Westinghouse Non-Proprietary Class 3

WCAP-12772
Revision 1

Westinghouse Revised Thermal Design Procedure Instrument Uncertainty Methodology for Alabama Power Farley Nuclear Plant Units 1 and 2 (Uprating to 2785 MWt NSSS Power)

Westinghouse Energy Systems

Westinghouse Non-Proprietary Class 3

WCAP-12772
Revision 1

Westinghouse Revised Thermal Design Procedure Instrument Uncertainty Methodology for Alabama Power Farley Nuclear Plant Units 1 and 2 (Uprating to 2785 MWt NSSS Power)

Westinghouse Energy Systems

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-12772
Rev.1

WESTINGHOUSE REVISED THERMAL DESIGN PROCEDURE
INSTRUMENT UNCERTAINTY METHODOLOGY
FOR ALABAMA POWER
FARLEY NUCLEAR PLANT
UNITS 1 AND 2
(UPRATING TO 2785 MWT NSSS POWER)

JUNE, 1997

S.V. Andre'
W.H. Moomau

Westinghouse Electric Corporation
Nuclear Services Division
P.O. Box 355
Pittsburgh, Pennsylvania 15230

LOG/RJM:1:20 PM

ACKNOWLEDGEMENTS

The authors wish to recognize the contributions of Messrs. Michael G. Eidson (Southern Nuclear Operating Company) and Steven L. Hartsfield (Southern Company Services) for their careful review of this report.

PREFACE

The Westinghouse Revised Thermal Design Procedure (RTDP) was initially used in 1991 to develop the Reactor Core Safety Limits (Technical Specifications Figure 2.1-1) for Farley Nuclear Plant in support of licensing activities required to implement VANTAGE-5 Fuel. The RTDP methodology is described in NRC-approved WCAP-11397, "Revised Thermal Design Procedure," April 1989. Use of this methodology results in improved analysis and/or operating margins because the uncertainties associated with plant operating parameters, fuel fabrication parameters, nuclear and thermal parameters, and DNB correlations are combined statistically rather than deterministically. In addition, RTDP allows the use of nominal operating values for RCS temperature, pressurizer pressure, and reactor power as input assumptions for accident analyses that are DNB limiting events, and the uncertainties associated with these operating parameters are included in the derivation of the DNBR limits for the analyses.

Since the RTDP method is sensitive to changes in the correlations and codes, the NRC Safety Evaluation in WCAP-11397 stipulated that use of this methodology requires verification that the input parameter variances and distributions be justified on a plant-by-plant basis. As such, Farley-specific instrument uncertainty calculations were performed as documented in WCAP-12771, "Westinghouse Revised Thermal Design Procedure Instrument Uncertainty Methodology For Alabama Power Farley Nuclear Plant Units 1 And 2," May 1991. The results of the calculations presented in this WCAP demonstrated that the Farley-specific instrumentation uncertainties associated with controlling RCS temperature and pressurizer pressure, and measuring reactor power and RCS flow were bounded by the corresponding RTDP input assumptions. The transient and accident analyses which used core safety limits derived by the RTDP methodology are described in Chapter 15 of the Farley FSAR.

In 1996, the RTDP was used to develop new core safety limits in support of the Farley power uprate project; therefore, the uncertainty calculations in WCAP-12771 were revised to reflect current plant equipment, calibration, and operating practices. The results of the updated calculations confirm that the RTDP input assumptions remain bounding for Farley as documented herein (i.e., WCAP-12771, Revision 1).

TABLE OF CONTENTS

SECTION	TITLE	PAGE
I.	Introduction	1
II.	Methodology	2
III.	Instrumentation Uncertainties	6
IV.	Conclusions	31
	References	32

LIST OF TABLES

TABLE NUMBER	TITLE	PAGE
1	Pressurizer Pressure Control System Uncertainty	8
2	Rod Control System Uncertainty	11
3	Flow Calorimetric Instrumentation Uncertainties	20
4	Flow Calorimetric Sensitivities	21
5	Calorimetric RCS Flow Measurement Uncertainty	22
6	Loop RCS Flow Uncertainty	25
7	Power Calorimetric Instrumentation Uncertainties	28
8	Power Calorimetric Sensitivities	29
9	Secondary Side Power Calorimetric Measurement Uncertainty	30

LIST OF ILLUSTRATIONS

FIGURE NUMBER	TITLE	PAGE
1	Calorimetric RCS Flow Measurement	34
2	Calorimetric Power Measurement	35

WESTINGHOUSE REVISED THERMAL DESIGN PROCEDURE INSTRUMENT UNCERTAINTY METHODOLOGY FOR ALABAMA POWER FARLEY NUCLEAR PLANT UNITS 1 AND 2 (UPRATING TO 2785 MWT NSSS POWER)

I. INTRODUCTION

Four operating parameter uncertainties are used in the uncertainty analysis of the Revised Thermal Design Procedure (RTDP). These parameters are Pressurizer Pressure, Reactor Coolant System (RCS) Average Temperature (T_{avg}), Reactor Power, and RCS Total 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 (calorimetric measurement) once every 24 hours. RCS flow is monitored by the performance of a calorimetric flow measurement at the beginning of each cycle. 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 the control system. This report is based on the elimination of RTD Bypass Loops in the design to measure hot and cold leg reactor coolant system temperatures and is applicable for 2785 Mwt NSSS power. The RTDP[14] is used to predict the plant's DNBR design limit. The RTDP methodology considers the uncertainties in the system operating plant parameters, fuel fabrication and nuclear and thermal parameters and includes the use of various DNB correlations. Use of the RTDP methodology requires that variances in the plant operating parameters be justified. The purpose of the following evaluation is to define the specific Farley Nuclear Plant (FNP) instrument uncertainties for the four primary system operating parameters.

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 determination of all FNP instrumentation uncertainties for RTDP parameters and protection functions.

The uncertainty calculations in this report are being revised for the FNP uprating to 2785 Mwt NSSS power and are based on a detailed review of FNP procedures for instrument calibration and calorimetric measurements. The evaluation of calorimetric measurement uncertainties includes both the calorimetric RCS total flow measurement used for the beginning of cycle surveillance and normalization of the loop RCS flow indicators as well as the plant process computer calorimetric measurement used for the daily nuclear instrumentation alignment surveillance.

II. METHODOLOGY

The methodology used to combine the uncertainty components for an instrument channel is the square root of the sum of the squares of those groups of components which 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. 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 uncertainty components and the channel instrument uncertainty allowance are variations of the basic Westinghouse Setpoint Methodology[12][15] and are defined as follows:

1. For precision parameter indication using special test equipment or a DVM at the input to the racks, and with no trending of transmitter calibrations and drift;

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

2. For parameter indication utilizing the plant process computer, and with no trending of transmitter calibrations and drift;

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

3. For parameters which have closed-loop automatic control systems and with no trending of transmitter calibrations and drift, the calculation takes credit for [

]$^{+a,c}$. There is a functional dependency between the transmitters/racks and the automatic control system/indicator where an uncertainty in the transmitters/racks is common to the automatic control system/indicator when the indication is taken from the same transmitter/rack. That is, an uncertainty in the high direction in the transmitter/racks will result in a high uncertainty in the automatic control system/indicator. To account for the functional dependency, a square root function is used for the transmitter/racks/reference signal, and a square root function is used for the controller/indicators;

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

where,

CSA	=	Channel Statistical Allowance
PMA	=	Process Measurement Accuracy
PEA	=	Primary Element Accuracy
SRA	=	Sensor Reference 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, gauge or indicator)
CA	=	Control Accuracy
CMTE	=	Control Measurement and Test Equipment Accuracy
A/D	=	Analog to Digital Conversion
REF	=	Reference signal for automatic control system.

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 uncertainties, e.g., temperature stratification of a fluid in a pipe;

PEA - uncertainties due to a metering device, e.g., elbow, venturi, orifice;

SRA - reference accuracy for a sensor/transmitter based on manufacturer specifications;

SCA - calibration tolerance for a sensor/transmitter based on plant calibration procedures;

SMTE - measurement and test equipment used to calibrate a sensor/transmitter;

SPE - change in input-output relationship due to a change in static pressure for a d/p transmitter;

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 - rack calibration accuracy for all rack modules in a loop or channel assuming the loop or channel is string calibrated, or tuned, to this accuracy;

RMTE - measurement and test equipment used to calibrate rack modules;

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,local test gauge, a digital voltmeter or multimeter on its most accurate applicable range for the measured parameter, or 1/2 of the smallest division increment on an indicator (IND);

CA - control accuracy of the rack module(s) that performs the comparison and calculates the difference between the controlled parameter and the reference signal;

CMTE - measurement and test equipment used to calibrate the rack module(s) that perform(s) the comparison between the controlled parameter and the reference signal;

A/D - the analog to digital conversion of an electronic signal;

REF - the reference signal uncertainty for a closed-loop automatic control system;

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

A more detailed explanation of the Westinghouse methodology noting the interaction of several parameters is provided in references 5, 12, and 15.

III. INSTRUMENTATION UNCERTAINTIES

The instrumentation uncertainties will be discussed first for the two parameters which are controlled by closed-loop automatic control systems -- Pressurizer Pressure and RCS average temperature (T_{avg}). Then the development of the uncertainties for the RCS flow and the secondary side power calorimetric measurements will be discussed.

1. PRESSURIZER PRESSURE

Pressurizer pressure is normally controlled automatically to simplify plant operation and to maintain pressure within the normal steady state envelope of operation assumed in the safety analysis. To ensure that pressure is restored within its limit following load changes and other expected transient operation, a 12 hour surveillance of pressurizer pressure through instrument readout is included in the Technical Specifications (see DNB Parameter Limits).

Pressurizer pressure is controlled by a closed-loop automatic control system that compares the measured vapor space pressure to a reference value. This uncertainty calculation has been revised to take credit for the closed-loop control system design where [ ]$^{+a,c}$. The control channel uncertainties for the automatic control system uncertainty calculation include allowances for the control system transmitters, the control system process racks, and the control system reference signal, i.e., setpoint. At Farley the pressurizer pressure setpoint signal is generated by the setting of the variable setpoint potentiometer on the Main Control Board manual/automatic station. The reference setpoint (Pref) is defined by the Farley Precautions, Limitations, and Setpoints Document and verified by voltage measurements in the process racks.

This uncertainty calculation also includes the indication uncertainty for verification of the automatic control system performance. For FNP, the control board indicators from the protection system channels are used to verify the automatic control system performance, and the indication uncertainties are consistent with the Technical Specification DNB Parameter

Limit uncertainties for pressurizer pressure.

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 control system uncertainty, 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 including indication is [ ]+a,c which results in a standard deviation of [ ]+a,c assuming a normal, two sided probability distribution.

TABLE 1

PRESSURIZER PRESSURE CONTROL SYSTEM UNCERTAINTY

Control
(Foxboro E11GM transmitter)

+a,c

REF =
SRA =
SCA =
SMTE =
STE =
SD =
BIAS =
RCA =
RMTE =
RTE =
RD =
CA =
CMTE

Protection
(Barton 763 transmitter)
(for indication)

+a,c

SRA =
SCA =
SMTE =
STE =
SD =
BIAS =
RCA_{IND} =
$RMTE_{IND}$ =
RTE_{IND} =
RD_{IND} =
$RDOUT_{IND}$ =

* % of instrument span. Span = 800 psig.

+a,c

Electronic Uncertainty =

+a,c

Controller Uncertainty =

This calculation is performed assuming that:

+a,c

2. T_{avg}

T_{avg} is normally controlled automatically through the rod control system to simplify plant operation and to maintain T_{avg} within the normal steady state envelope of operation assumed in the safety analysis. To ensure that temperature is restored within its limit following load changes and other expected transient operation, a 12 hour periodic surveillance of RCS T_{avg} through instrument readout is included in the Technical Specifications (see DNB Parameter Limits).

T_{avg} is controlled by a closed-loop automatic control system that compares the median T_{avg} from the Median Signal Selector, which selects the median Tavg signal from the protection channel loops, with a programmed reference temperature signal (T_{ref}) which is derived from the turbine first stage impulse chamber pressure. T_{avg} is the average of the RCS loop narrow range T_H and T_C values. T_{ref} is the programmed temperature signal generated as the turbine is ramped from no-load to full power. The programmed T_{ref} values are defined by the Farley Precautions, Limitations, and Setpoints document. This uncertainty calculation has been revised to take credit for the closed-loop control system design where [ ]$^{+a,c}$. The channel uncertainties for the automatic control system uncertainty calculation include allowances for the RTDs, the control system process racks, and the control system reference signal that is generated by one of two turbine impulse pressure transmitters selected by the plant operator.

This uncertainty calculation also includes the indication uncertainty for verification of the automatic control system performance. For FNP, the control board indicators from the protection system channels are used to verify the automatic control system performance, and the indication uncertainties are consistent with the Technical Specification DNB Parameter Limit uncertainties for Tavg.

As noted on Table 2, the CSA for this function is dependent on the type of RTD, pressure transmitter, and the location of the RTDs, i.e., in the hot and cold legs. Based on the assumption that 2 T_H (with 1 failed hot leg RTD) and 1 T_C cross-calibrated RTDs (cross-calibration is performed every other fuel cycle) are used to calculate T_{avg} and the RTDs are located in the hot and cold legs, 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 control system uncertainty 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:

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

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

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

With s_T = [ ]$^{+a,c}$, the control system uncertainty is [ ]$^{+a,c}$. An additional [ ]$^{+a,c}$ (in terms of T_{avg}) is included for cold leg streaming.

TABLE 2

ROD CONTROL SYSTEM UNCERTAINTY

Tavg   TURB PRES (Foxboro E11GM transmitter) (REF)

+a,c

PMA =
SRA =
SCA =
SMTE =
STE =
SD =
BIAS =
R/E =
RMTE =
RCA =
RMTE =
RD =
CA =
CMTE =
RCA_{IND} =
$RMTE_{IND}$ =
RTE_{IND} =
RD_{IND} =
$RDOUT_{IND}$ =

* % of Tavg span. Span = 100 °F (530-630°F)
** % of Turbine pressure span. Span = 700 psi (0-700 psig)
*** % of R/E span. Span = 120 °F (Th:530-650°F) (Tc:510-630°F)

\# RTDs USED - TH = 2 TC = 1

+a,c

ELECTRONICS UNCERTAINTY =
ELECTRONICS SIGMA =

CONTROLLER SIGMA =
CONTROLLER UNCERTAINTY =
CONTROLLER BIAS =

**** Includes the controller deadband of ± 1.5 °F.

This calculation was performed assuming that:

+a,c

3. RCS FLOW

Calorimetric RCS Flow Measurement Uncertainty (Using Feedwater Venturis)

RTDP and the plant Technical Specifications require three RCS flow surveillances: a total RCS flow measurement every fuel cycle every 18 months which is also used to calibrate (i.e., normalize) the RCS flow instrument channels; a monthly total RCS flow measurement; and a qualitative RCS flow verification every 12 hours. These surveillances ensure RCS flow is maintained within the assumed safety analysis value, i.e., Minimum Measured Flow (MMF). The 18 month RCS flow surveillance is satisfied by a secondary power-based calorimetric RCS flow measurement; the monthly RCS flow surveillance is satisfied by a process computer measurement from the loop RCS flow instrument channels whose calibration is based on the 18 month calorimetric RCS flow measurement; and the 12 hour RCS flow surveillance is satisfied by confirmation of control board RCS flow indicator readings.

18 months drift is assumed in this uncertainty analysis for hot and cold leg RTDs. 18 months drift is assumed for all transmitters. Recent transmitter drift evaluations performed by Westinghouse on 24-month fuel cycle evaluations indicate that transmitter drift is time-independent. Therefore, 18 months is used as the basis for transmitter drift. Feedwater temperature RTDs are checked on a rotating basis such that one feedwater loop is checked every cycle. It is also assumed that the calorimetric RCS flow measurement is performed at the beginning of a cycle (i.e., no allowances have been made for mid cycle feedwater venturi fouling) and at 100% RTP. For a calorimetric flow measurement at 90% RTP, multiply the flow uncertainty by 1.1 and add the resultant flow uncertainty to the minimum flow requirement used in the FNP safety analysis.

The calorimetric RCS flow measurement is performed by determining the steam generator thermal output (corrected for the RCP heat input and the loop's share of primary system heat losses) and the enthalpy rise (Delta-h) of the primary coolant. Assuming that the primary and secondary sides are in equilibrium, the RCS total vessel flow is the sum of the individual primary loop flows, i.e.,

$$W_{RCS} = N(W_L). \qquad \text{Eq. 4}$$

The individual primary loop volumetric flows are determined by correcting the thermal output of the steam generator for steam generator blowdown (if not secured), subtracting the RCP heat addition, adding the loop's share of the primary side system losses, dividing by the primary side enthalpy rise and multiplying by the cold leg specific volume. The equation for this calculation is:

$$W_L = \frac{(A)\{Q_{SG} - Q_P + (Q_L/N)\}(V_C)}{(h_H - h_C)} \qquad \text{Eq. 5}$$

where,

W_L	=	Loop flow (gpm)
A	=	0.1247 gpm/(ft^3/hr)
Q_{SG}	=	Steam generator thermal output (Btu/hr)
Q_P	=	RCP heat addition (Btu/hr)
Q_L	=	Primary system net heat losses (Btu/hr)
V_C	=	Specific volume of the cold leg at T_C (ft^3/lb)
N	=	Number of primary side loops
h_H	=	Hot leg enthalpy (Btu/lb)
h_C	=	Cold leg enthalpy (Btu/lb).

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

$$Q_{SG} = (h_s - h_f)W_f \qquad \text{Eq. 6}$$

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:

$$W_f = (K)(F_a)\{(p_f)(d/p)\}^{1/2} \qquad \text{Eq. 7}$$

where,

W_f	=	Feedwater loop flow
K	=	Feedwater venturi flow coefficient

F_a = Feedwater venturi correction for thermal expansion

ρ_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 steam pressure. The venturi pressure drop is obtained from the output of the differential pressure transmitter 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 and heat inputs.

The hot leg and cold leg enthalpies are based on the measurement of the hot leg temperature, cold leg temperature and pressurizer pressure. The cold leg specific volume is based on measurement of the cold leg temperature and pressurizer pressure.

The RCS flow measurement is thus based on the following plant measurements:

Steamline pressure (P_s)
Feedwater temperature (T_f)
Feedwater venturi differential pressure (d/p)
Hot leg temperature (T_H)
Cold leg temperature(T_C)
Pressurizer pressure (P_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 (ρ_f)
Feedwater pressure (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)
Hot leg enthalpy (h_H)
Cold leg enthalpy (h_C).

These measurements and calculations are presented schematically on Figure 1.

The derivation of the measurement uncertainties and flow uncertainties on Table 5 are noted below.

Secondary Side

The secondary side uncertainties are in four principal areas -- feedwater flow, feedwater enthalpy, steam enthalpy and net RCS heat addition which is the net effect of the RCP heat input and the system gains and losses. 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 the calculated RCS loop flow is related to the calculated steam generator thermal output which in turn 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. The venturis should be inspected, and cleaned if necessary, prior to performance of the calorimetric RCS flow measurement. If fouling is present but not removed, its effects must be treated as a flow bias. At Farley, the plant Preventative Maintenance (PM) Program includes a task to inspect, and if necessary, clean each feedwater flow venturi during refueling outages.

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, 304 stainless steel. For this material, a change of $\pm$ 4.1 °F in the nominal feedwater temperature range changes F_a by $\pm$ 0.008 % 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 $\pm$ 5 %. This results in an additional uncertainty of [ ]$^{+a,c}$ in feedwater flow.

Using the NBSNRC 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.

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

% flow = (d/p uncertainty)(1/2)(transmitter span/100)^2.

The feedwater flow transmitter span is [ ]$^{+a,c}$ of nominal flow.

Using the NBSNRC Steam Tables, 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 RCS heat uncertainty is derived from the combination of the primary system net heat losses and RCP heat addition which are summarized for Farley as follows:

System heat losses	-17.5 MWt
System heat gains (other than pump heat)	+16.4 MWt
Component conduction and convection losses	-0.8 Mwt
Pump heat adder	+12.5 Mwt
Net Heat input to RCS	+10.6 MWt

A value of 10 Mwt is applied to the RCS flow calculation to account for variations in plant conditions. The uncertainty on system heat losses, which is essentially all due to letdown and spray flows, has been estimated to be [ ]$^{+a,c}$ of the calculated value. The uncertainty on system heat gains, which is essentially all due to charging and surge 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 RCS heat uncertainty, the combined uncertainties are less than [ ]$^{+a,c}$ of the total which is [ ]$^{+a,c}$ of core power.

Primary Side

The primary side uncertainties are in three principal areas -- hot leg enthalpy, cold leg enthalpy and cold leg specific volume. These are specifically noted on Table 5. Three primary side parameters are actually measured, i.e., T_H and T_C, and pressurizer pressure. Hot leg enthalpy is influenced by T_H, pressurizer pressure and hot leg temperature streaming. The uncertainties for the instrumentation are noted on Table 3, and the sensitivities are provided on Table 4. The hot leg streaming is split into random and systematic components. For the Farley units with RTDs located in thermowells placed in the scoops (bypass manifolds eliminated), the streaming uncertainty is [ ]$^{+a,c}$ random and [ ]$^{+a,c}$ systematic components.

The cold leg enthalpy and specific volume uncertainties are impacted by T_C and pressurizer pressure. Table 3 notes the T_C instrument uncertainty and Table 4 provides the sensitivities.

Noted on Table 5 is the plant specific RTD cross-calibration systematic allowance. When necessary, an allowance is made for a systematic temperature uncertainty due to the RTD cross-calibration procedure. No allowance was necessary for this plant.

Parameter dependent effects are identified 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 RCS flow. The same work 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 Table 5, the 3 loop uncertainty equation (with biases) is as follows:

[ ]+a,c

Based on the number of loops; number, type, and measurement method of RTDs; the averaging of the three hot leg temperatures; and the vessel Delta-T, the uncertainty for the calorimetric RCS total flow measurement is:

# of loops	flow uncertainty (% flow)
3	[ ]+a,c

TABLE 3

FLOW CALORIMETRIC INSTRUMENTATION UNCERTAINTIES

(% SPAN)	FW TEMP	FW PRESS	FW d/p	STM PRESS	T_H	T_C	PRZ PRESS
SRA =							+a,c
SCA =							
SMTE =							
SPE =							
STE =							
SD =							
BIAS =							
R/E =							
RCA =							
RMTE =							
RTE =							
RD =							
A/D =							
RDOUT=							
CSA =							

NUMBER OF INSTRUMENTS USED

	1/LOOP	1/LOOP	1/LOOP	1/LOOP	3/LOOP	1/LOOP	2
	°F(1)	psig(2)	%d/p(3)	psig(1)	°F(4)	°F(4)	psig(5)
INST SPAN =	200.	2000.	123%Flow	1200.	120.	120.	800. +a,c
INST UNC. (RANDOM) =							
INST UNC. (BIAS) =							
NOMINAL =	443	775-898 psia	100%Flow	675-798 psia	603.8-613.3°F	530.6-541.1°F	2250 psia

Notes: (1) Based on permanently installed plant instrumentation and read from the plant computer.

(2) A steam pressure measurement is read from the plant computer and is substituted for a feedwater pressure measurement. A conservative uncertainty value is used.

(3) Measured with a Rosemount transmitter and read from the plant computer. This does not include the venturi uncertainty.

(4) Temperature measured with a Fluke Helios Data Acquisition System at the input to Westinghouse process instrumentation using an RTD test rig.

(5) Based on permanently installed plant instrumentation and read from the control board indicators.

(6) Included in RCA.

These calculations were performed assuming that:

+a,c

TABLE 4

FLOW CALORIMETRIC SENSITIVITIES

FEEDWATER FLOW

F_a		
TEMPERATURE	=	[ ] +a,c
MATERIAL	=	
DENSITY		
TEMPERATURE	=	
PRESSURE	=	
DELTA P	=	
FEEDWATER ENTHALPY		
TEMPERATURE	=	
PRESSURE	=	
h_s	=	1199.1 BTU/LBM
h_f	=	423.0 BTU/LBM
Dh(SG)	=	776.1 BTU/LBM

STEAM ENTHALPY

PRESSURE	=	[ ] +a,c
MOISTURE	=	
HOT LEG ENTHALPY		
TEMPERATURE	=	
PRESSURE	=	
h_H	=	632.1 BTU/LBM
h_C	=	535.9 BTU/LBM
Dh(VESS)	=	96.3 BTU/LBM
$Cp(T_H)$	=	1.503 BTU/LBM-°F

COLD LEG ENTHALPY

TEMPERATURE	=	[ ] +a,c
PRESSURE	=	
$Cp(T_C)$	=	1.221 BTU/LBM-°F

COLD LEG SPECIFIC VOLUME

TEMPERATURE	=	[ ] +a,c
PRESSURE	=	

TABLE 5

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTY

(Page 1 of 2)

COMPONENT	INSTRUMENT UNCERTAINTY	FLOW UNCERTAINTY
FEEDWATER FLOW		+a,c
VENTURI		
THERMAL EXPANSION COEFFICIENT		
TEMPERATURE		
MATERIAL		
DENSITY		
TEMPERATURE		
PRESSURE		
DELTA P		
FEEDWATER ENTHALPY		
TEMPERATURE		
PRESSURE		
STEAM ENTHALPY		
PRESSURE		
MOISTURE		
NET RCS HEAT ADDITION		
HOT LEG ENTHALPY		
TEMPERATURE		
STREAMING, RANDOM		
STREAMING, SYSTEMATIC		
PRESSURE		
COLD LEG ENTHALPY		
TEMPERATURE		
PRESSURE		
COLD LEG SPECIFIC VOLUME		
TEMPERATURE		
PRESSURE		
RTD CROSS-CAL SYSTEMATIC ALLOWANCE		

*, **, +, ++ INDICATE SETS OF DEPENDENT PARAMETERS

TABLE 5 (CONTINUED)

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTY

(Page 2 of 2)

COMPONENT		FLOW UNCERTAINTY
BIAS VALUES		+a,c
FEEDWATER PRESSURE	DENSITY	
	ENTHALPY	
STEAM PRESSURE	ENTHALPY	
PRESSURIZER PRESSURE	ENTHALPY - HOT LEG	
	ENTHALPY - COLD LEG	
	SPECIFIC VOLUME - COLD LEG	
FLOW BIAS TOTAL VALUE		

		+a,c
SINGLE LOOP UNCERTAINTY	(WITHOUT BIAS VALUES)	
3 LOOP UNCERTAINTY	(WITHOUT BIAS VALUES)	
3 LOOP UNCERTAINTY	(WITH BIAS VALUES)	

Loop RCS Flow Uncertainty (Using Plant Computer Readout)

The calorimetric RCS flow measurement is used as a reference for the normalization of the loop RCS flow plant computer readouts (cold leg elbow taps). Table 6 notes the instrument uncertainties for normalization of the loop RCS flow plant computer channels with two loop RCS flow plant computer readouts per loop. The d/p transmitter uncertainties are converted to % flow on the same basis as the feedwater venturi d/p. The loop RCS flow plant computer readout uncertainty is then combined with the calorimetric RCS flow measurement uncertainty. This combination of uncertainties results in the following total RCS flow uncertainty :

# of loops	flow uncertainty (% flow)
3	± 1.9 .

The corresponding standard deviation value is:

# of loops	standard deviation (% flow)
3	[ ] +a,c .

TABLE 6

LOOP RCS FLOW UNCERTAINTY

PLANT COMPUTER READOUT

INSTRUMENT UNCERTAINTIES

(Foxboro E13DH transmitter)

+a,c

	% d/p SPAN	% FLOW
PMA =		
PEA =		
SRA =		
SCA =		
SMTE=		
SPE =		
STE =		
SD =		
BIAS=		
RCA =		
RMTE=		
RTE =		
RD =		
A/D =		
FLOW CALORIM. BIAS =		
FLOW CALORIMETRIC =		
INSTRUMENT SPAN =		

+a,c

AVERAGE OF TWO LOOP RCS FLOW
COMPUTER READOUTS PER LOOP
(1 RCS FLOW CHANNEL)

3 LOOP RCS FLOW UNCERTAINTY
(WITHOUT BIAS VALUES) =

3 LOOP RCS FLOW UNCERTAINTY
(WITH BIAS VALUES) = 1.9 % FLOW

Notes: 1) Included in RCA.

4. REACTOR POWER

In accordance with the plant Technical Specification surveillance test requirements, a 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 (i.e, typically 2% Rated Thermal Power).

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:

$$RP = \frac{\{(N)\{Q_{SG} - Q_P + (Q_L/N)\}\}(100)}{H} \qquad \text{Eq. 8}$$

where,

RP	=	Core power (% RTP)
N	=	Number of primary side loops
Q_{SG}	=	Steam generator thermal output (BTU/hr) as defined in Eq. 6
Q_P	=	RCP heat adder (Btu/hr) as defined in Eq. 5
Q_L	=	Primary system net heat losses (Btu/hr) as defined in Eq. 5
H	=	Core rated Btu/hr at full power.

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 measurement is taken. Measurements performed at lower power levels will result in different uncertainty values primarily due to errors associated with feedwater flow. 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 secondary side power calorimetric equations and effects are the same as those noted for the calorimetric RCS flow measurement (secondary side portion), equations 6 and 7. Table 7 provides the instrument uncertainties for those measurements performed. Since it is necessary to make this determination daily, the plant process computer is used for the measurements. The sensitivities are shown on Table 8. As noted on Table 9, Westinghouse has determined the dependent sets in the calculation and the direction of interaction. This is the same as that performed for the calorimetric RCS flow measurement, but applicable only to power. The same was performed for the bias values noted. It should be noted that Westinghouse does not include any allowance for feedwater venturi fouling. At Farley, periodic inspection of the feedwater venturis indicate that the venturis are not prone to fouling. However, should mid-cycle fouling occur, the effect is to result in an indicated power higher than actual which is conservative.

Using the power uncertainty values noted on Table 9, the 3 loop uncertainty (with bias values) equation is as follows:

+a,c

[ ]

Based on the number of loops and the instrument uncertainties for the four parameters of feedwater temperature, feedwater pressure, feedwater flow and steam pressure, the uncertainty for the secondary side power calorimetric measurement is:

# of loops	power uncertainty (% RTP)
3	[ ] +a,c .

TABLE 7

POWER CALORIMETRIC INSTRUMENTATION UNCERTAINTIES

(% SPAN)	FW TEMP	FW PRESS	FW d/p	STM PRESS
SRA =				
SCA =				
SMTE=				
SPE =				
STE =				
SD =				
BIAS=				
RCA =				
RMTE=				
RTE =				
RD =				
A/D =				
CSA =				

+a,c

NUMBER OF INSTRUMENTS USED				
	1/LOOP	1/LOOP	1/LOOP	1/LOOP
	°F(1)	psig(2)	% d/p(1)	psig(1)
INST SPAN =	200.	2000.	123% Flow	1200.
INST UNC (RANDOM) =				
INST UNC (BIAS) =				
NOMINAL =	443°F	775-898 psia	100%Flow	675-798 psia

+a,c

Notes:

(1) Based on permanently installed plant instrumentation and read from the plant computer.
(2) A steam pressure measurement is substituted for a feedwater pressure measurement. A conservative uncertainty value is used.
(3) Included in RCA.

TABLE 8

POWER CALORIMETRIC SENSITIVITIES

FEEDWATER FLOW			
F_a			+a,c
TEMPERATURE	=		
MATERIAL	=		
DENSITY			
TEMPERATURE	=		
PRESSURE	=		
DELTA P	=		
FEEDWATER ENTHALPY			
TEMPERATURE	=		
PRESSURE	=		

h_s	=	1199.1 BTU/LBM
h_f	=	423.0 BTU/LBM
Dh(SG)	=	776.1 BTU/LBM

STEAM ENTHALPY			
PRESSURE	=		+a,c
MOISTURE	=		

TABLE 9
SECONDARY SIDE POWER CALORIMETRIC MEASUREMENT UNCERTAINTY

COMPONENT		INSTRUMENT UNCERTAINTY	POWER UNCERTAINTY
			+a,c
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)	

IV. CONCLUSIONS

The preceding sections provide the Westinghouse methodology for a reasonable accounting of instrument uncertainties for pressurizer pressure, RCS temperature, power and RCS flow. The uncertainty calculations have been performed for Farley Nuclear Plant Units 1 and 2 with the plant-specific instrumentation and calibration procedures. The following table summarizes the results and the uncertainties that are used in the Farley RTDP and associated safety analysis.

Parameter	Calculated Uncertainty	Uncertainty Used in Safety Analysis
Pressurizer Pressure	±48.1 psi (random) - 1.5 psi (bias)	±50.0 psi (random)
Tavg	±3.7 °F (random) -1.0 °F (bias)	±6.0 °F (random)
Power	±1.1% RTP (random)	±2.0% RTP (random)
RCS Flow	±1.9% TDF (random)	±2.1% TDF (random)

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. Westingh[illegible] letter NS-TMA-1835, T. M. Anderson to E. Case, NRC, dated 6/22/7[illegible]

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, Part I, 1994, "Setpoints for Nuclear Safety-Related Instrumentation".

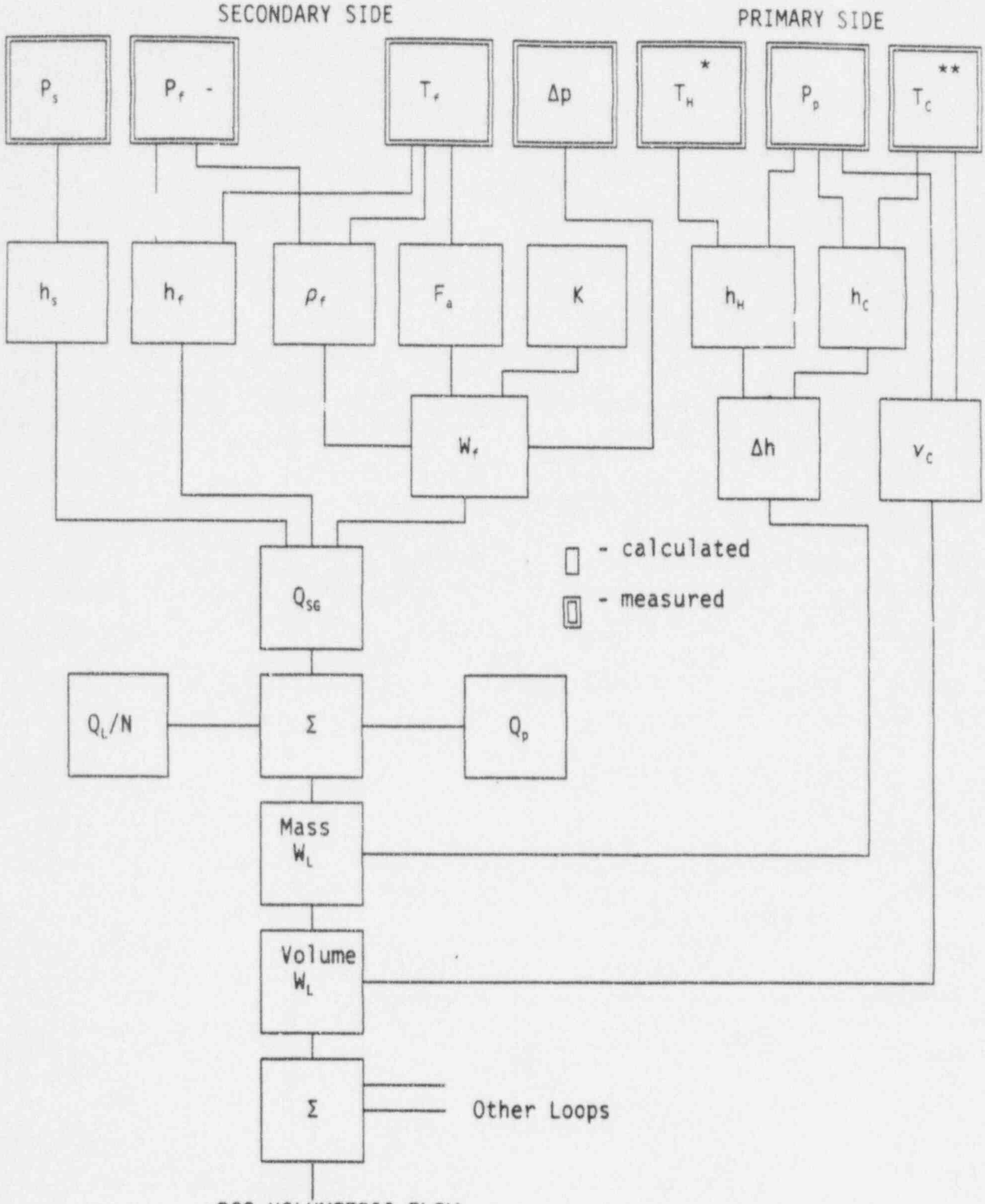
12. Tuley, C. R., Miller, R. B., "Westinghouse Setpoint Methodology for Control and Protection Systems", IEEE Transactions on Nuclear Science, February, 1986, Vol. NS-33 No. 1, pp. 684-687.

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

14. Westinghouse WCAP-11397-P-A, "Revised Thermal Design Procedure", dated April, 1989.

15. Tuley, C. R., Williams, T.P., "The Significance of Verifying the SAMA PMC 20.1-1973 Defined Reference Accuracy for the Westinghouse Setpoint Methodology", Instrumentation, Controls and Automation in the Power Industry, Vol.35, Proceedings of the Thirty-Fifth Power Instrumentation Symposium (2nd Annual ISA/EPRI Joint Controls and Automation Conference), Kansas City, Mo., June, 1992, p. 497.

16. ANSI Standard ANSI/ISA-S51.1-1979, "Process Instrumentation Terminology".



* Three hot leg temperatures per loop are measured and averaged.

** One temperature per loop is measured.

Figure 1
CALORIMETRIC RCS FLOW MEASUREMENT
(USING FEEDWATER VENTURI)
SECONDARY SIDE

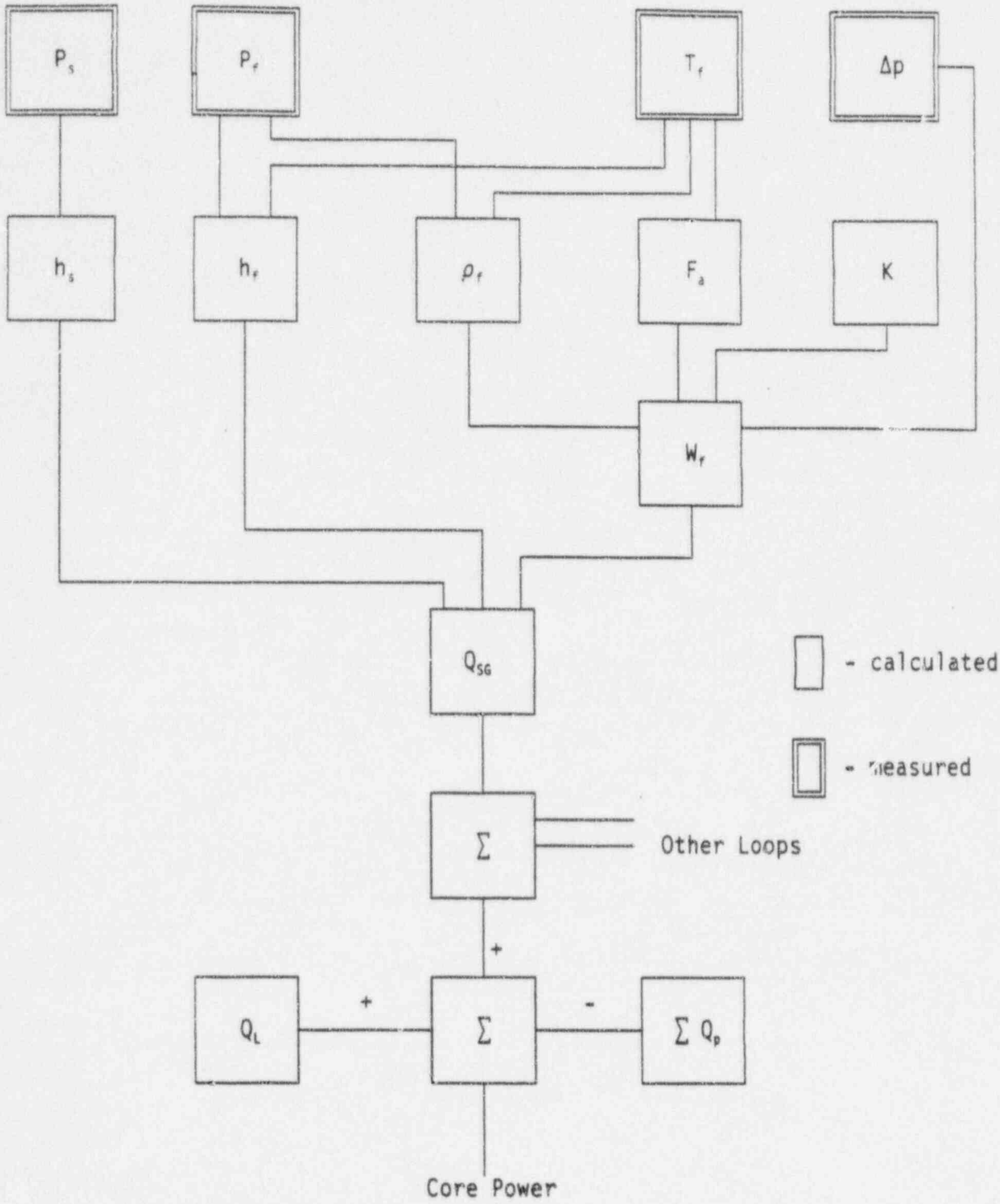


Figure 2
CALORIMETRIC POWER MEASUREMENT
(USING FEEDWATER VENTURI)