ENCLOSURES TO NL-02-155

A. Westinghouse authorization letter dated November 15, 2002 (CAW-02-1575), with the accompanying affidavit, Proprietary Information Notice, and Copyright Notice

B. WCAP-15904-P, Rev 0, "Power Calorimetric Uncertainty for the 1.4 Percent Uprating of Indian Point Unit 2," dated November 2002. (Proprietary)

C. WCAP-15904-NP, Rev 0, "Power Calorimetric Uncertainty for the 1.4 Percent Uprating of Indian Point Unit 2," dated November 2002. (Non-Proprietary)

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ENTERGY NUCLEAR OPERATIONS, INC.
INDIAN POINT NUCLEAR GENERATING UNIT NO. 2
DOCKET NO. 50-247

WCAP-15904-NP
Revision 0

November 2002

Power Calorimetric Uncertainty for the 1.4% Uprating for Entergy Indian Point Unit 2

Westinghouse

WCAP-15904-NP, Rev. 0

POWER CALORIMETRIC UNCERTAINTY FOR THE 1.4-PERCENT UPRATING OF INDIAN POINT UNIT 2

November 2002

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POWER CALORIMETRIC UNCERTAINTY FOR THE 1.4-PERCENT UPRATING OF INDIAN POINT UNIT 2

I.   INTRODUCTION

The purpose of this analysis is to determine the uncertainty in the daily power calorimetric for the 1.4% uprating. Reactor power is monitored by the performance of a secondary-side heat balance (power calorimetric) at least once every 24 hours. The daily power calorimetric uncertainty must be a value small enough to account for the increase in nominal operating power.

Westinghouse has been involved with the development of several techniques to treat instrumentation uncertainties. An early version used the methodology outlined in WCAP-8567, "Improved Thermal Design Procedure,"[1,2,3] which is based on the conservative assumption that the uncertainties can be described with uniform probability distributions. Another approach is based on the more realistic assumption that the uncertainties can be described with random, normal, two-sided probability distributions.[4] This approach is used to substantiate the acceptability of the protection system setpoints for many Westinghouse plants, e.g., Millstone Unit 3, Diablo Canyon, Farley, and others. The second approach is now utilized for the determination of all instrumentation uncertainties for the Revised Thermal Design Procedure (RTDP) parameters and protection functions.

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II. METHODOLOGY

The methodology used to combine the error components for a channel is the square root of the sum of the squares (SRSS) of those groups of components that are statistically independent. Those uncertainties that are dependent are combined arithmetically into independent groups, which are then systematically combined. The uncertainties used are considered to be random, two-sided distributions. This technique has been utilized before as noted above, and has been endorsed by the NRC staff[5,6,7,8] and various industry standards.[9,10]

The relationships between the error components and the channel instrument error allowance are variations of the basic Westinghouse setpoint approach[11] and are based on Indian Point Unit 2 specific procedures and processes. These relationships are defined as follows.

For parameter indication utilizing the plant process computer:

$$CSA = \{(PMA)^2 + (PEA)^2 + (SMTE + SCA)^2 + (SPE)^2 + (STE)^2 + (SRA)^2 +$$
$$(SMTE + SD)^2 + (RMTE + RCA)^2 + (RTE)^2 + (RMTE + RD)^2 + (COMPREF)^2 +$$
$$(COMPMTE + COMPCAL)^2 + (COMPTE)^2 + (COMPMTE + COMPDRIFT)^2\}^{1/2} +$$
$$BIAS$$

Eq. 1

Where the acronyms are defined as:

CSA	=	Channel Statistical Allowance
PMA	=	Process Measurement Accuracy
PEA	=	Primary Element Accuracy
SMTE	=	Sensor Measurement and Test Equipment accuracy
SCA	=	Sensor Calibration Accuracy
SPE	=	Sensor Pressure Effects
STE	=	Sensor Temperature Effects
SRA	=	Sensor Reference Accuracy
SD	=	Sensor Drift
RMTE	=	Rack Measurement and Test Equipment accuracy
RCA	=	Rack Calibration Accuracy
RTE	=	Rack Temperature Effects
RD	=	Rack Drift
COMPREF	=	Plant Computer Reference accuracy
COMPMTE	=	Plant Computer Measurement and Test Equipment accuracy

COMPCAL	=	Plant Computer Calibration accuracy
COMPTE	=	Plant Computer Temperature Effects
COMPDRIFT	=	Plant Computer Drift

Many of the parameters above are defined in Reference 11 and are based on ANSI/ISA 51.1-1979 (Reaffirmed 1993).[12] However, for ease in understanding, they are paraphrased below:

CSA -	Uncertainty as defined by Eq. 1
PMA -	Non-instrument-related measurement errors, e.g., temperature stratification of a fluid in a pipe
PEA -	Errors due to a metering device, e.g., elbow, venturi, orifice
SMTE -	Measurement and test equipment used to calibrate a sensor/transmitter
SCA -	Calibration tolerance for a sensor/transmitter
SPE -	Change in input-output relationship due to a change in static pressure for a differential pressure (Δp) cell
STE -	Change in input-output relationship due to a change in ambient temperature for a sensor or transmitter
SRA -	Reference accuracy for a sensor/transmitter
SD -	Change in input-output relationship over a period of time at reference conditions for a sensor or transmitter
RMTE -	Measurement and test equipment used to calibrate rack modules
RCA -	Calibration accuracy for all rack modules in a loop or channel, assuming the loop or channel is string calibrated, or tuned, to this accuracy
RTE -	Change in input-output relationship due to a change in ambient temperature for the rack modules
RD -	Change in input-output relationship over a period of time at reference conditions for the rack modules
COMPREF -	Allowance encompassing the effects of linearity, hysteresis, and repeatability for the plant computer
COMPMTE -	Measurement and test equipment used to calibrate the plant computer
COMPCAL -	Calibration accuracy for the plant computer in the loop or channel, assuming the loop or channel is string calibrated, or tuned, to this accuracy
COMPTE -	Change in input-output relationship due to a change in ambient temperature for the plant computer

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COMPDRIFT - Change in input-output relationship over a period of time at reference conditions for the plant computer

BIAS - A one-directional uncertainty for a sensor/transmitter or a process parameter with a known magnitude

A more detailed explanation of the Westinghouse approach noting the interaction of several parameters is provided in Reference 11.

III. INSTRUMENTATION UNCERTAINTIES

In this section, the reactor power measurement algorithm will be discussed first, followed by the results of the power calorimetric uncertainty calculations.

Reactor Power Measurement .

The daily power measurement is based on the measurement of the feedwater (FW) flow using the Caldon Leading Edge Flow Meter (LEFM) system.

Assuming that the primary and secondary sides are in equilibrium, the core power is determined by:
- Summing the thermal output of the steam generators (SGs)
- Subtracting the reactor coolant pump (RCP) heat addition
- Adding the primary-side system losses
- Dividing by the core Btu/hr at rated full power

The equation for this calculation is:

$$RP = \frac{\{(\Sigma Q_{SG}) + Q_L - Q_P\}(100)}{H} \qquad \text{Eq. 2}$$

Where:

$$
\begin{array}{lcl}
RP & = & \text{Core power (\% rated thermal power -- RTP)} \\
Q_{SG} & = & \text{Steam generator thermal output (Btu/hr)} \\
Q_L & = & \text{Primary system net heat losses (Btu/hr)} \\
Q_P & = & \text{RCP heat addition (Btu/hr)} \\
H & = & \text{Rated core power (Btu/hr)}
\end{array}
$$

For the purposes of this uncertainty analysis (and based on H noted above) it is assumed that the plant is at 100% RTP when the measurements are taken. Measurements performed at lower power levels will result in different uncertainty values.

The thermal output of the steam generator is determined by a secondary-side calorimetric measurement, which is defined as:

$$Q_{SG} = [(h_s - h_f)W_f] - [(h_s - h_{bd})W_{bd}] \qquad \text{Eq. 3}$$

Where:
Q_{SG} = Steam generator thermal output (Btu/hr)
h_s = Steam enthalpy (Btu/lb)
h_f = Feedwater enthalpy (Btu/lb)
W_f = Feedwater flow (lb/hr)
h_{bd} = Steam generator blowdown enthalpy (Btu/lb)
W_{bd} = Steam generator blowdown flow (lb/hr)

The steam enthalpy is based on the measurement of steam generator outlet steam pressure, assuming saturated liquid conditions. The feedwater enthalpy is based on the measurement of feedwater temperature and feedwater pressure. Steam generator blowdown enthalpy is based on the measurement of steam generator outlet steam pressure, assuming saturated conditions. The measurement of steam generator blowdown flow is made with a venturi and Δp transmitter, and is compensated by a measured blowdown temperature. The feedwater flow is determined by a single LEFM device (Caldon) in each of four feedwater lines.

The power measurement is thus based on the following plant measurements:
- Steamline pressure (P_s)
- Feedwater temperature (T_f)
- Feedwater pressure (P_f)
- Steam generator blowdown flow (W_{bd})
- Feedwater flow (W_f) (from Caldon system)
- Moisture carryover (affects h_s)

The power measurement is also based on the following calculated values:

- Feedwater density (ρ_f)
- Feedwater enthalpy (h_f)
- Steam enthalpy (h_s)
- Primary system net heat losses (Q_L)
- RCP heat addition (Q_p)
- Steam generator blowdown enthalpy (h_{bd})

Power Calorimetric Uncertainties

The secondary-side uncertainties are in four principal areas: feedwater flow, feedwater enthalpy, steam enthalpy, and steam generator blowdown flow. These areas are identified in Tables 1 through 3.

For the measurement of feedwater flow, the Caldon LEFM has a stated accuracy of [   ]$^{+a,c}$, which Entergy provided to Westinghouse to use in the calculations. Since the calculated steam generator thermal output is proportional to feedwater flow, the flow coefficient uncertainty is expressed as [   ]$^{+a,c}$.

An allowance of [   ]$^{+a,c}$ was used for the steam generator blowdown venturi flow coefficient. This resulted in an uncertainty of [   ]$^{+a,c}$.

The uncertainty applied to the steam generator blowdown venturi thermal expansion correction (F_a) is based on the uncertainties of the temperature and the coefficient of thermal expansion for the venturi material, type 304 stainless steel. For this material, a change of $\pm 1.0°F$ in the nominal temperature range changes F_a by [   ]$^{+a,c}$ but the change in steam generator thermal output is negligible.

An uncertainty of 5.0% in F_a for type 304 stainless steel is used in this analysis. This results in an additional uncertainty bounded by [   ]$^{+a,c}$. This allowance is included to account for the variations in material composition that could exist for the venturi.

Using the NBS/NRC steam tables, it is possible to determine the sensitivities of various parameters to changes in feedwater temperature and pressure. Table 1 notes the instrument uncertainties for the hardware used to perform the parameter measurements. Table 2 lists the

various parameter sensitivities. Both feedwater temperature and feedwater pressure uncertainties have an effect on feedwater density and feedwater enthalpy.

Steam generator blowdown transmitter Δp uncertainties are converted to % steam generator blowdown flow using the following conversion factor:

$$\% \text{ flow} = (\Delta p \text{ uncertainty})(1/2)(\text{transmitter span} / 100)^2 \qquad \text{Eq. 4}$$

Using the NBS/NRC steam tables, it is possible to determine the sensitivity of steam enthalpy to changes in steam pressure and steam quality. Table 1 notes the uncertainty in steam pressure and Table 2 provides the sensitivity. For steam quality, the steam tables were used to determine the sensitivity at a moisture content of [ ] $^{+a,c}$. This value is noted in Table 2.

With respect to primary-side uncertainties, the net pump heat addition uncertainty allowance is 12.0 MWt. The overall uncertainty is estimated to be less than [ ] $^{+a,c}$ of the net heat input, which is less than [ ] $^{+a,c}$ of core power.

The calorimetric power measurement determination is performed using a computerized formulation or a manual calculation. As noted in Table 3, Westinghouse has determined the dependent sets in the calculation and the direction of interaction.

Using the power uncertainty values noted in Table 3, the 4-loop uncertainty equation is:

$$\varepsilon = \left[\right]^{+a,c} \qquad \text{Eq. 5}$$

Where:

ε	=	Power calorimetric uncertainty
SGBF_V	=	Steam generator blowdown flow venturi (basic accuracy)
$\text{SGBF}_{\Delta p}$	=	Steam generator blowdown flow Δp
h_{SP}	=	Steam enthalpy (as a function of pressure)
Fa_t	=	Steam generator blowdown flow F_a (as a function of temperature, inferred from steam pressure)

h_{SG_LIQ} = Steam generator blowdown flow enthalpy (as a function of steam pressure)

ρ_{SG_P} = Steam generator blowdown flow density (as a function of steam pressure)

Fa_m = Steam generator blowdown flow F_a (as a function of material)

ρ_p = Feedwater flow density (as a function of pressure)

h_p = Feedwater flow enthalpy (as a function of pressure)

N = Number of primary-side loops

LEFM = Feedwater flow (mass flow accuracy of Caldon system)

NPHA = Net pump heat addition

$h_{s\ moist}$ = Steam enthalpy (as a function of moisture)

$$\varepsilon = \left[\right]^{+a,c} \qquad \text{Eq. 6}$$

Based on the number of loops and the instrument uncertainties for the four parameters, the uncertainty for the secondary-side power calorimetric measurement for use in the safety analyses is:

Number of loops	Power Uncertainty (% RTP)
4	[ ]$^{+a,c}$

TABLE 1
POWER CALORIMETRIC INSTRUMENTATION UNCERTAINTIES

	FW Temp. °F	FW Press. % Span	FW Header % Mass Flow	SG Blowdown % Flow	Steam Press. % Span	+a,c
LEFM						
SRA						
SCA						
SMTE						
SPE						
STE						
SD						
BIAS						
EA						
COMPREF						
RCA						
COMPCAL						
RMTE						
COMPMTE						
RTE						
COMPTE						
RD						
COMPDRFT						
RTDDRFT						
CSA						
# Instruments Used						
Units	°F	psig	Mass Flow	% Flow	psig	
Instrument Span	N/A **	N/A *		32,085 lbm/hr	1400	+a,c
Instrument Uncertainty (Random)						
Nominal	431.8°F	664 psia		12,032 lbm/hr	564 psia	

*   Parameter not directly measured for power measurement. Input based on bounding value as provided by Entergy

**   Included in LEFM mass flow by Caldon

***   Provided by Entergy/Caldon

TABLE 2
POWER CALORIMETRIC SENSITIVITIES

+a,c

Feedwater Flow

Feedwater Density
    Temperature
    Pressure

Feedwater Enthalpy
    Temperature
    Pressure

h_s

h_f

Δh (SG)

Steam Enthalpy
    Pressure
    Moisture

SG Blowdown Enthalpy
    Pressure

SG Blowdown Flow
    Fa
        Temperature
        Material
    Density
        Pressure
    Δp

* Effects included in feedwater mass flow uncertainty provided by Entergy/Caldon

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TABLE 3
POWER CALORIMETRIC MEASUREMENT UNCERTAINTY

Component	Instrument Uncertainty	Power Uncertainty (% Power)
		+a,c
Feedwater Flow		
SG Blowdown Flow		
Venturi (SGBF$_v$)		
Thermal Expansion		
Coefficient		
Temperature (Fa$_t$)		
Material (Fa$_m$)		
Density		
Pressure (ρ_{SG_P})		
Δp (SGBF$_{\Delta p}$)		
SG Blowdown Liquid Enthalpy		
Pressure (h$_{SG\_LIQ}$)		
Feedwater Density		
Temperature (ρ_t)		
Pressure (ρ_p)		
Feedwater Enthalpy		
Temperature (h$_t$)		
Pressure (h$_p$)		
Steam Enthalpy		
Pressure (h$_{SP}$)		
Moisture (h$_{s\ moist}$)		
Net Pump Heat Addition (NPHA)		
4-Loop Uncertainty for use in the safety analyses		

* *, * * * Indicates sets of dependent parameters

* * * * Effects included in feedwater flow uncertainty provided by Entergy/Caldon

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IV. RESULTS/CONCLUSIONS

The preceding sections provided the methodology to account for the power calorimetric uncertainties for the 1.4% uprating. The uncertainty calculations have been performed for Indian Point Unit 2 utilizing plant-specific instrumentation and calibration procedures. A power calorimetric uncertainty value of [ ]$^{+a,c}$ will be used in the Indian Point Unit 2 safety analysis.

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5. NRC letter, S. A. Varga to J. Dolan, Indiana and Michigan Electric Company, dated 2/12/81.

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12. ANSI/ISA-51.1-1979 (Reaffirmed 1993), "Process Instrumentation Terminology."