Enclosure 10

Cameron Document ER-1123NP, “Bounding Uncertainty Analysis for Thermal Power Determination at Hope Creek Unit 1 Nuclear Generating Station Using the LEFM √+ System,” Revision 2 (Non-Proprietary Version)

Caldon® Ultrasonics

Engineering Report: ER-1123NP Rev 2

BOUNDING UNCERTAINTY ANALYSIS FOR THERMAL POWER DETERMINATION AT HOPE CREEK UNIT 1 NUCLEAR GENERATING STATION USING THE LEFM✓+ SYSTEM

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1.0 INTRODUCTION

The LEFM✓ and LEFM✓+1 are advanced ultrasonic systems that accurately determine the volume flow and temperature of feedwater in nuclear power plants. Using a feedwater pressure signal input to the LEFM✓ and LEFM✓+: mass flow can be determined and, along with the temperature output are used along with plant data to compute reactor core thermal power. The technology underlying the LEFM✓ ultrasonic instruments and the factors affecting their performance are described in a topical report, Reference 1, and a supplement to this topical report, Reference 2. The LEFM✓+, which is made of two LEFM✓ subsystems, is described in another supplement to the topical report, Reference 3. The exact amount of the uprate allowable under a revision to 10CFR50 Appendix K depends not only on the accuracy of the LEFM✓+ instrument, but also on the uncertainties in other inputs to the thermal power calculation.

It is the purpose of this document to provide an analysis of the uncertainty contribution of the LEFM✓+ System [ ] to the overall thermal power uncertainty of Hope Creek Unit 1 Nuclear Generating Station (Appendix B). Trade Secret & Confidential Commercial Information

The uncertainties in mass flow and feedwater temperature are also used in the calculation of the overall thermal power uncertainty (Appendix B). [ ] A detailed discussion of the methodology for combining these terms is described in Reference 3. Trade Secret & Confidential Commercial Information

This analysis is a bounding analysis for the Hope Creek Unit 1 Nuclear Generating Station. This report is being published following the calibration of the spool piece, when a precise estimate of the uncertainty in the profile factor (also referred to as the profile correction factor, or the meter factor) is available. [ ] The commissioning tests for the LEFM✓+, to be performed following its installation in the plant, will confirm that in fact, the time measurement uncertainties are within the bounding values used in this analysis. Trade Secret & Confidential Commercial Information

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2.0 SUMMARY

For Hope Creek Unit 1 Nuclear Generating Station, Revision 2 results are as follows:

1. The mass flow uncertainty approach is documented in Reference 3. The uncertainty in the LEFM✓+'s mass flow of feedwater is as follows:
   - Fully Functional LEFM✓+ system mass flow uncertainty is [ ]
   - Maintenance Mode LEFM✓+ system mass flow uncertainty is [ ]

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   [ ]

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2. The uncertainty in the LEFM✓+ feedwater temperature is as follows:
   - Fully Functional LEFM✓+ system temperature uncertainty is [ ]
   - Maintenance Mode LEFM✓+ system the uncertainty is [ ]

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3. The total thermal power uncertainty approach is documented in Reference 3 and Appendix B of this document. The total uncertainty in the determination of thermal power uses the LEFM✓+ system parameters and plant specific parameters, i.e., heat gain/losses, etc. and is as follows:
   - Thermal power uncertainty using a Fully Functional LEFM✓+ system is [ ]
   - Thermal power uncertainty using a Maintenance Mode LEFM✓+ system is [ ]

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   [ ]

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3.0 APPROACH

All errors and biases are calculated and combined according to the procedures defined in Reference 4 and Reference 5 in order to determine the 95% confidence and probability value. The approach to determine the uncertainty, consistent with determining set points, is to combine the random and bias terms by the means of the RSS approach provided that all the terms are independent, zero-centered and normally distributed.

Reference 4 defines the contributions of individual error elements through the use of sensitivity coefficients defined as follows:

A calculated variable P is determined by algorithm f, from measured variables X, Y, and Z.

$$P = f(X, Y, Z)$$

The error, or uncertainty in P, dP, is given by:

$$dP = \left.\frac{\partial f}{\partial X}\right|_{YZ} dX + \left.\frac{\partial f}{\partial Y}\right|_{XZ} dY + \left.\frac{\partial f}{\partial Z}\right|_{XY} dZ$$

As noted above, P is the determined variable--in this case, reactor power or mass flow-- which is calculated via measured variables X, Y, and Z using an algorithm f (X, Y, Z). The uncertainty or error in P, dP, is determined on a per unit basis as follows:

$$\frac{dP}{P} = \left\{\frac{X}{P}\left.\frac{\partial f}{\partial X}\right|_{YZ}\right\}\frac{dX}{X} + \left\{\frac{Y}{P}\left.\frac{\partial f}{\partial Y}\right|_{XZ}\right\}\frac{dY}{Y} + \left\{\frac{Z}{P}\left.\frac{\partial f}{\partial Z}\right|_{XY}\right\}\frac{dZ}{Z}$$

where the terms in brackets are referred to as the sensitivity coefficients.

If the errors or biases in individual elements (*dX/X, dY/Y, and dZ/Z* in the above equation) are all caused by a common (systematic) boundary condition (for example ambient temperature) the total error dP/P is found by summing the three terms in the above equation. If, as is more often the case, the errors in X, Y, and Z are independent of each other, then Reference 4 and 5 recommends and probability theory requires that the total uncertainty be determined by the root sum square as follows (for 95% confidence and probability):

$$\frac{dP}{P} = \sqrt{\left[\left(\left\{\frac{X}{P}\left.\frac{\partial f}{\partial X}\right|_{YZ}\right\}\frac{dX}{X}\right)^2 + \left(\left\{\frac{Y}{P}\left.\frac{\partial f}{\partial Y}\right|_{XZ}\right\}\frac{dY}{Y}\right)^2 + \left(\left\{\frac{Z}{P}\left.\frac{\partial f}{\partial Z}\right|_{XY}\right\}\frac{dZ}{Z}\right)^2\right]}$$

Obviously, if some errors in individual elements are caused by a combination of boundary conditions, some independent and some related (i.e., systematic) then a combination of the two procedures is appropriate.

4.0 OVERVIEW

The analyses that support the calculation of LEFM✓+ uncertainties are contained in the appendices to this document. The function of each appendix is outlined below.

Appendix A.1, LEFM✓+ Inputs

This appendix tabulates dimensional and other inputs to the LEFM✓+. The spreadsheet calculates other key dimensions and factors from these inputs (e.g., the face-to-face distance between pairs of transducer assemblies), which is used by the LEFM✓+ for the computation of mass flow and temperature.

Appendix A.2, LEFM✓+ Uncertainty Items/Calculations

This appendix calculates the uncertainties in mass flow and temperature as computed by the LEFM✓+ using the methodology described in Appendix E of Reference 1 and Appendix A of Reference 3[3], with uncertainties in the elements of these measurements bounded as described in both references[4]. Reference 5 provides a detailed comparison of the equations used in Appendix A of Reference 3 and this report. The spreadsheet calculations draw on the data of Appendix A.1 for dimensional information. It draws from Appendix A.4 for [

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Appendix A.3, Meter Factor Calibration and Accuracy Assessment

The calibration test report for the spool piece(s) establishes the overall uncertainty in the profile factor of the LEFM✓+. The elements of the profile factor uncertainty include [

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Appendix A.4, [ ]

[ ]

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Appendix A.5, [ ]

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Appendix B, Total Thermal Power and Mass Flow Uncertainties using the LEFM ✓+ System

The total thermal power uncertainty due to the LEFM✓+ is calculated in this appendix, using the results of Appendix A.2, A.4 and A.5. Plant supplied steam conditions (which enter into the computation of errors due to feedwater temperature) are used for this computation. This appendix also computes the fraction of the uncertainty in feedwater temperature that is systematically related to the mass flow uncertainty.

5.0 REFERENCES

1) Cameron Topical Report ER-80P, "Improving Thermal Power Accuracy and Plant Safety While Increasing Operating Power Level Using the LEFM Check System", Rev. 0.

2) Cameron Engineering Report ER-160P, "Supplement to Topical Report ER 80P: Basis for a Power Uprate with the LEFM System", May 2000.

3) Cameron Engineering Report ER-157(P-A), "Supplement to Cameron Topical Report ER-80P: Basis for Power Uprates with an LEFM Check or an LEFM CheckPlus", dated May 2008, Revision 8 and Revision 8 Errata.

4) ANSI/ASME Power Test Code 19.1-2013, Measurement Uncertainty.

5) Cameron Engineering Report ER-972, "Traceability Between Topical Report (ER-157P-A Rev. 8 and Rev. 8 Errata) and the System Uncertainty Report", Rev. 2, March 2012.

6) ASME Steam Tables, Sixth Edition.

7) ER-1132 Rev.1, "Meter Factor Calculation and Accuracy Assessment for the LEFMCheckPlus Meters at Hope Creek Unit 1", dated December 2016.

8) ALD-1164 Rev 2, Hydraulic Calibration Plan for Hope Creek Unit 1.

Appendix A

Appendix A.1, LEFM✓+ Inputs

Appendix A.2, LEFM✓+ Uncertainty Items/Calculations

Appendix A.3, Meter Factor Calibration and Accuracy Assessment

Appendix A.4, [ ]

Appendix A.5, [ ]

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Appendix A.1

LEFM✓+ Inputs

No attachment to follow as Appendix is Proprietary in its Entirety

Appendix A.2

LEFM✓+ Uncertainty Items/Calculations

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Appendix A.3

LEFM✓+ Spool Piece(s) Meter Factor Calculation and Accuracy Assessment

Reference Cameron Engineering Report ER-1132 Rev.1, "Meter Factor Calculation and Accuracy Assessment for the LEFMCheckPlus Meters at Hope Creek Unit 1", dated December 2016

Appendix A.4

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No attachment to follow as Appendix is Proprietary in its Entirety

Appendix A.5

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No attachment to follow as Appendix is Proprietary in its Entirety

Appendix B

Total Thermal Power and Mass Flow Uncertainty using the LEFM✓+ System

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