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WESTINGHOUSE IMPROVED THERMAL DESIGN PROCEDURE INSTRUMENT UNCERTAINTY METHODOLOGY

VIRGIL C. SUMMER NUCLEAR POWER STATION

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I. INTRODUCTION

This report provides the Improved Thermal Design Procedure (ITDP) instrument uncertainty methodology used at South Carolina Electric and Gas Company's Virgil C. Summer Nuclear Power Station with Westinghouse Vantage 5 nuclear fuel. Four operating parameter uncertainties are used in the uncertainty analysis of the ITDP. These parameters are Pressurizer Pressure, Primary Coolant Temperature (T_{avg}), Reactor Power, and Reactor Coolant System Flow. They are frequently monitored and several are used for control purposes. Reactor power is monitored by the performance of a secondary side heat balance (power calorimetric) once every 24 hours. RCS flow is monitored by the performance of a precision flow calorimetric at the beginning of each cycle. The RCS Cold Leg elbow taps are normalized against the precision calorimetric and used for monthy surveillance (with a small increase in uncertainty). Pressurizer pressure is a controlled parameter and the uncertainty reflects the control system. T_{avg} is a controlled parameter via the temperature input to the rod control system and the uncertainty reflects this control system.

Westinghouse has been involved with the development of several techniques to treat instrumentation uncertainties. An early version (for D. C. Cook 2 and Trojan) 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 (for McGuire and Catawba) 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., D. C. Cook 2(5), V. C. Summer, Wolf Creek, Millstone Unit 3 and others. The second approach is now utilized for the Westinghouse determination of all instrumentation errors for both ITDP parameters and protection functions.

II. METHODOLOGY

The methodology used to combine the error components for a channel is the square root of the sum of the squares of those groups of components which are statistically independent. Those errors 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. The sum of both sides is equal to the range for that parameter, e.g., Rack Drift is typically [$]^{+a,c}$, the range for this parameter is [$]^{+a,c}$. This technique has been utilized before as noted above, and has been endorsed by the NRC staff(6,7,8,9) and various industry standards(10,11).

The relationships between the error components and the channel instrument error allowance are variations of the basic Westinghouse Setpoint Methodology(12) and are defined as follows:

1. For precision parameter indication using Special Test Equipment or a DVM at the input to the racks;

$$CSA = \{(SCA + SMTE + SD)^2 + (SPE)^2 + (STE)^2 + (RDOUT)^2\}^{1/2} \qquad \text{Eq. 1}$$

2. For parameter indication utilizing the plant process computer;

$$CSA = \{(SCA + SMTE + SD)^2 + (SPE)^2 + (STE)^2 + (RCA + RMTE + RD)^2 + (RTE)^2 + (ID)^2 + (A/D)^2\}^{1/2} \qquad \text{Eq. 2}$$

3. For parameters which have control systems;

$$CSA = \{(PMA)^2 + (PEA)^2 + (SCA + SMTE + SD)^2 + (SPE)^2 + (STE)^2 + (RCA + RMTE + RD + CA)^2 + (RTE)^2\}^{1/2} \qquad \text{Eq. 3}$$

where:

CSA = Channel Allowance
PMA = Process Measurement Accuracy
PEA = Primary Element Accuracy
SCA = Sensor Calibration Accuracy
SMTE = Sensor Measurement and Test Equipment Accuracy
SPE = Sensor Pressure Effects
STE = Sensor Temperature Effects
SD = Sensor Drift
RCA = Rack Calibration Accuracy
RMTE = Rack Measurement and Test Equipment Accuracy
RTE = Rack Temperature Effects
RD = Rack Drift
RDOUT = Readout Device Accuracy (DVM or gauge)
ID = Computer Isolator Drift
A/D = Analog to Digital Conversion Accuracy
CA = Controller Accuracy

The parameters above are as defined in references 5 and 12 and are based on SAMA Standard PMC 20.1, 1973(13). However, for ease in understanding they are paraphrased below:

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,
SCA - reference (calibration) accuracy for a sensor/transmitter,
SMTE- measurement and test equipment accuracy for calibration of sensor/transmitter, assumed to be less than 10% of the calibration accuracy (and therefore neglected) unless otherwise stated.
SPE - change in input-output relationship due to a change in static pressure for a d/p cell,
STE - change in input-output relationship due to a change in ambient temperature for a sensor/transmitter,

SD - change in input-output relationship over a period of time at reference conditions for a sensor/transmitter,

RCA - reference (calibration) accuracy for all rack modules in loop or channel assuming the loop or channel is string calibrated, or tuned, to this accuracy.

RMTE- measurement and test equipment accuracy for calibration of the rack modules, assumed to be less than 10% of the calibration accuracy (and therefore neglected) unless otherwise stated.

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,

RDOUT- the measurement accuracy of a special test local gauge, digital voltmeter or multimeter on it's most accurate applicable range for the parameter measured,

ID - change in input-output relationship over a period of time at reference conditions for a control/protection signal isolating device,

A/D - allowance for conversion accuracy of an analog signal to a digital signal for process computer use,

CA - allowance for the accuracy of a controller, not including deadband.

A more detailed explanation of the Westinghouse methodology noting the interaction of several parameters is provided in references 5 and 12.

III. Instrumentation Uncertainties

The instrumentation uncertainties will be discussed first for the two parameters which are controlled by automatic systems, Pressurizer Pressure, and T_{avg} (through Rod Control).

1. PRESSURIZER PRESSURE

Pressurizer Pressure is controlled by comparison of the measured vapor space pressure and a reference value. Allowances are made for the transmitter and the process racks/controller. As noted on Table 1, the electronics uncertainty for this function is [$]^{+a,c}$ which corresponds to an accuracy of [$]^{+a,c}$. In addition to the controller accuracy, an allowance is made for pressure overshoot or undershoot due to the interaction and thermal inertia of the heaters and spray. Based on an evaluation of plant operation, an allowance of [$]^{+a,c}$ was made for this effect. Therefore, a total control system uncertainty of [$]^{+a,c}$ is calculated, which results in a standard deviation of [$]^{+a,c}$ (assuming a normal, two sided probability distribution).

TABLE 1

PRESSURIZER PRESSURE CONTROL SYSTEM ACCURACY

SCA = +a,c
M&TE=
STE =
SD =
BIAS=
RCA =
M&TE=
RTE =
RD =
CA =

+a,c

ELECTRONICS UNCERTAINTY = (RANDOM)
PLUS (BIAS)

ELECTRONICS UNCERTAINTY = (RANDOM)
PLUS (BIAS)

CONTROLLER UNCERTAINTY =

[ ]+a,c

2. T_{AVG}

T_{avg} is controlled by a system that compares the auctioneered high T_{avg} from the loops with a reference, usually derived from the First Stage Turbine Impulse Chamber Pressure. T_{avg} is the average of the narrow range T_H and T_C values. The highest loop T_{avg} is then used in the controller. Allowances are made (as noted on Table 2) for the RTDs, transmitter and the process racks/controller. The CSA for this function is dependent on the type of RTD, pressure transmitter, and the location of the RTDs, i.e., in the RTD bypass manifold or in the Hot and Cold Legs. Based on the assumption that 1 T_H and 1 T_C cross-calibrated RdF RTDs are used to calculate T_{avg} and the RTDs are located in the RTD bypass manifold, the CSA for the electronics is [$]^{+a,c}$. Assuming a normal, two sided probability distribution results in an electronics standard deviation (s_1) of
[$]^{+a,c}$.

However, this does not include the controller deadband of ± 1.5 °F. The controller accuracy is the combination of the instrumentation accuracy and the deadband. The probability distribution for the deadband has been determined to be [
$]^{+a,c}$. The variance for the deadband uncertainty is then:

$$(s_2)^2 = [\qquad]^{+a,c}.$$

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

$$(s_T)^2 = (s_1)^2 + (s_2)^2 = [\qquad]^{+a,c}$$

The controller s_T = [$]^{+a,c}$ for a total uncertainty of
[$]^{+a,c}$.

TABLE 2
ROD CONTROL SYSTEM ACCURACY

Tavg TURB PRES

+a,c

PMA =
SCA =
M&TE=
STE =
SD =
BIAS=
RCA =
M&TE=
M&TE=
RTE =
RD =
CA =
BIAS=

RTDs USED - TH = 1 TC = 1

+a,c

ELECTRONICS CSA =
ELECTRONICS SIGMA =

CONTROLLER SIGMA =
CONTROLLER BIAS =
CONTROLLER CSA =

3. RCS FLOW

ITDP, and the Virgil Summer Technical Specifications, requires an RCS flow measurement with a high degree of accuracy. It is assumed that a precision calorimetric flow measurement is performed at the beginning of a cycle, i.e., no allowances have been made for Feedwater venturi fouling, and above 70% RTP. The reactor coolant system flow uncertainty of 2.1% was provided by the South Carolina Electric and Gas Company and is not discussed in this report.

4. REACTOR POWER

The plant performs a primary/secondary side heat balance once every 24 hours when power is above 15% Rated Thermal Power. This heat balance is used to verify that the plant is operating within the limits of the Operating License and to adjust the Power Range Neutron Flux channels when the difference between the NIS and the heat balance is greater than that required by the plant Technical Specifications.

Assuming that the primary and secondary sides are in equilibrium; the core power is determined by summing the thermal output of the steam generators, correcting the total secondary power for Steam Generator blowdown (if not secured), subtracting the RCP heat addition, adding the primary side system losses, and dividing by the core rated Btu/hr at full power. The equation for this calculation is:

$$RP = \frac{\{(N)\{Q_{SG} - Q_P + (Q_L/N)\}\}(100)}{H} \qquad \text{Eq. 4}$$

where;

RP = Core power (% RTP)

N = Number of primary side loops

Q_{SG} = Steam Generator thermal output (BTU/hr) as defined in Eq. 5

Q_P = RCP heat adder (Btu/hr) as discussed below

Q_L = Primary system net heat losses (Btu/hr) as discussed below

H = Core rated Btu/hr at full power.

For the purposes of this uncertainty analysis (and based on H noted previously) it is assumed that the plant is at 100% RTP when the measurement is taken. Measurements performed at lower power levels will result in different uncertainty values. However, operation at lower power levels results in increased margin to DNB far in excess of any margin losses due to increased measurement uncertainty.

The thermal output of the Steam Generator is determined by precision secondary side calorimetric measurement, which is defined as:

$$Q_{SG} = (h_s - h_f)W_f \qquad \text{Eq. 5}$$

where; h_s = Steam enthalpy (Btu/lb)
h_f = Feedwater enthalpy (Btu/lb)
W_f = Feedwater flow (lb/hr).

The Steam enthalpy is based on measurement of Steam Generator Outlet Steam pressure, assuming saturated conditions. The Feedwater enthalpy is based on the measurement of Feedwater temperature and Steam pressure. The Feedwater flow is determined by multiple measurements and the following calculation:

$$W_f = (K)(F_a)\{(p_f)(d/p)\}^{1/2} \qquad \text{Eq. 6}$$

where; K = Feedwater venturi flow coefficient
F_a = Feedwater venturi correction for thermal expansion
p_f = Feedwater density (lb/ft^3)
d/p = Feedwater venturi pressure drop (inches H_2O).

The Feedwater venturi flow coefficient is the product of a number of constants including as-built dimensions of the venturi and calibration tests performed by the vendor. The thermal expansion correction is based on the coefficient of expansion of the venturi material and the difference between Feedwater temperature and calibration temperature. Feedwater density is based on the measurement of Feedwater temperature and Feedwater pressure. The venturi pressure drop is obtained from the output of the differential pressure cell connected to the venturi.

RCP heat addition is determined by calculation, based on the best estimate of coolant flow, pump head, and pump hydraulic efficiency.

The primary system net heat losses are determined by calculation, considering the following system heat inputs and heat losses:

Charging flow
Letdown flow
Seal injection flow
RCP thermal barrier cooler heat removal
Pressurizer spray flow
Pressurizer surge line flow
Component insulation heat losses
Component support heat losses
CRDM heat losses.

A single calculated sum for 100% RTP operation is used for these losses or heat inputs.

The power calorimetric measurement is thus based on the following plant measurements:

Steamline pressure (P_s)
Feedwater temperature (T_f)
Feedwater venturi differential pressure (d/p)
Steam Generator blowdown (if not secured)

and on the following calculated values:

Feedwater venturi flow coefficients (K)
Feedwater venturi thermal expansion correction (F_a)
Feedwater density (p_f)
Feedwater enthalpy (h_f)
Steam enthalpy (h_s)

Moisture carryover (impacts h_s)
Primary system net heat losses (Q_L)
RCP heat addition (Q_p)

These measurements and calculations are presented schematically on Figure 1.

The derivation of the measurement errors is noted below.

Secondary Side

The secondary side uncertainties are in four principal areas, Feedwater flow, Feedwater enthalpy, Steam enthalpy and RCP heat addition. These four areas are specifically identified on Table 5.

For the measurement of Feedwater flow, each Feedwater venturi is calibrated by the vendor in a hydraulics laboratory under controlled conditions to an accuracy of [$]^{+a,c}$. The calibration data which substantiates this accuracy is provided to the plant by the vendor. An additional uncertainty factor of [$]^{+a,c}$ is included for installation effects, resulting in a conservative overall flow coefficient (K) uncertainty of [$]^{+a,c}$. Since RCS loop flow is proportional to Steam Generator thermal output which is proportional to Feedwater flow, the flow coefficient uncertainty is expressed as [$]^{+a,c}$. It should be noted that no allowance is made for venturi fouling. Venturi fouling, found to date, has resulted in indicated feedwater flow higher than actual. This results in an indicated secondary side power higher than actual, which is the conservative direction.

The uncertainty applied to the Feedwater venturi thermal expansion correction (F_a) is based on the uncertainties of the measured Feedwater temperature and the coefficient of thermal expansion for the venturi material, usually 304 stainless steel. For this material, a change of ± 1.0 $^{\circ}$F in the nominal Feedwater temperature range changes F_a by ± 0.002 % and the Steam Generator thermal output by the same amount.

Based on data introduced into the ASME Code, the uncertainty in F_a for 304 stainless steel is ± 5 %. This results in an additional uncertainty of [$]^{+a,c}$ in Feedwater flow. Westinghouse uses the conservative value of [$]^{+a,c}$.

Using the 1967 ASME Steam Tables it is possible to determine the sensitivities of various parameters to changes in Feedwater temperature and pressure. Table 3 notes the instrument uncertainties for the hardware used to perform the measurements. Table 4 lists the various sensitivities. As can be seen on Table 4, Feedwater temperature uncertainties have an impact on venturi F_a, Feedwater density and Feedwater enthalpy. Feedwater pressure uncertainties impact Feedwater density and Feedwater enthalpy. As noted on Figure 1, Virgil C. Summer does not measure feedwater pressure. Instead the measured value for steamline pressure is used. For conservatism Westinghouse used a measurement uncertainty of approximately twice the steamline pressure value for the feedwater pressure uncertainty. The SCA value on Table 3 was chosen to allow internal calculation of this uncertainty.

Feedwater venturi d/p uncertainties are converted to % Feedwater flow using the following conversion factor:

$$\% \text{ flow} = (\text{d/p uncertainty})(1/2)(\text{transmitter span}/100)^2$$

Typically, the Feedwater flow transmitter span is [$]^{+a,c}$ nominal flow.

Using the 1967 ASME Steam Tables again, it is possible to determine the sensitivity of Steam enthalpy to changes in Steam pressure and Steam quality. Table 3 notes the uncertainty in Steam pressure and Table 4 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 on Table 4.

The net pump heat uncertainty is derived from the combination of the primary system net heat losses and pump heat addition and are summarized as follows:

System heat losses	-2.0 MWt
Component conduction and convection losses	-1.4
Pump heat adder	+13.5
Net Heat input to RCS	+10.1 MWt

The uncertainty on system heat losses, which is essentially all due to charging and letdown flows, has been estimated to be [ ]$^{+a,c}$ of the calculated value. Since direct measurements are not possible, the uncertainty on component conduction and convection losses has been assumed to be [ ]$^{+a,c}$ of the calculated value. Reactor coolant pump hydraulics are known to a relatively high confidence level, supported by system hydraulics tests performed at Prairie Island II and by input power measurements from several plants, therefore, the uncertainty for the pump heat addition is estimated to be [ ]$^{+a,c}$ of the best estimate value. Considering these parameters as one quantity, which is designated the net pump heat uncertainty, the combined uncertainties are less than [ ]$^{+a,c}$ of the total, which is [ ]$^{+a,c}$ of core power.

Table 3 provides the instrument uncertainties for the measurements performed. Since it is necessary to make this determination daily, it has been assumed that the plant process computer will be used for the measurements. The sensitivities calculated are noted on Table 4. As noted on Table 5, Westinghouse has determined the dependent sets in the calculation and the direction of interaction, i.e., whether components in a dependent set are additive or subtractive with respect to a conservative calculation of core power. The same was performed for the instrument bias values. As a result, the calculation explicitly accounts for dependent effects and biases with credit taken for sign (or direction of impact).

Using the power uncertainty values noted on Table 5, the 3 loop uncertainty (with bias values) equation is as follows:

[ ] +a,c

[ ]$^{+a,c}$

After consideration of bias and conservatism, a value of [ ]$^{+a,c}$ was used in the ITDP analysis calculations.

IV. CONCLUSIONS

The preceding sections provide the methodology for what Westinghouse believes is a reasonable means of accounting for instrumentation uncertainties for pressure, temperature and power. The plant-specific instrumentation has been reviewed for Virgil C. Summer and the uncertainty calculations are completed for use in the ITDP analysis.

TABLE 3
POWER CALORIMETRIC INSTRUMENTATION UNCERTAINTIES

(% SPAN)	FW TEMP	FW PRES	FW d/p	STM PRESS
SCA =				
M&TE=				
SPE =				
STE =				
SD =				
BIAS=				
RCA =				
M&TE=				
RTE =				
RD =				
ID =				
A/D =				
CSA =				
	°F	psia	% d/p	psia

+a.c

INST SPAN =	500.	1500.	120.	1300.
INST UNC (RANDOM) =				
INST UNC (BIAS) =				
NOMINAL =	435.	968.		868.

+a,c

TABLE 4

POWER CALORIMETRIC SENSITIVITIES

FEEDWATER FLOW
F_a
TEMPERATURE = [+a,c
MATERIAL =
DENSITY
TEMPERATURE =
PRESSURE =
DELTA P =
FEEDWATER ENTHALPY
TEMPERATURE =
PRESSURE =]
h_s = 1197.4 BTU/LBM
h_f = 413.9 BTU/LBM
Dh(SG) = 783.5 BTU/LBM
STEAM ENTHALPY
PRESSURE = [ ] +a,c
MOISTURE =

TABLE 5

SECONDARY SIDE POWER CALORIMETRIC MEASUREMENT UNCERTAINTIES

+a,c

COMPONENT		INSTRUMENT ERROR	POWER UNCERTAINTY
FEEDWATER FLOW			
VENTURI			
THERMAL EXPANSION COEFFICIENT			
TEMPERATURE			
MATERIAL			
DENSITY			
TEMPERATURE			
PRESSURE			
DELTA P			
FEEDWATER ENTHALPY			
TEMPERATURE			
PRESSURE			
STEAM ENTHALPY			
PRESSURE			
MOISTURE			
NET PUMP HEAT ADDITION			
BIAS VALUES			
FEEDWATER DELTA P			
FEEDWATER PRESSURE	DENSITY		
	ENTHALPY		
STEAM PRESSURE	ENTHALPY		
POWER BIAS TOTAL VALUE			

*, ** INDICATE SETS OF DEPENDENT PARAMETERS

SINGLE LOOP UNCERTAINTY	(WITHOUT BIAS VALUES)	
3 LOOP UNCERTAINTY	(WITHOUT BIAS VALUES)	
3 LOOP UNCERTAINTY	(WITH BIAS VALUES)	

REFERENCES

1. Westinghouse letter NS-CE-1583, C. Eicheldinger to J. F. Stolz, NRC, dated 10/25/77.

2. Westinghouse letter NS-PLC-5111, T. M. Anderson to E. Case, NRC, dated 5/30/78.

3. Westinghouse letter NS-TMA-1837, T. M. Anderson to S. Varga, NRC, dated 6/23/78.

4. Westinghouse letter NS-EPR-2577, E. P. Rahe Jr. to C. H. Berlinger, NRC, dated 3/31/82.

5. Westinghouse Letter NS-TMA-1835, T. M. Anderson to E. Case, NRC, dated 6/22/78.

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

7. NUREG-0717 Supplement No. 4, Safety Evaluation Report related to the operation of Virgil C. Summer Nuclear Station Unit No. 1, Docket 50-395, August, 1982.

8. Regulatory Guide 1.105 Rev. 2, "Instrument Setpoints for Safety-Related Systems", dated 2/86.

9. NUREG/CR-3659 (PNL-4973), "A Mathematical Model for Assessing the Uncertainties of Instrumentation Measurements for Power and Flow of PWR Reactors", 2/85.

10. ANSI/ANS Standard 58.4-1979, "Criteria for Technical Specifications for Nuclear Power Stations".

11. ISA Standard S67.04, 1982, "Setpoints for Nuclear Safety-Related Instrumentation Used in Nuclear Power Plants"

12. 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.

13. Scientific Apparatus Manufacturers Association, Standard PMC 20.1, 1973, "Process Measurement and Control Terminology".

FIGURE 1
POWER CALORIMETRIC SCHEMATIC