December 20, 2001

Mr. Michael A. Krupa
Director
Nuclear Safety & Licensing
Entergy Operations, Inc.
1340 Echelon Parkway
Jackson, MS 39213-8298

SUBJECT: WATERFORD STEAM ELECTRIC STATION, UNIT 3; RIVER BEND STATION; AND GRAND GULF NUCLEAR STATION - REVIEW OF CALDON, INC. ENGINEERING REPORT ER-157P (TAC NOS. MB2397, MB2399, AND MB2468)

Dear Mr. Krupa:

The Nuclear Regulatory Commission (NRC) staff has completed its review of the Caldon, Inc. (Caldon) Engineering Report ER-157P, Revision 5, "Supplement to Topical Report ER-80P: Basis for a Power Uprate with the LEFM [leading edge flow meter]✓™ or LEFM CheckPlus™ System" submitted by Entergy Operations, Inc. (the licensee) on July 6, 2001, as supplemented by letters dated September 14, October 9, and October 30, 2001. Revision 5 of the engineering report, submitted on October 30, 2001, incorporated the resolution of all comments received from the NRC on the review of Revisions 3 and 4 submitted in the July 6 and October 9, 2001, supplemental letters, respectively.

On the basis of our review, the staff finds the subject report to be acceptable for referencing in power uprate license applications for Waterford Steam Electric Station, Unit 3 (Waterford 3), Grand Gulf Nuclear Station (GGNS), and River Bend Station (RBS), to the extent specified, and under the limitations delineated in the report, and in the enclosed safety evaluation (SE). The SE defines the basis for NRC acceptance of the report.

Pursuant to 10 CFR 2.790, we have determined that the enclosed SE does not contain proprietary information. However, we will delay placing the SE in the public document room for a period of ten (10) working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in the enclosure is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.790.

The staff will not repeat its review and acceptance of the matters described in the report, when the report appears as a reference in power uprate applications for Waterford 3, GGNS, and RBS, except to assure that the material presented is applicable to the specific plant involved. Our acceptance applies only to the matters described in the report.

Should our criteria or regulations change so that our conclusions as to the acceptability of the report are no longer valid, Caldon and the licensees referencing the topical report will be expected to revise and resubmit their respective documentation, or to submit justification for the continued effective applicability of the report without revision of their respective documentation.

Sincerely,

***/RA/***

Stuart A. Richards, Director
Project Directorate IV
Division of Licensing Project management
Office of Nuclear Reactor Regulation

Docket Nos. 50-382, 50-458,
and 40-416

Enclosure: Safety Evaluation

Should our criteria or regulations change so that our conclusions as to the acceptability of the report are no longer valid, Caldon and the licensees referencing the topical report will be expected to revise and resubmit their respective documentation, or to submit justification for the continued effective applicability of the topical report without revision of their respective documentation.

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Stuart A. Richards, Director
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Enclosure: Safety Evaluation

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# SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

# CALDON, INC. ENGINEERING REPORT ER-157P

# "SUPPLEMENT TO TOPICAL REPORT ER-80P: BASIS FOR A POWER UPRATE WITH THE LEFM [LEADING EDGE FLOW METER]✓™ OR LEFM CHECKPLUS™ SYSTEM"

## 1.0 INTRODUCTION

By letter dated July 6, 2001, (Reference 1), as supplemented September 14, 2001, October 9, 2001, and October 30, 2001, Entergy Operations, Inc.(Entergy) submitted Engineering Report (ER) ER-157P, Revision 3, "Supplement to Topical Report ER-80P: Basis for a Power Uprate With the LEFM✓™ or LEFM CheckPlus™ System." In response to the staff comments, Entergy submitted Revisions 4 and 5 via letters dated October 9, 2001 (Reference 2), and October 30, 2001 (Reference 3), respectively. This engineering report documents theory, design, and operating features of the LEFM CheckPlus™ System and includes calculation of power measurement uncertainty using LEFM✓™ or LEFM CheckPlus™ System for feedwater flow and temperature measurements in a typical power plant.

ER-80P describes the principles and performance characteristics of the Caldon, Inc. (Caldon) LEFM✓™ System. The staff safety evaluation report (SER) dated March 8, 1999, (Reference 4) approved this report for referencing it in licensee's request for an exemption to 10 CFR Part 50, Appendix K requirement and a 1 percent power uprate using the Caldon LEFM✓™ System for feedwater flow and temperature measurements. Subsequently, following publication of the final rule to amend 10 CFR Part 50, Appendix K requirements, the staff SER dated January 19, 2001 (Reference 5), approved Caldon Engineering Report ER-160P, a supplement to ER-80P, for a 1.4 percent power uprate using the Caldon LEFM✓™ System for feedwater flow and temperature measurements.

ER-157P describes the Caldon LEFM CheckPlus™ System and includes calculations to establish its measurement uncertainties. The report also includes re-calculations of LEFM✓™ System measurement uncertainty, which is slightly better than that reported in ER-160P. Most of the information contained in several appendices of ER-80P are applicable and necessary for understanding the material presented in ER-157P. Some of the information in ER-157P is proprietary (Appendix A) and, therefore, the staff SER includes only the nonproprietary information which describes the LEFM✓™ and LEFM CheckPlus™ Systems and their ability to achieve the reported accuracies.

## 2.0 BACKGROUND

Nuclear power plants are licensed to operate at a specified core thermal power and the uncertainty of the calculated values of this thermal power determines the probability of exceeding the power levels assumed in the design-basis transient and accident analyses. In this regard, Appendix K to 10 CFR Part 50 requires loss-of-coolant accident and emergency core cooling system analyses to assume that the reactor has been operating continuously at a power level at least 102.0 percent of the licensed thermal power to allow for uncertainties, such as instrument error. In order to reduce an unnecessarily burdensome regulatory requirement and to avoid unnecessary exemption requests, the Nuclear Regulatory Commission (NRC) published an associated final rule in the *Federal Register* on June 1, 2000 (65 FR 34913). The final rule amended the Appendix K requirements to allow licensees the option of justifying a smaller margin for power measurement uncertainty by using more accurate instrumentation to calculate the reactor thermal power or maintaining the current margin of 2 percent power.

The reactor core thermal power (RCTP) is continuously indicated by the neutron flux instrumentation, which must be periodically calibrated to accommodate the effects of fuel burnup, flux pattern changes, and instrumentation setpoint drift. The RCTP is determined by automatic or manual calculation of the energy balance of the plant nuclear steam supply system. This calculation is called a "secondary calorimetric" in the case of a pressurized water reactor, and a "heat balance" in the case of a boiling water reactor. The accuracy of this calculation depends primarily upon the accuracy of feedwater flow and feedwater net enthalpy measurements. As such, an accurate measurement of feedwater flow and temperature is necessary for an accurate calibration of the nuclear instrumentation. Of the two instruments (flow and temperature), the most important in terms of calibration sensitivity is the feedwater flow (1 percent error in flow instrumentation calibration produces a corresponding 1 percent error in the nuclear instrumentation calibration).

The elements used for measuring feedwater flow are, typically, an orifice plate, a venturi meter, or a flow nozzle, which generate a differential pressure proportional to the feedwater velocity in the pipe. Of the three differential pressure devices, the venturi meter is the most widely used for feedwater measurement in nuclear power plants. The major advantage of the venturi meter is the relatively low head loss as the fluid passes through the device. However, fouling of the device is the major disadvantage of this meter or any other nozzle-based flow meter. Fouling is a metallic plating on the throat area of the meter, which causes the meter to indicate a higher differential pressure and thus a higher than actual flow rate. This result leads plant operators to calibrate nuclear instrumentation high. Calibrating nuclear instrumentation high is conservative with respect to reactor safety, yet it causes the electrical output to be proportionally low when the plant is operated at its thermal power rating. In addition to fouling, the transmitter and the analog-to-digital converter of the venturi meter introduce errors in the flow measurement, thus necessitating removal, cleaning, and re-calibration of the flow device.

Because of the need to improve flow instrumentation uncertainty to operate the plant at the license rating, the industry assessed alternate flow measurement techniques and found ultrasonic flow meters (UFMs) to be a viable alternative. The UFMs are electronic transducers controlled by computer and do not have differential pressure elements which are susceptible to fouling. Caldon developed a UFM called the "Leading Edge Flow Meter (LEFM)" and named it the "LEFM✓™" System. The LEFM CheckPlus™ System is a new development by Caldon and has demonstrated higher accuracy of measurement than the LEFM✓™ System. Both of these UFMs have demonstrated better measurement accuracies than the current instrumentation (venturi), and provide continuous verification that the UFM is operating within its uncertainty bounds.

## 3.0 EVALUATION

ER-80P and its supplement, ER-160P, provide a detail description of the LEFM✓™ System theory, characteristics, measurement uncertainties, and the basis of a plant thermal power uprate using the LEFM✓™ System for feedwater flow and temperature measurements. The staff evaluation of these two reports and the LEFM✓™ System capability to achieve the reported accuracy to support a power uprate is provided in References 4 and 5. The subject ER-157P, a supplement to ER-80P, provides a detailed description of theory, construction, and characteristics of the LEFM CheckPlus™ System and includes calculations determining flow and temperature measurement uncertainties and the basis for a plant thermal power uprate using LEFM✓™ or LEFM CheckPlus™ System.

Both ✓™ and CheckPlus™ LEFMs measure the transit times of pulses of ultrasonic energy traveling along chordal acoustic paths through the fluid flowing in a pipe. This system is called the "Chordal Time-of-Flight" ultrasonic flow measurement system and typically consists of an array of transducers housed in fixtures in a pipe so as to form parallel and precisely defined acoustic paths. The chordal placement of the transducers are selected to facilitate an accurate numerical integration of the axial velocity profile. The electronics associated with this system measures the times of flight of ultrasonic pulses traveling along the acoustic paths, with and against the direction of flow. Using these time measurements and the known path length, the fluid velocity along each acoustic path is determined. This velocity and the angle that the path makes with the flow axis, are used to determine the axial fluid velocity. Using Gaussian quadrature integration, the velocities measured along the multiple acoustic paths are combined to determine an average volumetric flow through the pipe cross-section. This numerically calculated volumetric flow is multiplied by a factor called the "Profile factor," which accounts for acoustic biases and biases introduced due to integrating the axial and transverse velocities in a circular pipe cross section. This profile factor is determined in a full scale test of the spool piece in a certified hydraulic test facility, which typically includes a full scale model of the upstream feedwater system hydraulic configuration. The LEFM measured sound velocity is used, along with the feedwater pressure input, to determine fluid temperature, density, and enthalpy. The volumetric flow and the density are multiplied to obtain mass flow of the fluid. Feedwater mass flow and enthalpy, along with the steam enthalpy and an accounting of heat gain and losses, are used to calculate thermal power.

Using the principles outlined above, Caldon developed a mass flow algorithm for the LEFM system. An examination of the algorithm shows that the uncertainty in the chordal LEFM flow measurement can be grouped for analysis into four categories as follows:

1. Hydraulic Uncertainties - the uncertainties associated with measuring, in a test facility, the profile factor for a specific installation and applying this factor to an LEFM measurement in a power plant;

2. Geometric Uncertainties - the dimensional uncertainties of angles, lengths, placement of the acoustic paths and internal pipe diameter, and thermal expansion;

3. Time Measurement Uncertainties - the biases and errors associated with measuring the transit time of the acoustic pulses and the non-fluid delays; and

4. Correlation Uncertainties - the biases in the correlations between the fluid temperature, its pressure, the sound velocity, and the fluid density measurements.

Out of these factors, only the LEFM clock and pressure transducer accuracies are subject to drift. The LEFM clocks have repeatedly demonstrated minuscule drift (proprietary value) and the pressure transducer drift is a plant-specific factor to be controlled by the power plant. The LEFM systems are provided means for checking and, if necessary, revising uncertainties in each of the four categories that affect their performance. These means are employed as part of commissioning an instrument for flow measurement, and periodically thereafter, to confirm that performance has not changed. With a few exceptions, most of the errors in an LEFM measurement are fixed biases and do not randomly vary with time.

Each one of the four categories of measurement errors are translated into percent thermal power uncertainty of a typical power plant and statistically combined as shown in Table 1 of the subject ER. The total power measurement uncertainty is a statistical combination of LEFM measurement uncertainties, and the plant-specific temperature and pressure measurement uncertainties translated into percent thermal power with a 95 percent confidence limit. These uncertainties in a typical power plant are shown as budgeted values in Table 1 of the ER and based on the proprietary calculations in Appendix A of the ER. The calculation methodology used in the Appendix A calculations was approved by the staff in Reference 4. The staff review indicated that the measurement uncertainties calculations in Appendix A followed the staff-approved methodology.

Following is the staff evaluation of LEFM CheckPlus™ System's measurement capability and the basis for plant thermal power uprate using LEFM✓™ or LEFM CheckPlus™ Systems, as described in ER-157P.

## 3.1 LEFM CheckPlus™ System

LEFM✓™ System, as described in ER-80P, consists of a spool piece with eight transducer assemblies forming the four chordal acoustic paths in one plane of the spool piece. The system includes an electronics unit with hardware and software installed to provide flow and temperature measurements and an on-line verification of these measurements. An LEFM CheckPlus™ System, both hydraulically and electronically, is made up of two LEFM✓™ Systems in a single spool piece. This layout has two sets of four chordal acoustic paths in two planes of the spool piece which are perpendicular to each other. The electronics for the two subsystems, while electrically separated, are housed in a single cabinet. To ensure independence, the two measurement planes of an LEFM CheckPlus™ System have independent clocks for measuring transit times of the ultrasound pulses.

The fluid velocity measured by an acoustic path in one plane consists of the vector sum of the axial fluid velocity as projected on the path and any transverse component of the fluid velocity projected on the same path. When the net velocity measured by this acoustic path is averaged with the net velocity measured by its companion path in the second plane, the transverse components of the fluid velocity will be canceled and the averaging will only be of the axial velocities. Thus, the numerical integration of four axial velocities, averaged of the measurements in two planes and without the transverse component, is inherently a more accurate computation of the volumetric flow than that provided by a single plane of four acoustic paths in an LEFM✓™ System. Also, since there are twice as many acoustic paths in an LEFM CheckPlus™ System, errors due to uncertainties in transit time measurements are reduced. Due to the redundancy of the two measurement planes, the operation of an LEFM CheckPlus™ System is less affected by component failures than an LEFM✓™ System, where a component failure will generally require a reduction in power. Thus, a continued plant operation at an uprate power level can be justified for any single component failure in an LEFM CheckPlus™ System. Additionally, it is noted that the calibration of an LEFM CheckPlus™ System is less sensitive to the specifics of a hydraulic configuration than that of an LEFM✓™ System. However, it is noted that, in certain hydraulic configurations where transverse components of the fluid velocity is very small, an LEFM✓™ System can produce equally accurate results.

3.2 Power Uprate With LEFM✓™ or LEFM CheckPlus™ System

Core thermal power measurement uncertainty affects neutron flux instrumentation calibration and determines the percentage power uprate of a nuclear power plant. This uncertainty is based upon feedwater flow, temperature, and pressure instrumentation uncertainties, steam pressure, temperature, moisture instrumentation uncertainties, and certain plant-specific thermal energy gains and losses. Feedwater flow and temperature instrumentation uncertainties are determined by Caldon (LEFM✓™ or LEFM CheckPlus™ System supplier), whereas the rest of the instrumentation uncertainties and thermal energy gains and losses are plant-specific. Table 1 in the ER includes bounding values of LEFM✓™ and LEFM CheckPlus™ System's measurement uncertainties and typical values of the plant-specific instrumentation uncertainties in terms of percent thermal power with a 95 percent confidence level. These uncertainties were calculated in Appendix A of the report for a typical power plant using data bounding the actual performance of LEFM✓™ or LEFM CheckPlus™ System. In this calculation, the combined total of the LEFM-related error element is the largest contributor to the power measurement uncertainty, and the profile factor of the LEFM (hydraulics-related factors) is the largest contributor to the LEFM-related error.

The actual performance of a 33 inch LEFM✓™ spool piece in a typical plant feedwater system configuration at a certified hydraulic laboratory, demonstrated a significant reduction in profile factor uncertainty from the budgeted ± 0.4 percent to ± 0.2 percent. A similar test on an LEFM CheckPlus™ spool piece in an extremely complex hydraulic configuration (as shown in Figure 5 of the subject ER), demonstrated a reduction in profile factor uncertainty from the budgeted ± 0.25 percent to ± 0.22 percent. In Appendix A, Caldon referenced two plant-specific ERs documenting the calibration of LEFM✓™ and LEFM CheckPlus™ System profile factors. The staff review found the two plant-specific ERs confirming the above stated reductions in the LEFM✓™ and LEFM CheckPlus™ System profile factors.

The LEFM✓™ System's measurement uncertainty components in Table 1 of the subject report are shown to have achieved better values than those calculated in ER-80P to support a 1.4 percent power uprate. This is because the calculations in Appendix A of this report were performed with the data for a two loop versus a single loop configuration, larger internal diameter of the feedwater pipe, higher feedwater velocity, and more precise geometry, pressure, and transit time measurements. This lower measurement uncertainty of an LEFM✓™ System can support a somewhat higher power uprate. The subject ER stated that the thermal power measurement using an LEFM✓™ System can provide an overall uncertainty of better than ± 0.6 percent. The calculations in the report found this uncertainty to vary from ± 0.51 percent to ± 0.47 percent, depending upon the uncertainty of the steam moisture content (respectively, from ± 0.25 percent to zero). The report also stated that licensees using an LEFM✓™ System and applying for an uprate greater than 1.4 percent of rated thermal power, may choose to reference this document. Similarly, a total power measurement uncertainty for a representative system using an LEFM CheckPlus™ System was calculated varying from ± 0.39 percent to ± 0.33 percent, depending upon the uncertainty of steam moisture content.

As stated above, the instrumentation uncertainties included in Table1 of the subject ER are bounding values for the LEFM system and typical values for other plant-specific thermal power measurement uncertainties. Caldon calculated these bounds, the probability of operation within bounds, and the odds of exceeding the high-side bound for one to five standard deviations for the venturi, LEFM✓™, and LEFM CheckPlus™ Systems. The results are listed in Table 2 of the report, and were used to develop graphs in Figures 6, 7, and 8 of the report. These graphs compare the probability of exceeding the licensed thermal power (LTP) of a plant operating at 100 percent LTP and using a venturi, with that of an LEFM✓™ or an LEFM CheckPlus™ System.

The graphs indicate that the probability of exceeding the analyzed power level of 102 percent is the same for a plant operating at 100 percent of LTP and using the current instrumentation (venturi) as that for a plant operating at 101.4 percent of the LTP and using an LEFM system or a plant operating at 101.7 percent of the LTP and using an LEFM CheckPlus™ System. Additionally, the LEFM system continuously verifies that it is operating within its design bounds, whereas the current instrumentation has no such feature, and no indication of thermal power measurement accuracy is available to the plant operator. To illustrate the benefit of on-line verification, the results of a survey of sustained overpower events reported in Licensee Event Reports (LERs) from 1981 through 1999 are shown in Figure 9 of the subject ER. These results show that an LEFM system with an on-line verification would have prevented all significant sustained overpower events. Because of this feature, the report concludes that power increase using LEFM systems increases safety. Also, since the LEFM display indicates the value as well as the validity of the thermal power measurement at the same location in the main control room, the operator can use the display to maintain reactor power at or below the licensed thermal power rating. For example, an audible alarm tells the operator when the LEFM is not operating within its design basis accuracy. Since the LEFM system provides a valid and accurate volumetric flow indication from 100 percent to zero flow, the LEFM✓™ or LEFM CheckPlus™ System can be used for thermal power determination from synchronization (10 percent to 15 percent power) to full power.

The ER recommended that each licensee will submit, as part of the power uprate package, a detailed accounting of the uncertainties applicable to the licensed facility, and will maintain, as part of the plant design documents, the LEFM calibration and other data justifying the proposed power uprate. In addition to the guidelines outlined in ER-80P and ER-157P, the following requirements shall be addressed by licensees referencing ER-157P in their request for a power uprate:

1. The licensee should discuss the maintenance and calibration procedures that will be implemented with the incorporation of the LEFM. These procedures should include processes and contingencies for an inoperable LEFM and the effect on thermal power measurement and plant operation.

2. For plants that currently have LEFM installed, the licensee should provide an evaluation of the operational and maintenance history of the installation and confirm that the installed instrumentation is representative of the LEFM system, and bounds the analysis and assumptions set forth in ER-80P.

3. The licensee should confirm that the methodology used to calculate the uncertainty of the LEFM in comparison to the current feed water instrumentation is based on accepted plant setpoint methodology (with regard to the development of instrument uncertainty). If an alternate methodology is used, the application should be justified and applied to both venturi and the LEFM for comparison.

4. Licensees for plant installations where the LEFM was not installed with flow elements calibrated to a site-specific piping configuration (flow profiles and meter factors not representative of the plant-specific installation), should provide additional justification for use. This justification should show either that the meter installation is independent of the plant-specific flow profile for the stated accuracy, or that the installation can be shown to be equivalent to known calibrations and the plant configuration for the specific installation, including the propagation of flow profile effects at higher Reynolds numbers. Additionally, for previously installed and calibrated LEFM, the licensee should confirm that the piping configuration remains bounding for the original LEFM installation and calibration assumptions.

## 4.0 CONCLUSION

On the basis of review of ER-157P, Revision 5 (Proprietary and Non-Proprietary), the staff concludes that Caldon LEFM✓™ and LEFM CheckPlus™ Systems are designed and tested to achieve the flow measurement uncertainties calculated and credited in the report for thermal power measurement uncertainty of a typical power plant. The staff also concludes that a licensee's application for power uprate may reference ER-157P for power measurement uncertainty of an LEFM✓™ or LEFM CheckPlus™ System.

## 5.0 REFERENCES

1. Caldon, Inc. Engineering Report ER-157P, Revision 3, "Supplement to Topical Report ER-80P: Basis for a Power Uprate With the LEFM✓™ or LEFM CheckPlus™ System," dated February 2001, transmitted to NRC by Michael A. Krupa (Entergy) letter dated July 6, 2001.

2. Caldon, Inc. Engineering Report ER-157P, Revision 4, "Supplement to Topical Report ER-80P: Basis for a Power Uprate With the LEFM✓™ or LEFM CheckPlus™ System," dated October 2001, transmitted to NRC by Michael A. Krupa (Entergy) letter dated October 9, 2001.

3. Caldon, Inc. Engineering Report ER-157P, Revision 5, "Supplement to Topical Report ER-80P: Basis for a Power Uprate With the LEFM✓™ or LEFM CheckPlus™ System," dated October 2001, transmitted to NRC by Michael A. Krupa (Entergy) letter dated October 30, 2001.

4. John N. Hannon (NRC) letter to C. L. Terry (TU Electric), "Staff Acceptance of Caldon Topical Report ER-80P: Improving Thermal Power Accuracy While Increasing Power Level Using The LEFM System," dated March 8, 1999.

5. Robert Martin (NRC) letter to J. A. Scalice (Tennessee Valley Authority), "Staff Acceptance of TS [Technical Specification] Changes, Power Uprate Request, and Caldon Topical Report ER-160P," dated January 19, 2001.

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Date: December 20, 2001

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