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RS-03-025

February 5, 2003

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Byron Station, Unit 1
Facility Operating License No. NPF-37
NRC Docket No. STN 50-454

Subject: Byron Station, Unit 1, Licensed Thermal Power Limit Verification

Reference: Letter from J. A. Zwolinski (U.S. NRC) to J. L. Skolds (Exelon Generation Company, LLC), "Licensed Thermal Power – Byron Station, Unit 1," dated January 22, 2003

By letter dated January 22, 2003, the NRC notified Exelon Generation Company, LLC (EGC), that due to a number of plant performance indications and observations, the NRC is concerned that Byron Station, Unit 1 may be operating above its licensed thermal power level. The referenced letter requested that EGC expeditiously provide the NRC with assurance that Byron Station, Unit 1 is operating within its licensed thermal power limit.

On January 24, 2003, representatives of EGC met with NRC staff members to further discuss this issue and identify specific information to be provided to the NRC. Attachment 1 to this letter provides the requested information.

In summary, Attachment 1 contains the following information associated with Byron Station, Unit 1:

1. an assessment of conformance to the guidance provided in NRC Regulatory Issue Summary (RIS) 2002-03, "Guidance on the Content of Measurement Uncertainty Recapture Power Uprate Applications," dated January 31, 2002, related to feedwater flow measurement technique and power measurement uncertainty;
2. an assessment of Unit 1's electric power output;
3. an assessment of Unit 1's fuel burnup rate; and
4. a discussion of Unit 1's turbine limitations after implementation of power uprate.

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As detailed in Attachment 1, we have concluded that the ultrasonic feedwater flow instrumentation for Byron Station, Unit 1 was installed consistent with the guidance in RIS 2002-03; and that Byron Station, Unit 1 is operating within its licensed thermal power limit.

Should you have any questions related to this letter, please contact J. A. Bauer at (630) 657-2801.

Respectfully,

Keith R. Jury

Keith R. Jury
Director – Licensing
Midwest Regional Operating Group

Attachment 1: Byron Station, Unit 1, Licensed Thermal Power Limit Verification

cc: Regional Administrator – NRC Region III
NRC Senior Resident Inspector – Byron Station
Office of Nuclear Facility Safety – Illinois Department of Nuclear Safety

bcc: NRC Project Manager, NRR - Braidwood and Byron Stations
Senior Reactor Analyst - IDNS
Manager of Energy Practice - Winston and Strawn
Site Vice President - Byron Station
Director - Licensing, Mid-West Regional Operating Group
Manager - Licensing, Byron and Braidwood Stations
Regulatory Assurance Manager - Byron Station
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Attachment 1

Byron Station Unit 1
Licensed Thermal Power Limit Verification

The following information is presented to verify that Byron Station, Unit 1 is operating within its licensed thermal power limit.

1. Assessment of conformance to the guidance provided in NRC Regulatory Issue Summary (RIS) 2002-03, "Guidance on the Content of Measurement Uncertainty Recapture Power Uprate Applications," dated January 31, 2002, related to feedwater flow measurement technique and power measurement uncertainty.
2. Assessment of Unit 1's electric power output.
3. Assessment of Unit 1's fuel burnup rate.
4. Discussion of Unit 1's turbine limitations after implementation of power uprate.

1. RIS 2002-03 Guidance Assessment

In Attachment 1 of NRC RIS 2002-03, "Guidance on the Content of Measurement Uncertainty Recapture Power Uprate Applications," dated January 31, 2002, the NRC provided guidance related to feedwater flow measurement techniques and power measurement uncertainty.

The below assessment addresses Byron Station's conformance to the guidance given in RIS 2002-03, Attachment 1, Items I.1.A-F.

I. Feedwater Flow Measurement Technique and Power Measurement Uncertainty

1. A detailed description of the plant-specific implementation of the feedwater flow measurement technique and the power increase gained as a result of implementing this technique. This description should include:

A. Identification (by document title, number, and date) of the approved topical report on the feedwater flow measurement technique

<u>Response to Item A</u>

The topical report on the feedwater flow measurement technique approved by the NRC is the Asea Brown Boveri/Combustion Engineering (ABB/CE) Nuclear Power Topical Report, CENPD-397-P-A, Revision 01, "Improved Flow Measurement Accuracy using Crossflow Ultrasonic Flow Measurement Technology", dated May 2000.

B. A reference to the NRC's approval of the proposed feedwater flow measurement technique

<u>Response to Item B</u>

The feedwater flow measurement technique described in the subject topical report was approved by the NRC in a letter from S. A. Richards (NRC) to Ian C. Rickard (ABB/CE), "Acceptance for Referencing of CENPD-397-P, Revision-01-P, 'Improved Flow Measurement Accuracy using Crossflow Ultrasonic Flow measurement Technology,' (TAC No. MA6452)," dated March 20, 2000.

C. *A discussion of the plant-specific implementation of the guidelines in the topical report and the staff's letter/safety evaluation approving the topical report for the feedwater flow measurement technique*

Response to Item C

The plant specific implementation of the Crossflow technology for Byron Station, Unit 1 was documented in calculation 059-PENG-CALC-084, Revisions 0 and 1, "Feedwater Flow Measurement Using the Crossflow Ultrasonic Flowmeter at ComEd Byron Unit 1." This validated the testing that was conducted in May 1999. The Crossflow meter locations are documented in Revision 0 of the calculation, Attachment B, pages B23 through B26 for Feedwater Loops A through D, respectively. The meter locations are installed on each steam generator (S/G) feedwater loop in horizontal straight 16" schedule 120 pipe downstream of a standard 1.5 diameter (D) elbow trending vertical to horizontal. The minimum distance to the centerline of the elbow on all the meters is 413 inches, or nominally 30.4 length/diameter (L/D) from the elbow. The meters were installed in accordance with ABB/CE procedure, MISC-PENG-TOP-003, Revision 04, "Standard Procedure for Ultrasonic Measurement of Feedwater Flow," dated April 23, 1999, as documented in calculation 059-PENG-CALC-084, Revision 0. This guidance preceded both the topical report and the associated NRC safety evaluation. The vendor has provided written confirmation that this guidance is consistent with the requirements of Topical Report CENPD-397-P-A, Revision 01, "Improved Flow Measurement Accuracy using Crossflow Ultrasonic Flow Measurement Technology", dated May 2000. The instruments and the current calibration records of the instruments, used to determine outside diameter, wall thickness, transducer spacing, temperature of pipe, calibration block, and brackets are specifically delineated in Attachment B to calculation 059-PENG-CALC-084, Revision 0, pages B18 through B40. The instruments were in current calibration at the time of use with certification from a laboratory with traceability to the National Institute of Standards and Testing (NIST) standards. Documentation of the internal time delay check is on page B18 of the calculation, as is the make/model and serial number of the Crossflow computer, signal conditioning unit (SCU), multiplexer, mounting brackets, transducers, type of cable and couplant, and software version.

In response to Byron Station Condition Report 91771, a detailed re-evaluation of the installation was performed. The Crossflow installation was reviewed by Exelon Generation Company, LLC (EGC) with Westinghouse Electric Company (Westinghouse) and the Advanced Measurement Analysis Group (AMAG) participation in February 2002, and the documentation brought up to the current standards for that time in Revision 1 of calculation 059-PENG-CALC-084. This calculation updated the software and configuration files. These files were verified by the user prior to use of the instrument. The hardware installation remained unchanged.

D. *The dispositions of the criteria that the NRC staff stated should be addressed (i.e., the criteria included in the staff's approval of the technique) when implementing the feedwater flow measurement technique.*

Response to Item D

In a letter from S. A. Richards (NRC) to Ian C. Rickard (ABB/CE), "Acceptance for Referencing of CENPD-397-P, Revision-01-P, 'Improved Flow Measurement Accuracy using Crossflow Ultrasonic Flow measurement Technology,' (TAC No. MA6452)," dated March 20, 2000, the NRC issued a safety evaluation (SE) approving the subject topical report. In Section 3.4,"Crossflow [Ultrasonic Flow Measurement] UFM File Implementation," of the SE, in addition to the guidelines outlined in Topical Report CENPD-397-P, the NRC specified criteria that needed to be addressed by licensees. These criteria and our associated responses are given below.

(1) *The licensee should discuss the development of maintenance and calibration procedures that will be implemented with the Crossflow UFM installation. These procedures should include process and contingencies for an inoperable Crossflow UFM and the effect on thermal power measurement and plant operation.*

Response to SE Item (1)

Westinghouse provided quality assured calculations, 059-PENG-CALC-084, Revisions 00 and 01, which define the software configuration files for the Crossflow UFM and the accuracy of the systems flow measurements. This calculation is consistent with the requirements of Topical Report CENPD-397-P-A, Revision 01, "Improved Flow Measurement Accuracy using Crossflow Ultrasonic Flow Measurement Technology," dated May 2000. Westinghouse also provided a Certificate of Conformance that contains additional information concerning the SCU commissioning and self-test requirements.

Byron Station procedure, BVP 800-44, "Feedwater Venturi Calibration, Unit 1 and 2," controls the calculation and implementation of the feedwater flow correction factor (CF). This procedure verifies the Crossflow system is within calibration frequency, performs Crossflow system time delay testing as required by the vendor, provides the Crossflow system set up information and provides the CF calculation methodology. The CF calculation methodology is the ratio of the feedwater flow calculated by Crossflow to the feedwater flow calculated using the venturi. This ratio is then entered into the process computer by the operations department per procedure where it is used in the on line calorimetric program. The calorimetric program calculates feedwater flow using the venturis, multiplies this value by the appropriate CF, and uses the corrected feedwater flow measurement to determine thermal power. At Byron Station, feedwater flow is not a direct reactor protection input.

Byron Station performs routine CF calculations not less frequently than every nine months, which is controlled by the station surveillance program. This frequency ensures a CF is performed no less than once during a steady state cycle run and does not exceed the required 18 month calibration frequency of the installed feedwater flow instrumentation. Trending of the calculated CF since initial testing in 1999 has not observed any change in CF that can be attributed to changing feedwater venturi fouling. In addition, every weekday, an accounting of the unit megawatt-electric (MWe) output is performed to ensure stable operation of the unit. If there is any change in CF it will manifest itself as a deviation from expected generation and will be investigated.

The calculation of new CF values is required by station procedures in the event of a potential defouling incident (i.e., reactor trip or turbine off-line) or feedwater venturi differential pressure transmitters calibration adjustment. Validation of installed CF stability is also required after significant load reductions. All of these requirements are contained in approved station procedures, (i.e., in Byron General Procedures, BGP 100-3, "Power Ascension 5% to 100%," and BGP 100-4, "Power Decension"). The actual experience in the past year has been five recalculations of the CF on Byron Station, Unit 1 (i.e., two associated with a reactor trip, one associated with a refueling outage, and two associated with feedwater venturi differential pressure transmitter calibration).

As stated in the NRC safety evaluation which accepted the Crossflow UFM technology provided in Topical Report CENPD-397-P, Revision-01-P, "the Crossflow UFM may be used by the licensee for the in-plant capability to periodically recalibrate the feedwater venturi for the effect of fouling, thereby allowing recovery of the lost generating capacity while staying within the plant's licensed operating power level". Consistent with this use, Byron Station does not continuously run the Crossflow UFM (i.e., UFM is periodically used to recalibrate the venturis). The UFM is used for megawatt recovery due to potential fouling of the feedwater venturi flow elements, which would result in overestimation of feedwater flowrate. The installation of the Crossflow UFM was not intended to support a 10 CFR 50, Appendix K related power uprate. The periodic use of the UFM is expected to be conservative in the event that additional fouling occurs between periodic measurements (i.e., additional fouling over time would result in reduction of actual reactor power). Therefore, no contingencies are required for an inoperable Crossflow UFM.

Since implementation of power uprate, the Unit 1 CF has maintained a value of .976 ± 0.002. In the industry, feedwater CFs have ranged from approximately 0.97 to 1.03.

During the Crossflow re-validation performed in February 2002, multiple computers, electronics, software versions, and hardware were tested in various combinations to determine if there were any effects on the CF calculation. The results of this testing did not find any differences in the CF calculation. A complete hardware installation verification was also performed. During this same validation effort, all of the significant calorimetric inputs were reviewed. These inputs were: final feedwater temperature, feedwater pressure, calorimetric program, calorimetric input constants, feedwater tempering line flow instrumentation, and S/G blowdown flow instrumentation. There were no deficiencies with any of the instrumentation.

(2) *For plants that currently have the Crossflow UFM installed, the licensee should provide an evaluation of the operational and maintenance history of the installed UFM and confirm that the instrumentation is representative of the Crossflow UFM and is bounded by the requirements set forth in Topical Report CENPD-397-P.*

Response to SE Item (2)

To ensure that the equipment uncertainty remains bounded by the installation analysis, certain hardware and software configuration parameters are to be controlled. These parameters are contained in Appendix J to calculation 059-PENG-CALC-084, Revision 01 and in Byron Station Procedure BVP 800-44. These requirements are covered in the Byron Station procedure BVP 800-44 and are consistent with the requirements of Topical Report CENPD-397-P-A, Revision 01, "Improved Flow Measurement Accuracy using Crossflow Ultrasonic Flow Measurement Technology", dated May 2000. These parameters are verified during every Crossflow system setup to assure proper operation. The vendor has been on site to assist with re-verification of the equipment from original installation through Spring 2002, and confirmed on each visit that the equipment was performing within specification. The vendor has been used to recalibrate the SCU on the appropriate schedule specified in Certificate of Conformance, Order Number 01034984-2001753, dated April 30, 2001. The vendor has confirmed that the Byron, Unit 1 hardware, software and electronics are consistent with those used at all plants that have implemented an Appendix K related uprate using the Crossflow system. To date there have been no Crossflow equipment deficiencies identified that have or could have resulted in incorrect CF calculations.

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

Response to SE Item (3)

The uncertainty of the Crossflow UFM system is calculated in accordance with the procedure outlined in Topical Report CENPD-397-P-A, Revision 01 "Improved Flow Measurement Accuracy using Crossflow Ultrasonic Flow Measurement Technology," dated May 2000. Calculation 059-PENG-CALC-084, Revision 01, documents the uncertainty analysis for Byron Station Unit 1. This calculation uses the methodology from American National Standards Institute/Instrument Society of America (ANSI/ISA)-S67.04 Part I-1994, "Setpoints for Nuclear Safety-Related Instrumentation," and ISA-RP67.04 Part II-1994, "Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation," which is consistent with the methodology used at Byron Station in the determination of setpoints and instrument uncertainty. The error analysis methodology used for the Crossflow UFM provides the EGC required 2-sigma, 95% confidence level for the calorimetric power function (i.e., there is a 95% probability that the true value is within the stated accuracy of the reported measurement). Byron Station has confirmed that the ABB methodology described above is consistent to the EGC methodology used to determine the uncertainty of the existing feedwater venturi flow elements and overall calorimetric power measurement. The accuracy of the feedwater venturi flow elements is documented in Byron Station calculation NED-I-EIC-0233, Revision 1, "Daily Power Calorimetric Accuracy Calculation." Errors associated with all of the inputs to the calorimetric program, including both Crossflow UFM and feedwater venturi, are evaluated using the methodology presented in EGC Standard NES-EIC-20.04, Revision 0, "Analysis of Instrument Channel Setpoint Error and Loop Accuracy." This EGC standard is based upon and is consistent with ANSI/ISA-S67.04, Part I-1994 and ISA RP67.04, Part II-1994. Therefore, the methodology utilized by ABB/CE to determine the accuracy of the Crossflow UFM is consistent and acceptable within the requirements of EGC instrument setpoint methodology (i.e., an alternative methodology was not used to determine the uncertainty of the Crossflow UFM).

The Byron Station calorimetric accuracy calculation (NED-I-EIC-0233, Rev. 1) provides calculated uncertainties when using the feedwater venturi flow instrument loops by themselves (i.e., original design) and when using the Crossflow UFM to provide a "flow correction factor" to normalize venturi flowrate to UFM flowrate internal to the calorimetric software. The Crossflow UFM has a maximum mass flow uncertainty of 0.69% flow (per calculation 059-PENG-CALC-084, Revision 1) and the feedwater venturi flow elements have a calculated uncertainty of 1.07% flow (per calculation NED-I-EIC-0233, Revision 1). To evaluate the accuracy of the Crossflow UFM in the same manner as the feedwater venturis, the UFM % flow error is converted to differential pressure units of "inches of water column" ("wc) for combination and propagation of related error terms throughout the uncertainty calculation. By establishing consistent units representing feedwater flowrate, the methodology for combining all errors related to both the venturi and UFM are consistent within the accuracy calculation when converted to final error units of % reactor thermal power (RTP). This calculation concluded that the acceptance criteria of ≤2% RTP is satisfied when using either the venturi instrument loops as originally designed or when using the Crossflow UFM "flow correction factor". Note that the accuracy of other factors used in the calorimetric reactor power program (e.g., steam pressure, feedwater temperature, tempering line flow, and S/G blowdown flow) were not affected or altered when evaluating the use of the Crossflow UFM. Also note that EGC conservatively assumed a 1.0% flow error for the Crossflow UFM in the calorimetric uncertainty calculation in order to bound, with high confidence, the actual maximum stated error of 0.69% mass flow. This assumption provides conservative margin within the calculation.

For comparison purposes, the following provides a summary of the accuracy difference between the venturi flow instrument loops and the use of the Crossflow UFM for providing a "venturi flow correction factor", as stated in the Byron Station calorimetric accuracy calculation, NED-I-EIC-0233, Revision 1.

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Accuracy of Feedwater Flow Measurement (Flow Units of "wc)

- Venturi Flow Elements Alone: Random Error = 10.41"wc
  Non-Random Error = 15.68"wc
- Crossflow UFM CF Applied to Venturi Indicated Flow: Random Error = 8.82"wc
  Non-Random Error = 13.85"wc

Accuracy of Overall Calorimetric Power Program (Units of % RTP)

- Use of Venturi Flow Elements Alone (Original Design): Total Error = ±1.72% RTP
- Use of Crossflow UFM CF: Total Error = ±1.56% RTP

This level of uncertainty satisfies the existing calorimetric accuracy acceptance criteria of ±2% RTP, with significant margin remaining.

Pre-Uprate and Post-Uprate CF Values

The below tables show the "pre-uprate" and "post-uprate" CF values and the associated feedwater (FW) flow changes (Δ) for the Byron and Braidwood units.

Pre-Uprate Cross Flow Calorimetric Correction Factor				
Unit	Byron Unit 1	Byron Unit 2	Braidwood Unit 1	Braidwood Unit 2
CF Average	0.981956	0.983375	0.9960291	.9945170
% FW Flow Δ	1.80%	1.62%	0.40%	0.55%

Post-Uprate Cross Flow Calorimetric Correction Factor				
Unit	Byron Unit 1	Byron Unit 2	Braidwood Unit 1	Braidwood Unit 2
CF Average	0.976022	0.98168	0.9915424	0.9890957
% FW Flow Δ	2.39%	1.83%	0.85%	1.09%

(4) The licensee of a plant at which the installed Crossflow UFM was not calibrated to a site-specific piping configuration (flow profile and meter factors not representative of the plant-specific installation) should submit additional justification. This justification should show that the meter installation is either independent of the plant-specific flow profile for the stated accuracy, or that the installation can be shown to be equivalent to known calibration and plant configurations for the specific installation, including the propagation of flow profile effects at higher Reynolds numbers Additionally, for previously installed and calibrated Crossflow UFM, the licensee should confirm that the plant-specific installation follows the guidelines in the Crossflow UFM topical report.

Response to SE Item (4)

In accordance with Topical Report CENPD-397-P-A, Revision 01, "Improved Flow Measurement Accuracy using Crossflow Ultrasonic Flow Measurement Technology," dated May 2000, feedwater flow can be considered fully developed for meters located 15 or more pipe diameters downstream of a 90-degree elbow. The Crossflow UFM meters for Byron Unit 1 are located over 30 pipe diameters downstream of 90-degree elbows. Hence, a plant specific calibration is not required. As previously noted, the plant-specific installation follows the guidelines of the Topical Report CENPD-397-P-A, Revision 01, "Improved Flow Measurement Accuracy using Crossflow Ultrasonic Flow Measurement Technology," dated May 2000.

E. *A calculation of the total power measurement uncertainty at the plant, explicitly identifying all parameters and their individual contribution to the power uncertainty*

Response to Item E

The calculated accuracy of the UFM, combined with other calorimetric uncertainties, supports the existing power level margin of 2% used in the plant safety analysis. The overall calorimetric power uncertainty, when utilizing the Crossflow UFM as a method of "correcting" feedwater venturi indicated flowrate, is ±1.56% RTP (±1.72% RTP for venturi instrument loops as originally designed). Note that the accuracy of other factors used in the calorimetric reactor power program (e.g., steam pressure, feedwater temperature, tempering line flow, and S/G blowdown flow) were not affected or altered when evaluating the use of the Crossflow UFM. This magnitude of error is well within the ±2% RTP acceptance criteria and provides conservative margin in meeting design requirements.

F. *Information to specifically address the following aspects of the calibration and maintenance procedures related to all instruments that affect the power calorimetric:*

   i. *maintaining calibration*

   Response

   Contained within Byron Station's implementation procedure, BVP 800-44, is the step to verify the Crossflow system is within its calibration requirements. All inputs into the site's on-line calorimetric program are periodically calibrated (i.e., on an 18 month frequency) with the exception of final feedwater temperature. The required instrument calibrations are performed and controlled via the site's surveillance program. The components of the feedwater temperature instrumentation (i.e., thermocouples and computer input resistors) are not subject to time dependent instrument drift. Therefore, there is no calibration frequency requirement related to final feedwater temperature within the accuracy calculation. However, for conservatism, EGC applies a "point drift" allowance of 1.0 °F in addition to the other evaluated errors related to overall feedwater temperature uncertainty. This is consistent with the on-line calorimetric uncertainty calculation, NED-I-EIC-0233, Revision 1.

ii. controlling software and hardware configuration

Response

The Crossflow system was installed via the site's controlling procedures for configuration changes. Any changes to the Crossflow system hardware installed in the plant would be installed and controlled per procedure CC-AA-103, "Configuration Change Control." Any change to the Crossflow system software is controlled and installed per procedure IT-AA-101, "Digital Technology Systems (DTS) Quality Assurance Procedure."

iii. performing corrective actions

Response

If any Crossflow system acceptance criteria are exceeded per station procedure BVP 800-44, a condition report would be generated and entered into the corrective action program; and the current results would not be implemented.

iv. reporting deficiencies to the manufacturer

Response

If any Crossflow deficiencies are identified, this item would be entered into the station's corrective action program and the Crossflow vendor would be contacted.

v. receiving and addressing manufacturer deficiency reports

Response

Information is sent and received through the operating experience program. Information is also shared through the Crossflow Owners Group, of which EGC is a member. Westinghouse, as a part of their corrective actions process, notifies Crossflow owners of equipment and/or software problems that could affect their specific Crossflow system. This process defines the method of identifying, documenting and resolving issues that require corrective or preventive action.

2. Assessment of Unit 1's Electric Power Output

Prior to implementation of the ultrasonic feedwater measurement adjustments and power uprates, all Braidwood and Byron units were performing at essentially the same MWe output, adjusted for seasonal conditions and off-normal operation. American Society of Mechanical Engineers (ASME) PTC-6A, "Appendix A to PTC 6, the Test Code for Steam Turbines," was performed at both Braidwood Station, Unit 1 and Byron Station, Unit 1 before and after their respective power uprates. The purpose of the ASME PTC-6A tests was to normalize and correct the test outputs to common and standard conditions for comparison. The pre-uprate tests were performed after implementation of the ultrasonic feedwater measurement adjustments and indicated Byron Station, Unit 1 was producing 12.9 MWe more than Braidwood Station, Unit 1 before uprate. Post-uprate tests supported this difference indicating Byron Unit 1 was producing 16.0 MWe more than Braidwood Unit 1. The variation between the pre-uprate and post-uprate unit differences is within the accuracy of the ASME test ability.

Considering the MWe difference between Byron Unit 1 and Braidwood Unit 1 after implementation of the ultrasonic feedwater corrections, EGC expected to see a similar scale difference between secondary cycle plant parameter data, with Byron Unit 1 indicating higher key flows and pressures than Braidwood Unit 1. Analysis and continued data gathering indicate key parameter data for Byron Unit 1 trending approximately 1% higher than Braidwood Unit 1, which supports this conclusion.

3. Assessment of Byron Station Unit 1 Fuel Burnup Rate

The NRC indicated that there appears to be evidence of higher fuel burnup rate at Byron Unit 1 as compared to Braidwood Unit 1. The EGC Nuclear Fuels Group has reviewed the fuel burnup rates at both Byron Unit 1 and Braidwood Unit 1 after Crossflow was implemented. Specifically, the review was performed by examining the respective unit's fuel cycle boron letdown curve focusing on the point where the cycle loses full power capability. Based on examination of boron concentration measurements alone, no conclusion can be drawn regarding the actual value of reactor power level.

Prior to each refueling outage, the core design process is initiated to determine the next cycle's energy requirements, optimum uranium order, core loading pattern, cycle operating characteristics, and acceptability of the core design from a neutronic, thermal-hydraulic, and safety analysis perspective. Fuel management for the Byron and Braidwood units utilize the NRC-approved Westinghouse ANC / Phoenix computer codes and methods. Energy planning and operation uncertainties are incorporated into the core design process to accommodate fuel management flexibility and potential extended cycle operations (i.e. coastdown). Factors that influence the energy requirements for a specific fuel cycle and ultimately the amount of uranium procured for each core design include the expected number of operating days, the predicted operating capacity factor, load follow requirements, extended cycle operations, the ANC code bias associated with loss of full power capability (LFPC), and the fuel assembly multi-cycle energy requirements plan. After consideration of these aspects of the future cycle's operating characteristics, the Nuclear Fuels Group establishes the core-loading pattern.

Part of the design requirements mentioned above was the ANC code bias. An ANC code bias is used to adjust the cycle energy based on differences seen, from cycle to cycle, between the predicted and actual end of cycle energies. This bias is the energy equivalent of the difference in boron concentration between where the fuel cycle actually reaches LFPC (i.e., where the critical boron concentration at "all rods out, hot full power," is zero) and where the cycle should be on the predicted boron letdown curve. The boron letdown curve is generated as part of the ANC hot full power depletion cases and is expressed in ppm boron versus core burnup in megawatt-days per metric tonne uranium (MWD/MTU). Westinghouse methods, with respect to LFPC predictions, have shown a generic industry bias of 10 ppm boron. This 10 ppm bias is based on Westinghouse's historical design practices. A 10 ppm bias is equivalent to approximately three days of full power operation for Byron and Braidwood Stations. The 10 ppm bias is a statistical value based on the results of all Westinghouse designs; however, each individual unit normally has a bias that varies somewhat from the Westinghouse statistical average.

The bias for Byron Unit 1 has historically been in the range of 15 to 20 ppm, but has increased to approximately 50 ppm. This bias is within the range of recent fuel cycle bias variations (i.e., approximately 10 ppm to 60 ppm) observed on the other Byron/Braidwood units. The LFPC bias for a given cycle can be influenced by a number of issues, such as changes in plant parameters, plant uncertainties, methodologies, etc. Other known factors such as Axial Offset Anomaly (AOA) and Boron-10 depletion are not expected to significantly impact the LFPC bias. These are local factors and their impact would be manifested as "measured to predicted" differences in the monthly Technical Specification reactivity surveillance results. There is currently no definitive indication that a burnup rate higher than the corresponding licensed thermal power limit is actually being experienced on Byron Station, Unit 1.

Specific bias data for the Byron and Braidwood units "pre" and "post" Crossflow implementation are presented below. Note that the Crossflow technology was implemented in May 2000 for Byron Station, Units 1 and 2, and June 1999 for Braidwood Station, Units 1 and 2.

<u>Byron 1</u>
Cycle 9 - 15 ppm (Fall 1997 to Spring 1999).
Cycle 10 - 30 ppm (Spring 1999 to Fall 2000). Crossflow implemented May 2000.
Cycle 11 - 50 ppm (Fall 2000 to Spring 2002). Power uprate implemented May 2001.
Cycle 12 - currently in middle of cycle - LFPC bias indeterminate. Used bias of 35 ppm.

<u>Byron 2</u>
Cycle 8 - 20 ppm (Spring 1998 to Fall 1999).
Cycle 9 - 20 ppm (Fall 1999 to Spring 2001). Crossflow was implemented May 2000.
Cycle 10 - 60 ppm (Spring 2001 to Fall 2002). Power uprate implemented May 2001.
Cycle 11 - early in cycle - LFPC bias indeterminate. Used bias of 35 ppm for cycle planning.

<u>Braidwood 1</u>
Cycle 7 - 10 ppm (Spring 1997 to Fall 1998).
Cycle 8 - 15 ppm (Fall 1998 to Spring 2000). Crossflow implemented June 1999.
Cycle 9 - 25 ppm (Spring 2000 to Fall 2001).
Cycle 10 - 35 ppm (Fall 2001 to Spring 2003). Projected bias as we approach Spring 2003 outage). Power uprate implemented at beginning of cycle in October 2001.

<u>Braidwood 2</u>
Cycle 7 - 10 ppm (Fall 1997 to Spring 1999).
Cycle 8 - 15 ppm (Spring 1999 to Fall 2000). Crossflow implemented June 1999.
Cycle 9 - 10 ppm (Fall 2000 to Spring 2002).
Cycle 10 – currently in middle of cycle - LFPC bias indeterminate. Used 20 ppm bias for cycle planning. Power uprate implemented at beginning of cycle in April 2002.

The above data is presented in the table below.

Braidwood and Byron Stations
LFPC Bias Data

	Byron 1	Byron 2	Braidwood 1	Braidwood 2
Actual Bias for cycle immediately prior to Crossflow implementation	15 ppm	20 ppm	10 ppm	10 ppm
Actual Bias for cycle during which Crossflow was implemented	30 ppm	20 ppm	15 ppm	15 ppm
Actual Bias for first complete cycle after Crossflow implementation	50 ppm	60 ppm	25 ppm	10 ppm
Current bias used or projected for cycle design	35 ppm	35 ppm	35 ppm	20 ppm

The Nuclear Fuels Group will continue to monitor the design bias for Byron Unit 1 on a cycle basis. This evaluation will occur as the data becomes available (i.e., after the unit reaches LFPC for the current / future cycles). Any change in the Byron Station, Unit 1 bias will be evaluated, not only for the impact on future fuel loadings but also for any implications associated with design methods or operating processes. Nuclear Fuels will also apply the same monitoring actions to the other Byron and Braidwood units.

4. Discussion of Unit 1's Turbine Limitations After Implementation of Power Uprate

Power Uprate Modification Design Inputs

As part of the Power Uprate Feasibility Study, EGC provided design input data to Westinghouse (i.e., the Nuclear Steam Supply System (NSSS) contractor for the power uprate project) in February 1999. The information was based upon plant calorimetric data from 1998. Plant data from all four units (i.e., Byron Units 1 and 2 and Braidwood Units 1 and 2) such as reactor power, steam pressure, and steam/feedwater flow, were utilized to predict various NSSS parameters for the 3586 MW-thermal uprated power level. The most important of these parameters for Byron Unit 1 were S/G outlet pressure and reactor coolant Tavg temperature.

Byron Unit 1 and Braidwood Unit 1 data from 1998 (i.e., prior to Crossflow implementation) were used as a common basis for predicting the S/G outlet pressure, mass flow rates and steam line pressure. Multiple options were then developed with respect to varying levels of turbine modifications and the predicted MWe gains for each option. EGC selected the turbine modification option that provided a 72 MWe increase for Byron Unit 1 based on a S/G outlet pressure of 1035 psia, turbine throttle inlet pressure of 1004 psia, at a reactor coolant Tavg temperature of 588°F, with a 2% flow margin in the turbine.

Early in the design process (i.e., in August 1999) the Tavg analytical band was set at 575°F – 588°F. A target Tavg of 586°F was selected to provide operating margin as the S/Gs aged and tubes were plugged.

In July 1999, EGC authorized vendor engineering to begin to support modification installation at the first Byron unit in the fall of 2000. The engineering team considered the impact of the Crossflow factors into the high pressure (HP) turbine redesign but concluded the 2% flow margin included in the redesign would be sufficient for the Crossflow values seen through testing at that time. The CFs at that time were approximately 1% for Braidwood and 2% for Byron. The Crossflow program was implemented at Braidwood in June 1999.

Design Versus Actual Final Power Level

In May 2000, Byron Station implemented Crossflow. As a result of that work, the Byron Unit 1 main feedwater flow was increased approximately 1.7% to bring the unit to the 100% thermal design output. The Power Uprate Team performed a review of this issue and concluded that as long as the turbine throttle inlet pressure condition of 1004 psia was satisfied, the 72 MWe upgrade would still be achieved. These predictions were based on the changes to the turbine, not the reactor coolant system (RCS) flow or any other calorimetric data.

In August 2000, the Unit 1 "Pre-MWe Verification Test" was performed prior to the replacement of the Byron Unit 1 HP rotor to establish the baseline unit performance upon which the 72 MWe guarantee would be based. The corrected results showed the unit to be generating slightly above the baseline heat balance (i.e., 1173 MWe vs. 1169 MWe).

The turbine HP rotor was replaced during the September 2000 refueling outage. Following startup, it was noted that the #4 governor valve went from approximately 25% open to 38% open. Since the unit was operating at the same T_{AVG} of 582°F, a concern was raised regarding whether the turbine could support the additional volumetric flow rate necessary to achieve the guaranteed 72 MWe. The possibility was raised that the unit could be at "valves wide open" (VWO) prior to reaching the uprated 100% rated thermal power as the remaining valve stroke on the #4 governor valve would only accommodate approximately another 1.7% flow. The turbine generator contractor was again contacted with respect to the position of the #4 governor valve and the turbine impulse pressure. The response was that the valve was approximately where it was expected to be and that impulse pressure was very close to the predicted value.

In March 2001, the Power Uprate Team conducted a verification test on the HP turbine for Byron Unit 1 to confirm the pre-MWe test data for throttle inlet and steam generator outlet pressures. This data confirmed the accuracy of the pre-MWe verification test.

Several sensitivity studies were performed whose results concluded that for a T_{AVG} of 586°F, an expected S/G outlet pressure of 1020 psia was predicted without Crossflow. If Crossflow were included, the prediction would be lowered to 1015 psia. Further considerations concluded that the effect of the 1.7% increase post-Crossflow was to reduce steam pressure by an additional 5 psi.

Based upon predictions in March 2001, the throttle pressure was expected to be 16 psia lower than that shown on the uprate heat balance. The 16 psi approximated the reduction anticipated for a 2°F reduction in T_{AVG}.

In later discussions in March 2001, the turbine generator contractor confirmed that the unit conditions closely matched their model used to develop the uprate heat balance. It was noted that as steam pressure increased the machine's capability to pass the flow increased proportionally. Therefore, as Tavg is increased, the S/G outlet pressure increased and the #4 governor valve would go closed proportionally. It was also predicted that the unit would go to VWO when turbine throttle pressure reached 984 psia.

In May 2001, the Byron Unit 1 on-line uprate was performed and the unit reached VWO at a turbine throttle inlet pressure of 990 psia with indicated reactor power at 98.3%. The Crossflow CF averaged 2.3%. This included an operating RCS average temperature of 586°F that is below the design point of 588°F.

In April of 2002, Tavg was raised to the upper licensed limit of 588°F and the unit was ramped to approximately 99.0% reactor power. The below table shows Byron Unit 1 design and actual values for key secondary system parameters.

Byron Station Unit 1
Post Power Uprate
Design vs. Actual Secondary System Parameter Values

Parameter	Units	Design Value*	Actual Post Uprate @100% Power**
Total FW Flow (Calorimetric)	KBH	16027	16135
Condensate Booster (CB) Pump flow	KBH	10841	11417
Heater Drain (HD) Pump Flow	KBH	5188	5371
CB+HD Pump Flow	KBH	16029	16788
FW Pump Flow	KBH	16037	16290
Final Feed Temp Average	°F	444.7	444.6
Impulse Pressure	Psig	748.7	760
#7 FW Heater Pressure	Psig	406	400
#6 FW Heater Pressure	Psig	270	273
#5 FW Heater Pressure	Psia	181.7	185
MSR 1st Stage Pressure	Psig	417	399.8
HP Turbine Exhaust Pressure	Psig	170.7	168.6
Average Main Steam pressure	Psia	1030	1025.5
Average Crossflow CF	N/A	1.000	0.976

* Design value represents the vendor's power uprate thermal kit guaranteed values.
** Data taken on May 10, 2002
KBH – Kilo-pounds/hour

Byron Station Unit 1
Licensed Thermal Power Limit Verification

<u>Two Percent Design Margin Not Obtained</u>

The 2% margin included in the original power uprate turbine design was intended to account for manufacturing tolerances by the turbine generator contractor.

Based upon post-uprate reviews it was concluded that the 2% margin was used up by a combination of several factors:

1. Following the May 2001 on-line uprate, Byron Unit 1 was operating at an RCS temperature of 586°F, which is below the design point of 588°F (this reduced temperature resulted in a lower steam pressure, which reduced the ability of the turbine to pass adequate flow). In April of 2002, Tavg was raised to the upper licensed limit of 588°F and the unit was ramped to approximately 99.0% reactor power;

2. Turbine manufacturing tolerances, and

3. Higher Crossflow CF than what was originally reviewed in mid-1999.

EGC is currently reviewing the uprated turbine design and current operating parameters to evaluate the feasibility of restoring flow margin into the turbine.

Conclusion

Based on the above discussion, we have concluded that the Byron Station, Unit 1 ultrasonic feedwater flow instrumentation was installed consistent with the guidance in RIS 2002-03; and that Byron Station, Unit 1 is operating within its licensed thermal power limit.