UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555 - 0001

February 20, 2003

Mr. Ernest M. Hauser
President, Nuclear Division
Caldon, Inc.
1070 Banksville Avenue
Pittsburgh, Pennsylvania 15216

SUBJECT: INSPECTION OF CALDON, INC. (NRC INSPECTION REPORT 99901311/2002-201) AND NOTICE OF NONCONFORMANCE

Dear Mr. Hauser:

This letter forwards the report of the Nuclear Regulatory Commission (NRC) inspection of Caldon, Inc., at your Pittsburgh facility on November 4-6, 2002, and of your activities at Alden Research Laboratories of Holden, Massachusetts, on October 28-30, 2002, by Stephen Alexander of this office and Steven Arndt of the Office of Nuclear Regulatory Research. The purpose of the inspection was to examine your equipment and observe its operation first hand, to examine the calibration apparatus of Alden Laboratories and observe its operation, to review pertinent documentation and to hold discussions with you, your staff, and some of your sub-contractors. This enabled us to obtain independent verification of selected portions of the information contained in your topical reports, ER-80, ER-157 and ER-262, as well as resolving several specific questions regarding the accuracy and calibration of both your external and chordal path ultrasonic flow meters and their safety classification by NRC licensees.

The detailed results of the inspection are documented in the enclosed report. The inspectors were able to confirm that the information submitted in your topical reports, as discussed in the associated NRC safety evaluation reports (SERs), adequately supports the accuracy claims made for your flow measurement systems.

However, in reviewing selected aspects of your program to implement the applicable requirements of 10 CFR Part 21, the inspectors identified two minor violations of this regulation. Because these violations were minor, we will not issue a separate notice of violation, but the details are discussed in the enclosed report. You must correct the deficiencies in your 10 CFR Part 21 program, but you are not required to respond to us formally regarding them.

In addition, the inspectors found that certain aspects of your quality assurance program intended to meet the requirements of 10 CFR Part 50, Appendix B, imposed upon you by contract with your NRC-licensee clients, were deficient. These deficiencies are cited in the enclosed notice of nonconformance as well as being explained in detail in the enclosed inspection report. You are requested to respond to the nonconformance within 30 calendar days of the date of this letter in the manner prescribed in the notice of nonconformance. Should you require additional time to respond, timely requests for extensions may be granted for reasonable cause.

In accordance with 10 CFR Part 2.790 of the NRC "Rules of Practice," a copy of this letter and its enclosures and your response will be placed in the NRC's Public Document Room (PDR) and also in the publically accessible portion of the NRC's Agency-wide Document Access and Management System (ADAMS). To the extent possible, your response should not include personal, private, proprietary or safeguards information so that your response can be placed in the PDR without redaction. However, should you find it necessary to include such information, you should clearly identify that which you desire not be placed in the PDR and provide the justification for withholding from public disclosure as delineated in 10 CFR 2.790.

The responses requested by this letter and the enclosed notice of nonconformance are not subject to the clearance procedures of Office of Management and Budget as required by the Paperwork Reduction Act of 1980, Public Law No. 96-511.

Should you have any questions concerning this inspection, please contact Stephen Alexander at 301-415-2995 or sda@nrc.gov .

Sincerely,

/RA/

Theodore R. Quay, Chief
Equipment and Human Performance Branch
Division of Inspection Program Management
Office of Nuclear Reactor Regulation

Enclosures:
1. Notice of Nonconformance
2. Inspection Report No. 99901311/2002-201

In accordance with 10 CFR Part 2.790 of the NRC "Rules of Practice," a copy of this letter and its enclosures and your response will be placed in the NRC's Public Document Room (PDR) and also in the publically accessible portion of the NRC's Agency-wide Document Access and Management System (ADAMS). To the extent possible, your response should not include personal, private, proprietary or safeguards information so that your response can be placed in the PDR without redaction. However, should you find it necessary to include such information, you should clearly identify that which you desire not be placed in the PDR and provide the justification for withholding from public disclosure as delineated in 10 CFR 2.790.

The responses requested by this letter and the enclosed Notice of Nonconformance are not subject to the clearance procedures of Office of Management and Budget as required by the Paperwork Reduction Act of 1980, Public Law No. 96-511.

Should you have any questions concerning this inspection, please contact Stephen Alexander at 301-415-2995 or sda@nrc.gov .

Sincerely,

/RA/

Theodore R. Quay, Chief
Quality Assurance, Vendor Inspection,
Maintenance and Allegations Branch
Division of Inspection Program Management
Office of Nuclear Reactor Regulation

Enclosures: 1. Notice of Nonconformance
2. Inspection Report No. 99901311/2002-201

Distribution: (w/encl)
PDR RIDS Code IE:09 DIPM Reading File IEHB Reading File
OAC ADAMS
ADAMS: ML030510406

DOCUMENT NAME: G:\iqmb\draft\alexander\Caldon2002-201LTR.wpd

To receive a copy of this document, indicate in the box: "C" = Copy without enclosures **"E"** = Copy with enclosures **"N"** = No copy

OFFICE	IEHB/DIPM	E	RES	E	SC:QMS/IEHB		BC:IEHB/DIPM		0	
NAME	SAlexander:		SArndt		DThatcher		TRQuay			
DATE	2/19/03		2/19/03		2/20/03		2/20/03			

OFFICIAL RECORD COPY

NOTICE OF NONCONFORMANCE

Caldon, Inc. Docket No. 99901311
Pittsburgh, Pennsylvania Report No. 2002-201

Based on the results of the Nuclear Regulatory Commission inspection, conducted November 4-6, 2002, of your activities supporting the design, manufacture and supply of ultrasonic feed water flow measurement systems to NRC-licensed facilities, it appears that certain of your activities were not conducted in accordance with NRC requirements.

Criterion VII, “Control of Purchased Material, Equipment, and Services,” of Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to Part 50, “Domestic Licensing of Production and Utilization Facilities,” of Title 10, “Energy,” of the *Code of Federal Regulations* (10 CFR Part 50, Appendix B) requires, in part, that measures be established to assure that purchased material, equipment, and services, whether purchased directly or through contractors and subcontractors, conform to the procurement documents. These measures shall include provisions, as appropriate, for source evaluation and selection, objective evidence of quality furnished by the contractor or subcontractor, inspection at the contractor or subcontractor source, and examination of products upon delivery. Documentary evidence that material and equipment conform to the procurement requirements shall be available at the nuclear power plant or fuel reprocessing plant site prior to installation or use of such material and equipment. This documentary evidence shall be retained at the nuclear power plant or fuel reprocessing plant site and shall be sufficient to identify the specific requirements, such as codes, standards, or specifications, met by the purchased material and equipment.

Contrary to the above, documentation of a quality assurance implementation audit of the principal supplier of pipe stock material used in the fabrication of your flow meter spool pieces could not be produced from your files at the time of the inspection. In addition, a certificate of conformance from this same supplier that you had on file, and had accepted as evidence from the supplier that the technical and quality requirements imposed on the supplier in your procurement documents had been met, were deficient in that they did not contain the required information in a form that was technically valid.

Please provide a written statement or explanation to the U.S. Nuclear Regulatory Commission, ATTN: Document Control Desk, Washington, D.C. 20555, with a copy to the Chief, Equipment and Human Performance Branch, Division of Inspection Program Management, Office of Nuclear Reactor Regulation, within 30 days of the date of the letter transmitting this Notice of Nonconformance. This reply should be clearly marked as a "Reply to a Notice of Nonconformance" and should include for each nonconformance: (1) a description of steps that have been or will be taken to correct these items; (2) a description of steps that have been or will be taken to prevent recurrence; and (3) the dates your corrective actions and preventive measures were or will be completed.

Issued this, the 20th day of February, 2003
at Rockville, Maryland

U.S. NUCLEAR REGULATORY COMMISSION

Enclosure 2

OFFICE of NUCLEAR REACTOR REGULATION
DIVISION of INSPECTION PROGRAM MANAGEMENT
EQUIPMENT and HUMAN PERFORMANCE BRANCH
QUALITY ASSURANCE and MAINTENANCE SECTION

INSPECTION REPORT

VENDOR NAME:	Caldon, Inc.
DOCKET/REPORT NO.	99901311/2002-201
ADDRESS:	1070 Banksville Avenue, Pittsburgh, PA 15216
CONTACT:	Mr. Ernest Hauser, President, Nuclear Div., 412-341-9920
ALTERNATE:	Mr. Joe Whitehead, QA Manager, 412-341-9920
NUCLEAR INDUSTRY ACTIVITY:	Caldon supplies both external clamp-on and installed spool piece ultrasonic feed water flow meters of the “leading-edge” flow meter (LEFM) type to various licensees who use LEFM signals for direct feed flow indication or as a correction for their venturi differential-pressure flow meters. Caldon also supplies the software and support services for their LEFM systems.
INSPECTION DATES: and LOCATIONS	28-30 October, 2002, at Alden Research Laboratories, Holden, Massachusetts, and 4-6 November, 2002, at Caldon, Inc., Pittsburgh, Pennsylvania, facility
TEAM MEMBERS:	Stephen Alexander, Reactor Engineer, IEHB, Lead Steven Arndt, Senior I&C Engineer, RES

SUBMITTED: ***/RA/*** Date 2/13/03
Stephen D. Alexander. QMS/IEHB

APPROVED: ***/RA/*** Date 2/14/03
Dale F. Thatcher, SC, QMS/IEHB

EXECUTIVE SUMMARY

As a followup to the NRC's review of the topical reports submitted by Caldon on its leading-edge flow meters (LEFMs), the inspectors reviewed the technical capabilities and practices of Caldon. This included an inspection at Caldon headquarters and at Alden Research Laboratory as well as a review of documents supporting the design, construction, testing and operation of the Caldon flow meters used in Nuclear Power Plant (NPP) feed water flow measurements. The inspection preparation included an independent review of the current state-of-the-art of flow measurement in Nuclear Power Plants, and a review of both Caldon's and Alden Research Laboratory's procedures, uncertainty analysis and research papers. The inspection team found that some of the procedures and analysis used by Alden and Caldon could have been more complete and the calibration and installation decisions affecting uncertainty could have been better documented. Nevertheless, Caldon's accuracy and uncertainty claims were, overall, adequately supported, and its ongoing research, development and analysis work are adequate for use of Caldon external LEFMs in support of power recovery. In addition, the inspection confirmed that the accuracy of Caldon installed, chordal multi-path LEFMs is verifiable and is sufficient for the power uprates that have been granted based on the use of these instruments.

BACKGROUND ON ULTRASONIC FLOW METERS

Pressurized water reactor (PWR) plants typically use a secondary-side heat balance calculation (calorimetric) to calibrate their power-range nuclear instruments (reactor power indication based on neutron flux) and to verify that the plant is operating within its Technical Specification licensed power limit. The thermal power limit is based on the measurement uncertainties needed to maintain the 10 CFR Part 50, Appendix K, power limit of 102% of design thermal power. This limit is assumed in design-basis accident analysis. Nominally, 70% of the total uncertainty in the calorimetric calibration comes from the determination of the mass flow rate of feed water which is derived from direct measurement of volume flow rate and feed water temperature. Ultrasonic technology is capable of highly accurate flow and temperature measurements. As a result, Caldon, among others, has developed several ultrasonic flow meters (UFMs) with very high accuracy for use in reducing the uncertainty in the secondary-side heat balance and permitting nuclear power plants to operate at an increased thermal power while maintaining the same safety margin they had with traditional measurement equipment (e.g., venturi-differential pressure measurement).

The Caldon "leading-edge" (so called because of its use of the leading edge of the ultrasonic pulse) ultrasonic flow measurement system (commonly referred to as a leading-edge flow meter or LEFM) determines the real-time flow velocity. Based on this technology, Caldon has submitted several topical reports. Caldon Engineering Report (ER)-80P, "Improving Thermal Power Accuracy and Plant Safety While Increasing Operating Power Level Using the LEFM System," covered its clamp-on external meter. This report was supplemented by ER-157, which provided additional information on the external meters while primarily covering the spoolpiece chordal type meters. After issuing safety evaluation reports (SERs) on these topical reports, the NRC has granted several nuclear power plants power "uprates" based on these topical reports for the LEFM Check® (Check) and LEFM CheckPlus® (CheckPlus) systems. At the time of this writing, nine plants have been granted power uprates based on use of the Caldon Check LEFM and nine more have been granted uprates based on using the CheckPlus LEFM system; although not all of these have been installed.

Most recently, Caldon submitted ER-262, which provided additional information based on lessons learned during continuing research and testing on meter accuracy and flow velocity disturbances. Before plant power uprates, UFMs were and still are used to support “megawatt recovery” programs. As the originally installed venturi- or nozzle-type flow meters have become less accurate in the conservative direction due to nozzle fouling effects, plants have “lost megawatts” due to this bias. The fouling causes a greater differential pressure across the nozzle than the system is calibrated for, thus indicating higher-than-actual thermal power. Caldon has provided 26 domestic nuclear power plants with its external LEFMs to recover these lost megawatts.

There are several types of UFMs which can use both sound path transit time techniques and so-called “correlation” or “cross-correlation” techniques. The Caldon Check and CheckPlus systems reviewed as part of this inspection use the transit time technique. This technique can be used with sensors mounted through the pipe wall to operate in contact with the flow stream, i.e., wetted sensor type flow meter (as is the case for the Caldon Check and CheckPlus systems). In most cases these systems are mounted in a special pipe segment with two flanges for installation into the piping. This kind of system is sometimes referred to as a spool piece type system. Transit time techniques can also be used with externally mounted or so-called “clamp-on” senors such as the Caldon LEFM external systems. One of the principal differences between the two is that the ultrasonic sound path in the external meter is necessarily diametrical, i.e., sensing the flow velocity only through the centerlines of the pipe; whereas, the spool piece meters use multiple chordal paths, allowing them to sample the flow velocity at several locations from the center towards the periphery of the flow, thus approximating the actual flow velocity profile. By contrast, cross-correlation type meters are used to determine flow rate in feed water piping by determining the average time needed for turbulence in the flow to past between two fixed points.

For ultrasonic flow meters, particularly of the transit time kind (like the Caldon Check and CheckPlus systems), to be accurate to the levels of interest for feed water flow measurement, the design and fabrication of the meters must be of very high precision. Additionally, detailed information needs to be known about the flow conditions in the pipe. Because the assumption is that all the measured flow is in the axial direction, if there is radial or tangential flow, the flow measurement can be in error. This is because most flow meters, including differential pressure measurement systems, that were originally installed in most U.S. nuclear power plants and the ultrasonic flow meters discussed here measure total flow not just axial flow. This can lead to inaccurate flow indications beyond the stated accuracy of the flow meters and violations of Technical Specification power limits in plants that have increased their power based on over-stated accuracy of the flow meters.

The flow velocity profile depends on several factors, including pipe diameter, pipe wall roughness, fluid density, bulk velocity of the fluid (Reynolds Number), and location of upstream fluid disturbances, such as single and double elbows, flow straighteners, valves, orifices, etc.. These factors not only affect the flow profile at any given point and time, they also cause it to vary from one point to another in the pipe as well as varying in time. Therefore, the exact flow profile is difficult to predict for any given pipe or at any given location in the pipe. It has been well documented in the technical literature that the conventional wisdom, that fully developed flow profiles (i.e., with a relatively constant, predictable shape) will be well established within 10-50 pipe (inside) diameters from the last upstream disturbance, is not always the case. Because phenomena such as vortices, cross flow and swirl can affect the flow readings, it is important that their effects be accounted for. This has been done in several ways. In many flow meters, particularly external transit time meters, like the Caldon LEFM external systems, the effects, once characterized and bounded, can be calibrated out by use of a calibration factor. This method is acceptable if the calibration is done properly and conditions in the pipe do not change appreciably between calibrations. As previously stated, wetted sensor type flow meters, such as the Caldon Check and CheckPlus systems, use multiple chordal paths across the pipe, providing a direct real-time measurement of the velocity profile as influenced by any vortices, cross flow and swirl that may be present at the meter location. By measuring the flow at multiple points (four in the case of the Check meter) the flow velocity profile can be well estimated, and corrected for. In many cases, particularly when very high accuracy is needed, these meters are also calibrated using independent NIST-traceable standards. One additional advantage of the multiple chordal path meters is that changes in the flow profile between calibrations can be detected, and corrective action taken.

REPORT DETAILS

1.0 PURPOSE:

1.1 To verify independently certain information in Caldon Topical Reports ER-80, and 157, as discussed in the associated NRC SERs, based on which the NRC has granted power uprates.

1.2 To determine the reasons for the larger error of the Caldon external clamp-on LEFM (about 2.0%) and to determine if this error has caused any plants that use the external meter for power recovery to have exceeded their 10 CFR Part 50, Appendix K, power limit (102%)

1.3 To determine if the Check and/or CheckPlus models are susceptible to similar design, manufacturing, or calibration attributes that would reduce their claimed accuracy.

1.4 To determine the appropriate safety classification of (a) the Caldon LEFMs, (b) the associated software, and (c) the support services, i.e., should they be considered basic components as defined in 10 CFR Part 21 when used in an NRC-licensed facility for the purpose of calorimetric calibration of nuclear instruments

1.5 If so, determine whether they are supplied as basic components, or should be. If used as basic components in plants, determine whether they can be dedicated.

1.6 If so, to determine if appropriate QA requirements have been imposed by licensees and, if applicable, how effective is their implementation by Caldon.

1.7 To evaluate Caldon’s oversight of its principal subcontractors, especially the test lab, Alden Research Laboratories, Inc., of Holden, MA, and the spoolpiece fabricator, Ionics, Inc., of Pittsburgh, PA

2.0 REGULATORY BASIS:

2.1 Part 21, “Reporting of Defects and Noncompliance,” of Title 10, “Energy,” of the *Code of Federal Regulations* (10 CFR Part 21) and

2.2 Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to Part 50, “Domestic Licensing of Production and Utilization Facilities,” of Title 10 of the *Code of Federal Regulations* (10 CFR Part 50, Appendix B)

3.0 STATUS OF PREVIOUS INSPECTION FINDINGS:

None outstanding

4.0 INSPECTION FINDINGS and OTHER COMMENTS

4.1 NIST VISIT

a. Inspection Scope:

In preparation for the inspection of Caldon activities at Alden Laboratories and direct inspection of Caldon at its own facility, the inspectors visited the Fluid Mechanics Laboratory (Process Measurements, Fluid Flow Group facility) of the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland, for familiarization with LEFM technology and flow instrument calibration processes and practices. Here the inspectors had discussions with Dr. George Mattingly and Dr. T.T. Yeh, both internationally respected experts in the field of fluid flow measurement. The inspectors were briefed on the history and state-of-the-art of both external and spoolpiece type ultrasonic flow meters.

b. Observations and Findings:

During this visit, the inspectors learned principally about (1) problems inherent in high-Reynolds-number extrapolations, (2) determining flow velocity profiles, and (3) the state of the art in measuring delivered volume/mass over time. The NIST experts provided the team with information on several studies of ultrasonic flow measurement accuracy. Included was a study carried out as part of a joint research program of NIST with the Electric Power Research Institute (EPRI) in the early 1990's. The study focused on external flow meters and included an evaluation of meter accuracy and uncertainty analysis. The NIST experts characterized the inherent accuracies of the various types of industrial flow meters currently available and what kind of development, installation, and calibration is appropriate for ultrasonic flow meters. In their experience, multi-path chordal, transit-time, wetted-sensor type meters like the Caldon Check and CheckPlus LEFM systems are the most inherently accurate system currently available. NIST is even considering using them as transfer standards for fluid flow calibration standards.

Flow conditions in pipes can be carefully measured in a number of ways. The most common and accurate ways are traveling pitot-static measurement or laser Doppler measurement. Although measurements with these kinds of systems can provide the most detailed information on the flow conditions in pipes, they are not practical for most industrial applications. They are used however to determine if the assumptions inherent in other less intrusive measurement devices are accurate. The advantage the these instruments is that they can measure the flow profile directly within the pipe. Caldon has used both of these methods to verify the accuracy of their multi-path chordal meters. By evaluating the flow simultaneously with a pitot-static or laser Doppler probe and a chordal meter, it can be seen how faithfully the chordal meter can predict the flow profile. The NIST experts recommended that ultrasonic flow meters be compared to other independent measurements and also that they be calibrated to NIST traceable standards commensurate with the level of accuracy needed or the amount of uncertainty that can be tolerated.

The NIST facilities include a flow meter calibration laboratory that uses a large catch tank, the weight of which can be measured very accurately and a very accurate timing system with which to measure the time it takes to fill the tank. This sophisticated system is commonly referred to in the field as the “bucket and stop watch” calibration method and is similar to that used at Alden Laboratories. The NIST facility is accurate to better than 0.1 % up to a Reynolds Number of 2E+6. The Alden calibration facility can calibrate up to a Reynolds Number of 6E+6. For comparison, the typical flow in a main feed water line in a PWR plant has a Reynolds Number of up to 30E+6. The NIST experts also provided the team with information on how best to evaluate calibration and accuracy clams by ultrasonic meter vendors that included the need to review both repeatability and reproducibility of test data, calibration lab uncertainty, and installation effects.

c. Conclusions:

The inspectors concluded that in order to demonstrate that Caldon’s accuracy claims for their chordal LEFM systems were supportable, they would have to show the following: (1) that their system can directly measure the actual flow profile in real time with sufficient accuracy because its accuracy depends heavily on flow velocity profile measurement to minimize the importance of Reynolds number extrapolation, (2) that the calibration facility can model the plant-specific flow conditions with sufficient fidelity and vary the various profile-affecting parameters and design elements sufficiently to characterize the instrument’s response to those effects and to bound them in determining meter calibration or correction factors, and (3) that the calibration laboratory has sufficient accuracy and has rigorously determined and bounded the uncertainties in measuring the true volume of water delivered to the tank and the time in which it is delivered.

4.2 EVALUATION OF ALDEN LABORATORY TEST FACILITY AND ACTIVITIES

a. Inspection Scope:

The inspectors observed flow calibration testing of a Caldon CheckPlus system (for a Japanese plant), examined Alden calibration apparatus, interviewed/held discussions with Alden and Caldon personnel, and reviewed/obtained copies of relevant documentation including Caldon and Alden procedures, data, and analyses.

b. Findings and Observations:

Alden was founded by Worcester Polytechnic Institute in 1894. The calibration laboratory at Alden employs nine full-time staff including three calibration technicians. Alden maintains several testing laboratories including two large test loops for flow calibrations. The high flow loop in Building 2 is the one used for calibration of nuclear power plant feed water flow meters. The test loop has a maximum flow rate of approximately 20,000 gallons per minute (gpm) at 65 psig and 100 °F. This yields a maximum Reynolds Number of approximately 6E+6. The typical nuclear power plant flow in a main feed water pipe would have a Reynolds Number of approximately 30E+6. However, a Reynolds number scaling of about 5:1 is a comparatively less important factor affecting the accuracy of the calibration of a UFM that can measure flow profile directly. The Reynolds number describes the generic flow characteristics associated with viscous flow in a theoretical pipe (infinitely long and perfectly straight). It captures the effects of fluid density, bulk fluid velocity, fluid viscosity and properties of the pipe, such as the size and pipe wall surface roughness. Reynolds number extrapolation error arises from the degree to which the theoretical fully developed (regular, stable) flow profile achievable in a laboratory pipe section deviates from that theoretically developed in a relatively larger plant pipe section with greater flow rate and higher temperature. However, the Reynolds number does not characterize the localized, sometimes radical, flow perturbations caused by twists, bends and obstructions in the piping upstream of the flow meter. These variations in flow velocity taken together, comprise the total flow velocity profile which can be measured by multi-chordal-path UFMs. Since a meter factor thus determined depends little on assumptions about the flow profile predicted by the Reynolds number, Reynolds number extrapolation error is generally small compared with the effects of flow perturbations on flow profile.

One important part of determining both the uncertainty of the flow meter and the calibration constants for the meter is testing under known conditions. This can be done by comparison of the flow meter under test with another way of determining the flow. In some cases this is done by comparison in-situ with another flow meter of known accuracy. This method, however is limited by the accuracy of the other meter and not generally used for high-accuracy meters. Alternately, the flow meter under test can be compared to what is known as a “bucket and stopwatch” measurement in a lab. The “bucket and stopwatch” is literally a large container to catch the fluid that is flowing out the end of a pipe. The mass of the fluid in the catch tank and the time it takes to fill it can be measured with extreme accuracy. This system of calibration of the meter is generally thought to be the most accurate and with the most readily quantifiable uncertainties because the calibration standards can be directly traced back to NIST standards for time, temperature, mass and pressure. This system of calibration can have as high an accuracy as 0.1% for relatively high Reynolds numbers.

Because Caldon accuracy requirements for the Check and CheckPlus are quite high (0.5% and 0.3% accuracy), and because each plant’s feed water system is different, Caldon determined that all of their Check and CheckPlus meters sold for power uprate application will be individually tested using the “bucket and stopwatch” method at Alden. This type of calibration allows Caldon to achieve a higher level of accuracy by removing any known bias and by using a calibration constant (referred to as the “profile factor“). By calibrating the actual flow meter to be used in the plant at as close to prototypical plant conditions as possible, the sensitivity to flow profiles and other in-situ biases can be calibrated out. To accomplish this, Caldon has Alden build a full-scale model of the relevant portions of the main feed system piping, including its most flow-affecting design elements, upstream of the flow meter for each plant for which a Check or CheckPlus flow meter is to be used.

As noted in the report of the Nuclear Procurement Issues Council (NUPIC) joint utility commercial-grade survey of Alden, led by North Atlantic Energy Service Corporation (NAESC Report No. 18213) (hereinafter referred to as the NAESC survey), there were several weaknesses in the measuring and test equipment (M&TE) management system and customer calibration proposals that were reviewed and also in several of the procedures including, QA-AGF-7-86, "Procedure For Calibration of Flow Meters," Rev-6, dated May 15, 2002. These weaknesses were due to procedural issues, such as not updating internal laboratory calibration procedures or not maintaining the instrument calibration database. Although the weaknesses found in the NAESC survey did not lead the survey team to find any non-acceptable items or non-conformances, this NRC inspection team was concerned at the less-than-completely-rigorous nature of the calibration lab's procedures.

Alden claims at least 0.25% accuracy for all of its calibrations, and 0.15% for customers, such as Caldon that need higher levels of accuracy. To support this, it provides its customers with analysis that is based on ASME PTT-6. The analysis is based on developing an estimate of the uncertainly of all the information that goes into the calculation of the flow, the mass of the water collected, the time in which it takes to collect the water, the density of the water and a buoyancy correction for the displaced air in the container. Each of these is further broken down into other parameters, such as water temperature, water purity and model uncertainly for the density calculation. While precision uncertainties are estimated from test data, systematic uncertainties are estimated from experience. For example, in the H.B. Robinson CheckPlus calibration uncertainty calculation provided to the team for review, systematic uncertainties such as aging and leakage were estimated, even though Alden's technical director, Dr. Nystrom, stated that he did not measure these uncertainty effects. When asked if there had been a formal analysis to bound these kind of systematic uncertainties, Dr. Nystrom indicated that they had, developed a so-called "best-practice" estimate for these parameters but have not done a formal analysis. Alden does not maintain specific environmental controls for calibrations; nor do they measure humidity or other environmental conditions, other than temperatures, during the calibration process. Certain environmental factors that have been observed to be formally addressed at other calibration laboratories are not factored into to the Alden analysis. These include night-to-day variations and beginning-to-end-of-week type systematic uncertainties. When asked about these uncertainties, the Alden personnel acknowledged that they could be factors but did not believe they were issues at their facility.

The accuracy of the measurements also depends on the repeatability and reproducability of the measurements. The repeatability can be calculated based on the number of measurements taken and results obtained. Although this uncertainty could be included as part of the facility uncertainty, Caldon carries it as a separate part of their overall uncertainty calculation. Reproducability of the measurement has mostly to do with external factors that are part of the operation of the meter, but usually beyond the control of a laboratory to correct. These can include both environmental factors, such as humidity, and factors intrinsic to the test rig, such as problems with the pumps, that would lead to different readings from day to day during a calibration or a diverter that allows a lot of spray to go to the wrong side (i.e., into the return and not the collection tank when filling or vice versa between runs) and introduces a bias. The inspectors discussed these types of uncertainties with Alden personnel, but they stated that based on their experience, uncertainties of this type and magnitude did not appreciably affect their laboratory's measurements.

While the NRC inspection team was present, the Tokai plant flow meter (Caldon CheckPlus LEFM) was being tested. The testing at Alden included straight pipe testing, testing using upstream piping elements that modeled the Tokai piping and parametric variation of the upstream conditions. For each configuration, the flow was established and let run until it was constant. Then measurements were taken. This sequence was repeated for five redundant tests for each of five different flow rates. Based on the results of these tests, a profile factor for the meter was determined. Because of the additional information that can be gathered by the Caldon CheckPlus systems, primarily path velocity data and single plane data, the calibration can be checked to see if the same basic flow conditions are present at the plant as were present during calibration at Alden. Although not conclusive, this provides additional assurance that the conditions at the plant were well modeled in the calibration apparatus at Alden.

Alden uses an automated data collection system for all its calibration tests. Caldon personnel set up and operate the flow meter electronics and record the flow measurement. Then they feed these data to the Alden data collection system to be included in the calculation of the profile factor for the meter.

c. Conclusions:

Alden has done an acceptable job of providing a facility for full-scale testing and calibration, or more precisely, instrument response characterization of high-precision flow meters at well modeled and bounded flow conditions, for nuclear power plant use. However, the rigor of the Alden uncertainty analysis would be improved by a more fully developed and detailed uncertainty analysis for certain parameters that Alden considers of minimal importance; and hence, about which Alden makes some simplifying assumptions based on engineering judgement and experience. A more formal review and analysis of systematic uncertainty at Alden could provide a more definitive estimate of the amount of conservatism in Alden's 0.15% calibration accuracy estimate.

Nevertheless, the uncertainty factors for the Alden facility used, for example, in the calibration of the Caldon LEFM for the H.B. Robinson plant resulted in a lab uncertainty well within the 0.15% used by Caldon in its overall uncertainty analysis. The margin between the calculated value and the potentially higher real value due to non-measured factors is believe to be well within the conservative range. Therefore, the Alden uncertainty analysis is sufficient for use in high-precision calibrations up to and including 0.15%.

4.3 INSPECTION at CALDON, INC.

4.3.1 Accuracy of Check and CheckPlus LEFMs

a. Inspection Scope:

At Caldon's headquarters in Pittsburgh, the inspectors listened to/viewed Caldon presentations, interviewed/held discussions with Caldon personnel, reviewed/obtained copies of relevant documents (Including technical, QA, and procurement documents of licensees and Caldon), examined Caldon equipment and physical plant, visited Ionics, Inc., the flow meter spoolpiece manufacturing facility for Caldon chordal LEFMs, had a presentation by Ionics on their QA program and current activities, examined Caldon spool pieces in process and observed repair work on the Caldon chordal LEFM that had suffered leakage at the pipe wall penetration sleeve welds when installed at the Beaver Valley plant.

b. Findings and Observations:

The Caldon Check LEFM determines the real-time flow velocity profile by directly measuring the flow velocities across the flow area using four ultrasonic beams projected typically along horizontal chordal (non-diametrical) paths arranged in a vertical plane that is oriented diagonally across the flow. It can be shown that knowledge of the actual flow profile that varies not only with Reynolds number, but much more profoundly with upstream disturbances due to piping elements, enables one to integrate the flow velocity over the flow area and time-average the time-dependent variations and accurately determine the real-time flow. This method gives a claimed accuracy of 0.5% of full feed flow (i.e., % of span) to the flow measurement. The Caldon CheckPlus LEFM system uses four additional beams in a vertical plane that is perpendicular to the first. This provides information that can be used to cancel out or negate additional errors and achieve a claimed accuracy of 0.3 % of full flow. By doing so it reportedly can detect real-time variance of the flow profile even at what would be assumed to be nominally steady-state conditions. These variances can be complicated flow gyrations including, vortices, cross flow and swirl, which can continually change the instantaneous flow velocities at every point over the surface of the flow profile. Calibration of the system against a NIST-traceable independent standard such as timing the filling of a large tank (the so-called "bucket and stopwatch" method) under varying conditions can produce a profile-dependent meter factor. During testing at the Alden Research lab, conditions that affect flow parameters are varied to determine the meter's sensitivity to them. The test setup is a mock-up of the actual plant-specific feed flow piping section that will contain the flow meter with the most important upstream flow-affecting elements (twists and bends) accurately modeled. The configurations that affect flow measurement are varied until the effects on the meter's response are bounded. Then the meter factor can be adjusted to account for the worst-case credible variance from the test conditions that may be encountered in the plant. After the meter is installed, the flow profile is measured directly and the degree of conformance or deviation of the meter's response in-situ from that of the laboratory conditions can be determined and fine adjustments made accordingly.

As part of Caldon's procedure for selection of the location in a plant's main feed water system for the installation of a Check or CheckPlus meter [ref 10], Caldon engineers review and walk down the system to develop an understanding of the hydraulic conditions present. This includes selecting a position where the fluid velocity profile can be determined or readily modeled. Based on this information a calibration test plan can be developed that accurately models the upstream hydraulic configuration. All calibration plans are required to include a parametric model that tests the sensitivity of the calibration to changing swirl conditions or changing velocity profile shape. Caldon procedures for calculating and combining errors and biases are in accordance with ASME and ISA standards [see ref 11 and 12]. These methods are appropriate, provided that all the terms are independent, zero-centered and normal distributed. The Caldon uncertainty calculation is broken down into hydraulic (profile factor) uncertainty, Geometry (dimensions, alignment, thermal expansion) uncertainty, time (transit times and non-fluid delays) uncertainty, and feed water density uncertainty.

As discussed above, the facility uncertainty includes the calibration uncertainty associated with the Alden calibration. The test measurement uncertainty includes, uncertainty in the measurement of the flow including, the delta time measurements needed to calculate flow and the spool piece uncertainties, such as changes in the pipe diameter due to thermal expansion. The Reynolds number extrapolation bias, is due to the fact that the calibrations are done at a lower Reynolds Number than that seen in the plant. As the Reynolds number increases, the flow profile flattens. This is partially accounted for as part of the flow profile verification associated with the Check and CheckPlus Gaussian integration. The uncertainty associated with the extrapolation is determined by taking the no extrapolation case, and the worst case extrapolation case assuming a Reichardt flow profile. This is further tested using sensitivity studies. The modeling uncertainty is a measure of the relative sensitivity of the method of determining profile coefficients to hydraulic uncertainties. This uncertainty estimates factors in all parametric variations associated with the sensitivity of the profile factor model. The last input is the observational uncertainty. This is associated with data scatter. As discussed above, the data scatter is associated with both the repeatability and reproducibility of the measurements. The repeatability is calculated based on the number of measurements taken as part of the baseline calibration of the meters and carried as a separate observation uncertainty. Caldon therefore, includes facility uncertainty, and observational uncertainty, which have to do with the certainty to which they can calibrate their meter, measurement uncertainty, which has to do with their ability to accurately measure the flow, and Reynolds Number Extrapolation, and modeling uncertainty, which has to do with how well they know the flow conditions in their uncertainty analysis. The analysis includes all known major sources of errors for ultrasonic flow meters.

c. Conclusions:

Based on the information provided by Caldon, review of test and calibration data, examination of test apparatus and equipment, observation of testing and the best practices currently in use, the inspectors concluded that the claimed accuracies for the Caldon chordal LEFMs are justifiable depending on the accuracy of the laboratory calibration; and as discussed above, the calibration uncertainty of 0.15% used in the Caldon overall uncertainty analysis is achievable by the laboratory used by Caldon. Therefore, the Caldon testing program is effective at developing a plant-specific, traceable flow calibration for feed system conditions used for determining the meter uncertainty due to flow profile effects. The inspectors further concluded that Caldon's practice of taking post-installation measurements significantly enhances the validity of its meter response characterization. Finally, based on the review of the testing taking place at the time of the visit to Alden and the data provided by Caldon for the CP&L Robinson plant as an example, the assumed uncertainties discussed in ER-80P were conservative.

4.3.2 Field Tests and Other Operational Experience.

Both external and chordal type ultrasonic flow meters have been used since the late 1970's in nuclear power plant main feed system applications. In 1989 Caldon purchased the LEFM technology from Westinghouse. In 1990 Caldon introduced the Model 8300 Electronic Unit platform to address some of the issues associated with the Model 801 platform, including aliasing problems due slow sampling rates and drift. The Caldon External LEFM with the Model 8300 electronic unit was the UFM used in a field test at the Shearon Harris nuclear plant sponsored by the Electric Power Research Institute (EPRI). Prior to the Shearon Harris tests, an external meter was installed on the Nine Mile Point, Unit-2 main feed water system. The installation location selected in the plant was downstream from a 0.55-beta-ratio venturi followed by two s-bends. The profile factors were based upon hydraulic testing downstream from the s-bends. However the modeling did not include the venturi elements and used two separate pipe schedules, introducing a separate hydraulic effect that did not exist in the plant. Subsequent testing under better modeled plant conditions demonstrated the sensitivity of the external meters to the kind of hydraulic disturbances observed. In 1995, a main feed system fouling assessment (megawatt recovery) project was carried out that included the EPRI review of varius feed water flow meters. As part of the program, Caldon external meters were calibrated at Alden and installed at Shearon Harris. The calibration test plan included upstream venturis and downstream bends to test sensitivities. Both 0.48- and 0.68-Beta-Ratio venturis were tested at multiple distances from the downstream external meters to assess the profile factor and bound the uncertainties. The venturi in the plant had a 0.53 beta ratio. The tests demonstrated a significant sensitivity of the external meter to both the distance from the flow disturbance and the venturi Beta Ratio. These two installations led to Caldon's use of both detailed testing in prototypical flow arrangements and flow profile sensitivity studies (parametric variation and bounding) for all installations. It also led to establishing Caldon's process for developing test plans specific to each plant installation based on these considerations.

As a result of that experience, Caldon currently calibrates their Check and CheckPlus LEFMs in a hydraulic laboratory in piping that is geometrically similar to the plant installation in the most important ways, i.e., all feed water piping system elements that could have an appreciable effect on flow profile are modeled. In addition, Caldon conducts parametric tests that are intended to bound the uncertainty in modeling the exact plant configuration. Finally, with the development of the Check and CheckPlus systems, Caldon has been able to observe the flow conditions in the plant after the systems are installed and operating in order to confirm the fidelity of the modeling and adequacy of the parametric studies. During subsequent plant operation, the LEFMs can monitor changes in flow profiles and has continued to study flow profile effects on ultrasonic flow meter accuracy after the systems are installed in the plant.

As discussed earlier, the profile factor for a flow meter can in some cases be significantly different from that associated with fully developed flow even if the flow meter is in the ASME-recommended position. This is particularly true in case of upstream elbows and bends that tend to induce swirl. For ultrasonic flow meters that cannot correct for this effect, particularly external meters, it has been seen that this can cause as much as a 3.9 % non-conservative bias. These effects can also be seen in ASME venturi type flow meters. Therefore, as stated in the Safety Evaluation Report on Caldon's Topical Report ER-80P plant installations where the UFM was not calibrated to a site-specific piping configuration require additional justification for there use because the modeling uncertainly cannot be defined as well for the specific flow conditions in the plant installation.

c. Conclusions:

The inspectors confirmed that Caldon's response to the EPRI test was not inappropriate given the information available at the time. Although the review and inspection did not focus on Caldon's LEFM external systems, review of available information on Caldon's responses to this recent information confirmed the that velocity profile changes over time in Nuclear Power plant installations could significantly effect the calibration of external meters. The inspectors further confirmed on the basis of published information, that Caldon has examined each of the 26 LEFM external Systems that have been in service to determine whether adequate allowances have been made to accommodate velocity profile changes of the magnitude recently revealed. In every case but one it was shown that the original design basis could be supported. In the case of the exception, the external system was replaced by a Check system and is no longer in service.

4.3.3 Safety Classification of Caldon Feed Water Flow Measurement Systems

a. Inspection Scope:

As one part of the evaluation in order to establish an NRC staff position on the appropriate safety classification for Caldon flow measurement systems, and hence, to determine if those systems should be considered basic components as defined in 10 CFR Part 21, the inspectors reviewed procurement documents to determine the safety classification of the equipment assigned by Caldon's licensee clients.

b. Findings and Observations:

Review of selected Caldon client procurement documents revealed that some treated the hardware, software and services as basic components as evidenced by the statement of applicability of 10 CFR Part 21 to the procurement. Others procured the software and/or services as basic components, but not the hardware, and some treated everything procured from Caldon as non-safety-related or commercial-grade.

c. Conclusions:

Because several licensees stated in procurement documents for Caldon equipment or services that Part 21 was applicable to that procurement, then the goods and/or services delivered or offered for use at the NRC-licensed facility must be treated as basic components. This required Caldon to have a program for implementing Part 21 requirements. Such a program must have certain elements as dictated by the several specific requirements of Part 21 applicable to suppliers of basic components. First, pursuant to §21.21(a), Caldon would have to have adopted procedures to ensure that (1) deviations and failures to comply are evaluated to identify defects and failures to comply related to substantial safety hazards within 60 days of discovery, (2) an interim report is sent to the NRC within 60 days of the discovery of a deviation or failure to comply if the evaluation cannot be completed with the 60 days, and (3) that within five working days of the completion of the evaluation, any defects or failures to comply associated with a substantial safety hazard are reported to a director or responsible officer. Then there are several other things a supplier of basic components must do under Part 21, but they are not specifically required to be prescribed by procedures. First, §21.21(b) requires that a supplier that determines that it is incapable of performing an evaluation per §21.21(a)(1) of a deviation or failure to comply in a supplied basic component inform all affected licensees or purchasers within five working days of making that determination. Section §21.21.6(a) requires posting of Section 206 of ERA-74, the Part 21 procedures and the latest revision of Part 21 itself, or alternatively, [§21.6(b)] Section 206 and a notice describing the regulation and the procedures, stating where they may be viewed, and the giving the name of the person to whom reports should be made. Caldon also must specify the applicability of Part 21 in its procurement documents for any basic components it may purchase as such [§21.31]. Finally, under §21.51, Caldon must retain records of all evaluations and notifications under Part 21 for five years and retain the names of clients to whom basic components were supplied for 10 years.

4.3.4 10 CFR Part 21 and QA Review

a. Inspection Scope:

The inspectors reviewed Caldon procedures adopted pursuant to 10 CFR 21.21, Caldon procurement documents, 10 CFR Part 21-related records, §21.6 posting, and Caldon's handling of the Beaver Valley flow meter leakage problem with regard to Part 21 compliance. In addition, the inspectors reviewed selected Caldon QA procedures and records including certificates of conformance (CofCs) and reports of audits and commercial-grade surveys.

b. Findings and Observations:

Review of QA records indicated that Caldon did not have any audit report for its subcontractor, Wisconsin Centrifugal Division of MetalTek, that supplied the material with which Ionics fabricates spool pieces for Caldon chordal meters. In addition, Caldon had accepted a questionable CofC from this supplier. Caldon Purchase Order (PO) 019547-00 (orig), dated February 20, 2002, specified that 10 CFR Part 21 was applicable to the material, some 18-inch-diameter cast pipe sections, to be supplied under the PO. The CofC stated that the material had been manufactured under a "quality system which complies with 10CFR21" [sic]. This statement is meaningless and indicated a lack of understanding of the applicable regulations on the part of the pipe supplier. The CofC simply restated the mis-stated PO requirement to "Test and inspect in accordance with 10CFR50 Appendix B, safety related, and 10CFR21, (Reporting of Defects and Nonconformances)" [sic]. The CofC also stated that the material had been "...manufactured under a quality system which complies with 10 CFR 50 Part B" [sic]. Not only was this statement incorrect in itself, but the only evidence Caldon had of the basis of this supplier's quality assurance program indicated that it only conformed to ISO 9002, Rev 8, 06 August, 1999.

Review of Caldon's Part 21 procedures also revealed some deficiencies. Caldon's Quality Control Procedure (QCP) 13.1 was titled "Potential Part 21 Procedure" with an effective date of 11/03/2002. It was nominally the principal procedure for implementation of Part 21 requirements, but it contained provisions not related to Part 21 and lacked some provisions that would be necessary to meet the requirements of §21.21.(a). For example, the procedure required Caldon employees to document defects; whereas defects as defined in Part 21 would normally not be expected to be within the capability of Caldon as a company, let alone any of its employees to identify. In general, defects are identified on the basis of a §21.21(a)(1) evaluation and in almost all cases, Caldon would not be considered qualified to perform such an evaluation. Instead, it would be more appropriate for Caldon to inform licensees and affected purchasers per §21.21(b) of any deviations or failures to comply that it cannot evaluate.

Finding QCP 13.1 deficient with respect to Part 21 requirements, the inspectors reviewed Revision 4 of QCP 13.0, "Non-Conformance Procedure" with an effective date of 06/27/2000. This procedure nominally would be expected to implement Criterion XV, "Control of Non-conforming Conditions," of 10 CFR Part 50, Appendix B. However, it also contained some provisions for implementing 10 CFR Part 21.

Thus, the Part 21 procedures were deficient in that they would not, as written, assure that Caldon employees or the company would properly identify deviations and failures to comply so that they could be evaluated per §21.21(a) or reported to licensees or affected purchasers under §21.21(b). In addition, Caldon's posting per §21.6 was deficient in that it did not have all the required elements.

c. Conclusions:

These deficiencies constituted minor violations of 10 CFR 21.21(a) and 10 CFR 21.6. However, Caldon's handling of a major Part 21 issue, i.e., leakage in its meter at Peach Bottom due to use of a faulty welding process, was handled satisfactorily with regard to Part 21 compliance as well as QA requirements. Their prompt root-cause evaluation, corrective action, evaluation of extent of condition to other customers and notifications was quite satisfactory.

Caldon's failure to produce evidence of proper qualification of one of its suppliers and its acceptance of a questionable CofC constitute a nonconformance with respect to Criterion VII, "Control of Purchased Equipment, Material and Services," of 10 CFR Part 50, Appendix B, and is identified as Nonconformance 2002-201-01.

DOCUMENTS EXAMINED

NRC IR 99901311/89-01

EPRI TR-107323

Caldon ER-80 topical report and corresponding SER

Caldon ER-157 topical report and corresponding SER

Caldon ER-262 topical report and corresponding SER

Caldon ER-286, Rev 0, “Profile Factor Calculation and Data Comparison for the Prototype LEFM CheckPlus-Plus Spool Piece,” April 2002 (Caldon Proprietary)

ASME PTC 19.1-1995, “Measurement Uncertainty”

ISA-RP67.04-2000, Methodologies for the Determination of Set Points for Nuclear Safety-Related Instrumentation.

NUPIC (NAESCo) Commercial Grade Survey Report 18213 (June 2002) on Alden Labs

NUPIC (Shearon Harris) QA Audit Report on Caldon

ANSI/NCSL Standard Z540-1-1994 (Cal Lab and M&TE General Requirements)

MIL-Standard 45662, latest revision

NRC High-Accuracy flow meter questions

Hauser, E.; Regan, J.; and Estrada, H.; *Impact of Flow Velocity Profile on Ultrasonic Measurement Accuracy For Feedwater Flow in Nuclear Power Plants*, “Proceedings of the 10th International Conference on Nuclear Engineering,” Arlington, Virginia, April 14-18, 2002.

Yeh, T.T., and Espina, P.I.; *Special Ultrasonic Flowmeters for In-Situ Diagnosis of Swirl and Cross Flow,* “Proceedings of the 2001 ASME Fluids Engineering Division Summer Meeting, FEDSM’2001-18037,” New Orleans, Louisiana, May 29-June 1, 2002.

Yeh, T.T. and Mattingly, G.E.; *Computer Simulations of Ultrasonic Flow Meter Performance in Ideal and Non-Ideal Pipeflows*, “Proceedings of the 1997 ASME Fluids Engineering Division Summer Meeting,” FEDSM’97-3012, June 22-27, 1997.

NIST Technical Note 1429, “NIST’s Ultrasonic Technology Assessment Program to Improve Flow Measurements,” G.E. Mattingly and T.T. Yeh

Yeh, T.T.; Espina, P.I.; and Osella, S.A.; *An Intelligent Ultrasonic Flow Meter for Improved Flow Measurement and Flow Calibration Facility*, “Proceeding of the IEEE Instrumentation and Measurement Technology Conference,” Budapest, Hungary, May 21-23, 2001.

QA-AGF-7-86, “Procedure for Calibration of Flow Meters,” Revision 6, May 15, 2002

sample of data collection system log output (e-mail from Nov 1, 2002)

Caldon Procedure EP402, “Site Selection for LEFM Installations,” December, 2, 2002.

PERSONS CONTACTED

Ernest M. Hauser, President, Nuclear Division, Caldon Inc.
Jennifer Regan, President, Key Technologies, Inc.
James B. Nystrom, Senior Vice President, Alden Research Laboratory, Inc.
George E. Mattingly, National Institute of Standards and Technology
T.T. Yeh, National Institute of Standards and Technology
Calvin Hastings, President/CEO, Caldon, Inc.
Joe Whitehead, QA Manager, Caldon, Inc.

References:

1. North Atlantic Energy Service Corporation, Commercial Grade Survey No. 18213, June 2002

2. QA-AGF-7-86, “Procedure For Calibration of Flow Meters”, Rec-6, dated May 15, 2002

3. Methodology for Comparison of Diverse Feedwater Flow Measurements, EPRI TR-107323, Draft final report, March 1999.

4. Caldon presentation material provided to Inspection Team, October 29, 2002.

5. Hauser, E.; J. Regan, and H. Estrada, *Impact of Flow Velocity Profile on Ultrasonic Measurement Accuracy For Feedwater Flow in Nuclear Power Plants*, “Proceedings of the 10th International Conference on Nuclear Engineering,” Arlington, VA, April 14-18, 2002.

6. Doebelin, Ernest O.; *Measurement Systems, Application and Design*, McGraw-Hill, New York, 1966

7. Safety Evaluation by the Office of Nuclear Reactor Regulation dated January 25, 1999 for Topical Report ER-80P “Improving Thermal Power Accuracy and Plant Safety While Increasing Operation Power Level Using the LEFM Systems”

8. Yeh T.T. and G.E. Mattingly, *Computer Simulations of Ultrasonic Flow Meter Performance in Ideal and Non-Ideal Pipeflows*, “Proceedings of the 1997 ASME Fluids Engineering Division Summer Meeting,” FEDSM’97, June 22-27, 1997.

9. Yeh, T.T., P.I. Espina and S.A. Osella, *An Intelligent Ultrasonic Flow Meter for Improved Flow Measurement and Flow Calibration Facility*, “Proceeding of the IEEE Instrumentation and Measurement Technology Conference,” Budapest, Hungary, May 21-23, 2001.

10. Caldon Procedure EP402, “Site Selection for LEFM Installations,” December, 2, 2002.

11. ASME PTC 19.1-1985, “Measurement Uncertainty”

12. ISA-RP67.04-2000, “Methodologies for the Determination of Set Points for Nuclear Safety-Related Instrumentation”