NRR-PMDAPEm Resource

From:	Holden, Leslie E.:(GenCo-Nuc) [Leslie.Holden@exeloncorp.com]
Sent:	Thursday, January 30, 2014 2:24 PM
To:	Wiebe, Joel
Cc:	Borton, Kevin F:(GenCo-Nuc); Gullott, David M.:(GenCo-Nuc)
Subject:	RE: Braidwood/Byron MUR Package for Proprietary and Factual Error Review - Part 2
Attachments:	20140130 MUR Package for Proprietary and Factual Error Review - Part 2 LEH.docx

Joel

Again, we appreciate you providing us the draft and also the opportunity to comment.

Based on our review this morning we would like to offer you the following comments for your consideration:

Pages 9 & 10/20 - Tempering flow is normally 40,000 lb/hr per loop (i.e., 160,000 lb/hr total based on 4 loops). During our troubleshooting, one tempering line at a time was isolated and correspondingly the LEFM/venturi flow was expected to increase by 40,000 lb/hr. This was validated for loops A. B and C (nearly identical decrease in each loops; i.e., the decrease in flow values between each of the loops was within <2,000 lb/hr of each other and close to 40,000 lb/hr/loop), however, when loop D tempering line flow was isolated, the LEFM/venturi flow increased by 46,000 lb/hr. Since the tempering line flow indication was 41,000 lb/hr before isolation, there was an approximately 5,000 lb/hr difference between expected and observed. Considering that the other three loops performed as expected, the total tempering line flow error of 5,000 lb/hr into a total feedwater flow of 16,000,000 lb/hr (4*40,000 lb/hr) results in an error of approximately 0.03% (5,000/16,000,000 = 0.0003). This error was much smaller than the observed shift in secondary parameters from May to September, 2011 (0.2%-0.3%) and as such it was not considered as a cause of the secondary parameter shift. [Reference EC 388706, "Byron Unit 1 Observation of Upward Trend in Secondary Parameters," (Section 4.6) that was provided during the audit.] {Provided similar comment in e-mail dated 10/9/13}

Page 15/20 - 2nd ¶ after table beginning "Estrada" – May want to consider restating or deleting or rewording the 3rd sentence; *"The **NRC staff does not understand** the rationale for fitting ARL data where MFs were less than one to a line where the MFs were greater than one."*

Page 19/20 - To clarify, Byron is going to continue to perform the detailed trending assessments through start-up and power ascension after the next outage (RFO B1R19), if the parameters remain consistent with each other during these changing conditions it will further validate that the parameters are properly trending with each other and then we will return to the normal monitoring and trending. Suggested wording is provided. We would like to clarify this since we do not intend to continue the detailed trending indefinitely.

These comments, as well as other minor editorial comments are indicated in "track changes" in Word "Review" mode on the attached. I had problem with the spell checking in this document and we noticed that there was a fair number of words misspelled, so I don't know if you have a better way of spell checking.

Please feel free to give me a call if you have any questions.

Thank you,

Leslie

Leslie E. Holden
Senior Regulatory Engineer
Power Uprate

Cantera Office
4300 Winfield Road
Warrenville, IL 60555
Office: 630 657 3316 | Cell: 630 291 7329 | Fax: 630 657 4300
Leslie.Holden@ExelonCorp.com www.ExelonCorp.com

From: Wiebe, Joel [mailto:Joel.Wiebe@nrc.gov]
Sent: Thursday, January 30, 2014 7:23 AM
To: Holden, Leslie E.:(GenCo-Nuc)
Subject: Braidwood/Byron MUR Package for Proprietary and Factual Error Review - Part 2

Leslie,

Here is Part 2 of the MUR package for Proprietary and Factual Error Review.

Joel

Hearing Identifier: NRR_PMDA
Email Number: 1083

Mail Envelope Properties (242AFBA318413548869FC73CD15D0EDA068DA3)

Subject: RE: Braidwood/Byron MUR Package for Proprietary and Factual Error Review - Part 2
Sent Date: 1/30/2014 2:23:47 PM
Received Date: 1/30/2014 2:24:35 PM
From: Holden, Leslie E.:(GenCo-Nuc)

Created By: Leslie.Holden@exeloncorp.com

Recipients:
"Borton, Kevin F:(GenCo-Nuc)" <kevin.borton@exeloncorp.com>
Tracking Status: None
"Gullott, David M.:(GenCo-Nuc)" <David.Gullott@exeloncorp.com>
Tracking Status: None
"Wiebe, Joel" <Joel.Wiebe@nrc.gov>
Tracking Status: None

Post Office: EXCHM-CCC-22.exelonds.com

Files	**Size**	**Date & Time**
MESSAGE	3536	1/30/2014 2:24:35 PM
20140130 MUR Package for Proprietary and Factual Error Review - Part 2 LEH.docx	124701	

Options
Priority: Standard
Return Notification: No
Reply Requested: No
Sensitivity: Normal
Expiration Date:
Recipients Received:

Other Thermal Power Calculation Considerations

Steam Moisture Content

Qualification 5 in the NRC Staff's August 16, 2010, SE states:

> An applicant assuming large uncertainties in steam moisture content should have an engineering basis for the distribution, of the uncertainties or, alternatively, should ensure that their calculations provide margin sufficient to cover the differences shown in Figure 1 of Reference 18 [Cameron ER-764, "The Effect of the Distribution of the Uncertainty in Steam Moisture Content on the Total Uncertainty in Thermal Power (ADAMS Accession No. ML100820167)].

In its June 23, 2011, submittal, the licensee states:

> The uncertainty associated with steam enthalpy due to moisture content for Byron Units 1 and 2 and Braidwood Units 1 and 2 respectively are ±0.0034%, ±0.0061%, ±0.0021%, and ±0.0044%. These values are based on actual in-plant moisture carryover tests. . . . these uncertainty values are relatively small in comparison to the other uncertainties associated with the power uncertainty calculation . . .

Based on the above, the NRC staff concludes that this qualification is not applicable to this application and that the steam moisture content meets the regulatory guidance in the NRC staff's SE dated August 16, 2010.

Deficiencies and Corrective Actions

The licensee identified its process for addressing Cameron deficiency reports as well as reporting deficiencies to the manufacturer. In each case Byron and Braidwood Stations will use their corrective action program. In the case of receiving deficiency reports, Byron and Braidwood Stations will document and address applicable deficiencies in its corrective action program as well.

Reactor Power Monitoring

Licensees should identify guidance to ensure that reactor thermal power licensing requirements are not exceeded. Proposed guidance was addressed by the NRC in a letter dated October 8, 2008 (ADAMS Accession No. ML082690105).

The NRC staff assessment provided in its October 8, 2008, letter and the licensee response to Criterion 1, as summarized in Section 3.1.1.1, Item D, above, provides an acceptable description to ensure operation consistent with the NRC staff guidance to prevent overpower operation. The NRC staff therefore concludes that the licensee's reactor power monitoring meets the regulatory guidance.

Uncertainty

The NRC staff provided an assessment that addressed uncertainty in Section 3.1.1.1, Item D, 3~~.~~, above. The following discussion provides supplemental information.

Cameron considers flow rate uncertainty associated with the test facility, measurement (including transducer installation), extrapolation from test conditions to plant operating conditions, modeling, and data scatter. The NRC staff's evaluation of these factors is discussed below.

Test Facility Uncertainty

The budgeted test facility uncertainty is consistent with past NRC staff evaluations. The NRC staff finds this uncertainty is acceptable.

Measurement Uncertainty

The licensee addresses uncertainty due to such contributors as thermal expansion; dimensions; temperature, pressure, and density determination; and transducer installation. The contribution of some of these contributors was evaluated in Section 3.1.1.1, Item D and Section 3.1.1.2 (this section), above. Based on its evaluations, the NRC staff concludes that measurement uncertainty is acceptably addressed.

Extrapolation Uncertainty

Although calibration tests were performed, they were conducted at room temperature. This resulted in Reynolds numbers about a factor of 10 less than would occur in the plant and an extrapolation is necessary to obtain an in-plant calibration factor. A positive aspect of the CheckPlus is that the calibration factor is close to one and small errors in the extrapolation do not significantly affect extrapolation accuracy. Another aspect is that the Check and CheckPlus characteristics permit an alternate extrapolation approach that is typically less sensitive to error than a Reynolds number extrapolation. This involves the flatness ratio (FR), which for the CheckPlus is defined as the ratio of the average axial velocity at the outside chords (chords 1, 4, 5, and 8) to the average axial velocity at the inside chords (chords 2, 3, 6, and 7) [1]:

$$FR = (V1 + V4 + V5 + V8) / (V2 + V3 + V6 + V7)$$

Where FR is a function of Reynolds number, pipe wall roughness, and the piping system configuration.

The effect of the configuration is evaluated in laboratory tests. The effect of Reynolds number is deduced from the fully developed flow inverse power law profile which may be written in several forms including the following:

$$\frac{V}{V_{max}} = \{X|R\}^{\frac{1}{n}}$$

where X = radial location, R = pipe radius, and the exponent *n* varies with Reynolds number and is determined from experimental data. The advantage of this approach is that a plot of FR versus calibration factor is linear and the calibration factor is insensitive to variation in FR. These results are consistent with analytic predictions and have been confirmed via ARL tests of many plant configurations. Further, minor changes in calibration factor observed in different hydraulics configurations are predictable and can be confirmed analytically. Therefore, if plant

[1] Details of this method are proprietary. This discussion is taken from the non-proprietary References T and U.

conditions result in a change in flatness ratio~~n~~ (FR), the calibration factor may be adjusted to reflect the change in the FR.

Cameron also uses swirl rate, defined as:

$$\text{Swirl Rate} = \text{Average}\left[\frac{V_1 - V_5}{2 - y_S}, \frac{V_8 - V_4}{2 - y_S}, \frac{V_2 - V_6}{2 - y_L}, \frac{V_7 - V_3}{2 - y_L}\right]$$

Where y_S and y_L are normalized chord locations for outside/short and inside/long paths.

Cameron also uses swirl rate to characterize behavior obtained during ARL tests.

The applicant provided experimental data of calibration factor as a function of FR and swirl rate for each of the CheckPlus instruments in Appendices A.3 to Appen~~i~~dices 8a-8d of the submittal.

Cameron includes an uncertainty term for extrapolation from laboratory conditions to plant conditions that is computed from empirical equations to account for change in Reynolds number and other effects such as a difference in pipe wall roughness. The calibration factor is shown to change in the fifth significant figure over a factor of ten change in Reynolds number between the test and plant conditions. With respect to extrapolation uncertainty, some of the uncertainty was likely already addressed by parametric testing over Reynolds numbers and FRs.

Based on the very small change in calibration factor between the test and plant conditions, as well as the parame~~n~~tric testing over Reynolds numbers and FRs, the NRC staff concludes that extrapolation uncertainty has been acceptably addressed.

Modeling Uncertainty

Cameron uses FR and swirl rate to characterize the velocity distribution and to validate the experimentally determined calibration factor when installed in a plant. Don Augenstein in a paper presented in September 2008 discussed application of calibration data obtained at ARL for 330 hydraulic configurations with 75 CheckPlus UFMs with an average calibration factor of 1.002 with a standard deviation of ± 0.0039.

Cameron discussed its experience in calibrating over 100 UFMs with 500 different test configurations since typically 4 or 5 configurations were tested for each UFM. An approach is discussed where different numbers of subsets of configurations were considered applicable to the licensee's installation and modeling sensitivity was computed using that information. Based on the small standard deviation and Cameron's calibration experience, the NRC staff concludes that the ~~the~~ licensee's use of Cameron's method for determining modeling uncertainty is acceptable.

Data Scatter Uncertainty

The precision with which the calibration factor is determined includes all calibration data for each CheckPlus and 95 percent confidence limits are calculated. The NRC staff concludes that the licensee's determination of data scatter uncertainty is acceptable because it is consistent with the method considered acceptable in the NRC staff's SE dated October 15, 2010.~~.~~

<u>Conclusion</u>

Based on the above evaluation, the NRC staff concludes that the licensee has adequately implemented topical reports ER-80P and ER-157P.

3.1.1.3 Evaluation of Trends for Byron, Unit No. 1

Introduction to and summary of NRC Audit and Licensee Response to Byron, Unit No. 1, LEFM vs. Plant Parameter Discrepancies

The LEFMs were installed at Byron, Unit No. 1 during refueling outage (RFO) B1R17. Following the outage, in late April 2011, poly acrylic acid (PAA) was injected to control SG crud buildup.[2] Multiple indications showed a rise in thermal power when thermal power was held constant by controlling via the LEFMs from May to September 19, 2011 (Byron, September 19, 2011.), and an extensive troubleshooting effort was initiated to investigate the discrepancy between the LEFMs and other multiple indications. The troubleshooting investigation was conducted by Exelon, Cameron, and Dominion Engineering and subjected to an in-depth review by MPR Associates, ILD Inc., and Dominion Engineering. Troubleshooting was completed in April 2012 (Borton, October 9, 2012, Attachment 2), and did not clearly identify the cause of the observed behavior. Byron, Unit No. 2, and the Braidwood units did not exhibit as large a discrepancy and no other plants had a similar discrepancy. The licensee reported that no other plants used PAA injection.

The NRC staff has audited the troubleshooting investigation and has conducted independent calculations based on data provided by Exelon and Cameron. One aspect of the trouble shooting was a determination that there was no significant deposit on the LEFM aperatures. The NRC staff did not accept the assumptions and analysis approach but confirmed the conclusion via independent analysis as discussed below.

On the basis of observed FR[3] data and the assumption that the power law or the modified Reichardt equation represented the flow profile, and study of operating data, the NRC staff determined that the effective change in CheckPlus calibration was less than 6×10^{-4} percent and therefore was negligible.

Estrada (March 2012), concluded that analyses from all elements of the LEFM algorithm were in the range of + 0.05 percent to + 0.079 percent, in the opposite direction of the postulated LEFM drift that would be consistent with the best estimate based on other plant variable trends that indicated a LEFM change of about - 0.4 percent. He also concluded that the difference between LEFM indication and the best estimate was within the root sum square of the ± 0.3 percent LEFM uncertainty and the best estimate uncertainty of ± 0.55 percent.

The average difference between the LEFM and other parameters that can be used to determine feedwater flow rate or thermal power was about 0.25 percent at the end of the increased difference that occurred from May, 2011 to September, 2011. Operating parameters from October, 2011 to May, 2013 established that differences had stabilized and were no longer increasing. The requested increase in thermal power corresponds to a power uncertainty of 0.37 percent, the calculated bounding value for system mass flow rate uncertainty was < 0.3 percent and the thermal power uncertainty was < 0.4 percent. The staff concluded that the

[2] Industry experience had shown that PAA could reduce iron oxide accumulation on secondary side SG surfaces and that it could remove previously deposited iron-based corrosion products from secondary plant surfaces.
[3] The CheckPlus determines average flow velocities along straight line paths of two lengths. FR is the ratio of the measured velocity via the shorter path to the measured velocity via the longer path. Flow rate is determined by multiplying each velocity by the flow area it is assumed to represent and correcting for the angle between the measurement and the direction of flow.

observed differences are smaller than the uncertainties that Caldon calculated that were part of the basis for the LAR. On this basis alone, the observed differences between LEFM and other plant indications are not sufficient to invalidate the feedwater flow rate indicated by the LEFMs. Further, the NRC staff concluded that the LEFMs are not affected by PAA injection and the observed deviation in thermal power and feedwater flow rates are not due to the LEFMs.

Examination of the data strongly indicates that the venturis are affected by PAA injection although the reasons are not clear nor are the differences between Byron, Unit Nos 1 and 2, fully understood.

Reasons for deviation in other plant parameters have been postulated by the licensee's troubleshooting team, but were not accepted by all team members and are not sufficiently supported to lead to firm conclusions.

Discussion

Information provided during an audit conducted at Cameron's headquarters on May 14, 2013, was that Byron and Braidwood are the only stations that use PAA injection in feedwater. Thus, Byron considered that there was a lack of data concerning possible impact of PAA on LEFM operation. With respect to FW venturis and steam flow rate indications, PAA was known to have an impact.

Byron initiated an extensive troubleshooting plan when an upward trend in secondary parameters occurred that indicated Byron, Unit No. 1, thermal power was increasing in contrast to LEFM indications that thermal power was constant. This included securing PAA injection for two months and injecting PAA at an increased concentration after that. Securing PAA was accomplished to see if the upward trend would be reversed. Increasing PAA concentration was to discern if accumulation of PAA or PAA byproducts occurred that would cause secondary parameters to reach a higher magnitude.

Observed power behavior

During the time between May 2011, and September 2011, Byron, Unit No. 1, was operated so that flow rate indicated by the LEFMs was essentially constant and other plant parameters indicated an increasing flow rate. The Byron observations of the effect on thermal power, and NRC staff estimates of the changes, were as follows:

Item	Percent Change	
	Byron	NRC estimate from Data
Impulse Pressure	0.21	0.20
First Stage Pressure	-	0.29
SG Steam Flow	0.20	0.25
LEFM Temperature	-	0.02
Pump Flow	0.23	0.20
RCS Differential Temperature	0.26	0.49[4]
Core Thermal Power	0.25	-
Venturi Thermal Power	0.27	-

[4] Hot leg streaming changes will influence this parameter and could cause significant error.

LEFM Thermal Power	0.01	-
LEFM Flow Rate	~0.05[5]	0.04

The largest change in the difference between flow rates occurred between the LEFMs and venturies. The correspondence of multiple indications of an increasing flow rate and thermal power with a close-to-constant LEFM indication raised questions regarding LEFM calibration drift and accuracy.

Byron troubleshooting program

Summary

The LEFMs were installed at Byron, Unit No. 1, during RFO B1R17 that ended in late April 2011. Following start-up, PAA was injected to control SG crud buildup. Multiple indications showed a gradual rise in thermal power when thermal power was held constant by controlling via the LEFMs from May to September 19, 2011 (Byron, September 19, 2011.), and Byron initiated an extensive troubleshooting effort to investigate the discrepancy. The troubleshooting investigation was conducted by Exelon, Cameron, and Dominion Engineering and subjected to an in-depth review by MPR Associates, ILD Inc., and Dominion Engineering. Troubleshooting was completed in April, 2012 (Borton, October 9, 2012 Attachment 2), and did not identify the cause of the observed behavior. Byron, Unit No. 2, and the Braidwood units did not exhibit as large a discrepancy and no other plants had a similar discrepancy.

Key results of Exelon's troubleshooting program and the NRC staff findings included the following:

- Cameron used many diagnostic indicators to conclude that there were no LEFM anomalies. It concluded that LEFM performance was within its design basis. The NRC staff agrees.

- PAA build-up or PAA byproducts on LEFM surfaces were determined not to be a cause. The NRC staff did not identify any phenomenon that would contradict this conclusion.

- No anomalies were identified where hydraulic impacts, secondary parameter instrumentation drift, erosion/corrosion, or calorimetric program errors were identified that would result in the observed secondary parameter drifts. The NRC staff identified some anomalies that were not explained and Cameron identified interactions that it posited could explain the behavior.

The licensee provided the following observations based on further study:

- A best estimate methodology based on five power system conversion measurements (secondary parameters) was used to calculate thermal power. Byron concluded that current thermal power was consistent with the previous two cycles that operated on the venturis at 100 percent power. NRC staff review of a comparison of indicated thermal power (ITP) versus Best Estimate Thermal Power (BETP) established the following:

    - BETP > ITP from April 2008 to Refueling Outage B1R17 in 2011.

[5] Cameron estimate of maximum bias (Ultrasonics, May 14, 2013).

- BETP < ITP in May, 2011 and gradually increased to equal ITP in September, 2011. Operation was with LEFM controlling IPT.

- BETP > ITP for several following months when operating under venturi control.

- BETP = ITP subsequently until February, 2012 when operating under LEFM control.

- Comparison with Byron, Unit No. 2, and Braidwood, Unit 2, startups in 2011, failed to show similar upward trends in secondary parameters. The NRC staff confirmed this conclusion by examining the data.

- Review of industry operating experience did not identify differences between LEFM and venturi indication that occurred at Byron 1.

- Byron found no significant issues or errors in inputs to the plant calorimetric that would result in the observed drifts.

- Byron did not identify any power plant failure mechanisms that would explain the drifts.

With regard to the last two items, the NRC staff notes that Cameron believes it identified reasons for drifts in steam flow rate and venturi behavior. The Cameron conclusions and additional unexplained anomolies identified by the NRC staff are discussed below.
NRC staff review of operating parameters from October 2011 to May 2013, established that differences had stabilized and were no longer increasing. This is important because it eliminates a potential concern that continued drift could raise questions regarding LEFM operating outside its uncertainty limits.

Discussion of selected aspects of troubleshooting program

The licensee's troubleshooting investigation was described in its submittal dated October 9, 2012, and updated during an audit conducted at the Cameron offices on May 14, 2013. Potential failures, licensee conclusions, and NRC staff evaluations (**in bold to differentiate from licensee discussion**) were as follows:

(1) "Installation configuration results in hydraulic impacts causing the LEFM to read lower than actual."

- There were no significant differences in piping configurations between trains and UFM installation was consistent with specifications.
- There were no upstream obstructions that could affect the LEFMs

Review complete and determined not to be a cause.

(2) "Plant process computer (PPC) interface to LEFM is causing errors in the data."

- LEFM flow indication was determined to be accurately communicated to and displayed on the PPC.

- Modeling of programs and flow calculations to handle net flow and tempering line flows were determined to be correct. **See Item (6), below.**

Review complete and determined not to be a cause.

(3) "LEFM problem causing erroneous readings."

- Commissioning changes such as software changes; cable lengths; and alarm, hydraulic, and setup configurations were determined to not significantly affect LEFM readings.

- No significant differences were found between trains or with respect to Alden Labs test results. **The NRC staff notes that Train B FR [flow regulator], decreased from May to September, 2011, whereas Trains A, C, and D, increased. This difference has not been explained beyond an observation that the changes are within expectations and do not significantly affect meter fac~~a~~tor (MF). The overall effect is to decrease change in the average FR and change in the already small MF change when the four loops are averaged. The NRC staff concluded that this does not change the conclusions in this SE.**

- Environmental conditions were within specifications.

- Operating experience (OE) review found no new applicable information.

- Power supplies were within specifications.

- Pressure and temperature inputs have not drifted which eliminates bad sensor input as a cause.

- No significant integration errors were found with internal integration.

- Evaluation of transfer to ~~V~~venturi control and observance of trends to identify potential LEFM problems did not identify errors.

Byron concluded that no anomalies were identified and this failure mode was not a cause.

(4) "Venturi calibration or drift issue is causing the d~~e~~iscrepancy."

- Byron stated there were no unexplained drifts or deviations. **The NRC staff observed that there were unexplained differences between venturi and other indications. It also observed that venturi differential pressures for A, B, and D, decrease by about one inch from May to September 2011, while C increased by the same amount. The licensee provided information during the audit that venturis were known to be affected by PAA injection (see Item (5), below). Cameron and the NRC staff reached the same conclusion.**

- No secondary calibrations of the flow elements or correction factors have been applied to the venturi~~e~~s that would cause large bias or uncertainty.

- No significant diverging trends were found in the LEFMs compared with other balance of plant (BOP) parameters. **Diverging trends were evident from the plant data. The key is whether or not they were significant. This is addressed below in the conclusion to this section (3.1.1.3).**

- Venturi bypass flow has been stable and there are no gaps to allow bypass flow. **The NRC staff concludes that this is an important consideration. Tempering flow does bypass both the LEFMs and venturis and is further addressed in (6), below.**

- Newly developed discharge coefficients were correctly implemented and the discharge coefficient extrapolation method was determined not to be in error.

Byron concluded that no anomalies were identified and this failure mode was not a cause.

(5) "External interaction with venturi/LEFM spools by either PAA or erosion/corrosion."

- PAA injection was expected to cause an indicated 0.2 percent increase in flow rate indicated by the venturi~~e~~s. An uncertainty of 0.3 percent was added to the calorimetric to compensate for the increase. Byron concluded that the impact on the venturi~~e~~s did not change. Further, it stated that PAA injection was not expected to affect the LEFMs. **This is addressed further below in the section titled: "Effect of changing PAA injection concentration."**

Byron concluded that no anomalies were identified and this failure mode was not a cause.

(6) "Calorimetric input or program fault."

- FW flows, SD flow, FW temperature, and steam temperature, and steam pressure calorimetric inputs were verified as correct. However, two issues were identified:

- Tempering lines normally are expected to pass about 40,000 lbs/hr/loop [pounds per hour per loop] of FW flow that bypasses the LEFMs and venturis. These lines were isolated with the expectation that measured feedwater flow would increase by something less than 2000 lbs/hr per loop. This occurred in three feedwater loops but the Loop D difference was 5000 lbs/hr. Byron stated that this anomaly would represent a 0.03 percent change in thermal power and would not be the cause of the observed drifts in secondary parameters.

  The NRC staff observes that the expected increase in total measured feedwater flow was 8000 lbs/hr. Byron calculated the 0.03 percent change from 5/16,000 = 0.0003. Feedwater flow rate is about 16 X 10^6 lbs/hr and the Byron calculation is consistent with 5000 / 16 X 10^6. 40,000 / 16 X 10^6 = 0.003 ≡ 0.3 percent = percent of feedwater flow that is normally understood to be bypassed. Since bypass flow is measured, the NRC staff understands it is included in the heat balance, and presumably bypass flow was equal in each of the four loops prior to isolation, the unexpected behavior should not impact

the heat balance unless there is an unidentified flow path or the flow measurement is in error.

The normal tempering flow in Loop D should have been about 10,000 lbs/hr. Isolation was expected to result in an increase in measured feedwater flow of 2000 lbs/hr, not 5000 lbs/hr. This may imply that tempering flow was significantly greater than 10,000 lbs/hr and not negligible with respect to the plant heat balance.

The NRC staff concludes that this does not change the conclusions of this SE as discussed in the conclusion of this section (3.1.1.3).

- SG blowdown flow was isolated with the expectation that feedwater flow rate indicated by the venturis and the LEFM would decrease by the same amount. Most loops showed a nearly identical decrease of < 2000 lbs/hr but Loop B changed by 10,000 lbs/hr. Byron concluded that this change would have a conservative impact of core thermal power, not the non-conservative impact that was observed.

  The NRC staff comments in the case of tempering flow directly above apply to the blowdown flow anom~~o~~aly.

- Program was reviewed against plant parameters and verified to correctly calculate thermal power.

  Byron concluded that this failure mode was not a cause. **The NRC staff does not accept this conclusion because of the tempering and blowdown flow anom~~o~~alies described above. The NRC staff concludes that this does not change the conclusions of this SE as discussed in the conclusion of this section (3.1.1.3).**

<u>Effect of changing PAA injection concentration</u>

The PAA was injected following startup from RFO B1R17 in late April 2011, until November 2011. The venturis and other secondary side parameters that can be related to thermal power showed a linear increase relative to the LEFMs from May 2011, until September 2011, while the LEFMs were used to control FW flow rate and thermal power to a steady state. A power reduction then occurred after which the venturi to LEFM ratio appeared to stablize at a value slightly larger than before the reduction. PAA injection was stopped for two months starting in November 2011. Within a day of stopping PAA, the venturi indication decreased relative to the LEFMs. There was no further change in the difference between the venturis and LEFMs while PAA was stopped. Upon re-initialization of PAA, the venturi indication increased by about 0.15 percent in less than a day relative to the LEFM; a reversal of the behavior when PAA was stopped.

The PAA injection rate was increased in Byron, Unit No. 1 in February 2012. With one exception, there was no change in the venturi to LEFM comparison through mid-March 2012. The exception was a short time when PAA injection stopped. During this time, the ratio changed as described in the above paragraph.

PAA injection was increased in Byron, Unit No. 2, in February 2012. LEFM and venturi tracked closely into March 2012, with a slightly closer correspondence in March. This convergence was

Comment [LEH1]: Tempering flow is normally **40,000 lb/hr per loop** (i.e., 160,000 lb/hr total based on 4 loops). During our troubleshooting, one tempering line at a time was isolated and correspondingly the LEFM/venturi flow was expected to increase by 40,000 lb/hr. This was validated for loops A. B and C (nearly identical decrease in each loops; i.e., the decrease in flow values between each of the loops was within <2,000 lb/hr of each other and close to 40,000 lb/hr/loop), however, when loop D tempering line flow was isolated, the LEFM/venturi flow increased by 46,000 lb/hr. Since the tempering line flow indication was 41,000 lb/hr before isolation, there was an approximately 5,000 lb/hr difference between expected and observed. Considering that the other three loops performed as expected, the total tempering line flow error of 5,000 lb/hr into a total feedwater flow of 16,000,000 lb/hr (4*40,000 lb/hr) results in an error of approximately 0.03% (5,000/16,000,000 = 0.0003). This error was much smaller than the observed shift in secondary parameters from May to September, 2011 (0.2%-0.3%) and as such it was not considered as a cause of the secondary parameter shift. [Reference EC 388706, "Byron Unit 1 Observation of Upward Trend in Secondary Parameters," (Section 4.6) that was provided during the audit.]

Comment [LEH2]: Based on our above comment we would appreciate this be reconsidered.

more pronounced when compared to other plant parameters with an initial relative correspondence of about 0.998 and a March correspondence of 0.999.

The NRC staff concludes that the above venturi behavior with variation in PAA injection is a clear demonstration that PAA affected the Byron 1 venturis.

Several investigators concluded that PAA had no impact on the LEFMs. The NRC staff finds this conclusion acceptable based on stable LEFM behavio~~u~~r.

Best estimate (BE) comparisons

A BE methodology can be developed that combines independent variables on the basis of including their individual uncertainties as weighting factors to obtain an estimate with an uncertainty that is less than any of the individual variables. Three BE methodologies were developed by different investigators and applied to compare indicated thermal power to BE thermal power from April 2008, to February, 2012. From 2008 until RFO B1R17 indicated power was less than BE power, a comparison that continued following RFO~~-~~ B1R17 until LEFMs were used to control thermal power. At this time, LEFM thermal power reversed and was greater than BE thermal power. The two then converged until September 2011, when power control was changed to the venturis and the pre-RFO B1R17 behavior was observed. A change back to LEFM control resulted in close correspondence that continued into February 2012, when the Byron report comparison terminated.

Assessment of LEFM

The NRC staff independently examined aspects of the observed behavior. This examination is summarized below.

Dimensional information

(Spadaro, July, 2010) provided drawings of the ARL configurations that specified spool piece dimensions and Cameron provided tolerances and as-built dimensions during the May 14, 2013, audit that established that the as-built LEFMs were within tolerances. As-buil~~d~~t wall thicknesses were measured in May 2010, and again in March 2012, following 11 months of operation (Estrada, March, 2012). Neglecting measurement uncertainty, Cameron calculated that the change would introduce a net change in internal diameter of – 0.024 percent and a flow error of + 0.012 percent (Ultrasonics, May 14, 2013). Dimensional changes are not a likely cause of the observed behavior.

Effect of deposit in transducer apertures

Estrada reported that the drift from May 2011, to November 2011, due to a postulated corrosion layer in the apertures was ruled out on the basis of measurements that established that there was little wall thickness change and a rationale that a small deposit on aperture walls "is not sufficiently thick to transmit acoustic energy and, therefore, not capable of altering the effective sound velocity in the aperture."

The NRC staff does not agree with Cameron's rationale. First, Cameron concluded that evidence of little change in spool piece diameter established that there was no deposit on the spool piece walls and, therefore, there was no deposit in the apertures. While the NRC staff agrees that there was no significant change in diameter based on the measurements, this is not justification regarding deposits in the apertures. It is possible for a deposit to form in the apertures while the spool piece walls remain deposit-free. While Cameron's conclusion that a small deposit on the aperture walls is not thick enough to transmit acoustic energy may be correct, this does not address the effect of a deposit on the aperture window that reduces the measured time from one transducer to another due to decrease in transmission distance and the change in velocity of sound between water and a deposit in the volume where the deposit displaced water.

Assuming a deposit affects all apertures equally, the Cameron LEFM can indicate the effect of a deposit on the transducer housings in the apertures because there will be a larger effect on the measured short path sound velocity in comparison to the long path sound velocity. This can be expressed in terms of the "flatness ratio," FR, defined by the following equation:

$$FR = \frac{V_1 + V_4 + V_5 + V_8}{V_2 + V_3 + V_6 + V_7}$$

where V_1, V_4, V_5, and V_8 are velocities measured along the outside chords (the short paths) and V_2, V_3, V_6, and V_7 are velocities measured along the inside chords (the long paths)

A change in FR can be approximated by the following equation:

$$\frac{y_s'}{y_l'} = \frac{y_s}{y_l} + \Delta FR$$

where: y_s = short path length
y_l = long path length

and the prime indicates the new path length.

If an effective deposit thickness, x, increases on the transducer window surfaces that is identical on all windows and has the properties of water, then:

$$y_s - y'_s = 2x \qquad y_l - y' = 2x$$

and:

$$y_s - y'_s = y_l - y'$$

so that:

$$y_l' = \frac{y_s - y_l}{\frac{y_s}{y_l} + \Delta FR - 1}$$

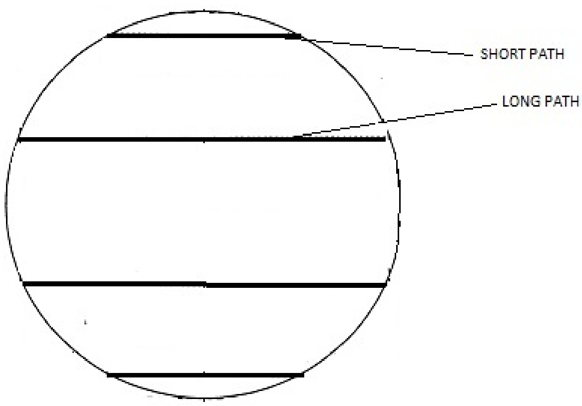
Estrada provided FR changes during a seven month period starting in May, 2011. Using these data, the NRC staff estimated the predicted thickness changes would change flow rate by less than 0.01 percent, in agreement with Cameron's conclusion. This is not a likely cause of the observed behavior.

Effect of flatness ratio (FR) change on meter factor (MF)

FR, as discussed above, is defined as:

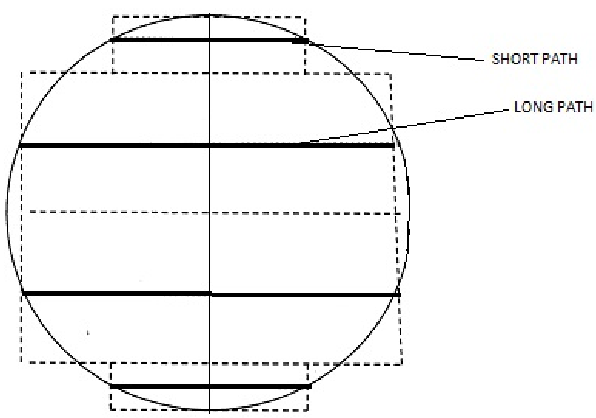
$$FR = \frac{V_1+V_4+V_5+V_8}{V_2+V_3+V_6+V_7} = \frac{V_S}{V_L}$$

where V_1, V_4, V_5, and V_8 are velocities measured along the outside chords (the short paths), V_2, V_3, V_6, and V_7 are velocities measured along the inside chords (the long paths), V_S is the mean short part velocity, and V_L is the mean long path velocity. The paths are illustrated by the horizontal lines in the following figure that correspond to the paths between the CheckPlus transducers[6]:



FR can be determined experimentally, such as by testing at ARL where the CheckPlus will provide the velocity data.

Once the V's are determined, the flow rate determined by the CheckPlus can be calculated by multiplying the rectangular vertical widths (weighting factors) indicated in the following figure by the dash lines by the corresponding velocities times two:



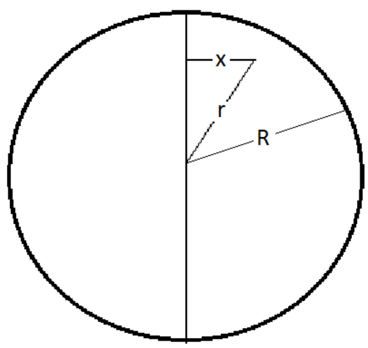
---

[6] Measurements are at an angle with respect to pipe length. Velocities are translated into this configuration for calculation purposes.

Cameron uses the same weighting factors for all of its nuclear applications. As is demonstrated below, this does not appear to be consistent with theoretical analyses when FR is compared to MF in an analysis of the ARL data obtained with the Byron, Unit No. 1, LEFMs.

Once the CheckPlus flow rate has been calculated, MF can be determined by comparing the CheckPlus flow rate to the experimentally determined data.

FR and MF can also be calculated using an assumed symmetric velocity distribution that is a function of pipe radius, expressed as V(r), where r is the reduced radial position with the origin at the pipe centerline and $0 \leq r \leq 1$. Since the CheckPlus determines a mean velocity along the path, the calculation must be based on the same path, as illustrated by the "x" dimension in the following figure:



where the mean velocity is calculated by 1/X where x= X at r = R and V(x) is determined from the assumed V(r) where the relationship between x and r is obtained from the geometry illustrated in the figure.

The calculations define MF as the flow rate calculated by 2π divided by the calculated LEFM flow rate obtained by two times over the short and long path lengths multiplied by the corresponding weighting factors.

Spadaro described the velocity profile by the power law:

where V is the velocity normalized to the maximum value, and n is a function of Reynolds number and pipe roughness that changes the shape of the profile. FR and MF were calculated using an Excel spreadsheet with the calculation based on dividing the dimension spans into 1000 increments to provide an accurate calculation that addresses profile changes near the LEFM wall. The NRC staff used the same approach except it assumed the increment size was ten times smaller in the last 20 steps near the wall, a total of 1018 increments. The NRC staff assessed the calculation accuracy by changing the number of increments with the results summarized in the following table for a typical FR where the comparisons were obtained using the NRC staff methodology:

Nominal number of increments	Calculated relative short path velocity	Calculated relative long path velocity	Calculated relative FR	Calculated relative MF
1000	1.0000	1.0000	1.0000	1.0000
500	1.0000	1.0000	1.0000	1.0000
250	1.0001	1.0001	1.0000	1.0001

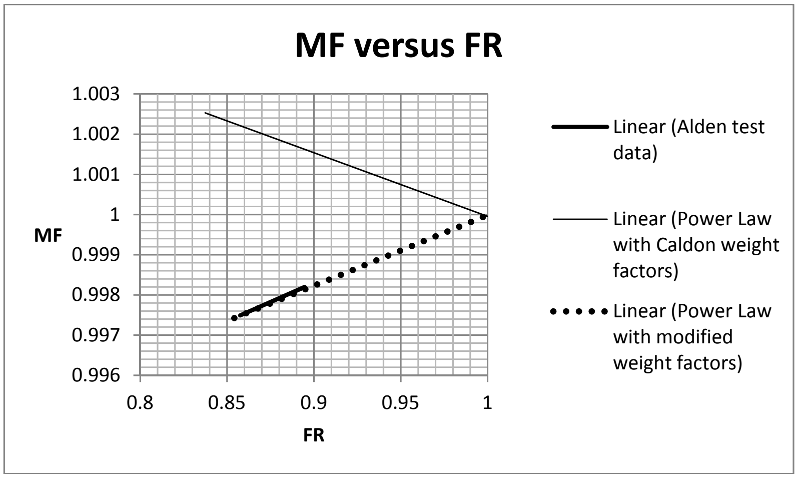
Clearly, the calculations using 1000 increments do not introduce a significant numerical error.

Estrada (Estrada, January 2002), used the power law and weighting factors determined by Caldon to calculate MF as a function of FR and found that the calculations could be fitted by a straight line. All MF's were greater than one for FR < 1 and the results converged to MF = 1 at FR = 1. The NRC staff does not understand the rationale for fitting ARL data where MFs were less than one to a line where the MFs were greater than one. The comparisons are illustrated below as well as the NRC's conclusions as to the significance of the different approaches.

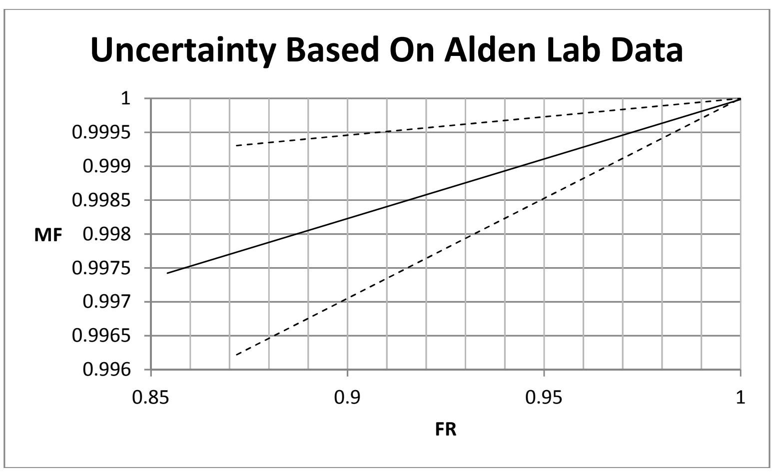
Comment [LEH3]: Joel, do you really want to put this in that the NRC staff does not understand?

Each of the four CheckPlus LEFMs installed at Byron, Unit No. 1, was tested at ARL. There were three test piping configurations in addition~~al~~ to a configuration to model the plant installation for each CheckPlus. More than one flow rate was included in each configuration test. The configuration variations were, for example, to introduce swirl to bracket any variations that would be encountered in the plant. The test report (Spadaro, July 2010), provided FR versus MF for each of the 16 test configurations. All MF's were less than one yet, as stated above, the results were plotted on Estrada's straight line where the line is limited to MF > 1. This was achieved by offsetting the MF for each meter such that the average MF was on the predicted curve. The off-set "data" correspondence to the straight line was an excellent fit. Caldon explained that the purpose of this work was to illustrate the dependence of MF on FR and, in this case, the change was small, as is discussed below.

In contrast, the NRC staff calculated MF behavior using the power law and the Caldon weighting factors and compared it to a straight line fit of the Alden Labs test results for the four LEFMs installed at Byron 1. The comparison is shown in the following figure where the upper solid line is the calculation and the lower solid line is a straight line fit to the data. There is effectively no correspondence. The NRC staff also modified the weighting factors so that the power law reproduced the mean MF and FR of the 16 ARL test results and, using the modified weighting factors, repeated the calculation to obtain the dash line. The fit of the power law to the data line is excellent.



The above calculations were based on nominal test values without considering the ARL flow rate uncertainty. There is significant scatter in the 16 data points, in part due to testing different configurations to bracket possible variations introduced in the plant installation. Simply obtaining the standard deviation, σ, without considering variation in FR, approximating uncertainty as two times σ, and applying the uncertainty at the mean FR of the data provided the following approximation of the data scatter. Note that the upper extreme never reaches



MF = 1 except at FR = 1 in contrast to the Caldon extrapolation of the data to the Caldon calculation that Caldon used to evaluate MF sensitivity. Further note that Caldon's approach results in a reduction in MF with increasing FR whereas the Alden data establishes that MF increases with increasing FR. In contrast, the absolute magnitude of the MF changes is identical due to the mirror image of the two calculations with respect to MF = 1.

The NRC staff used it's Excel spreadsheet to calculate the velocity distributions and effect on MF that corresponded to the observed FR's provided by Estrada for the May 2011, to November 2011, FR's. The NRC concluded that, regardless of which approach is used (which changes the curve that applies), the change in FR that occurred between May and September 2011, is predicted to introduce a maximum change in MF of about 6 X 10^{-6} which is negligible. Stated differently, the NRC staff concluded that the CheckPlus calibration is not calculated to have changed by more than about 6 X 10^{-4} percent. Further, an important consideration for determining the significance of Byron Unit ~~2~~1 trend is that the test data included the expected plant configuration and modifications that caused swirls that were greater than observed during plant operation. The NRC therefore concludes that Byron Unit ~~2~~1 trend was not significant and does not impact the conclusions of this SE.

Effect of thermal expansion

The NRC staff concludes that the coefficient of thermal expansion is a multiplier on both the numerator and denominator in calculation of MF and therefore thermal expansion has no effect on MF assuming there are no other effects that perturb the calculation.

Effect of a change in speed of sound of FR

The NRC staff concludes that a change in the speed of sound affects the numerator and denominator equally and, therefore, has no effect on FR assuming there are no other effects perturbing FR.

Coherent noise

Cameron investigated the interaction of coherent noise that can interact with the acoustic signals and can affect~~t~~ transit time measurements. Cameron concluded that coherent noise did not account for the LEFM trend in comparison with other plant parameters. The NRC staff finds this conclusion acceptable based on the Cameron investigation.

LEFM conclusions

The licensee did not identify any cause of a change in LEFM characteristics that would indicate a significant measurement error was caused by the LEFMs. Based on the NRC Staff's independent review discussed above, the NRC staff concludes the licensee's evaluation acceptable. Based on the information in this section, the NRC staff further concludes that the LEFMs are not affected by the PAA and LEFM characteristics remain within the initially established uncertainty bounds.

Cameron's examination of other indicators of flow rate[7]

Thermal power increased by about 0.5 percent from May 2011, to September 2011, by using the LEFM indications for control. Thus, for discussion purposes, thermal power based on LEFM indications may be treated as constant when assessing other parameters that may be used to determine thermal power. During this time, venturi flow, turbine pressure indicators, and total steam flow all indicated that thermal power was increasing at a greater rate. The venturi~~e~~s indicated a rate increase larger than the other indicators. Consequently, the NRC staff concludes that either the LEFM or the other indicators were providing erroneous information.

[7] Discussion based on information provided in the May 14, 2013 audit (Ultrasonics, May 14, 2013) unless otherwise stated.

As discussed above, no cause was identified that would change LEFM characteristics such that a significant measurement error would result. The NRC staff therefore concludes that the other parameters changed.

Venturis

The venturis are located downstream of the PAA injection location. Cameron stated that PAA is a dispersant that leads to a feed stream that contains collioidal corrosion products. These can be electrochemically attracted to the stainless steel surface in the venturi throat since the high throat velocity sweeps away the neutralizing free electrons. Cameron stated that this causes ven~~r~~turi fouling that, in turn, makes the venturis indicate a flow rate that is higher than actual.

Cameron also identified that PAA interaction that affected venturi calibration was observed before LEFM installation and pointed out that a brief cessation of PAA injection led to an immediate shift of 2 percent in indicated ven~~r~~turi flow indication relative to all other indicators of feedwater flow rate.

Cameron concluded that PAA changed feedwater calibration by approximately 3 percent or more and could explain the observed discrepency between the LEFM and venturi flow rate indications.

The NRC staff observed that there were differences between venturi indications. However, when each venturi flow rate was compared to the corresponding LEFM flow rate, all venturis exhibited a similar upward trend with approximately the same slope from May to September 2011. Based on the above the NRC staff concludes that the Cameron conclusions are acceptable.

Turbine pressure indicators and m~~e~~ain steam flow

There are two water paths to the SGs, FW flow that is measured by the LEFMs and venturi~~e~~s, and tempering flow that is also measured but bypasses the LEFMs and venturis. Tempering flow rate was approximately one percent of feedwater flow rate during the comparison period and was stated to be constant. As identified in (6), above, an anomaly related to the tempering flow was identified. However, the anomaly does not impact the conclusions of this SE.

There are two flow paths that exit the SGs, main steam flow, and blowdown flow. SG steam flow is therefore equal to tempering flow plus main feed flow minus blowdown flow. Blowdown flow rate is measured and was about 0.5 percent of total flow into the SGs during the comparison period. As identified in (6), above, an anomaly related to the blowdown flow was identified. However, the anomaly does not impact the conclusions of this SE.

Most of the steam flow enters the turbine with about 5 percent entering the second stage reheater. Cameron stated that there was no evidence that steam flow to the second stage reheater changed significantly as a fraction of total steam flow. Changes in SG steam flow in the comparison period were stated to be less than 0.1 percent.

First stage pressure is a measure of vapor flow rate and Cameron stated that, for practical purposes, is not affected by change in moisture content. Therefore Cameron concluded that if FW, blowdown, and tempering flow rates are constant, a decrease in steam moisture will increase vapor flow rate and first stage pressure. Cameron also stated that, “Because the steam flow and first stage pressure instruments respond differently to changes in moisture content, their indications can be used to estimate trends in moisture content." It also stated that changes in differential pressure across steam flow nozzles and first stage pressure "can be used to calculate the change in moisture carryover." A Cameron moisture trend calculation showed a moisture decrease "approximately equal to the discrepancy between turbine flows and LEFM flow."

Cameron concluded that:

- "The process change in moisture carry-over is the most plausible explanation consistent with all of the data."
- "The change in moisture carry-over should be expected given the effects intended with the PAA addition."
- "The investigation is therefore complete."

The NRC concludes that this is plausible because PAA caused a steam pressure increase "apparently due to removal of corrosion products from the SG tube surface" and "reduction of deposits on separator cans by a similar mechanism could lead to a reduction in moisture."

Recent plant characteristics

The PAA was restored in January 2012, during steady state operation after an extended period when PAA was not injected. Exelon provided data normalized to one after an initial transient that followed re-initiation of PAA. Upon re-initiation, steam flow indication immediately decreased by 0.5 percent and venturi indication increased by 0.16 percent before reaching a relative value of one while LEFM, best estimate core thermal power, impulse pressure, and MWt were unchanged. Although there were numerous power transients following re-initiation, indications that apply to flow rate remained consistent after the initial transient until the plant was shut down for RFO B1R18 in August 2012. The licensee identified that a divergence in steam mass flow rate occurred previously when PAA was isolated and an upward trend occurred that was attributed to likely occurrence of new deposits on secondary steam separator surfaces or the SG outlet nozzle venturi surfaces. These deposits were postulated to have cleared when PAA was restored in January 2012. The NRC staff considers this experience as supporting a conclusion that PAA affects both SG flow rate and venturi indication. Further it observes that PAA caused indicated SG flow rate to decrease and venturi flow rate to increase. The former is opposite to the 2011 behavior and twice as large whereas the venturi indicated flow rate change is essentially identical to the change that occurred in 2011. In both of these cases, the change was immediate in contrast to the change that occurred over several months from May to September in 2011.

After startup following RFO B1R18 in October 2012, until May, 2013, the parameters were essentially unchanged during full power operation. This indicated that whatever was causing the parameter divergence was no longer occurring. The licensee stated that it plans to continue to perform detailed trending assessments through start-up and power ascension following RFO B1R19 to further validate that the parameters continue to consistent with each other.

Comment [LEH4]: Leaves indefinite. What did we actually say?

Conclusion

As summarized, above, the average difference between the LEFM and other parameters that can be used to determine feedwater flow rate or thermal power was about 0.25 percent at the end of the increased difference that occured from May 2011, to September 2011. Operating parameters from October 2011, to May 2013, established that differences had stabilized and were no longer increasing. The requested increase in thermal power corresponds to a power uncertainty of 0.37 percent, the calculated bounding value for system mass flow rate uncertainty was < 0.3 percent and the thermal power uncertainty was < 0.4 percent. The observed differences are smaller than the uncertainties that Caldon calculated that were part of the basis for the LAR. On this basis alone, the NRC staff concluded that the observed differences between LEFM and other plant indications are not sufficient to invalidate the feedwater flow rate indicated by the LEFMs. Further, based on its review, the NRC staff concludes that the LEFMs are not affected by PAA injection and the observed deviations in thermal power and feedwater flow rates are not due to the LEFMs. As a result, the NRC staff further concludes that the anomalies noted and the NRC staff disagreement with specific methods and conclusions of the licensee's troubleshooting efforts, do not impact the conclusions of this SE and do not impact the NRC staff's conclusions in its August 16, 2010, SE.~~.~~

Based on the examination of the data the NRC concludes that the venturis are affected by PAA injection although the reasons are not as clear nor are the differences between Byron, Unit Nos 1 and 2, fully understood. Reasons for deviation in other plant parameters have been postulated but these are not accepted by all licensing personne~~a~~l and are not sufficiently supported to lead to firm conclusions. Since the venturi~~e~~s are affected as well as other plant parameters, but not the LEFMs, the conclusions in this SE are not impacted.

3.1.1.4 Conclusion

The above review covers the aspects of the requested 1.63 percent MUR thermal power uprate that are specific to the CheckPlus installations. Based on the above, the NRC staff concludes that the requested MUR thermal PU of 1.63 percent is acceptable with respect to the CheckPlus installations.