ATTACHMENT 7

Operating Parameter Uncertainties for the Byron/Braidwood Revised Thermal Design Procedure

Westinghouse Proprietary Class 3

OPERATING PARAMETER UNCERTAINTIES
for the
BYRON/BRAIDWOOD REVISED THERMAL DESIGN PROCEDURE

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OPERATING PARAMETER UNCERTAINTIES for the BYRON/BRAIDWOOD REVISED THERMAL DESIGN PROCEDURE

I. Introduction

The Revised Thermal Design Procedure (RTDP) determines the uncertainties of four process parameters used to establish bounding process conditions for various analyses. These parameters are Pressurizer Pressure, Primary Coolant Temperature (T_{AVG}), Reactor Power and Reactor Coolant System Flow. Pressurizer Pressure uncertainty results from the 7300 process control system uncertainties associated with the pressurizer pressure control system. T_{AVG} uncertainty results from the 7300 process control system uncertainties associated with the rod control channel. Reactor Power is obtained from daily power calorimetric calculated by the plant process computer. Uncertainty in Reactor Power results from the uncertainty in the process parameters that provide inputs to the plant process computer. Reactor Coolant System (RCS) Flow is obtained from the normalization of the RCS Cold Leg elbow taps to a precision flow calorimetric at the beginning of each cycle.

The uncertainty calculations for these process parameters are based on:

- Review of Byron and Braidwood station instrument channel calibration procedures.

- Existing environmental effects and current as-built conditions that potentially effect the instrument channel accuracies.

- Accuracy of measurement and test equipment (MTE) used by the Byron and Braidwood stations for calibration of the instrument channels.

- Sensitivity determination of the daily power calorimetric algorithm currently installed on the Byron and Braidwood stations plant process computers.

II. Methodology

The methodology used to determine the accuracy of the process parameters combines random and bias errors to determine a total error for the parameter. Random errors (σ) are considered to be normally distributed and statistically independent. Based on references 1 and 2 and various industry standards (references 12 and 13), random errors are combined using the square root of the sum of the squares. Bias errors (e) are combined arithmetically. The total random error is multiplied by 2 to ensure a 95% confidence value and combined with the total bias error to obtain a total error.

$$\text{Total Error} = 2\{(\Sigma\sigma^2)^{1/2}\} + \Sigma e$$

For the pressurizer pressure process errors, the loop accuracy analysis considers the pressurizer pressure signal and the process controller errors. The pressurizer pressure signal accuracy was previously determined in reference 5 and used a methodology consistent with the Westinghouse methodology in reference 3. The loop accuracy is determined by an equation of the form:

$$\text{loop accuracy} = (PMA^2 + PEA^2 + (SCA + SMTE + SD)^2 + SPE^2 + STE^2 + (RCA + RMTE + CA + RD)^2 + RTE^2)^{1/2} + TI$$

The parameters are described in references 3 and 5 and are briefly described below.

- Process Measurement Allowance (PMA) - allowance for non-instrument related effects which have a direct bearing on the accuracy of an instrument channel's reading, e.g. temperature stratification in a large diameter pipe.

- Primary Element Accuracy (PEA) - error due to the use of a metering device, e.g. venturi, orifice, or elbow. Typically, this is a calculated or measured accuracy for the device.

- Sensor Calibration Accuracy (SCA) - the reference (calibration) accuracy for a sensor or transmitter as defined by SAMA Standard PMC 20.1-1973.

- Sensor Maintenance & Test Equipment (SMTE) - the accuracy of the test equipment (typically a high accuracy local readout gauge and DVM) used to calibrate a sensor or transmitter in the field or in a calibration laboratory.

- Sensor Drift (SD) - the change in input-output relationship over a period of time at reference calibration conditions, e.g., at constant temperature.

- Sensor Pressure Error (SPE) - the change in input-output relationship due to a change in the static head pressure from the calibration conditions (if calibration is performed at line pressure) or the accuracy to which a correction factor is introduced for the difference between calibration and operating conditions for a Δp transmitter.

- Sensor Temperature Error (STE) - the change in input-output relationship due to a change in the ambient temperature (for expected normal operating conditions) from the reference calibration conditions about a transmitter.

- Rack Calibration Accuracy (RCA) - the reference (calibration) accuracy, as defined by SAMA Standard PMC 20.1-1973 for a process loop string.

- Rack Maintenance & Test Equipment (RMTE) - the accuracy of the test equipment (typically a transmitter simulator, voltage or current power supply, and DVM) used to calibrate a process loop in the racks.

- Controller Accuracy (CA) - the calibration accuracy for the proportional controller.

- Rack Drift (RD) - the change in input-output relationship over a period of time at reference conditions, e.g. at constant temperature.

- Rack Temperature Effect (RTE) - change in input-output relationship for the process rack module string due to a change in the ambient temperature from the reference calibration conditions.

- Thermal Inertia (TI) - allowance for the interaction of pressurizer heaters and spray.

For the T_{AVG} and power range process errors, the loop accuracy analysis performed to determine the total error is based on references 1 and 2. The Normal Loop Error (NLE) term is obtained from evaluation of the following:

- Instrument Reference Accuracy (RA) - The limit that an instrument measurement error should not exceed when a device is used under manufacturer's specified or reference operating conditions. A manufacturer may define this value to bound the effects of linearity, hysteresis, deadband, and repeatability.

- Calibration Error (CAL) - The error resulting from calibration methods, calibration components, measurement and test equipment (MTE) reference accuracy and measurement and test equipment reading error.

- Setting Tolerance (ST) - The inaccuracy of offset introduced into the calibration process due to procedural allowances given to technicians performing the calibration.

- Normal Operating Errors (Σen) - The summation of the non-random, deterministic errors. An error is non-random if its value can be related to specific environmental or operational conditions. Non-random errors can be further classified as symmetric or as a bias. Symmetric non-random errors are predictable in magnitude, but not in sign. Bias errors are predictable in both sign and magnitude.

  As shown in reference 2, the following is a list of typical non-random errors that are evaluated in the determination of instrument setpoint and control channel accuracies.

Non-random Error Source	Type
Density errors	bias
Process Measurement errors	bias
Flow element errors	symmetric
Temperature, Humidity, radiation, seismic and insulation resistance errors	bias or symmetric (depending on specific source)
Thermal expansion errors	bias
Configuration errors	symmetric
Drift	symmetric (without specific testing)
Static pressure error	bias
Power supply error	symmetric

The determination of the random error is defined by:

$$\sigma = (RA^2 + CAL^2 + ST^2 + \sigma_{INPUT}^2)^{1/2}$$

where: the RA, CAL and ST are as described above. The term σ_{INPUT} represents random errors that are present at the input to the instrument module or instrument channel.

The calibration error (CAL) is further defined as:

$$CAL = (MTE^2{}_{IN} + STD^2{}_{IN} + MTE^2{}_{OUT} + STD^2{}_{OUT})^{1/2}$$

where: MTE (measurement and test equipment error) - the inaccuracy introduced into the calibration process due to the accuracy of the measurement and test equipment used to calibrate the instrument module or channel.

STD (calibration standard error) - the inaccuracy introduced into the calibration process due to the accuracy of the standards used to calibrate the measurement and test equipment.

A detailed explanation of the above methodology and error terms is provided in reference 2.

III. Instrument Channel Uncertainty

The determination of the four process channel uncertainties for the Byron and Braidwood stations is discussed in the following sections.

1. Pressurizer Pressure

Pressurizer pressure is controlled by comparing a reference pressure setpoint to the measured pressurizer pressure. Uncertainties are evaluated for the pressure sensing instrumentation and the process control instrumentation. The uncertainties are combined, as described in section II, using a methodology consistent with the Westinghouse methodology. As shown in table 1, the channel uncertainty is ±3.76% span which corresponds to an accuracy of ±30.0 psi. Per reference 14, an additional allowance of [ ]$^{+a,c}$ is made for the thermal inertia (pressure overshoot or undershoot) due to the interaction of the heaters and sprays. Assuming a normal, two sided probability distribution, the total channel uncertainty at a 95% confidence level is [ ]$^{+a,c}$.

TABLE 1
PRESSURIZER PRESSURE CONTRCL SYSTEM ACCURACY

Sensor Uncertainties

SCA	= 0.50% span
SMTE	= 1.00% span
STE	= [ ] +a,c
SPE	=
SD	=

Process Rack and Controller Uncertainties

Controller CA	= 0.50% span
Controller RMTE	= 0.65% span
Driver RCA	= 0.50% span
Driver RMTE	= 0.18% span
Process Rack RCA	= 0.50% span
Process Rack RMTE	= 0.76% span
Process Rack RD	= [ ] +a,c
Process Rack RTE	=
Bias	=

The channel uncertainty equation is:

[ ] +a,c

2. TAVG (rod control channel)

T_{AVG} is controlled by comparing a reference temperature setpoint (obtained from the turbine impulse chamber pressure and power range flux signals) and the auctioneered high T_{AVG} signal from the narrow range T_H and T_C signals. Uncertainties are evaluated for the RTD's and T_{AVG} process errors (reference 6), the turbine impulse pressure process errors (reference 7) and the rod control process errors (reference 9). The uncertainties are combined using the methodology described in section II. As shown in table 2, the total error for the process signal is ±3.02°F random and 1.14°F bias.

Per reference 4, Westinghouse has determined that the controller deadband is represented by a uniform distribution where there is an equal probability throughout the range of the deadband. The variance of a ±4°F deadband is represented by:

$$(\sigma_{DB})^2 = (R^2)/12 = 5.33°F$$

Combining the variance for the process signal and the deadband results in a controller variance of:

$$\sigma^2 = (\sigma_P)^2 + (\sigma_{DB})^2 = (3.02)^2 + 5.33 = 14.45°F$$

The total channel accuracy is obtained by combining the T_{AVG} standard deviation (σ) of 3.80°F and the 1.14°F bias. Assuming a normal, two sided probability distribution, this results in an uncertainty of ±8.74°F at a 95% confidence level.

TABLE 2
TAVG - ROD CONTROL CHANNEL ACCURACY

UNCERTAINTY*	TURBINE IMPULSE PRESSURE	ROD CONTROL CALIBRATION MODULE 1	2	3	4	5
RA	0.10%	0.58%	0.14%	0.13%	0.13%	0.46%
CAL	0.14%	0.26%	0.07%	0.09%	0.09%	1.84%
ST	0.17%	0.33%	0.17%	0.17%	0.17%	0.17%
σINPUT	0.89%	1.65%	0.28%	0.85%	0.88%	19.93%

* In percent span

BIAS: Bulk Avg. Temp. = [ ] +a,c
Turb. Imp. Press. = 0.92% span

Channel Total Error (σ) = 3.02°F random
= 1.14°F bias

Deadband (σ^2) = 5.33°F random

At a 95% confidence level, the total uncertainty for the T_{AVG} instrument channel is:

$$2[\{(3.02°F)^2 + (5.33°F)\}^{1/2}] + 1.14°F = \pm 8.74°F$$

3. Reactor Power

Byron and Braidwood are required to determine reactor power to be in compliance with the station Technical Specifications. Reactor power is determined by a secondary power calorimetric that is computed by the plant process computer. The plant process computer determines reactor power level from values for instantaneous and time averaged signals using inputs from the following instrument channels:

- Feedwater Flow (FF): differential pressure across the feedwater venturies is provided to the process computer. The daily power calorimetric algorithm uses the flow coefficients for each venturi to determine feedwater flow.

- Feedwater Temperature (FT): thermocouple input is provided to the process computer.

- Steam Pressure (SP): a steam line pressure signal from the process control system is provided to the process computer.

- Blowdown Flow (BF): blowdown flow orifice differential pressures are measured, converted to flow and provided to the process computer.

- Tempering Line Flow (TF): tempering line flow orifice differential pressures are measured, converted to flow and provided to the process computer. The daily power calorimetric algorithm combines feedwater flow and tempering line flow to determine total feedwater flow.

In addition, the Power Range Neutron Flux channels are required to be adjusted when the difference between the indicated neutron flux power level and the reactor power determined by the daily power calorimetric is greater than that allowed by the Technical Specifications. This difference is effected by the accuracy of the reactor thermal power calculated by the daily power calorimetric which is dependent on:

1) The process instrument channel uncertainties for each of the process computer inputs. These uncertainties are determined using the methodology described in section II. The uncertainty of each process parameter is shown in table 3. Determination of the uncertainties assumes that the plant is at 100% reactor thermal power (RTP) when the daily power calorimetric is performed. At lower power levels, the increased measurement uncertainty is more than compensated for by the increased margin to DNB.

2) The effect of the process input uncertainties on the daily power calorimetric algorithm. Table 4 lists the sensitivities and relationship of each process error. It should be noted that an allowance for venturi fouling is not included since this uncertainty is accounted for in the station Technical Specifications.

The daily power range calorimetric algorithm determines reactor power from a heat balance across the steam generator. Assuming that the primary and secondary sides are in equilibrium, the thermal output of the steam generators is calculated from the combination of feedwater flow, tempering line flow, steam generator blowdown flow, and the associated enthalpies for each flow. In addition, calculated reactor thermal power accounts for reactor coolant pump heat addition and primary side system losses. Thermal power is divided by the core rated BTU/hr at full power to compute %RTP:

$$RP = N\left[Q_{SG} - Q_P + (Q_L / N)\right]\left(\frac{100}{H}\right) \qquad \text{eqn. 1}$$

where:
- RP - % reactor thermal power (RTP)
- N - number of primary side loops
- Q_{SG} - steam generator thermal output (BTU/hr)
- Q_P - RCP heat adder (BTU/hr)
- Q_L - primary system net heat loss (BTU/hr)
- H - Core rated BTU/hr at full power

Steam generator thermal output is determined from feedwater flow, tempering line flow and blowdown flow. Feedwater flow is computed from equation 2 for each of the two taps on the each loop's feedwater venturi.

$$W_{x,y} = (a_{x,y})(Fa_y)\sqrt{\frac{DP_{x,y}}{v_y}} \qquad \text{eqn. 2}$$

where:
- x - venturi tap number (1 or 2)
- y - loop number (1, 2, 3, or 4)
- W - feedwater flow in lbm/hr
- a - venturi constant specific to the tap
- Fa- thermal expansion factor of the venturi
- DP- venturi differential pressure process parameter
- v - feedwater specific volume which is a function of feedwater temperature and steam pressure

Tempering line and blowdown flows are determined by measuring the differential pressure across a flow orifice. The feed flows are averaged and combined with tempering line flow to obtain the total feed flow. The process computer converts total feed flow and blowdown flow from GPM to lbm/hr, and equation 3 is used to determine the loop steam generator power.

$$LP_y = (FF_y - BF_y)\, h_s + (BF_y)\, h_l - (FF_y)\, h_w \qquad \text{eqn. 3}$$

where:
- LP - loop steam generator power (BTU/hr)
- x - venturi tap number (1 or 2)
- y - loop number (1, 2, 3, or 4)
- FF - total feedwater flow in lbm/hr
- BF - blowdown flow in lbm/hr
- h_s - steam enthalpy calculated from steam pressure and steam quality
- h_l- saturated liquid enthalpy
- h_w- feedwater enthalpy from feedwater temperature and steam pressure

The instrument uncertainties (Table 3) for the feedwater flow, feedwater temperature, tempering line flow, blowdown flow and steam pressure measurements are combined with each parameters sensitivity (Table 4) to determine the overall reactor power uncertainty. The four loop reactor power uncertainty is determined as follows:

$$\sigma_{LOOP} = (\sigma_{FF}^2 + \sigma_{FT}^2 + \sigma_{TF}^2 + \sigma_{BF}^2 + \sigma_{SP}^2)^{1/2} \qquad \text{eqn. 4}$$
$$= (0.40^2 + 0.53^2 + 0.02^2 + 0.04^2 + 0.06^2)^{1/2}$$
$$= 0.67\%\ RTP$$

Based on the number of loops, the random error is 0.33% RTP and the bias error is:

$$\Sigma e = \Sigma en_{FF} - \Sigma en_{FT} + \Sigma en_{TF} - \Sigma en_{BF} - \Sigma en_{SP} \qquad \text{eqn. 5}$$
$$= 1.37 - 0 + 0.05 - 0.06 - 0.20$$
$$= 1.16\% \text{ RTP}$$

Assuming a normal, two sided probability distribution, the resulting daily power calorimetric uncertainty at a 95% confidence level is ±1.83% RTP.

TABLE 3
REACTOR POWER INSTRUMENT UNCERTAINTIES

Process	Random Error (σ)	Bias Error (Σen)
Feedwater Flow	±6.84 in.WC	23.54 in.WC
Feedwater Temperature	±2.87°F	0
Tempering Line Flow	±1.92 gpm	4.95 gpm
Blowdown Flow	±3.37 gpm	5.14 gpm
Steam Pressure	±13.79 psi	50.05 psi

TABLE 4
REACTOR POWER SENSITIVITIES

Process	Sensitivity	Interaction
Feedwater Flow	0.058%/in.WC	direct
Feedwater Temperature	0.185%/°F	reverse
Tempering Line Flow	0.011%/gpm	direct
Blowdown Flow	0.011%/gpm	reverse
Steam Pressure	0.004%/psi	reverse

4. Reactor Coolant System Flow

The uncertainties for Reactor Coolant System (RCS) Flow have not been explicitly determined at this time. Commonwealth Edison has assumed that the accuracy of this process parameter will not exceed ±3.5% RCS flow for Byron and Braidwood.

The NRC has reviewed and accepted a 3.5% RCS flow uncertainty for Commonwealth Edison's Zion Station as discussed in CECo letter dated May 26, 1992 from S. F. Stimac to Dr. Thomas E. Murley and subsequently approved in Zion license amendment #139/128 transmitted by C. P. Patel's letter to T. J. Kovach dated June 26, 1992. Based on the Byron/Braidwood Technical Specification Requirement to perform feedwater venturi inspections each refueling outage, we have a high level of confidence that the assumption of 3.5% RCS flow uncertainty is conservative.

IV. CONCLUSIONS

This evaluation of pressurizer pressure control, RCS temperature control, NIS power range and RCS flow uncertainties represents a reasonable methodology and a plant specific analysis of the Byron and Braidwood parameters effecting the RTDP design input. The Byron and Braidwood uncertainty values used in the RTDP analysis are equivalent to or more conservative than the values determined in the preceding sections.

REFERENCES

1. Commonwealth Edison Company Technical Information Document TID-E/I&C-10, Revision 0, "Analysis of Instrument channel Setpoint Error and Instrument Loop Accuracy"

2. Commonwealth Edison Company Technical Information Document TID-E/I&C-20, Revision 0, "Basis for Analysis of Instrument channel Setpoint Error and Instrument Loop Accuracy"

3. Tuley, C.R., Miller, R.B., "Westinghouse Setpoint Methodology for Control and Protection Systems", IEEE Transactions on Nuclear Science, February 1986, Vol. NS-33 No. 1, pp. 684-687.

4. Westinghouse letter NS-EPR-2577, E.P. Rahe to C.H. Berlinger, NRC, dated March 31, 1982, "Westinghouse partial response to the Improved Thermal Design Procedure (Proprietary)"

5. NED-I-EIC-0004, Revision 1, "Byron/Braidwood Pressurizer Pressure Channel Error Analysis"

6. NED-I-EIC-0014, Revision 1, "Byron/Braidwood Tavg - ΔT Channel Error Analysis"

7. NED-I-EIC-0167, Revision 0, "Byron/Braidwood Turbine Impulse Pressure Switch and Indicator Error Analysis"

8. NED-I-EIC-0221, Revision 0, "Byron/Braidwood Pressurizer Pressure Control System Instrument Loop Error Calculation"

9. NED-I-EIC-0223, Revision 0, "Byron/Braidwood Rod Speed Control Uncertainty Calculation"

10. NED-I-EIC-0233, Revision 0, "Byron/Braidwood Daily Power Calorimetric, Accuracy Calculation"

11. NED-O-MSD-8, Revision 0, "Sensitivity Factors for Byron/Braidwood Power Calorimetric"

12. ANSI/ISA Standard S67.04-1988, "Setpoints for Nuclear Safety-Related Instrumentation"

13. ANSI/ANS-58.4-1979, "Criteria for Technical Specifications for Nuclear power Stations"

14. Westinghouse Revised Thermal Design Procedure Instrument Uncertainty Methodology for Commonwealth Edison Zion Units 1 and 2 Nuclear Power Station, August 1991, WCAP 12801 (proprietary) and WCAP 12802 (non-proprietary).

ATTACHMENT 8

Commonwealth Edison Company
I & C Engineering Letter

March 1,1994

Electrical / I&C Engineering

NETS

March 1, 1994
In reply refer to
CHRON#
207699

To: G.K. Schwartz
Station Manager
Byron Station

K.L. Kofron
Station Manager
Braidwood Station

Subject: Overtemperature Delta T Setpoint

Reference: 1) CAE-93-220, CCE-93-244, October 1, 1993, "Byron and Braidwood Stations, Steam Generator Tube Plugging and Thermal Design Flow Reduction Analysis Program, Revised OTΔT/OPΔT Trip Setpoints"

2) Byron Letter 93-0579 (CHRON# 204964), October 21, 1993, "Delta T Constants for Steam Generator Tube Plugging Analysis"

Review of reference 1 has indicated an additional constraint on the OTΔT setpoint that was not initially evaluated as part of the Steam Generator Increased Tube Plugging program. The calculation performed by NETS I&C department for this setpoint incorporated changes to the channel gains, specifically changes to $k1_{MAX}$ and k3 from reference 1 and $K1_{NOM}$ from reference 2. The selection of $k1_{NOM} = 1.370$ by Byron and Braidwood was sufficiently conservative, at that time, with respect to the analyzed channel accuracy.

We have determined that the change to the positive ΔI gain must also be considered. This will require additional total allowance in the OTΔT setpoint. We have recommended and discussions with Penny Reister, Byron Tech Staff, have concluded that it would be acceptable to revise the $k1_{NOM}$ value to maintain the required positive margin.

Recalculation of the OTΔT setpoint accuracy results in the following required value:

$$k1_{NOM} \leq 1.3250$$

The change to the ΔI gain does not require any changes to the OPΔT or Low-Low T_{AVG} setpoints. If you have further questions, please call me at Downers Grove extension 7263.

Pete VandeVisse
I&C Engineer

3/4/94

Pete Wicyk
I&C Supervisor

cc: G.P. Wagner
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ATTACHMENT 6

Operating Parameter Uncertainties for the Byron/Braidwood Revised Thermal Design Procedure

Westinghouse Proprietary Class 2