Release all - no proprietary markings, no indication that it was submitted under 2.390

## 6. Condition Statement

Since initial AMAG testing was performed in May 1999, when implemented, there has been an observed difference in major plant parameters between Byron and Braidwood. The following major plant parameters indicate higher at Byron than Braidwood: Condensate Boost Pump flow, Heater drain pump flow, main feedwater pump flow, sum of condensate boost and heater drain pump flow, high pressure turbine impulse pressure, all high pressure turbine extraction steam pressures, final FW temperature, RCS delta Ts, electrical MWe, and AMAG correction factor. Each of these parameters will indicate higher at increased feedwater flow rates. Byron Station has previously determined this difference in plant operation was acceptable.

Following power uprate implementation, additional parameters suggested a difference between Byron and Braidwood. These parameters are: flow passing capability of 2 sets of HP turbines, pre and post MWe verification tests, and Siemens (main turbine vendor) evaluations. The Byron thermal performance engineer thinks these parameters indicate Byron is operating at higher feedwater flow rates than Braidwood. CR 91771 was initiated to document the thermal performance engineer's concern with the AMAG flow measurement system. The consequence of a feedwater flow metering error is the potential to exceed the station's licensed thermal power level (if the AMAG system indicates lower than actual flow) or lost generation and a non-conservative calculated RCS flow (if the AMAG system indicates higher than actual flow).

## 7. Event Description

AMAG (Advanced Measurement and Analysis Group) ultrasonic feedwater flow testing was performed at 8 of the 10 COMED nuclear generating units during April and May of 1999. Due to the large deviation from plant indicated feedwater flow at Byron and the more than 1% difference between Byron and Braidwood, an evaluation of plant data (Byron letter #99-0109) was performed by the Byron Thermal Performance Engineer in an effort to validate one of the main feedwater flow measurement systems (FW Flow venturies or AMAG). The plant evaluation focused on indications of water flow, steam flow, generator output, RCS/Core parameters and industry experience. The conclusion of that report was as follows: "Due to instrument accuracy and other conflicting data, it is not possible to determine if the Byron or Braidwood units are currently operating at 100%, 99%, or 98% reactor power. However, if the AMAG test results are implemented, plant parameters will indicate the Byron units will be operating at a 1% higher thermal power than the Braidwood units. This is based on the higher indication of water and steam flow through the secondary system, RCS Delta Ts and flows, Mwe indication, and industry experience."

The AMAG results were not implemented immediately due to the above concerns. During the remainder of 1999 there were several different reviews of station data. In January 2000 the various reviews were gathered and summarized into a Byron position document. This document contained much of the information contained in Byron letter 99-0109 and additional information from a Stone and Webster review, MWe assessment of Byron/Braidwood performed by corporate thermal performance engineer, reactor core burn up information, and input from other corporate sources. The conclusion of this document was that there was not enough evidence to refute a primary flow measurement standard like AMAG. Based on this document, Byron Station management decided to implement the AMAG system.

Following the power uprate implementation in 2001, additional station parameters suggested there was a real difference in main feedwater flow rate between Byron and Braidwood. The additional parameters were: 1. Flow passing capability of the new (and old) high pressure turbines 2. MWe generation 3. statements and evaluations performed by the turbine vendor. This prompted the initiation of CR 91771.

An independent review of Byron and Braidwood station data was performed by Mid Atlantic ROG engineers to identify the most apparent cause for the difference, and whether the apparent cause is justified. Their preliminary conclusion was the Byron units were operating at reactor power levels greater than indicated. They also stated the most likely apparent cause was linked to the AMAG implementation. See attachments A and B for the independent review exit notes. This report was reviewed with Byron management, and a decision to temporarily set the AMAG constants to 1, was made. A review of the core burn-up and power distribution was then performed by NFM and Westinghouse (Included as Attachment D). This review determined the core was within expected bounds and the previous AMAG constants were re-implemented.

A troubleshooting plan focusing on AMAG, the on line calorimetric, and AMAG constant calculation was then performed in an attempt to determine the cause of the difference. The AMAG review is included as attachment C. The result of the AMAG review is that there were no identified problems with the AMAG system (No items identified that affected the feedwater flow recorded by the AMAG system). The calorimetric and AMAG constant calculation review did not identify any causes for the Byron and Braidwood differences. The above mentioned troubleshooting plan involved several individuals over a 2 month time span (February and March 2002), but did not determine the cause of the Byron/Braidwood difference.

On 5/11/02 a post B1R11 review of Byron unit 1 data was performed. All unit parameters changed as predicted in the original CR (Attachment E – columns D and E). As of the time this ACE is written, all major unit parameters on Byron unit 1 indicate higher than on Braidwood unit 1 (Attachment E – columns H and E).

Following the rejection of this ACE by MRC on 5/13/02, Braidwood Engineering management was contacted by Byron Engineering management and was requested to perform an AMAG review similar to Byron. Braidwood Engineering did not accept this

action. To address the Byron recommendation to perform an AMAG review at Braidwood, Cantera Engineering performed a review of previously collected AMAG data from Braidwood. This data review looked for anomalies as described in the AMAG report contained in Attachment C. The anomalies include changes is data rejection rate and standard deviation. No anomalies were found and no further actions are planned at Braidwood.

Cantera engineering has provided an amended letter stating their acceptance of the AMAG system, operation, and assurance the Byron units are operating within their licensed power limits. As stated in their letter " Our conclusion from our review of the Byron data is that the Byron installation is correct. We find that the equipment is currently performing within specification, the data is being properly interpreted, the correction factor properly calculated and the calorimetric properly calculated. Specific calorimetric input data outside of feedwater flow were not examined in this review. It is a station responsibility to determine if other input values are correct. If this has been done and the station uses the calorimetric to determine core thermal power and maneuvers to stay under 3586.6 $MW_t$, the station will not have exceeded nor will exceed licensed thermal power. It is recommended that the station follow the recommendations presented in Reference 2. In summary, we recommend that the AMAG CROSSFLOW meter continue to be used at Byron Station." Their letter is included as Attachment G.

With regard to the Calorimetric inputs, all of the significant inputs were reviewed as part of the Cantera sponsered trouble shooting effort. The significant inputs are defined as: Final FW temperature, FW pressure, Calorimetric Program, Calorimetric input constants, FW Tempering line flow instrumentation, and steam generator (S/G) blowdown flow instrumentation. Final FW temperature and pressure inputs were reviewed with no significant discrepancies found (reference Attachment F section 6). The Calorimetric program was reviewed with no significant discrepancies found (reference Attachment F section 5). The Calorimetric input constants were reviewed by Braidwood engineer D. Hildebrant with no discrepancies found. Feedwater tempering line flow and S/G blowdown flow instrumentation was evaluated during performance and review of SPP 02-004 "unit one AMAG validation testing" with no discrepancies found. In essence, all of the calorimetric inputs have been reviewed. A summation of the calorimetric program review, calorimetric input review (as defined above), and the Cantera letter, leads to the conclusion the Byron units are not operating outside their licensed thermal power level.

**********

The ACE author does not agree with the above stated conclusion and believes there is sufficient evidence to suggest the Byron units may be operating above their licensed thermal power levels.

- Since AMAG implementation, <u>every</u> major plant parameter that provides an indication of feedwater flow, steam flow, and reactor power is higher on Byron unit 1 than Braidwood unit 1 and higher than plant design values (reference attachment E and Byron Letter 99-0109).
- NFM letter NFM-MW:02-074 states prior to AMAG implementation Byron and Braidwood observed similar reactor core neutronic design biases of 10-15 ppm

boron. Since AMAG implementation Braidwood's biases are 15-20 ppm and Byron's biases are 25-35 ppm (Byron's core is more burned than Braidwood's core).

- The temporary AMAG system that was installed on the main feedwater header (reference attachment F and 059-PENG-CALC-084 rev 01) indicated 0.7% higher flow than the permanent system.

All of the above indications could be explained by the permanent AMAG system under metering FW flow. OPEX also supports the most likely cause of this type of situation is FW flow measurement error.

One other nuclear site was faced with a similar situation, "Which of two FW flow measurement systems are correct?" That site performed several tests with several diverse FW flow measurement standards. The result of this work was one of the original two flow measurement systems did not agree with the aggregate of the others and was subsequently not used. This is an example of the type of effort that may be required to prove which of our FW flow measurement systems is correct.

The site has performed an extensive review of the AMAG system, station calorimetric, and calorimetric inputs without finding any deficiencies that could account in sole or aggregate for a greater than 1% core thermal power difference. However, just because we have not found the answer, does not mean the problem does not exist. Several meetings have been conducted since 5/5/02 in an attempt to convince senior management to pursue this further. The senior management team has determined there is not sufficient data to support further investigation of this issue (other than the two action tracking times for NFM contained within this ACE). Although these future actions provide some further review of the reactor core behavior, I am not convinced they are sufficient to fully evaluate unit performance and may not be timely. If the NFM review of the next 2 operating cycles worth of data suggests there is a reactor power difference between sites, the unit could have been in an over power condition for nearly 3 years.

In summary, my review of the above data indicates Byron unit 1 is operating at greater than 1% higher thermal power than Braidwood unit 1 with a possible situation being Byron unit 1 is operating at a core thermal power above 3586.6 MWth. We are never allowed to knowingly exceed our licensed thermal power and I am unsure of the regulatory and legal consequences of operating the unit at "100% indicated thermal power" when not one plant parameter supports it.

**********

The Senior Management Team recognizes and is aware of the concerns expressed by the ACE author. Specifically the concerns associated with the Unit 1 & 2 potentially operating above its licensed thermal power limits. The Senior Management Team has concluded after extensive review that further analysis of the AMAG coefficient differences between Byron and Braidwood is not warranted. The basis for this conclusion is the multiple validation reviews that have been performed by AMAG and the Corporate Exelon expert, on the physical and analytical setup of the cross flow System. Each of these reviews has concluded that the flow values obtained from the

cross flow System is within the expected tolerance of the instrumentation. Additionally the validation installed a temporary Cross Flow system on the common header providing diverse feedwater flow measurement. The measurement results as stated above indicated a .8% higher flow however were within the calculated instrument uncertainties and further confirmed correctness of the Cross Flow installation. Performance of a diverse flow test such as a tracer test would provide a third feedwater flow value (e.g. venturies and cross flow being the other two) and was discredited because it would neither validate nor invalidate the cross flow system. It would only give a third value within test and instrumentation uncertainty values. Also the NFM observations of core burn-up, between Byron and Braidwood concluded that the burn-up for Byron was within the expected uncertainty analysis. Accordingly since cross flow is a proven, licensed, accurate method of feedwater flow measurement and has been validated to be providing correct measurement values it is concluded that Byron is operating within its licensed power limits. The author's conclusion that Byron unit 1 is possibly operating above core thermal power limits is not seen as being valid. The data suggests, as identified by the Corporate Evaluator, that we are within our operating limits.

**********

One item to note is that the suggested (by the CR originator) independent review by non-EXELON personnel was never performed. In addition, other than the four day review performed by Mid Atlantic ROG personnel, the same individuals and companies that performed previous reviews performed this review. The EXELON management team overseeing this issue (Station and Corporate) decided a review of station data by MAROG personnel was sufficient in both technical skill and independence to accomplish the task. At that time, the CR originator informed Byron Station management that this was a deviation from what was recommended. Following the arrival of the MAROG review team, initial discussions between the team members and CR originator indicated they had the technical knowledge and adequate independence to perform the Byron review.

**8. Evaluation**

The apparent cause of the Byron and Braidwood differences (as documented by the independent review) is linked to the AMAG implementation. However, numerous technical reviews and troubleshooting plans that have focused on the calorimetric calculation and all its inputs (including AMAG installation, AMAG or plant process computer software problems, AMAG hardware interface problems, AMAG calibration, Feedwater tempering line flow elements, final feedwater temperature, feedwater pressure, main steam pressure, steam generator moisture carryover, and RCP net heat input) have failed to identify the actual apparent cause Therefore, the apparent cause of the Byron and Braidwood difference has not yet been determined.

This ACE recommends:

1) Continuing the search for the cause of the balance of plant (BOP) differences between Byron and Braidwood that explain why Byron appears to have higher power output and various system parameters. This will be performed as part of

the day to day thermal performance duties and quarterly EXELON thermal performance review calls.

2) Continue to ensure management awareness of the issue and endorsement of maintaining current maximum power levels by reviewing this ACE and the AMAG final report (CROSSFLOW system performance review) at PORC. (AT 91771-05)
3) Implement AMAG system monitoring improvements as recommended in AMAG final report (included in Attachment C). This will be tracked by AT 104562. (It is expected these changes will not alter the current AMAG constants)
4) Evaluation of the unit 1 end of cycle boron bias following each of the next two unit 1 refueling outages as recommended in NFM letter NFM-MW:02-074.

B. Causal Factor(s)

Since the apparent cause has not been determined there are no identified causal factors or corrective actions at this time.

Corrective actions will be committed (if required) following ACE presentation at MRC.

**New CA1**
**Description of Corrective Action To Be Taken: NFM to perform a review of the Byron core bias following the B1R12 refueling outage. This was a recommendation from letter NFM-MW:02-074. This action item was accepted by M. Chokran.**
**Assignee: A8063NFMPW**
**Due Date: one month after B1R12. (please code these outage related)**

**New CA2**
**Description of Corrective Action To Be Taken:. NFM to perform a review of the Byron core bias following the B1R13 refueling outage. This was a recommendation from letter NFM-MW:02-074. This action item was accepted by M. Chokran.**
**Assignee: A8063NFMPW**
**Due Date: one month after B1R13. (please code these outage related)**

**AT 91771-05**
**Description of Corrective Action To Be Taken:. Present AMAG ACE to PORC**
**Assignee: A8830NESTT**
**Due Date: Following MRC approval of this ACE.**

**AT 104562**

**Description of Corrective Action To Be Taken:.** Implement AMAG system monitoring improvements as recommended in AMAG final report (included in Attachment C). This will be tracked by AT 104562. (It is expected these changes will not alter the current AMAG constants)

**9. Extent of Condition**

The extent of condition, based on industry experience and the review performed is limited to the Byron and Braidwood units.

**10. Previous Events** (if applicable)
There have been numerous industry events on Reactor over power and venturi fouling (reactor under power) events. The Byron and Braidwood differences appear to fit one of these causes.

**11. Previous Corrective Actions Which Failed to Prevent This Issue** (if applicable)
Since there is no identified apparent cause, there can be no failed corrective actions.

**12. Evaluator and Reviewer**

| | |
|---|---|
| ___David Eder_____/_4/19/02_ | __Kevin Passmore_____/___4/19/02___ |
| ___David Eder_____/_7/9/02_ | __Kevin Passmore_____/___7/9/02___ |
| ___David Eder_____/_9/3/02_ | __Kevin Passmore_____/___9/3/02___ |
| ___David Eder_____/_9/6/02_ | __Kevin Passmore_____/___9/6/02__ |
| Evaluator Date | Approved by Dept. Manager Date |

Attachment A

The following had one correction from the original document. The document a reference to talking with S. Stimac, the team actually talked with S. Gackstetter.

# Independent Assessment of the Differences Between

# Power Production at Byron and That at Braidwood

*Chris Brennan – Skip Denny*

## BACKGROUND

Byron Unit 1 and Braidwood Unit 1 are essentially identical plants, and have operated as close to identical as any two plants can be expected. Today, however, a significant difference is clearly identified. Byron Unit 1, showing only at 98.6% RTP, is producing significantly more MWe than Braidwood Unit 1, which is indicating 100% RTP. Similar difference is also identified between Byron Unit 2 and Braidwood Unit 2, which are also essentially identical plants.

## PURPOSE

Provide an independent, one-week review of the information from Byron and Braidwood plants to identify the most apparent cause for the difference, and whether the apparent cause is justified.

## PROCESS

- Reviewed a timeline of BYR ½ and BRW ½ power generation and changes. From this timeline it was clearly seen that deviations began with the implementation of AMAG for the four units. The deviations have become progressively more noticeable as the deviation widens.
- Paul Smith (Power Uprate Test Director) discussed implementation of Power Uprate at the four units. Braidwood ascension went smooth and without any problems, and arrived at almost precisely where they expected. Byron saw many problems during ascension, all indicative that the BOP was seeing significantly more steam than anticipated and was challenging the equipment limits.
    - VWO
    - Low Suction Head Alarms
    - Pump motor amps
- Dave Eder (Thermal Performance Engineer) discussed the AMAG calibration.
    - Provided data used by AMAG used to determine true FW flows
    - Provided data used by Exelon to determine FW flow via venturi

- Steve Gackstetter (Operations Department) provided Shift Operations insights as to plant operations
- Ron Niederer provided boron concentration curves that indicate that the fuel is being burned at a higher rate than originally estimated. Whereas the Fuels model has been found to be accurate to about ±15 ppm, Byron has required a shift to about ±30 ppm.

## PRELIMINARY CONCLUSION

We agree with Byron Engineering and suspect that Byron Units 1 and 2 are operating at reactor power levels higher than indicated. This opinion is based on the many indications of higher than expected reactor power levels, e.g., plant output and fuel burnup. However, we were not able to identify the cause nor to quantify amount.

We also agree that the most likely fault is with the AMAG correction factors applied to Byron at about 2.0 whereas Braidwood is 0.6. This opinion is based on the identification that the divergence began at the time of AMAG implementation, and that this single change will result in the significant difference in plant outputs. Byron also uses an RCP heat input of 16.6 MWth whereas Braidwood uses the standard 16.0 MWth. However, if the Byron RCP is truly more standard (14.0 $MW_{th}$), then the overpower would only be about 0.6 $MW_{th}$, which might get about 0.2 MWe. Thus this alone could not account for the entire divergence.

## RECOMMENDATION

A more in-depth investigation should be planned to either justify the difference, or to identify the fault, be it at Byron or at Braidwood. We fully expect that a full review of the activities at each plant surrounding the AMAG implementation will ultimately identify the cause of the difference and therefore will identify either the fault or the justification for the difference. THE TRUTH IS OUT THERE.

We anticipate that such an investigation will likely require 2-4 individuals and at least one month to as much as three months. There are many factors and areas that should be investigated, e.g. the thermal kit models (PEPSI), pump performance indications for TDFW, MDFW, Condensate Primary and Booster pumps, venturi loss coefficients, the AMAG measurements and calculations, and fuel consumption underestimates.

Attachment B

# *Byron/Braidwood Thermal Performance Review*
# *Chris Brennan*

- Reviewed calcs. – consistent with W methodologies
  - NED-O-MSD-0010
  - NED-I-EIC-0233

- Reviewed W ANC application for core design for B/B
  - Pre-AMAG, critical bias was on the order of 15-20ppm boron for all four units
  - With AMAG, there was a prompt jump in Byron models bias to >30 ppm boron
  - Although overall small Braidwood models have remained steady
  - This suggests not a change in model bias, but plant conditions.
  - NFM/QNE intend to follow up with W

- Reviewed reactivity anomaly (boron letdown)
  - By1 has the AOA phenomenon, By2 does not (yet)
  - Overpower may increase AOA effects,
  - But AOA effects may mask the overpower
  - Even if AOA comes back out, we may still have a 45-50 ppm shortfall
  - NFM/QNE intend to follow up with W
  - NFM had suspected that something was odd, but they've compensated the fuel loading.

- Reviewed plant data
  - Complicated by plant modification timeline
  - (i.e. SGR, AMAG, HPT, Uprate, FHW bypass)
  - Most deviations from the thermal kit are relatively small
  - Any single datum variation is generally within the instrument uncertainty
  - However, preponderance of data suggested a bias in all toward the high steam flow condition
  - Ops interview
  - Core parameters Thot, Tcold, Tave, T
  - BOP parameters RFPT, CD/CB, etc.
  - Alden calibration of UVT
  - Generator output (guarantee, VWO, choke)
  - SWEC review of CD/CB/FW (RFPT)
  - Braidwood PEPSE model sensitivities

- Tave increase to 588°F
  - Some uncertainty in current license thermal power
  - Current Tave provides some margin to license
  - Increase in Tave will minimize/eliminate any margin to license
  - Control band tradeoff (i.e. TCVs vs. RFPT runout)

Attachment C

Westinghouse

**SUMMARY OF RECENT CROSSFLOW RELATED ACTIVITIES**
**TO SUPPORT BYRON STATION**
**April, 2002**

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Prepared by: Advanced Measurement and Analysis Group, Inc.
Approved by: Westinghouse Electric Company LLC


**SUMMARY OF RECENT CROSSFLOW RELATED ACTIVITIES**
**TO SUPPORT BYRON STATION**

## EXECUTIVE SUMMARY

CROSSFLOW measurement brackets were installed in Exelon's Braidwood Unit 1 & 2 and Byron Unit 1 & 2 in the early 1999 timeframe. Since the initial installation, periodic flow measurements have indicated a difference between Byron and Braidwood actual

feedwater flowrates and venturi correction factors (Cf), resulting in different Megawatt recoveries between the two stations (i.e. Byron is recovering and generating more Megawatts than Braidwood). It was decided to review in depth the implementation of CROSSFLOW at Byron as a first step and then make recommendations to Byron and Braidwood as applicable based on the findings.

Initial technical reviews at the Byron station indicated that the CROSSFLOW system does not perform in as consistent a manner as other industry CROSSFLOW installations. Specifically, the calculated venturi correction factor, Cf, varies significantly as a function of time-to-time calibration. The main objective for the current activities at Byron was to find an explanation for this behavior and validate the calculated value of Cf for the Byron units.

The results of the testing and evaluations documented within this Report indicate that the CROSSFLOW system components are performing in an appropriate manner and that the test criteria for acceptable CROSSFLOW system performance are being met. The following specific items were noted and addressed during the evaluation:

1. At Byron Unit 2, it was found that the Special Connector (SMA) nuts on the transducer pigtails were loose which caused a high noise level on the transducer response characteristics. The transducers were fixed by tightening the SMA nuts and the subsequent Received Signal Strength Indicator (RSSI) and tone burst test results were acceptable.

2. Review of previously collected data indicated a high percent of data rejection in Byron Unit 1 and Unit 2. This high rejection rate could cause an asymmetry on the flow measurement as seen on the measured flow histogram tool provided with the existing CROSSFLOW software. A modified CROSSFLOW configuration file was prepared and installed for both Units (e.g. frequencies were modified to re-tune the system for optimal performance.) New sets of plant data were collected using the modified configuration file. All the collected data satisfied the acceptance standards for rejection rate and standard deviation conditions.

3. A Feedwater flow oscillation of up to 3% was observed in Unit 1 and Unit 2 in several loops. The cause was determined to be the Feedwater regulating valve characteristics on each of the four loops for each unit at the Byron Station. The CROSSFLOW system was also re-tuned to re-optimize system parameters to accommodate the observed flow oscillations. This issue should be monitored with a long continuous run of data collection to determine if there is any correlation between the observed changes in calculated correction factor and this flow oscillation. The high oscillation could also be one of the sources of the high rejection rate indication. At this time, it was not possible to correlate the data further due to insufficient historical data on the Feedwater regulating valve oscillations.

Key recommendations include:

- AMAG/Westinghouse recommend that EXELON use the CROSSFLOW system to collect data from both Byron Units continuously for a period of six months. Continuous monitoring of correction factor fluctuation would provide a useful opportunity to observe and trend any sudden or gradual changes. Using continuous monitoring, it will be possible to correlate changes to plant data and conclusively identify the reason for the Cf fluctuations (which may be caused by plant realignment and plant instrumentation).
- Exelon personnel should be formally trained for more effective use of CROSSFLOW. In addition, it would be helpful if more individuals at the Exelon sites could be trained to provide effective backup support.

## PROBLEM OVERVIEW

CROSSFLOW measurement brackets were installed in Exelon's Braidwood Unit 1 & 2 and Byron Unit 1 & 2 in the 1999 timeframe. Since the initial installation, periodic flow measurements have indicated a difference between Byron and Braidwood actual feedwater flowrates and venturi correction factors (Cf), resulting in different Megawatt recoveries between the two stations (i.e. Byron is recovering and generating more Megawatts than Braidwood). This difference raised questions and initiated a series of actions over the years to review the CROSSFLOW installations and system operation at both stations.

The first action regarding this apparent discrepancy occurred early after initial system installation in July of 1999 and included a repeat measurement in one of the loops in Byron. The second test location was located a couple of feet down the pipe from the original installation and was performed to show the consistency of the CROSSFLOW system measurement. The measured flow at the second location was within ~0.1% agreement which is well within the expected 0.5% uncertainty range. Later in 2000, sets of new measurements were also collected in Braidwood at a new location downstream of the original location. These activities were performed in response to a concern that the internal surface of the Braidwood pipes (which were uniquely cleaned using a pressurized washing procedure) may lead to a pipe roughness greater than the unwashed pipes at Byron. The theory was that this could possibly create an issue that was preventing Braidwood from getting more megawatts (which would also reduce the differences between Byron and Braidwood.) The test results supported the consistency of the CROSSFLOW measurements (i.e. the local pipe wall roughness had no measurable effect on the results.)

Subsequent to the above events, Byron and Braidwood implemented a 5% uprate, and the issue of CROSSFLOW flow indication resurfaced due to the expected increase in power.

Since the uprate calculation was not based on original CROSSFLOW indications, a discrepancy was observed after the 5% uprate. This discrepancy indicated that the 5% uprate could not be achieved (because of turbine valve limitations) if CROSSFLOW were to be used as the true flow indication. This triggered another investigation and evaluation of both CROSSFLOW and plant instrumentation in Byron. The system evaluation started with review of plant performance and instrumentation. The plant technical review results did not identify a specific explanation for the existing differences and it was recommended that the CROSSFLOW performance be investigated as well.

Following this technical evaluation, the CROSSFLOW team (Westinghouse/AMAG) was involved in a series of technical investigations to evaluate the current CROSSFLOW system performance. Based on technical discussions with Exelon engineers, it was decided to re-evaluate (or re-confirm) measurement parameters for the four loops including physical dimensions (e.g. pipe internal diameter (ID) calculations and transducer spacing). This investigation identified other existing technical items associated with the use of the CROSSFLOW system. These issues are addressed further below and should be considered for future recommendations.

## BACKGROUND

The CROSSFLOW system has been used in Exelon for more than three years. The differences in megawatt output between Braidwood and Byron resulted in initiation of a series of technical actions associated with CROSSFLOW as well with the as plant instrumentation. Also, during these recent technical reviews, it was noted that the system does not perform in as stable a manner as in other industry CROSSFLOW installations. Specifically, the venturi correction factor (Cf) varies significantly as a function of time.

The CROSSFLOW installations for EXELON are somewhat unique in the industry in that the plants are outfitted with bracket assemblies and two sets of travelling electronics are intended to be rotated around the eight plants to provide periodic calibrations as opposed to continuous monitoring. The CROSSFLOW systems are used as a tool to obtain "snap shot" measurements periodically. This unique setup makes the investigation of Cf behavior more of a challenge. If observed changes in the calculated correction factor are based on snap shot measurements, it is difficult to correlate the Cf changes to any plant parameters. Based on recent observation in Byron Units 1 and 2, the Cf changes vary significantly as a function of time-to-time calibration. Since Byron has not shipped the CROSSFLOW equipment from site to site during the past 1.5 years, extra data is available from measurements performed on both Byron units. However, continuous measurements could provide more information to support the investigation than snap shot measurements. The main objective for the current activities in Byron is to find an

explanation for this behavior and validate the calculated value of Cf for the Byron units. The rest of this report presents the current technical evaluation findings associated with the CROSSFLOW system investigation at Byron, technical suggestions, and, where warranted, future recommended activities.

## FINDINGS

The installed CROSSFLOW bracket assemblies in Byron Units 1 & 2, and the associated travelling electronics were evaluated to determine if there were any parameters that were set incorrectly during the original system setup. Since there was a question about whether the physical parameter differences (ID and transducer spacing) could be the source of the difference in Braidwood and Byron, the technical evaluation began with a look into these parameters. The findings are summarized as follows:

- **Performed additional pipe wall thickness, OD (outside diameter), and spacing between the transducer measurements in Unit 1 and Unit 2:** The result is presented in Westinghouse Calculation 059-PENG-CALC-084, Rev.01, "Feedwater Flow Measurement Using the CROSSFLOW Ultrasonic Flowmeter at ComEd Byron Unit 1". In summary, it was verified that there were no significant differences with the original setup values in either Byron Unit.

**Following the physical measurements, all the CROSSFLOW system components were checked as follows:**

- **Transducers in Unit 1 and Unit 2:** The transducer characteristics were checked in Unit 1 and Unit 2 using the CROSSFLOW standard RSSI (Receive Signal Strength Indicator) and Tone-Burst procedures. The results indicate that the transducers in Unit 1 are fine, however, in Unit 2 it was found that the Special Connector (SMA)-nut on the transducer pigtails (for two loops) were loose. The loose nut caused a high noise level on the transducer response characteristics and it was easily identified. High noise level on the transducer signal increases the data rejection rate and it does not have a direct effect on Cf. The transducers were fixed by tightening the SMA-nuts and the subsequent RSSI and tone burst test results were acceptable. The issue was discussed with the Byron Station performance engineer in detail so that he could identify any possible future problem with the transducer characteristics.
- **Cables in Unit 1 and Unit 2:** All the cables were tested (ohmic-resistance & capacitance measurements). All tests were acceptable and no problems were identified for the cables.
- **SCU & Multiplexer evaluation:** The Byron Signal Conditioning Unit (SCU) & Multiplexer were checked by performing the CROSSFLOW standard internal test signal commissioning test for the SCU and the CROSSFLOW standard Multiplexer function test procedures. Both SCU and multiplexer test results satisfied the acceptance criteria in the testing procedures.

- **CROSSFLOW Software Verification:** The installed CROSSFLOW software (version M3.0.2) is the same in both Exelon computers. The software was checked and compared with the latest version of CROSSFLOW software (version M3.5.0). The results of the measurements were identical using the upgraded CROSSFLOW software. These results verify that the installed software is performing correctly.
- **Performed Flow Measurement on 30" Common Header in Byron Unit 1:** After completing the physical and CROSSFLOW components check, it was decided to perform a comparison measurement between the Feedwater Common Header and the four loop legs in Byron Unit 1. Therefore, a 30" bracket was installed on the common header in a long run downstream of a single elbow (standard CROSSFLOW installation). The results of this installation and comparison to the four loops are presented in Westinghouse Calculation 059-PENG-CALC-084, Rev. 01. This calculation verifies the four loops are being accurately measured within the CROSSFLOW expected uncertainties.
- **Temper Line Flow Indication Accuracy:** A test was also performed to compare the common header CROSSFLOW reading to the plant flow indications (venturi and temper lines). The ratio of the common header CROSSFLOW reading to the sum of the venturis in all four legs plus the temper lines was calculated for two different configurations—with and without the temper lines secured. Both ratios were very close which indicate that the temper lines flow is being accurately reported by plant instrumentation. During these tests which were performed February 27-28, 2002, the ratio of the common header flow to the venturis with the temper lines secured was 0.9927. The ratio increased to 0.9929 with the temper lines open. The results of these tests are further documented in Westinghouse Calculation 059-PENG-CALC-084, Rev. 01.
- **Common Header SCU Test:** Performed the standard CROSSFLOW hardware tests (Signal Conditioning Unit (SCU) internal test signal) on the electronics used for the common header flow measurement. All tests were acceptable.
- **Review plant piping isometric drawings and plant instrumentation**: For each Byron Unit, all the isometric drawings for the 4 loops and the common header piping were reviewed and the piping was walked down. No significant issue was identified with respect to piping geometry.
- **Reviewed previous data collection (partially) in Unit 1 and Unit 2:** Based on the previous calculated correction factors in both Byron Unit 1 and Unit 2, changes in the calculated correction factor were identified which are not experienced in CROSSFLOW installations at other power plants. Because only "snap shot" measurements were available per the practices utilized by EXELON, it was not possible to review a clear picture (continuous trend) of the observed changes. Review of previously collected data indicated a high percent of data rejection in Unit 1 and Unit 2 on specific loops (e.g. Loop D in Unit 1). This high rejection rate could cause an asymmetry on the flow measurement as seen on the measured flow histogram tool provided with the existing CROSSFLOW software. This issue was discussed with the plant performance engineer to identify possible sources of bias in the flow measurement. It was recommended that a new setting be used for data collection and

that the rejection rate parameter be observed to assure proper data collection conditions were satisfied. More detail regarding data collection criteria is presented in the recommendation section.

Following this evaluation, a modified CROSSFLOW configuration file was prepared and installed for Unit 1 (4 loops), e.g. frequencies were modified to re-tune the system for optimal performance. New sets of plant data were collected using the modified configuration file. All the collected data satisfied the acceptance standards for rejection rate and standard deviation conditions. The new configuration file setting was transmitted to the Byron plant performance engineer. The most recent and final configuration file that incorporates all adjustments presented as an attachment in Westinghouse Calculation 059-PENG-CALC-084, Rev. 01 and should be used by the station going forward.

A similar review is in process on Byron Unit 2 settings and a new configuration file has been transmitted to the site for further evaluation. Since the CROSSFLOW system has been collecting data in Unit 2 continuously for the last couple of weeks, the collected data could be used for further analysis on the Cf variability issue for Byron Unit 2.

- **Flow Oscillation:** Although not part of the original investigation scope, a flow oscillation of up to 3% was observed in Unit 1 and Unit 2 in several loops. The cause was determined to be the Feedwater Regulating Valve characteristics on each of the four loops for each unit at the Byron Station. The CROSSFLOW system was re-tuned to re-optimize system parameters to accommodate the observed flow oscillations. This issue should be monitored with a long continuous run of data collection to determine if there is any correlation between the observed changes in calculated correction factor and this flow oscillation. The high oscillation could be one of the sources of the high rejection rate indication. At this time, it was not possible to correlate the data further due to insufficient historical data on the Feedwater regulating valve oscillations.

## OVERALL SUMMARY

The technical evaluation of the CROSSFLOW system is summarized as follows for Byron Unit 1 and Unit 2:

### Byron Unit 1

The technical review of the Unit 1 results for the Common Header and the 4 loops comparison indicates that all the components in CROSSFLOW system installed in Unit 1 are functioning properly. Some technical issues were identified including the high rejection rate for collected data and the skewed flow histogram. This information was used to develop guidelines to help monitor the performance of future measurements. A modified configuration file was provided to accommodate these conditions. It is recommended that the new modified configuration file be used for future Unit 1 data collection activities, and that if there is a future high rejection rate (more than 25%) the

data not be used for calculations and an investigation be performed to trouble shoot the issues. Also, the sudden increase in standard deviation is another indication that can be used for system performance monitoring. The standard deviation value for Unit 1 should not be greater than 1.5% during data collection[1]. Significant changes in standard deviation should be investigated. By satisfying the rejection rate (≤25%) and standard deviation criteria (≤1.5%), the histogram will be normally distributed and these two parameters will satisfy the normally distributed measurement criteria. The modified and verified Byron Unit 1 configuration is presented as an attachment in the Westinghouse calculation and should be used to verify the current configuration. Finally, it should be noted that the criteria for an acceptable rejection rate and standard deviation limit is an additional criteria to the conditions presented in Westinghouse Calculation 059-PENG-CALC-084, Rev.01 for satisfying the calculated total uncertainty for the CROSSFLOW system.

Byron Unit 2
All the hardware and software installed in Byron Unit 2 were checked and the only findings were the problems with the transducer's SMA-nuts. Because the nuts were loose, the signals were very noisy. The problems were fixed by tightening the nuts. The standard CROSSFLOW RSSI and tone-burst tests were performed after tightening. The results were acceptable. Also, after fixing the noise issue, the Unit 2 configuration file was modified. The same criteria as on Unit 1 were used for Unit 2 configuration optimization. A high rejection rate was observed in the Unit 2 data collection that could cause the same asymmetry in collected data. The configuration file was modified to eliminate the possibility of this issue. A modified configuration file was provided to accommodate these conditions. The investigation in Byron Unit 2 is in progress.
Regarding the rejection rate criterion, the 25% maximum rejection rate is valid for Unit 2 as well. A standard deviation value has not yet been calculated for Unit 2, since the preliminary data collection was not completed due to of Unit 1 outage activities. As a starting point, the 1.5% standard deviation limit should be used for Unit 2.
Also, the same flow oscillation phenomena were observed in Unit 2. This could be one of the sources for high data rejection. However, the system configuration was modified to minimize the flow fluctuation effect. Finally, there is an opportunity to repeat the same type of cross checking of the CROSSFLOW readings in the existing 4 loops by measuring the common header using CROSSFLOW at the same time (as was done for Unit 1). This option is open and future activities should be determined by Exelon management.

## RECOMMENDATIONS

- Finalize Unit 1 and 2 configuration files evaluation by analyzing newly collected data with the optimized configuration and ensuring CROSSFLOW system performance continues to be satisfactory.

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[1] The numbers can be changed (reduced) by monitoring the system in a continuous mode.

- From CROSSFLOW system perspective, there are no indications that the calculated correction factor is not correct despite the variations from time-to-time with Cf. However, CROSSFLOW experience with other utilities typically indicates much less fluctuation in the correction factor. A continuous period of 6 months monitoring could help to ultimately identify and resolve the root cause for correction factor fluctuation. If it is decided to pursue continuous monitoring, the collected data should be analyzed and compared with plant data in periods of a week or shorter.

  Continuous monitoring of correction factor fluctuation would provide a useful opportunity to observe and trend any sudden or gradual changes. Using continuous monitoring, it will be possible to correlate changes to plant data and conclusively identify the reason for the Cf fluctuations (which may be caused by plant realignment and plant instrumentation). When comparing Byron to the Braidwood Units, the calculated correction factor fluctuates much more at Byron than at the Braidwood Units. After reviewing the plant flow oscillation indication it was noted that the valve characteristics in Braidwood and Byron are different, which could be one of the possible sources of the identified Cf fluctuation. Since variability in Cf was observed in both Unit 1 and Unit 2, AMAG/Westinghouse recommend that EXELON use the CROSSFLOW system to collect data from both Byron Units continuously. If the cables can be routed to one junction box that serves both Unit 1 and Unit 2, both Units could be monitored continuously using just one CROSSFLOW system (one of the two sets of electronics owned by EXELON). The alternative is to obtain a temporary system for the other Unit to enable data collection in both Units at the same time. This activity will be the most useful action that can be taken for analyzing the correction factor fluctuation in the future.
- Improved housekeeping practices for the CROSSFLOW equipment will have a positive benefit regarding the life of the components and possibly reduce data rejection due to causes like deteriorated connections. It is recommended that the electronics be mounted in a cabinet such as the one originally supplied by the CROSSFLOW Team. A thick layer of dust was also observed on the hanging connectors in steam tunnel (the BNC connectors with join the transducer's pigtail to the cable). Placement of a shrink tube on the connectors will provide increased protection from dirt and dust.
- Any anomaly or sudden change in data rejection rate should be discussed with AMAG/Westinghouse for further technical evaluation. At that time, the CROSSFLOW team can be more effective in helping resolve future issues if the plant data is provided for further investigation. If the plant data were to be provided for past periods of CROSSFLOW data collection, a comparison analysis could be started to review the previously collected CROSSFLOW data.
- EXELON should perform an RSSI test in the event of an increasing rejection rate. As an optional procedure, an RSSI test can be performed before and after any outage for verification of transducer performance. However, since the Byron computer does not

have the appropriate updated scope card, this procedure cannot be performed in Byron. An updated scope card could be installed in the Byron computer.

- There is an opportunity to provide a cross check of the Byron Unit 2 CROSSFLOW readings in the existing 4 loops by measuring the common header using CROSSFLOW at the same time (as was done for Unit 1). This option is open and future activities should be determined by Exelon management.
- During the general investigation, it was noted that the insulation blankets at Byron were installed appropriately around the CROSSFLOW brackets. Adequate insulation is important due to the "wind tunnel" effect of the main steam tunnel ventilation. At Braidwood, it was noted that there were small gaps in the insulation in the area of the bracket strong back. These gaps could possibly have a conservative effect on calculated Cf by up to 0.2%. It is therefore recommended that Braidwood either close the gaps with additional insulation or procure and install blankets the same size as those at Byron.
- **Observation:** Exelon personnel should be formally trained for more effective use of CROSSFLOW. (Note: The training to become a certified CROSSFLOW system operator was provided as part of the original scope. The training includes three full days of classroom instruction and hand-on applications at the AMAG offices and labs in Toronto. Exelon was not able to participate in this training and a classroom only version was offered at the plant site.) In addition, it would be helpful if more individuals at the Exelon sites could be trained to provide effective backup support. It would also be useful for Exelon key personnel to attend the upcoming CROSSFLOW Owners Group meeting in Pittsburgh in May. This forum provides the opportunity for significant information gathering and exchange regarding effective CROSSFLOW system operation.

Attachment D

Date: February 21, 2002
NFM-MW:02-074

To: William G. Kouba
Thomas E. Roberts

Subject: Byron AMAG Issue

Recently, Byron Station questioned the conservatism in their AMAG constants and chose to readjust those constants to 1.0 while assessing parameters that will provide confirmatory indications of reactor power. The decision, in part, was based upon questions concerning the units' burnup when compared to design predictions. This letter will discuss the impact of AMAG changes associated with nuclear design predictions. This letter will conclude that neither the differences seen in the development of reload cores nor the variations in cycle depletion data, since the implementation of AMAG, can confirm or repudiate the validity of the AMAG results.

Byron provides trending information monthly for both units. NFM has not identified any changes in the calculated to predicted burnups that have been considered anomalous or that were so large as to be unexplainable. Differences in calculated to predicted results due to Axial Offset Anomaly (AOA), Boron-10 depletion, and other core operating variations are normally part of the differences routinely seen in the monthly results. Core energy utilization and boron letdown trends continue to be within expected norms.

After the implementation of AMAG at both Byron and Braidwood Stations, there has been a change in the neutronic design biases historically used to project where a reload core will lose full power capability. This value has been typically 10-15 ppm Boron, a number which was consistent with other 4-loop core, nuclear plants utilizing Westinghouse OFA (0.360" rod diameter) fuel. The numbers currently seen for Braidwood are ~15 to 20 ppm and for Byron they are ~25 to 35 ppm. Over several cycles, NFM would not expect to consistently see this order of magnitude between site designs; however, since the database currently consists of only a couple of cycles, the difference is not statistically significant. A consistent difference in the biases over several cycles could indicate units are not operating at the same power levels. Design biases are based on the assumption that power levels generated by the core are accurate. As such, any change in the power actually generated through improved measurement techniques would be manifested as changes in the design bias. The new bias used for Byron reflects how the core is being depleted (i.e. increase in thermal power relates directly to an increase in the design bias). Since the bias is determined directly by core power, you cannot use a change in the bias to ascertain the validity of that change; all NFM can confirm is that it is different.

The question then becomes how do the changes in our biases compare to what is seen in other Westinghouse designed cores. Is Byron an outlier? NFM obtained Westinghouse's

design database which included measured to predicted EOL boron values. NFM performed a "rough" statistically evaluation of the data. The database does not contain enough updated information to make any definitive assessment. The database did not appear to contain cycle data for those reload cores that would most closely represent Exelon's Byron / Braidwood cycles operated with AMAG. The results did, however, show why Westinghouse can still utilize a 10 ppm bias as the definition of loss of unit full power capability. The Standard Deviation obtained from the database can support the use of biases that significantly vary from 10 ppm ( ± 20 ppm). Additionally, the Westinghouse Core Design group personnel were polled on what bias their core designs were utilizing. Westinghouse will not change the design bias unless it is specifically requested by the utility. The results of the interview show a large variation in what other utilities believe they need to load enough energy to prevent having extended coastdowns. Some utilities still utilize 10 ppm, one utility specifies an 80 ppm bias (a program to always overfeed the core), and one utility utilizes a 30 ppm bias similar to what we see at Byron. This information also supports no conclusion since each utility has a unique core loading strategy based upon business needs which ultimately impact the final bias used.

If you have any questions concerning this letter, please contact Everett Young at (630) 657-2177.

**Mark T. Chokran**
**Director**
**Nuclear Fuel Management**

EHY/pc

cc: J. R. Meister
R. W. Tsai
R. J. Niederer

Attachment E

| A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|
| | | 5/30/01 6:00 | | 11/5/01 4:00 | | 5/10/02 0:00 | 5/10/02 0:00 |
| Parameter | Units | BY-1 | By-1 + 2% | BW-1 | % difference | By-1 | By-1 at 100% |
| Reactor power | | 97.96 | 99.92 | 99.92 | | 99.59 | |
| total FW Flow (calorimetric) | KBH | 15742.74 | 16095.74 | 16042.53 | | 16070.38 | 16135.87 |
| A RCS Loop Delta T | DEG F | 60.23 | 61.44 | 59.36 | | 60.46 | |
| B RCS Loop Delta T | DEG F | 59.97 | 61.17 | 60.06 | | 61.39 | |
| C RCS Loop Delta T | DEG F | 59.85 | 61.05 | 59.26 | | 60.69 | |
| D RCS Loop Delta T | DEG F | 61.27 | 62.49 | 60.63 | | 61.07 | |
| average loop delta T | DEG F | 60.33 | 61.54 | 59.83 | 2.78 | 60.90 | 61.15 |
| CB Pp Flow | KBH | 11170.89 | 11388.09 | 11127.48 | 2.29 | 11371.21 | 11417.55 |
| HD Pp Flow | KBH | 5176.02 | 5312.12 | 5180.02 | 2.49 | 5349.65 | 5371.45 |
| FW Pp Flow | KBH | 15876.18 | 16229.18 | 15878.31 | 2.16 | 16223.96 | 16290.08 |
| CB + HD Flow | KBH | 16346.91 | 16700.21 | 16307.50 | 2.35 | 16720.86 | 16789.00 |
| Final Feed Temp ave | DEG F | 442.50 | 444.30 | 442.79 | 0.34 | 444.14 | 444.60 |
| Pimp | Psig | 738.47 | 756.77 | 746.93 | 1.30 | 756.94 | 760.02 |
| #7 FW heater press | Psig | 392.38 | 400.98 | 384.60 | 4.08 | 398.10 | 399.73 |
| MSR ist stage | Psig | 390.34 | 396.27 | 388.67 | 1.92 | 398.22 | 399.84 |
| #6 FW heater press | Psig | 267.31 | 273.31 | -13.66 | | 272.25 | 273.36 |
| #5 FW heater press | Psig | 180.95 | 183.95 | 180.40 | 1.93 | 184.17 | 184.92 |
| HP turbine EXH press | Psig | 164.61 | 167.88 | 166.45 | 0.85 | 167.93 | 168.62 |
| MWe performance test | MWe | | 1257.00 | 1234.00 | 1.83 | | |
| Ave MS Pressure | psia | 1005.02 | 1005.02 | 1011.22 | | 1025.47 | |
| | | | | | | | |
| Average AMag Factor | | 0.9777 | | 0.9942 | 1.65 | 0.9758 | |
| average indication difference | | | | | 2.03 | | |
| | | | | | | | |

Attachment F

To: Richard Lopriore
Site Vice President
Byron Station

From: Jim Meister
Vice President, Engineering

Subject: Review of Byron AMAG Feedwater Flow Instrumentation Installation and Performance

References:
1. Calculation 059-CALC-PENG-084 Rev. 1
2. Westinghouse Report "Summary of Recent Crossflow Related Activities to Support Byron Station, April, 2002"
3. Westinghouse LTR-NRC-02-14, dated 3 April, 2002

Since the installation of AMAG feedwater flow measurement systems at Byron and Braidwood, the flow corrections calculated for the four units have been different. The Byron units have normally had higher calculated corrections than the Braidwood units.

In February and March of this year, the Byron Units 1 and 2 CROSSFLOW installations were reviewed for physical installation, hardware, and software errors that could lead to errors in the output from the meter and account for differences in Byron and Braidwood results. Additionally, a new CROSSFLOW installation was made on the Unit 1 feedwater common header upstream of the feedwater regulating valves. This letter provides the corporate Engineering conclusions from our review of the Byron and Braidwood AMAG installation and performance.

The attachment to this letter provides results of the review.
Our review has concluded that there were no:

- installation physical parameter data errors,
- AMAG or plant process computer software problems,
- hardware interface problems or
- AMAG instrument calibration errors that could account for the differences between Byron and Braidwood performance. We conclude that the AMAG system accurately measures feedwater flow within the equipment uncertainties.

The areas assessed and the findings in those areas are as follows:

1. Plant temperature loop calibration methodology was reviewed and found acceptable, and not an issue with regard to AMAG equipment and calorimetric calculation methodology.

2. Reviews by NFM on fuel burnup concluded that there were no changes in the calculated to predicted burnups for Byron that have been considered anomalous.

3. The turbine driven feedwater pump (TDFWP) operating parameter review shows Unit 1 in close agreement with AMAG and Unit 2 the TDFWP flow is lower than that of the plant venturi. This implies that the plant venturies are conservatively in error.

4. The comparison of the common header to the four individual loops, as documented in calculation 059-CALC-PENG-084, Revision 1, was found to agree within the statistical limits for the data.

5. The AMAG report that was provided directly to the station contains several recommendations on how to improve the Byron AMAG correction factor repeatability and effectiveness. None invalidate the

existing installation. One recommendation contained therein (insulation) applies to Braidwood and may result in Braidwood performance improvement of up to 0.2%.

6. A review of Braidwood data found that Braidwood was not having as high a data rejection rate as Byron, nor were they evidencing a significant change in correction factor over the last year such as at Byron. Braidwood was also exhibiting a significantly lower standard deviation on their data than Byron was in the same period. Both stations have standard deviations within the AMAG acceptance criteria documented in Reference 2, and thus the data standard deviation is not a contributor to the differences noted between stations.

7. The issue of flow swirl was reviewed, and determined to not be an issue for AMAG in general or the Byron CROSSFLOW in specific. This is based on References 1 and 3.

Our conclusion from our review of the Byron data is that the Byron installation is correct. We find that the equipment is currently performing within specification, the data is being properly interpreted, the correction factor properly calculated and the calorimetric properly calculated. It is recommended that the station follow the recommendations presented in Reference 2. In summary, we recommend that the AMAG CROSSFLOW meter continue to be used at Byron Station.

If you have any questions, please contact Jeff Drowley at (630) 657-3834 or me.

Prepared: _____ Reviewed: _____

Jeffrey W. Drowley
Mechanical Engineering Manager
MWROG Engineering

William G. Kouba
Engineering Director
MWROG Engineering

Attachment: Byron AMAG installation review, February/March 2002

cc: T. Roberts
D. Eder
D. Hildebrant
R. Flowers

**Byron AMAG installation review, February/March 2002:**

As a result of a preliminary review of plant data, engineering personnel from the Mid-Atlantic Regional Operating Group determined that there was a need to further investigate the Byron AMAG installation, fuel performance, and some BOP indicators. A team was assembled with the scope to look into the following issues:

1. Review of fuel burn-up data
2. Validation of the AMAG installation physical data
3. Validation that the AMAG computers in use at Byron and Braidwood use the same software and provide consistent results
4. Validation of the methodology for the plant process computer correction factor
5. Validation of the Plant Process Computer methodology for determining the calorimetric
6. Review of the Feedwater Flow and Temperature Loop Calibration methodology and implementation
7. Review of Turbine Driven Feedwater Pump (TDFWP) operating parameters.

**1. Byron Fuel Burn-up review:**

There was an impression at Byron that the fuel burnup was higher than it should have been for the past cycle. NFM was asked to review and comment. This task has been completed as documented in memorandum NFM-MW:02-074 dated 2/21/02. The conclusion of this task was that the NFM review of Byron monthly trending information has not identified any changes in the calculated to predicted burn-ups that have been considered anomalous or that were so large as to be unexplainable. The fuel loads were specified for a boron concentration bias consistent with what is being seen now for loss of full load capability.

**2. VALIDATION OF THE BYRON AMAG INSTALLATION PHYSICAL DATA**

Inaccurate physical data from the original installation could cause potential errors in the CROSSFLOW™ system. To eliminate this as a contributor to errors in the calorimetric correction factor, the pipe OD, pipe wall thickness and transducer spacing on both Byron units were reverified. This task has been completed for Byron Units 1 and 2. The insulation was removed and the piping prepared for OD and wall thickness measurements in areas directly (+5", -5" and +10") adjacent to the existing brackets on S/G A/B/C/D feedwater flow loops.

The results of the installation physical data comparison is documented in Westinghouse Calculation 059-PENG-CALC-084 Revision 1, Appendix F, and concludes that the data from the original installation and those of the adjacent piping and re-measured transmitter spacing taken in February 2002 are statistically equivalent. Therefore, the original installation physical data are not contributors to an inaccuracy in the calorimetric correction factor at Byron or that would explain differences in MWe generated such as exist between Byron and Braidwood. Further, the cabling and transducers were tested

and found to be performing appropriately. On Unit 2, one cable nut was found loose which could contribute to data rejection: this was tightened and successfully rechecked for appropriate performance.

## 3. VALIDATION THAT THE AMAG COMPUTERS IN USE AT BYRON AND BRAIDWOOD USE THE SAME SOFTWARE AND PROVIDE CONSISTENT RESULTS

Potential errors in the CROSSFLOW™ system include software errors in the AMAG computer. A test was conducted to verify that the software comes up with similar answers (within the meter accuracy) on a single unit when tested sequentially using the "Byron" AMAG computer and then the "Braidwood" AMAG computer. During these tests, screen prints were performed to show that the AMAG system files have the same date/time stamp. The files showed that the Exelon owned AMAG executables had the same date time stamp, and the result of the tests was that the computers gave the same results. As an independent check, the AMAG owned laptop was used and also gave the same results.

## 4. VALIDATION OF THE METHODOLOGY FOR THE PLANT PROCESS COMPUTER CORRECTION FACTOR

Potential errors in the correction factors between units include the methodology implementation to determine the correction factor used in the calorimetric calculation. To validate the methodology for the correction factor used in the calorimetric calculation is the same between all four units, BCP-850-44 was reviewed against BwVP-850-20, and then Braidwood data was input into the Byron spreadsheet and vice versa. The output values for the same data in the two spreadsheets resulted in identical answers, largely as a result of the Root Cause analysis on the correction factor performed at Byron last year. At that point, the spreadsheets were consolidated and controlled with one master copy. The owner of this software is Don Hildebrant at Braidwood, who performed this exercise.

## 5. VALIDATION OF THE PLANT PROCESS COMPUTER METHODOLOGY FOR DETERMINING THE CALORIMETRIC

Another potential error source that would lead to errors in the correction factors used at Byron and/or Braidwood is the plant process computer changes put in place for the CROSSFLOW. To validate that this methodology was not a source of error in the correction factor and plant calorimetric, plant process computer data was taken at each unit for Byron and for Braidwood. An independent evaluation spreadsheet was set up to match the calorimetric process that was to have been used on all four units (software product SE0001). The plant process computer data was used as inputs into the independent evaluation spreadsheet to independently evaluate the calorimetric. The spreadsheet calorimetric values were then compared to the calorimetric values from the process computer. Within the significant digit accuracy of the independent spreadsheet,

the values matched exactly on a unit by unit basis. This validated that the Plant Process Computer Calorimetric software is the same for all four units and that the software is properly manipulating the values. The software owner for SE0001 is Don Hildebrant at Braidwood, who performed the independent evaluation as documented in "Calorimetric Application Test", performed on 2/20/02 by Don Hildebrant and Josh Watson.

Further, at the team's request, Josh Watson and Mike Khomutov of IT performed a review of the calorimetric software on the plant process computers at Byron and Braidwood, reported as "Calorimetric Software Comparison Results". They provided four checks, including a calorimetric executable comparison, a Process Computer startup script comparison, a calorimetric configuration parameter comparison, and it was verified that the same process computer points were used as inputs at all four plants. As a result, it was determined that all four units are running the same software. This software code was also verified to match the code on the development system.

## 6. REVIEW OF THE FEEDWATER FLOW AND TEMPERATURE LOOP CALIBRATION METHODOLOGY AND IMPLEMENTATION

During the investigation at Byron, it was reported that the feedwater thermocouples all had unique process computer curve fit data. As a result, it was determined that this issue required review for the effects of this uniqueness, including the instrument loop. The review of the feedwater flow temperature loop did not note any significant anomalies. The review revealed that the copper constantan thermocouples are not individually calibrated, but are considered a standard component. A data table furnished by the manufacturer is used for inputs to confirm the process output in the control room, and the plant process computer at both Byron and Braidwood have been confirmed to have the same table (input as a curve function) for conversion of the signal to a temperature.
The feedwater flow loop pressure instrumentation was reviewed. A difference between Byron and Braidwood was noted where Braidwood has a 20 pound head correction in their calibration to compensate for the elevation change from the pressure tap to the pressure transmitter. Byron does not install the head correction on the basis that they would then have to correct this in the opposite direction for velocity head. In any event, the sensitivity study demonstrates that a 20 psi difference between units does not result in a significant change (<0.055 MWt).
The FQY and FD components were reviewed. The FQY instruments are 4-20 ma, but use different cardinal points for calibration. The FD components are all Barton 752 models, but each has a specific calibration range, varying from 0-696 inches WC to 0-711 inches WC. Thus we employ the same methodology across units, but due to specific differences in the characteristics of the venturi, we end up with different scaling factors. This does not have an impact for the calorimetric, but may be worth examining for commonality of instrumentation.

## 7. Turbine Driven Feedwater Pump operating parameter review.

At Byron station request, the turbine driven feedwater pump performance was reviewed

by Byron design engineering personnel to see whether the predicted pump flow corresponded with the existing venturi flow meters or with the CROSSFLOW™. This review is complete, using data with the correction factor set to 1.00 at Byron. The approach used was to get the differential pressure across the pump corrected to datum and converted to feet of water. This was used with the pump speed and the pump curve to get the predicted pump flow. The predicted pump flow was then compared to the individually indicated pump flow in gpm.

The summed pump flows were also compared to the venturi flows in thousands of pounds per hour, with the result that the summed Feed pump flows indicate that the plant is overmetering venturi flows by 1.5% (15759/15529) on Unit 1 and 0.65% (15723/15621) on Unit 2, without correcting for flow through the tempering line. The Unit 1 results compare well with the CROSSFLOW™, and are the sum of the pump flows is lower than the sum of the venturi flows on Unit 2.

The data indicates that the 2C pump is overperforming, with measured flow 6.5% above that expected for the $\Delta P$ and rpm. This is an interesting side issue, but has no impact on the venturi or ultrasonic flow meters.

## 8. Comparison of Common Header to Individual Steam Generator Flows

To determine whether there was an issue with the tempering line flows or an unknown anomaly with the four existing ultrasonic flowmeter installation locations, an independent ultrasonic flowmeter was installed in the common header prior to the split for the feedwater regulating valves. This installation was documented in calculation 059-PENG-CALC-084, Revision 01. The results of the comparison are also documented in the same calculation. The common header measures the total feedwater flow, while the individual venturies and single loop CROSSFLOW ™ ultrasonic flowmeter components measure the flow less the tempering flows. A review was performed of the common header flow and the measured flow through the venturi flow meters with and without the tempering flows. This resulted in configuration ratios that were very close which indicate that the tempering flow is most likely being reported within the plant instrument uncertainty and were not the source of the differences between readings on the CROSSFLOW™ and venturi meters. In order to compare the common header flows to the individual loop flows it is necessary to either sum the loop flows and tempering lines flows, or subtract the tempering lines flows from the header flow. When this was done, the flow through the common header and the sum of the flows through the tempering lines and loop CROSSFLOW™ meters were found to agree within the statistical limits as documented in calculation 059-PENG-CALC-084, Revision 01. The difference between the individual loop venturi flows and the individual loop CROSSFLOW averaged 1.515%. The difference between the individual loop venturi flows and the common header CROSSFLOW averaged 0.809%.

## 9. AMAG Report Findings

AMAG previously submitted their report covering their on-site activities in February and March of this year (April 2002). This section summarizes the findings and recommendations from that report.

The results of the testing and evaluations documented indicate that the CROSSFLOW™ system components are performing in an appropriate manner and that the test criteria for acceptable CROSSFLOW™ system performance are being met. The following specific items were noted and addressed during the evaluation:

- Special connector nuts were found loose on a transducer on Unit 2 that contributed to high signal rejection rates. This was tightened and is performing satisfactorily.
- A high rejection rate for data, which could cause an asymmetry, was noted on both Units. The plant was provided a modified configuration file for each unit based on frequency test data. The modified configuration file was then tested and the resulting data satisfied the acceptance standards for rejection rate and standard deviation conditions.
- A Feedwater flow oscillation of up to 3% was observed in Unit 1 and Unit 2 in several loops. The cause was determined to be the Feedwater regulating valve characteristics on each of the four loops for each unit at the Byron Station. The CROSSFLOW™ system was also re-tuned to re-optimize system parameters to accommodate the observed flow oscillations. It was recommended that extensive data be taken to confirm whether a correlation exists between the flow oscillations and the CROSSFLOW™ results. The station has verbally advised that no change to the "AMAG Correction Factor" was noted as a result of these changes.
- The Correction Factors (CF) change from Byron test to Byron test, since the data is only a snapshot in time and the data is taken infrequently (predefine at 9 month intervals). This runs counter to the industry data (stable CF), but the latter is based on continuous runs of data. It is recommended that the CROSSFLOW™ instrumentation be run for 6 months or greater to get a baseline and determine if the CF changes are due to some traceable cause. With the current methodology, it is difficult to determine a cause for a change in CF.
- The original system setup was correct from the aspect of physical parameters, cabling (except the loose nut noted above), transducer characteristics, Signal Conditioning Unit (SCU) and Multiplexer functionality, and software functionality.
- The existing installation was checked against another installation on the common header. The common header installation was made following standard AMAG/Westinghouse installation procedures and is documented in calculation 059-PENG-CALC-084, REV 01. The two CROSSFLOW™ systems were compared and verify that the four loops are being accurately measured within the CROSSFLOW™ expected uncertainties.
- The tempering line flows were found to be accurately reported by the plant instrumentation.
- The plant piping was walked down and the isometrics reviewed. No significant issue was identified with respect to piping geometry.

Recommendations:

- Data rejection rate is acceptable up to 25% only. If a greater rejection rate is noted, the data set shall not be used and troubleshooting shall be performed to identify the cause of the high data rejection rate.
- The standard deviation of data obtained for either unit should not be greater than 1.5% during data collection.

- New configuration files were provided in calculation 059-PENG-CALC-084, REV 01. These configuration files are to supercede those previously used.
- Continuous data gathering should be performed for a period of 6 months or greater, with the data analyzed in periods of a week or shorter. This is recommended to help identify and resolve the root cause for the CF fluctuation. It was further recommended that the cabling from both units be routed to the CROSSFLOW™ Multiplexer (MUX) for simultaneous readings.
- Housekeeping should be improved by replacing the equipment in the cabinet originally supplied with the equipment, and by placement of shrink tubing on the connectors hanging in the steam tunnel.
- Any anomaly or sudden change in data rejection rate should be discussed with AMAG/Westinghouse for further technical evaluation.
- Consideration should be given to provide a cross check of the common header vs. the four loops using CROSSFLOW™ technology on Unit 2 as was performed on Unit 1.
- Insulation blankets at Braidwood have gaps in the area of the strongback on the AMAG bracket. These gaps could have a conservative effect on the calculated CF of up to 0.2% (bringing Byron and Braidwood power levels closer together). It is therefore recommended that these gaps be closed with additional insulation or new blanket insulation properly sized (as at Byron) be installed.
- Consider additional training for Exelon personnel on effective use of CROSSFLOW™.
- Key Exelon personnel should participate in the CROSSFLOW™ Owners Group meetings. This would provide the opportunity for significant information gathering and exchange regarding effective CROSSFLOW system operation.

### Braidwood review

The lessons learned from the Byron effort were considered for examination of their effects on the Braidwood calorimetric correction factors. Based on the findings at Byron that the installation physical dimensions, hardware, software and SCU and MUX functionality were acceptable, these items were not considered a likely source of differences between Byron and Braidwood. This was because the same crews were used at both sites using the same installation standards to perform the original installations, and therefore these items were not reviewed for Braidwood.

The AMAG recommendations for data rejection and standard deviation for data were reviewed for all the Braidwood tests after June 1999. The only record copies of the data had already been sorted to eliminate rejected data on a large portion of the data, but those that had all the data available did have a slightly higher than 25% rejection rate. The standard deviation did not exceed the 1.5% recommended limit from the date that Braidwood stopped taking data in sample sizes of 1 (Unit 1, 10/99, Unit 2, 4/2000). Current data sets (within the last two years) have no standard deviations greater than 1% on Unit 1, or greater than 1.40% on Unit 2. The Braidwood Unit 2 Loop D has standard deviations averaging half again as large as any other Loop at Braidwood, but still well within the AMAG recommended limit.

The correction factors at Braidwood, which were available from their data from January 2001 on, track together, unlike those at Byron.

The conclusion that may be drawn from this is that Braidwood data is behaving like the industry norm despite the use of "snapshots" for correction factor evaluation and that the standard deviation is well within the guidance provided by AMAG.

**11. Caldon Issues as they apply to AMAG CROSSFLOW™**

Caldon reported to the NRC in Engineering Report ER-262 that fluid velocity profiles are very dynamic and flow swirl can vary as much as 10% and more of the axial velocity measurement in [Caldon] systems that in turn can affect feedwater flow measurement accuracy. The report does not limit itself to transit time ultrasonic flow meters, but went on to comment about what effects these issues might have on cross-correlation ultrasonic flow measurement technology. Westinghouse/AMAG responded to this Caldon comment in WCAP-15689-P. Due to the proprietary nature of the document, only the public part will be quoted here.

"The CROSSFLOW™ cross-correlation based ultrasonic flowmeter is not as sensitive to flow perturbations as clamp-on transit-time flowmeters. The reason for the lower sensitivity is that the cross-correlation technology only tracks the axial velocity component of the fluid, while the transit time technology is impacted by all of the velocity components including not only the axial, but the radial and tangential components as well. ... Although abrupt changes in swirl have never been encountered in our [AMAG/Westinghouse] operating experience, if it were to occur, the CROSSFLOW™ software would detect the change and alert the operator, and in all cases the shift would be only in the conservative direction."

"The inherent limitations of model testing should be considered for all types of calibrations, including calibrations that compensate for manufacturing tolerance of a multi-path chordal spool piece. WEC/AMAG have elected to use in-situ calibrations whenever there is a question about the velocity profile being fully developed at the flowmeter installation location. This approach allows the calibration to be performed under operating conditions, which eliminates the need for most laboratory calibrations. The accuracy of the CROSSFLOW™ meter can, therefore, easily be shown to be outstanding under operating plant conditions."

"Caldon's conclusions are based on its operating experience with transit time technology and the limited information that is available in the public domain regarding cross-correlation technology; some of which has since been found to be in error. Due to the proprietary restrictions necessary to provide the continued commercial protection of CROSSFLOW™, most flow meter experts, in general, are not in a fully informed position to provide objective technical evaluations and public presentations or reports that accurately reflect the state-of-the-art of cross-correlation technology. It is, therefore, understandable why some flow engineers and transit-time specialists with limited knowledge of cross-correlation technology, assume that all clamp-on flowmeters are subject to similar reliability and performance issues. This is simply NOT the case. One example of the problem with drawing conclusions from old information is illustrated by the attached letter AMAG recently received from Dr. David Zobin of Ontario Power Generation (OPG). Dr. David Zobin (OPG) notes, in part of his greater input that:

The Caldon report specifically referenced a 1992 paper by Jim Sherin and myself and concluded that 'the sensitivity of a cross correlation meter to the axial velocity profile may be somewhat greater than that of an externally mounted transit time meter.'
Dr. Zobin then goes on to point out that while the Caldon quote is correct as a snapshot in time (circa 1992), it is incorrect as a current interpretation of the state-of-the-art as it has evolved since that time. Dr. Zobin writes,

'Originally it was believed that the flow profile strongly depends on the fluid velocity. The statement was based on the best fit to the laboratory test data collected in 1990. The conclusion turned out to be erroneous since the observed dependence is later proved to be due to the test loop characteristic behavior and not due to any flow profile changes.'"

"In summary, WEC/AMAG have determined that the conclusions presented in ER-262 regarding cross-correlation technology are NOT applicable to CROSSFLOW™ and that the CROSSFLOW™ technology is NOT subject to the specific technical issues associated with Caldon's transit-time flowmeter as documented in their report."

## Hope Creek OPEX from July 1, 2002

There was an OPEX that was received July 1, 2002 from Hope Creek that noted a problem with CROSSFLOW™ that resulted in an overpower event. To examine whether this had an impact on the Exelon fleet, Westinghouse was contacted for information on the event. The preliminary cause has been determined and agreed to between AMAG, Westinghouse and Hope Creek personnel. The problem occurred due to large temperature transients (>100°F/minute) that allowed the pipe to shrink faster than the AMAG bracket. Cal-Sil block insulation was used on this installation, and during the transient Cal-Sil dust/debris got between the bracket and the pipe and, over several such cycles, resulted in the bracket being bound in a new position and reduced transducer contact pressure.
The offset bracket position and reduced contact pressure for the transducer displaced the effective acoustic axis of the transmit-receive pair, which resulted in the effective probe spacing deviating from the design value, resulting in a biased flow measurement. In this instance, the effective distance increased, causing an corresponding reduction in measured flow velocity. After the event, a change in the relationship between CROSSFLOW™ and the plant venturies was observed. The result was that the plant exceeded its licensed power level by an average of 0.25% for eight hours.
The brackets were removed, the transducers replaced and the pipe and bracket cleaned to prevent further misalignment. The system was returned to service and the plant full power uprated on 6/7/02 with a temporary blanket insulation. Since the return to service, two other transients have been experienced with no adverse effects on CROSSFLOW™ system performance.
Byron and Braidwood stations use blanket style insulation. This type of event should have no impact on either plant.
AMAG is providing an interim recommendation that an RSSI (Received Signal Strength Indicator Test be performed after any feedwater system transient where the rate of temperature change exceeds 100°F/minute. Such measured RSSI should be compared with the baseline performed during the CROSSFLOW™ commissioning. This is to be

used as an indicator of a change in CROSSFLOW™ response, and the cause for the change should be investigated. It does not mean that CROSSFLOW™ is malfunctioning.

Exelon Nuclear

Attachment G

Date: 8/30/02

To: Richard Lopriore
Site Vice President
Byron Station

From: Jim Meister
Vice President, Engineering

Subject: Review of Byron AMAG Feedwater Flow Instrumentation Installation and Performance

References:
1. Letter, Meister to Lopriore, same subject, dated 7/9/02
3. Westinghouse Report "Summary of Recent Crossflow Related Activities to Support Byron Station, April, 2002"

This letter is written to supplement the Reference 1 letter. Based on a request from Byron Station, the conclusion paragraph from the reference letter is restated as follows:

Our conclusion from our review of the Byron data is that the Byron installation is correct. We find that the equipment is currently performing within specification, the data is being properly interpreted, the correction factor properly calculated and the calorimetric properly calculated. Specific calorimetric input data outside of feedwater flow were not examined in this review. It is a station responsibility to determine if other input values are correct. If this has been done and the station uses the calorimetric to determine core thermal power and maneuvers to stay under 3586.6 $MW_t$, the station will not have exceeded nor will exceed licensed thermal power. It is recommended that the station follow the recommendations presented in Reference 2. In summary, we recommend that the AMAG CROSSFLOW meter continue to be used at Byron Station.

If you have any questions, please contact Jeff Drowley at (630) 657-3834 or me.

Prepared: _____
Jeffrey W. Drowley
Mechanical Engineering Manager
MWROG Engineering

Reviewed: _____
William G. Kouba
Engineering Director
MWROG Engineering

Attachment: Letter, Meister to Lopriore dated 7/9/02

cc: T. Roberts
D. Eder
D. Hildebrant
R. Flowers