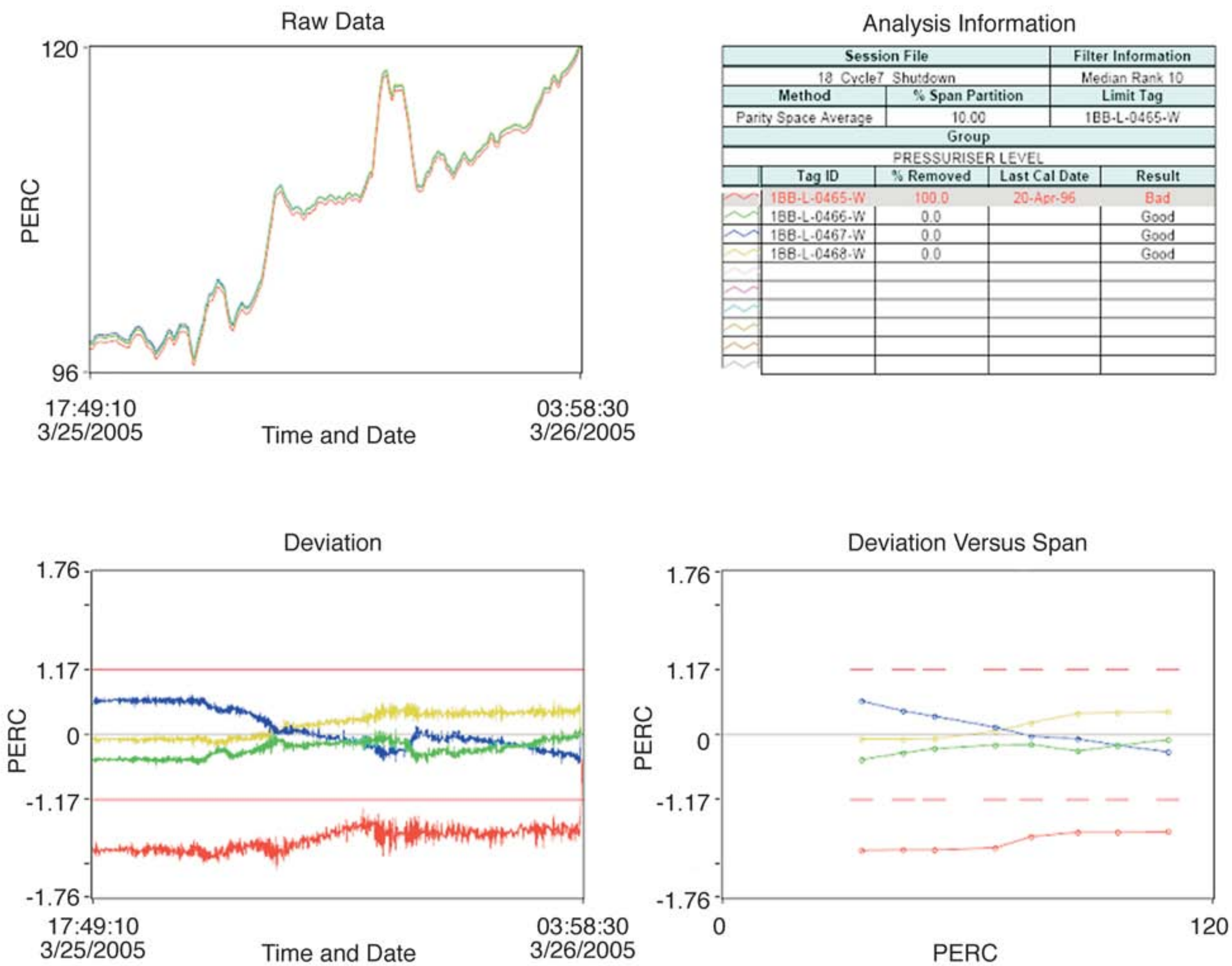


Figure 8-12
RCS Flow Loop 4 Data for a Cycle 7 Shutdown

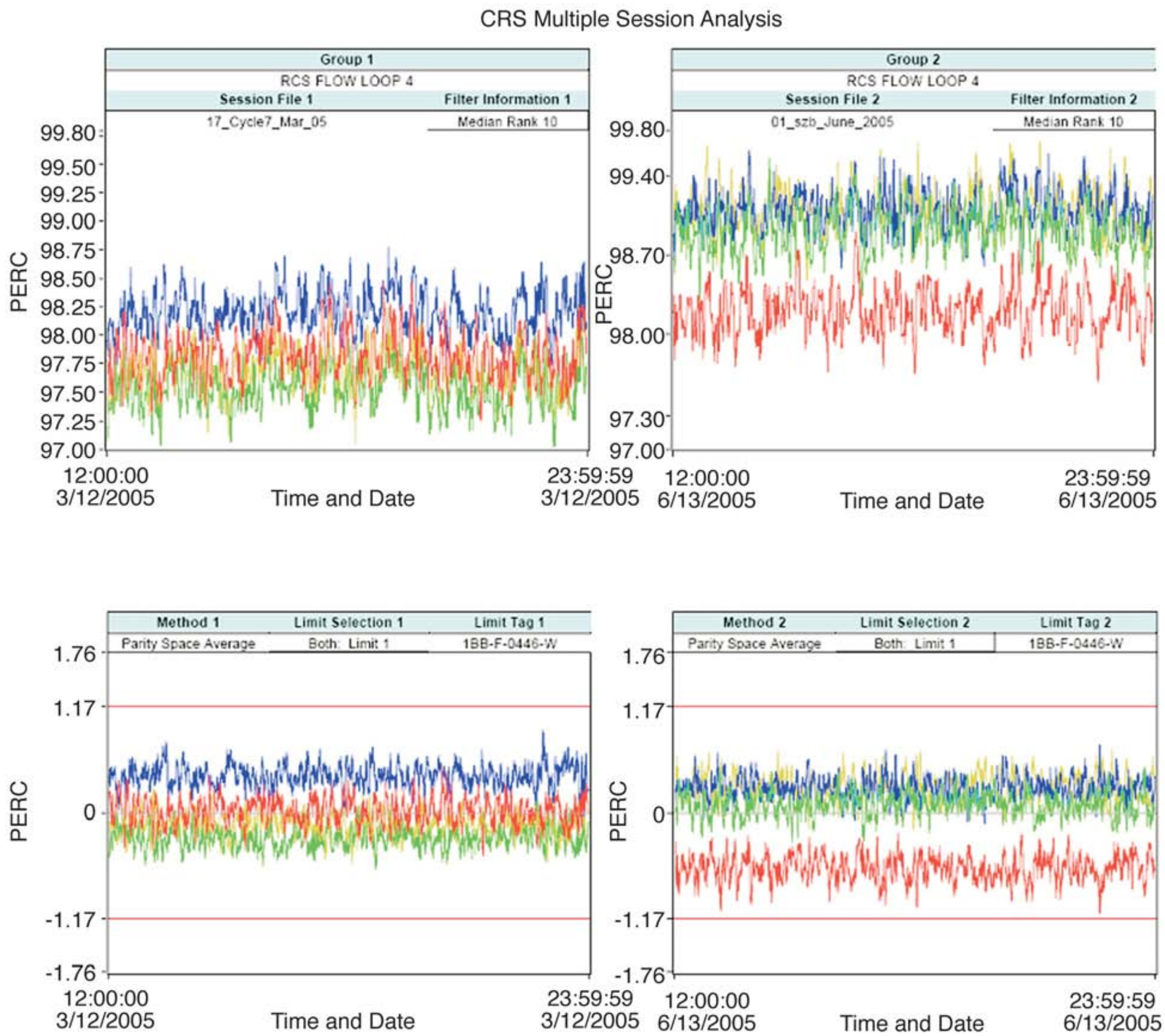


Figure 8-13
RCS Flow Loop 4 Data for Cycle 7 Steady State (left) and Cycle 8 Steady State (right)

Summary

Of all the results from the three cycles (Cycles 5–7), only one of the 12 non-conservative results had no discernable explanation. Also, it is curious that all 12 transmitters were found to exceed their high manual calibration limit. One would expect the nature of the deviation to be random and exhibit failures on both the high and low sides of the manual calibration limits. A possible explanation for this observation is a bias that results from the calibration test equipment being at the high end of its measurement uncertainty. This could cause transmitters to fail when they are marginally high.

A number of cases discussed in this section are good examples of the spillover effect into the process estimate caused by the averaging technique. Even with a redundancy of four signals, if two of the four have a large deviation within the acceptance limits, all four might pass the OLM acceptance limits (although two of them might need a calibration). This shows that modeling can play a role in supplementing the averaging technique and can help identify which two of the four deviating signals would actually exceed the manual calibration limits. Another option is to compare data between cycles to see which raw data values have changed. This works well only if the operating point for the parameter in question is the same between cycles—a bold assumption. However, it is still a good idea to see if there has been a change between cycles.

9 NUCLEAR REGULATORY ASPECTS OF OLM IMPLEMENTATION

The OLM approach for extending calibration intervals of pressure transmitters in nuclear power plants has received regulatory approval in France (1996), the United States (2000), and the UK (2005). The details of the French and UK approvals are not available, but that of the NRC is in the public domain and is summarized in this section.

All regulatory agencies that have examined this technology have agreed that nuclear power plants should be able to use OLM to extend the calibration interval of their instruments, provided that the work is performed under a formal QA program using validated software packages, calibrated data collection equipment, and trained personnel. In addition, each regulatory body has made its own stipulations. The NRC has reviewed the OLM approach documented in the EPRI report *On-Line Monitoring of Instrument Channel Performance* [5] and the NRC document *On-Line Testing of Calibration of Process Instrumentation Channels in Nuclear Power Plants* [1]. Based on review of these reports and other resources, in July 2000, the NRC approved the on-line calibration monitoring approach in its SER *Application of On-Line Performance Monitoring to Extend Calibration Intervals of Instrument Channel Calibrations Required by the Technical Specifications* [4]. The SER includes a number of stipulations, which are summarized in this section.

NRC Resources on OLM

The NRC has sponsored its own R&D projects to ensure that it has independent background in the OLM area for nuclear power plant applications. The results of these projects are documented in a number of NRC reports known as *NUREG/CR documents*. Two of these documents especially testify to the NRC's interest in the subject of OLM and their basis for rule-making when it comes to OLM in nuclear power plants. The first of these is *Technical Review of On-Line Monitoring Techniques for Performance Assessment* [16]. This report, published in two volumes, provides an overview of current technologies being applied in the United States for sensor calibration monitoring. Volume 1 presents a general overview of current sensor calibration monitoring technologies and their uncertainty analysis, a review of the supporting information needed to assess these techniques, and a cross-reference between the literature and the requirements listed in the SER. Volume 2 (to be published in 2007) provides an independent evaluation of the application of OLM methods to reduce the calibration frequency of instruments in nuclear power plants.

The second example is *On-Line Testing of Calibration of Process Instrumentation Channels in Nuclear Power Plants* [1]. This report summarizes the results of a three-year study that NRC contracted AMS to perform in order to determine the validity of OLM. The study involved both laboratory and in-plant validation tests, including the installation of a data acquisition system at the McGuire Nuclear Station. The study's results supported the feasibility of using OLM to assess an instrument's calibration while the plant is operating, and the report clearly states all of its benefits. Although the study ruled out physical modeling, it remained impartial to all other process estimation techniques. The report lists neural networks, parity space, simple and weighted averaging, empirical modeling, generalized consistency checking, sequential probability ratio tests, and process hypercube comparison as possible OLM techniques. The report presents a general summary of each of these techniques and the theory behind them. It does not give much information on the uncertainty associated with each technique. The study assumed that the process estimation uncertainties remained constant, meaning that drift detection was not affected by the uncertainty. However, the process estimation uncertainty does affect the determination of the allowable drift limit, a fact that is only briefly mentioned. The report does stress that data qualification is important, regardless of which OLM technique is applied.

Related NRC Documents on OLM

A number of NRC documents relate directly to the subject of this report. Two examples are included in this section. The first example is the 2000 SER in which the NRC approved the use of OLM for calibration monitoring of pressure transmitters in nuclear power plants. NRC Project 669 was the NRC's SER of the EPRI report *On-Line Monitoring of Instrument Channel Performance* [5]. The SER is entitled "Safety Evaluation by the Office of Nuclear Reactor Regulation: Application of On-Line Performance Monitoring to Extend Calibration Intervals of Instrument Channel Calibrations Required by the Technical Specifications - EPRI Topical Report (TR) 104965 'On-Line Monitoring of Instrument Channel Performance'."

EPRI's report proposed to replace the current time-directed traditional calibration with the new and advantageous calibrate-as-required approach using OLM. The NRC's evaluation of TR-104965 is given in this SER. The SER requires that the proposed OLM technique be able to perform all the required designated functions better than or as good as the current traditional calibration, with the same or better reliability. The SER states that if because of inherent deficiencies in the proposed technique, the proposed technique cannot be demonstrated to be better than or as good as the current practice, the justification should verify that the impact of the proposed technique on plant safety will be insignificant and the advantages of using it will outweigh the deficiencies. The SER also lists the 14 NRC-issued requirements that OLM systems must meet to gain regulatory approval. These requirements are the major factor in implementation of OLM.

The second example of an NRC document that relates to on-line calibration monitoring is NRC Regulatory Guide 1.105, *Setpoints for Safety-Related Instrumentation* [23]. This regulatory guide, the subject of which is setpoints for nuclear power plant instrumentation, cites the setpoint discrepancies in the nuclear industry that have led to a number of operational problems. It states that many of the discrepancies were caused by errors in calibration procedures and a lack of

understanding of the relationship between the setpoints and the allowable value. The guide also notes that plants do not typically verify whether setpoint calculation drift assumptions have remained valid for the system surveillance interval. To resolve these setpoint discrepancies, the guide directs plants to conform to ANSI/ISA-67.04.01 Setpoints for Nuclear Safety-Related Instrumentation. The guide lists the few clarifications and exceptions to the standard. The only notable exception listed is that whereas the standard states that the limiting safety system setting (LSSS) can be maintained in technical specifications or appropriate plant procedures, the LSSS actually must be specified as a limit defined by technical specification in order to satisfy the requirements of 10CFR50.36 and cannot be maintained in the plant procedure. The guide guarantees that conforming to this standard, with the few listed exceptions, ensures that the plant's method for establishing and maintaining setpoints for safety-related instrumentation within the technical specification limits will satisfy the NRC's regulations and staff.

NRC Stipulations for OLM Implementation in Nuclear Power Plants

The NRC's approval of OLM for on-line calibration monitoring of pressure transmitters in nuclear power plants was granted with a number of stipulations. The main stipulations are summarized in Table 9-1.

Table 9-1
Summary of NRC Stipulations

1	NRC approval is limited to pressure transmitters.
2	NRC approval is limited to transmitters alone, not the rest of the instrument channel.
3	Daily channel checks and quarterly surveillances must continue.
4	Plant implementation requires specific NRC approval.
5	The methods used must be able to distinguish between process drift and instrument drift.
6	OLM equipment is classified as M&TE and subject to 10CFR50 Appendix B, "Requirements for M&TE."
7	At least one redundant sensor must be calibrated per fuel cycle.
8	All *n* redundant sensors must be calibrated every *n* fuel cycles.
9	The maximum length of extension is eight years.
10	SPM must be accounted for using the penalty recommended in the EPRI report.

It should be pointed out that the NRC has agreed to the OLM concept only as a viable alternative to conventional calibration strategy in nuclear power plants and has not provided a blanket approval for all plants. In fact, each plant that will implement OLM for calibration monitoring must apply to the NRC and receive specific approval for a change in the plant's technical specification.

Summaries of the primary NRC stipulations for implementation of on-line calibration monitoring in nuclear power plants follow:

- Minimum calibration requirement. OLM for extending transmitter calibration intervals must include the stipulation that at least one transmitter from each group of redundant transmitters be calibrated at each refueling outage. Furthermore, this calibration must be performed on a rotational basis so that every transmitter in the redundant group is calibrated at least once every eight years, even if a particular transmitter has shown no calibration problems during the OLM process. This eight-year limit was established based on the fact that a majority of services, at least in U.S. plants, typically have four redundant transmitters and an operating cycle lasting two years. The purpose of this stipulation is to protect against common mode drift. For example, if four redundant transmitters drift at the same rate in the same direction and the process drift is in the opposite direction at the same rate, OLM might not correctly detect the drift. By calibrating one transmitter in a redundant group of transmitters at each refueling outage, the common mode drift will be revealed. Another approach to account for common mode drift is to use physical and/or empirical modeling to track the process independent of the transmitters being monitored; this will distinguish between instrument drift and process drift. However, physical or empirical modeling was not approved by the NRC as the sole means of monitoring for common mode drift. Rather, the NRC indicated that empirical and physical modeling techniques can be used as a supplementary means of accounting for common mode drift. The NRC left it to the user to decide which empirical and/or physical modeling algorithms to implement. However, in the SER, the NRC cited MSET as an example of an acceptable empirical modeling technique for on-line calibration monitoring. The NRC did not approve or disapprove of any particular modeling technique in the SER and pointed out that the user is responsible for verifying the validity of any technique used to draw any conclusions as to whether a pressure transmitter must be calibrated.
- SPM issue. Another important issue in the regulatory approval of the OLM approach is referred to as the *SPM issue*. Specifically, if OLM data are collected during normal plant operation, the data analysis verifies only the calibration of the instruments at the monitored point. To verify the calibration of instruments at other points over their entire operating range, OLM data must be collected not only during normal operation, but also during startup and shutdown periods. If this is not possible, the OLM approach is still acceptable according to the NRC, but the allowable calibration limits must be reduced by a specific allowance for SPM, as described in the EPRI report [5]. Adding this allowance to the OLM acceptance criteria was developed by EPRI to account for the inability to verify the calibration of a transmitter over its entire operating range.
- QA requirements. All software modules used for acquisition and analysis of OLM data must be developed under a formal QA program to include software V&V and formal procedures for handling of the OLM data and the results. Further, the calibration of OLM equipment that collects the data must be verified using calibration standards that are traceable to a national organization such as the National Institute of Standards and Technology (NIST). Also, prior to implementing on-line calibration monitoring, the user must examine the historical calibration data for the plant pressure transmitters and demonstrate that the transmitters have

had a stable history of acceptable calibrations. That is, a plant that has a history of unacceptable drift for a significant number of pressure transmitters might not be able to use on-line calibration monitoring.

- Data collection frequency. There is no specific requirement for the sampling frequency of OLM data or the type of equipment that can be used. The options range from very infrequent data collection (for example, once per cycle near the end of the cycle to demonstrate that the transmitters are still within their allowable calibration band) to continuous sampling of the data using the plant computer or a dedicated data acquisition system. However, if any modeling technique is to be used, computer data acquisition at relatively high sampling rates would be required. Also, the signals that are modeled together might have to be sampled simultaneously as the plant operates.
- Algorithms used for OLM. The algorithm used for OLM must be able to distinguish between the process variable drift (actual process going up or down) and the instrument drift and to compensate for uncertainties introduced by unstable processes, sensor locations, non-simultaneous measurements, and noisy signals. If the implemented algorithm and/or its associated software cannot meet these requirements, administrative controls could be implemented as an acceptable means to ensure that these requirements are met satisfactorily. All of the algorithms currently being considered for OLM were designed with the intent that they distinguish between the process variable drift and the instrument drift. In specific, MSET uses the correlation of the instrument channels to differentiate the instrument drift from process changes. MSET is not as susceptible to common mode drift because the correlation values for process drifts will be different from those for multiple instrument drifts. For any algorithm used, the maximum acceptable value of deviation should be such that accepting the deviation in the monitored value anywhere in the zone between the parameter estimate and the maximum acceptable value of deviation will provide a high level of confidence that the drift in the sensor-transmitter and/or any part of an instrument channel that is common to the instrument channel and the OLM loop is less than or equal to the value used in the setpoint calculations for that instrument.
- Exclusions from OLM. Instrument channels that monitor unstable systems, such as auxiliary feedwater flow and safety injection, should be excluded from OLM. Also excluded are instrument channels such as containment pressure that monitor systems that operate at the low or high end of the operating range. The EPRI report *On-Line Monitoring of Instrument Channel Performance, Volume 3: Applications to Nuclear Power Plant Technical Specification Instrumentation* [8] lists typical technical specification instrument channels that are both suitable and unsuitable for OLM.
- Calculations for acceptance criteria. Calculations for the acceptance criteria defining the proposed three zones of deviation (*acceptance*, *needs calibration*, and *inoperable)* should be done in a manner consistent with the plant-specific safety-related instrumentation setpoint methodology. By doing so, using the OLM technique to monitor instrument performance and extend its calibration interval will not invalidate the setpoint calculation assumptions and the safety analysis assumptions. If new or different uncertainties require the recalculation of instrument trip setpoints, it should be demonstrated that relevant safety analyses are unaffected. This stipulation originated from a concern that if a plant changes the method it

uses to compute a setpoint and the setpoint then changes, the OLM allowances will also change. A procedure needs to be in place to make sure that these items are always consistent. The OLM allowance and uncertainties do not affect the setpoint calculations; however, the setpoint calculations do affect the OLM allowances. The uncertainties unique to OLM, such as the process parameter estimate uncertainty and SPM uncertainty, reduce only the OLM drift allowance.

- Acceptable band or acceptable region. The EPRI report *On-Line Monitoring of Instrument Channel Performance, Volume 3: Applications to Nuclear Power Plant Technical Specification Instrumentation* [8] explains the basis for calculations that ensure that the requirement for an acceptable band or region is met. These calculations conform to all setpoint calculations standards. However, the plant must ensure that the methods used in calculating the setpoint and the OLM allowances are consistent. OLM introduces unique uncertainties—such as the process parameter estimate uncertainty and SPM uncertainty—that further reduce this drift allowance.
- Isolation and independence. Adequate isolation and independence as required by Regulatory Guide 1.75, General Design Criteria (GDC) 21, GDC 22, Institute of Electrical and Electronics Engineers (IEEE) Std 279 or IEEE Std 603, and IEEE Std 384 will be maintained between the OLM devices and class 1-E instruments being monitored. This requirement refers to Regulatory Guide 1.75. This regulatory guide provides a method acceptable to the NRC staff for complying with regulations related to the physical independence of circuits and electric equipment that are associated with safety-related functions. Both the EPRI report *On-Line Monitoring of Instrument Channel Performance* [5] and the NUREG *Validation of Smart Sensor Technologies for Instrument Calibration Reduction in Nuclear Power Plants* [10] discuss and diagram the OLM system's position relative to the rest of the instrument channel. These diagrams show that the OLM equipment boundary begins at the output of an isolator. This setup ensures that the isolation and independence between the OLM devices and class 1-E instruments meet all NRC regulations.

Sizewell Compliance with NRC Requirements

The Sizewell B plant is not regulated by the NRC. It is regulated by NII. Nevertheless, Sizewell has decided to comply with NRC requirements in addition to NII requirements. Table 9-2 shows the NRC stipulations for OLM implementation [4] and Sizewell's response as to how these stipulations will be accommodated. It should be pointed out that a number of the NRC requirements are not applicable to Sizewell B. For example, the SPM issue is not applicable to Sizewell B except for one or two transmitter services. For example, it is applicable to containment pressure transmitters because these transmitters are normally operated at about the same pressure, and startup or shutdown data cannot help verify their calibration over a wide range. For these transmitters, the SPM penalty can be implemented in arriving at the final results. In addition to using the SPM penalty, Sizewell plans to verify the calibration of the containment pressure transmitters over a wide range during the ILRT. Normally, ILRT takes place once every five years.

Table 9-2
NRC Requirements and How They Were Addressed for Sizewell B

NRC Requirement	Requirement Description	AMS Compliance for Sizewell
1	The submittal for implementation of the OLM technique will confirm that the impact on plant safety of the deficiencies inherent in the OLM technique (inaccuracy in process parameter estimate, SPM, and un-traceability of accuracy to standards) on plant safety will be insignificant, and that all uncertainties associated with the process parameter estimate have been quantitatively bounded and accounted for either in the OLM acceptance criteria or in the applicable setpoint and uncertainty calculations.	BE's safety submission addresses the impact on plant safety as a result of implementing the OLM technique. As part of that implementation, BE provided acceptance criteria to AMS, which were used to evaluate the Sizewell data. Section 6 of this report describes the methods used to determine the acceptance limits for the sensors. Except in a few cases, SPM is not a factor because both startup and shutdown data will be used to provide calibration information over most of the calibrated range of the transmitters being monitored. For those cases in which only one calibration point is monitored, the acceptance limits will be reduced by the SPM penalty described in the EPRI report *On-Line Monitoring of Instrument Channel Performance* [5] or by a penalty to be determined by AMS/BE from the evaluation of Sizewell's historical calibration and performance data. Traceability to national standards will be maintained because at least one transmitter from each redundant group will be calibrated each refueling outage.
2	Unless the licensee can demonstrate otherwise, instrument channel monitoring processes that are always at the low or high end of an instrument's calibrated span during normal plant operation will be excluded from the OLM program.	OLM data will be obtained for all the PPS transmitters, some of which are operating at the high or low end of the calibrated range. However, because data will also be obtained during startup and shutdown, some of these transmitters will be monitored at other points in their calibrated range and should thus be included in the OLM program. Transmitters, for which only one point is obtained at either the high or low end of the operating range, will continue to be monitored but will be excluded from the calibration extension program unless BE can demonstrate that the setpoints are sufficiently close to the operating point to obtain confidence in the results.

Table 9-2 (continued)
NRC Requirements and How They Were Addressed for Sizewell B

NRC Requirement	Requirement Description	AMS Compliance For Sizewell
3	The algorithm used for OLM will be able to distinguish between the process variable drift (actual process going up or down) and the instrument drift and will be able to compensate for uncertainties introduced by unstable process, sensor locations, non-simultaneous measurements, and noisy signals. If the implemented algorithm and its associated software cannot meet these requirements, administrative controls, including the guidelines in Section 3 of the topical report for avoiding a penalty for non-simultaneous measurement, could be implemented as an acceptable means to ensure that these requirements are met satisfactorily.	The algorithms used for OLM at Sizewell B will implement parity space and other averaging techniques to determine the process parameter estimate. This process estimate will track the process and allow instrument drift to be distinguished, except for common mode drift, which would be identified every cycle when one of the redundant sensors is calibrated. The data will be obtained from the plant computer simultaneously for all redundant transmitters, and a process estimate will be calculated for each simultaneous measurement. This simultaneous sampling of redundant signals eliminates any concerns about the effects of process fluctuations. As for process noise, it will be carefully filtered out. Some additional uncertainty might be introduced as a result of process effects and physical location of some sensors, but this is accounted for in the uncertainty analysis that results in the acceptance limits.
4	For instruments that were not included in the EPRI drift study, the value of the allowance or penalty to compensate for SPM must be determined by using the instrument's historical calibration data and by analyzing the instrument performance over its range for all modes of operation, including startup, shutdown, and plant trips. If the required data for such a determination are not available, an evaluation demonstrating that the instrument's relevant performance specifications are as good as or better than those of a similar instrument included in the EPRI drift study will permit a licensee to use the generic penalties for SPM given in EPRI report 104965.	For most of the transmitters included in the OLM project for Sizewell B, the data obtained and evaluated include points throughout the calibrated range of the transmitters in addition to the operating point. This is because startup and shutdown data are also evaluated, thus eliminating the concerns about monitoring the transmitters only at a single point. For those transmitters (if any) from which data can be obtained only at the operating point, the penalty recommended by EPRI will be used or a new penalty determined from analysis of historical data will be established. Any transmitters of a type that were not evaluated in the EPRI study will be evaluated to identify any necessary penalty for SPM.

Table 9-2 (continued)
NRC Requirements and How They Were Addressed for Sizewell B

NRC Requirement	Requirement Description	AMS Compliance For Sizewell
5	Calculations for the acceptance criteria defining the proposed three zones of deviation (Acceptable, Needs Calibration, and Inoperable) should be done in a manner consistent with the plant-specific safety-related instrumentation setpoint methodology so that using OLM technique to monitor instrument performance and extend its calibration interval will not invalidate the setpoint calculation assumptions and the safety analysis assumptions. If new or different uncertainties require the recalculation of instrument trip setpoints, it should be demonstrated that relevant safety analyses are unaffected. The licensee should have a documented methodology for calculating acceptance criteria that are compatible with the practice described in Regulatory Guide 1.105 and the methodology described in acceptable industry standards for trip setpoint and uncertainty calculations.	The acceptance criteria for the Sizewell B OLM program were calculated by BE.
6	For any algorithm used, the maximum acceptable value of deviation (MAVD) will be such that accepting the deviation in the monitored value anywhere in the zone between parameter estimate (PE) and MAVD will provide high confidence (level of 95%/95%) that drift in the sensor-transmitter or any part of an instrument channel that is common to the instrument channel and the OLM loop is less than or equal to the value used in the setpoint calculations for that instrument channel.	The acceptance limits for the OLM program at Sizewell B were calculated by BE. AMS will perform its analysis of the data with the understanding that the limits provided are MAVD limits and calculated in a way that provides high confidence that transmitters exceeding the limits would be identified for calibration.

Table 9-2 (continued)
NRC Requirements and How They Were Addressed for Sizewell B

NRC Requirement	Requirement Description	AMS Compliance For Sizewell
7	The instrument will meet all requirements of Requirement 6 for the acceptable band or acceptable region.	In using the acceptance limits, AMS will perform its analysis with the understanding that they are MAVD limits that meet Requirement 6. As such, any transmitter exceeding these limits will be identified by the AMS analysis. To obtain high confidence, the average value of each transmitter's deviation will be compared to the limits for each data set analyzed. Any transmitters operating between the parameter estimate and this limit (either above or below the parameter estimate) will be determined to meet requirements for continued use without the need for calibration.
8	For any algorithm used, the maximum value of the channel deviation beyond which the instrument is declared inoperable will be listed in the technical specifications with a note indicating that this value is to be used for determining the channel operability only when the channel's performance is being monitored with an OLM technique. It could be called *allowable deviation value for on-line monitoring* (ADVOLM) or whatever name the licensee chooses. The ADVOLM willl be established by the instrument uncertainty analysis. The value of the ADVOLM will be such to ensure that when the deviation between the monitored value and its parameter estimate is less than or equal to the ADVOLM limit, the channel will meet the requirements of the current technical specifications, and the assumptions of the setpoint calculations and safety analyses are satisfied and that until the instrument channel is recalibrated (at most until the next refueling outage), actual drift in the sensor-transmitter or any part of an instrument channel that is common to the instrument channel and the OLM loop will be less than or equal to the value used in the setpoint calculations and other limits defined in 10CFR 50.36 as applicable to the plant-specific design for the monitored process variable are satisfied.	AMS will perform its analysis of the data with the understanding that the limits provided are MAVD limits and not ADVOLM limits. Determining continued use or operability of transmitters analyzed using the OLM data will be left to BE.

Table 9-2 (continued)
NRC Requirements and How They Were Addressed for Sizewell B

NRC Requirement	Requirement Description	AMS Compliance For Sizewell
9	Calculations defining alarm setpoint (if any), acceptable band, the band identifying the monitored instrument as needing to be calibrated earlier than its next scheduled calibration, the maximum value of deviation beyond which the instrument is declared inoperable, and the criteria for determining the monitored channel to be an outlier will be performed to ensure that all safety analysis assumptions and assumptions of the associated setpoint calculation are satisfied and the calculated limits for the monitored process variables specified by 10CFR50.36 are not violated.	The calculations to determine acceptable limits and the related parameters will be performed such that all safety analysis and setpoint calculation assumptions are satisfied.
10	The plant-specific submittal will confirm that the proposed OLM system will be consistent with the plant's licensing basis and that there continues to be a coordinated defense-in-depth against instrument failure.	Implementation of the OLM program at Sizewell B, as described in BE's Safety Submission, includes conformance to the plant's licensing basis. Continued calibration checks of the instrument channels and other activities as outlined in the safety submission will remain in place to protect against instrument failure. OLM will provide better defense-in-depth because calibration information will be evaluated more often than current practice, which is once per cycle.
11	Adequate isolation and independence, as required by Regulatory Guide 1.75, GDC 21, GDC 22, IEEE Std. 279 or IEEE Std. 603, and IEEE Std. 384, will be maintained between the OLM devices and Class 1E instruments being monitored.	Data obtained from the plant computer system will be used for the OLM program. Because the computer is adequately isolated and no additional hardware is being attached to the plant, this requirement is satisfied.

Table 9-2 (continued)
NRC Requirements and How They Were Addressed for Sizewell B

NRC Requirement	Requirement Description	AMS Compliance For Sizewell
12	QA requirements as delineated in 10CFR Part 50, Appendix B will be applicable to all engineering and design activities related to OLM, including design and implementation of the on-line system, calculations for determining process parameter estimates, all three zones of acceptance criteria (including the value of the ADVOLM), evaluation and trending of OLM results, activities (including drift assessments) for relaxing the current technical specification-required instrument calibration frequency from “once per refueling cycle” to “once per a maximum period of 8 years,” and drift assessments for calculating the allowance or penalty required to compensate for SPM. The plant-specific QA requirement will be applicable to the selected OLM methodology, its algorithm, and the associated software. In addition, software will be verified and validated and meet all quality requirements in accordance with NRC guidance and acceptable industry standards.	Software design and development, related calculations, and data evaluations used for the analysis of OLM data and conducted by AMS will be performed under the AMS QA program. This program has been audited by BE and the Nuclear Procurement Issues Committee (NUPIC) and found to meet BE and applicable requirements of 10CFR Part 50, Appendix B. Any additional plant-specific requirements for software QA, in particular, the “Modest Integrity Guidelines,” will be met in the analysis of OLM data for Sizewell B. Records supporting these QA activities will be maintained at AMS and will be available for review.
13	All equipment (except software) used for collection, electronic transmission, and analysis of plant data for OLM purposes will meet the requirements of 10CFR Part 50, Appendix B, Criterion XII, “Control of Measuring and Test Equipment.” Administrative procedures will be in place to maintain configuration control of the OLM software and algorithm.	Data obtained for the OLM program will be retrieved from the Sizewell B plant computer, which already falls under plant-specific guidelines for data acquisition. The software for the analysis of the data by AMS will be developed using AMS procedures under the AMS Software Quality Assurance Program and procedures for software configuration management.

Table 9-2 (continued)
NRC Requirements and How They Were Addressed for Sizewell B

NRC Requirement	Requirement Description	AMS Compliance For Sizewell
14	Before declaring the OLM system operable for the first time, and just before each performance of the scheduled surveillance using an OLM technique, a full-features functional test, using simulated input signals of known and traceable accuracy, should be conducted to verify that the algorithm and its software perform all required functions within acceptable limits of accuracy. All applicable features will be tested.	The analysis of OLM data will be performed using software analysis modules that will be verified and validated using simulated input data with known characteristics. The analysis of the simulated data will be performed to verify that the software modules produce the expected results. All functions and features of the software modules will be fully tested and documented and might also be tested prior to any scheduled surveillance. Because the OLM system does not acquire the data, further tests using simulated input signals will not be necessary. The plant computer will perform the data acquisition function and is maintained under plant procedures and guidelines already in place.

In addition to complying with applicable NRC requirements, BE has satisfied all the requirements of NII. For example, all software programs developed for implementation of OLM at Sizewell B have been in accordance with formal QA requirements and BE personnel have, according to NII requirements, been trained in these software programs. Furthermore, the QA program used in this effort has been officially reviewed by BE.

10 CONCLUSIONS AND FUTURE WORK

Conclusions

On-line calibration monitoring is defined as a method of monitoring instrument performance and assessing instrument calibration while the plant is operating, without disturbing the monitored channels. In its simplest implementation, redundant channels are monitored by comparing each individual channel's indicated measurement to a calculated best estimate of the actual process value. By monitoring each channel's deviation from the process variable estimate, an assessment of each channel's calibration status can be made. This is exactly what has been implemented at the Sizewell B plant in the UK. The details of this implementation were presented in this report.

This implementation project has successfully demonstrated that OLM can identify drifting transmitters and thereby limit calibration activities to these transmitters. By contrast, current practice involves calibration of all transmitters. Furthermore, calibration problems and other instrument anomalies are identified as they occur; this contrasts with the current practice that normally finds the problems at the end of the cycle during the outage. As a result, plant safety is improved, and significant economic benefits are realized through reductions in outage duration, radiation exposure, labor, human errors, and so on.

Future Plans

EPRI Plans

EPRI plans to publish two updates to this report to cover the full implementation of OLM for PPS transmitters at Sizewell B. The next two reports will be published to cover Cycle 8 and Cycle 9 in 2007 and 2008, respectively.

BE Plans

The implementation work described in this report is expected to continue at Sizewell until all redundant PPS and SPS transmitters are covered by OLM. Beyond that, there is no firm commitment in place, but the plan is to expand OLM use to verify the calibration of secondary system transmitters and eventually for equipment and process condition monitoring. As mentioned, Sizewell has nearly 1200 pressure transmitters in its primary and secondary systems that are subject to periodic calibration. It is envisioned that OLM will eventually cover most or all of these transmitters.

Further R&D

AMS has an R&D contract with the DOE to develop commercial algorithms and software for analysis of OLM data not only for extension of calibration intervals of sensors and transmitters, but also for dynamic performance verification of transmitters, process diagnostics, and condition monitoring. It is anticipated that these new algorithms and software products will also be implemented at Sizewell once they are developed, tested, and validated. The vision for the future is an integrated OLM system that verifies the calibration and response time of pressure transmitters and provides for equipment condition monitoring and process diagnostics.

Nuclear power plants would be well served if they were equipped with automated data acquisition and data storage equipment. In upgrading I&C systems or the plant computers, it should be considered an important investment to incorporate data collection systems with high-speed sampling capability and a large data storage facility.

11
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3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com