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Westinghouse Improved Thermal Design Procedure Instrument Uncertainty Methodology Diablo Canyon Units 1 & 2 24 Month Fuel Cycle Evaluation

Westinghouse Energy Systems

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WESTINGHOUSE IMPROVED THERMAL DESIGN PROCEDURE INSTRUMENT UNCERTAINTY METHODOLOGY

DIABLO CANYON UNITS 1 AND 2

24 MONTH FUEL CYCLE EVALUATION

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WESTINGHOUSE IMPROVED THERMAL DESIGN PROCEDURE
INSTRUMENT UNCERTAINTY METHODOLOGY FOR
DIABLO CANYON UNITS 1 AND 2
24 MONTH FUEL CYCLE EVALUATION

I. INTRODUCTION

Four operating parameter uncertainties are used in the uncertainty analysis of the Improved Thermal Design Procedure (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 measurement once every 24 hours. RCS flow is monitored by the performance of a calorimetric RCS flow measurement at the beginning of each cycle. The RCS Cold Leg elbow taps are normalized to the calorimetric RCS flow measurement and used for shift surveillances (with a small increase in uncertainty). Pressurizer pressure is a controlled parameter and the uncertainty reflects the verification of the control system through indication. T_{avg} is a controlled parameter via the temperature input to the rod control system and the uncertainty reflects this control system. This work is applicable for 30 month instrumentation surveillance intervals.

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, and others. The second approach is now utilized for the determination of all instrumentation uncertainties for both ITDP parameters and protection functions.

II. METHODOLOGY

The methodology used to combine the uncertainty components for a 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 uncertainty components 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[6,7,8,9] and various industry standards[10,11].

The relationships between the uncertainty components and the channel statistical 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, and trending of transmitter calibration and drift;

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

2. For parameter indication utilizing the plant process computer, and trending of transmitter calibration and drift;

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

3. For parameters which have control systems verified through indication, and with trending of transmitter calibration and drift;

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

where:

CSA	=	Channel Statistical Allowance
PMA	=	Process Measurement Accuracy
PEA	=	Primary Element Accuracy
SRA	=	Sensor Reference Accuracy
SCA	=	Sensor Calibration Accuracy
SMTE	=	Sensor Measuring & Test Equipment Accuracy
SPE	=	Sensor Pressure Effects
STE	=	Sensor Temperature Effects
SD	=	Sensor Drift
CA	=	Controller Accuracy
RCA	=	Rack Calibration Accuracy
RMTE	=	Rack Measuring & Test Equipment Accuracy
RTE	=	Rack Temperature Effects
RD	=	Rack Drift
RDOUT	=	Readout Device Accuracy.

The parameters above are as defined in references 5 and 12 and are based on ISA S51.1-1979 (R93)[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 (calibration) accuracy for a sensor/transmitter,
SCA	-	calibration tolerance for a sensor/transmitter based on plant calibration procedures,
SMTE	-	measuring & 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 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,

CA - the accuracy of the controller,

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

RMTE - measuring & 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 accuracy of a special, local test gauge, a digital voltmeter or multimeter on it's most accurate applicable range, or 1/2 of the smallest increment on an indicator,

BIAS - a non-random uncertainty for a sensor/transmitter or a process parameter.

A/D - the uncertainty component is associated with a computer readout.

IND - the uncertainty component is associated with an analog indicator.

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 UNCERTAINTY

Pressurizer Pressure uses a closed-loop control system with a comparison of the measured vapor space pressure to a reference value. Proper operation of the control system is verified through indication. The control uncertainties established for use in the ITDP analysis are [ ]$^{+a,c}$. In conjunction with the move to a 24 month fuel cycle (30 month surveillance interval) the control uncertainties were determined consistent with the Diablo Canyon Units 1 and 2 administrative procedures and account for the verification that all three channels indicate above the limit. Uncertainties are from the transmitter and the process racks/indicators as shown in Table 1. Equation 3

has been modified to allow for a functional dependency between the transmitter/racks and the indicators or controller. That is, the indicators are independent of the controller; however, an error in the transmitter or rack modules will be common to both the indicator and the controller. As shown in Equation 4 below, the statistical combination of the uncertainties for this function results in a total uncertainty of [ ]$^{+a,c}$ when one of the 4 normal indicators is unavailable.

$$CSA = \{(PMA)^2 + (PEA)^2 + [(SMTE+SD)^2 + (SPE)^2 + (STE)^2 + (SRA)^2 + (SMTE+SCA)^2 + (RMTE+RD)^2_{EAI} + (RTE)^2_{EAI} + (RMTE+RCA)^2_{EAI} + (RMTE+RD)^2_{EAO} + (RTE)^2_{EAO} + (RMTE+RCA)^2_{EAO}] / (N-1)\}^{1/2} + \{(CA)^2 + [(RMTE+RD)^2_{IND} + (RTE)^2_{IND} + (RMTE+RCA)^2_{IND} + (RDOUT)^2_{IND}] / (N-1)\}^{1/2} + BIAS \quad \text{(Eq. 4)}$$

$$CSA = [\quad]^{+a,c}$$

In addition, 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. The high side of the controller also operates with a 10 psi no-action deadband between 2250 and 2260 psig. This value has been included in the uncertainty calculations as a 10 psi bias on the high side only. Therefore, a total pressurizer pressure uncertainty of [ ]$^{+a,c}$ is calculated for a 30 month surveillance interval as noted on Table 1 which is bounded by the ITDP analysis.

TABLE 1

PRESSURIZER PRESSURE CONTROL SYSTEM UNCERTAINTY

SENSOR/TRANSMITTER

+a,c

SRA =
SCA =
SMTE =
STE =
SD =
BIAS =

PROCESS RACKS

	EAI	EAO	CONTROLLER	IND
RCA =				
RMTE =				
RTE =				
RD =				
RDOUT =				
CA =				

+a,c

All above values in % of instrument span. Span = 1250 psi.

+a,c

ELECTRONICS UNCERTAINTY =
PLUS =

ELECTRONICS UNCERTAINTY =
PLUS =

CONTROLLER UNCERTAINTY =
(3 Indicators.Available)

2. TAVG UNCERTAINTY

Tavg uses a closed-loop control system that compares the auctioneered high Tavg from the loops to a reference derived from the First Stage Turbine Impulse Chamber Pressure. Proper operation of the control system is verified through indication. Tavg is the average of the narrow range Thot and Tcold values, and the highest loop Tavg is used in the controller. The control uncertainties established for use in the ITDP analysis are $[\quad]^{+a,c}$. In conjunction with the move to a 24 month fuel cycle (30 month surveillance interval) the control uncertainties were determined consistent with the Diablo Canyon Units 1 and 2 administrative procedures. Uncertainties are from hot leg and cold leg streaming, the RTDs, the turbine pressure transmitter, and the process racks/indicators (as noted on Table 2). Based on the assumption that 2 Thot and 1 Tcold cross-calibrated RTDs are used to calculate Tavg (assuming one failed Thot RTD per loop), Equation 3 has been modified to allow for a functional dependency between the transmitter/racks and the indicators or controller and to average the uncertainties associated with the multiple RTDs and the ERI cards. Using Equation 5 below, the electronics uncertainty is calculated to be $[\quad]^{+a,c}$. Assuming a normal, two sided probability distribution results in an electronics standard deviation (s_1) of $[\quad]^{+a,c}$.

$$
\begin{aligned}
CSA = \{\{ & (PMA_{TH})^2 + (PMA_{BETA})^2 + (PEA)^2 + \\
& \{([[(SMTE+SD)^2 + (SRA)^2 + (SMTE+SCA)^2]/N_H]^{1/2} + \\
& \quad [[(SMTE+SD)^2 + (SRA)^2 + (SMTE+SCA)^2]/N_C]^{1/2})/2\}^2 + \\
& \{([[(RMTE+RD)^2_{ERI} + (RTE)^2_{ERI} + (RMTE+RCA)^2_{ERI}]/N_H]^{1/2} + [[(RMTE+RD)^2_{ERI} + \\
& \quad (RTE)^2_{ERI} + (RMTE+RCA)^2_{ERI}]/N_C]^{1/2})/2\}^2 * (SPAN_{ERI}/SPAN_{Tavg})^2 + \\
& (RMTE+RD)^2_{EAO} + (RTE)^2_{EAO} + (RMTE+RCA)^2_{EAO}\}/(N-1) + \\
& [(SMTE+SD)^2_{TP} + (SPE)^2_{TP} + (STE)^2_{TP} + (SRA)^2_{TP} + (SMTE+SCA)^2_{TP} + \\
& (RMTE+RD)^2_{TP} + (RTE)^2_{TP} + (RMTE+RCA)^2_{TP}](TP\_Sen)^2\}^{1/2} + \{(CA)^2 + \\
& [(RMTE+RD)^2_{IND} + (RTE)^2_{IND} + (RMTE+RCA)^2_{IND} + (RDOUT)^2_{IND}]/(N-1)\}^{1/2} \quad \text{(Eq. 5)}
\end{aligned}
$$

$$CSA = [\qquad]^{+a,c}.$$

However, this does not include the controller deadband of ± 1.5 °F. The controller uncertainty is the combination of the electronics uncertainty 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 the electronics and the variance for the deadband results in a controller variance of:

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

The controller standard deviation s_C = [ ]$^{+a,c}$ results in a total random uncertainty for a 30 month surveillance interval of [ ]$^{+a,c}$ and a cold leg streaming bias of [ ]$^{+a,c}$, which are bounded by the ITDP analysis.

TABLE 2

TAVG CONTROL SYSTEM UNCERTAINTY

SENSOR/TRANSMITTER (All values in % span)

	Tavg	Turbine Pressure*
Span	100 F	620 psig

+a,c

PMA =
BETA =
SRA =
SCA =
SMTE =
STE =
SD =
BIAS =
TP_Sen =

PROCESS RACKS (All values in % span)

Tavg	ERI	EAO	INDICATOR	CONTROLLER	TURBINE
Span	150 F	100 F	100 F	100 F	620 psig

+a,c

RCA =
RMTE =
RTE =
RD =
RDOUT=
CA =

N_H = # HOT LEG RTDs = 2 N_C = # COLD LEG RTDs = 1

+a,c

ELECTRONICS CSA =
ELECTRONICS SIGMA =
CONTROLLER SIGMA =
CONTROLLER BIAS =
CONTROLLER CSA =

* Based on Rosemount uncertainties for Turbine Pressure. This bounds the results for the Barton transmitters.

** Sensitivity of Tref to Turbine Pressure uncertainties. Based on relationship between turbine pressure and Tref from no load to full power.

3. RCS FLOW MEASUREMENT UNCERTAINTY

Calorimetric RCS Flow Measurement

ITDP and plant Technical Specifications require a calorimetric RCS flow measurement every fuel cycle above 90% of Rated Thermal Power with a high degree of accuracy. It is assumed for this uncertainty analysis that the calorimetric RCS flow measurement is performed before feedwater venturi fouling is significant, therefore, no separate allowances have been made for feedwater venturi fouling. This analysis is based on information supplied by PG&E in References 15 and 17. Any changes in plant configuration or procedures made subsequent to that submittal will be addressed by PG&E.

The 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.,

$$W_{RCS} = N(W_L). \qquad \text{(Eq. 6)}$$

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:

$$W_L = \frac{(A)\{Q_{SG} - Q_P + (Q_L/N)\}(v_C)}{(h_H - h_C)} \qquad \text{(Eq. 7)}$$

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 secondary side calorimetric measurement, which is defined as:

$$Q_{SG} = (h_s - h_f)W_f - \rho_{BD}(h_s - h_{BD})V_{BD}/A \qquad \text{(Eq. 8)}$$

where; h_s = Steam enthalpy (Btu/lb)
h_f = Feedwater enthalpy (Btu/lb)
W_f = Feedwater flow (lb/hr)
ρ_{BD} = Blowdown density (lb/ft^3)
V_{BD} = Volumetric flowrate of blowdown (gpm)
h_{BD} = Blowdown enthalpy (Btu/lb).

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 an assumed feedwater pressure. The feedwater flow is determined by multiple measurements and the following calculation:

$$W_f = (K)(F_a)\{(\rho_f)(\Delta p)\}^{1/2} \qquad \text{(Eq. 9)}$$

where; K = Feedwater venturi flow coefficient
F_a = Feedwater venturi correction for thermal expansion
ρ_f = Feedwater density (lb/ft^3)
Δp = 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 an assumed feedwater 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 or heat inputs.

The hot leg enthalpy is based on the measurement of the hot leg temperature and the pressurizer pressure. The cold leg enthalpy and specific volume are based on measurement of the cold leg temperature and calculation of the cold leg pressure from the pressurizer pressure measurement.

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

Steamline pressure (P_s)
Feedwater temperature (T_f)
Feedwater pressure ($P_{f,}$ assumed value)
Feedwater venturi differential pressure (Δp)
Hot leg temperature (T_H)
Cold leg temperature (T_C)
Pressurizer pressure (P_p)

Steam generator blowdown (V_{BD})

and on the following calculated values:

Feedwater venturi flow coefficients (K)
Feedwater venturi thermal expansion correction (F_a)
Feedwater density (ρ_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)
Cold leg pressure (P_{CL})
Cold leg specific volume (v_C)
Blowdown density (ρ_{BD})
Blowdown enthalpy (h_{BD}).

These measurements and calculations are presented schematically on Figure 1. The derivation of the measurement uncertainties and flow uncertainties on Table 5 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 [$]^{+a,b,c}$. 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 an 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 ± 0.5 % flow. It should be noted that Westinghouse makes no explicit allowance for venturi fouling.

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 °F in the nominal feedwater temperature range changes F_a by ± 0.002 % and the steam generator thermal output by the same amount.

An uncertainty in F_a of ± 5 % for 304 stainless steel is used in this analysis. This results in an additional uncertainty of [ ]$^{+a,c}$ in feedwater flow. Westinghouse uses the conservative value of [ ]$^{+a,c}$.

Using the 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 Δp uncertainties are converted to % feedwater flow using the following conversion factor as defined in Table 3-28 of Reference 14:

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

The feedwater flow transmitter span is 115 % of nominal flow.

Using the 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 for Diablo Canyon as follows:

System heat losses	-2.3 MWt
Component conduction and convection losses	-1.1
Pump heat adder	+17.8
Net Heat input to RCS	+14.4 MWt

An additional component of 1.3 MWt has been identified by PG&E to account for heat losses on the core side between the hot and cold leg RTDs. 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, and are 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 approximately [ ]$^{+a,c}$ of the total net heat input. For this calculation, a conservative value of [ ]$^{+a,c}$ is used in Table 5.

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, T_H, 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 errors associated with measuring hot leg streaming are split into two components, one random and the other systematic. For Diablo Canyon Units 1 and 2, the streaming measurement uncertainty is [ ]$^{+a,c}$ random and

[ ]+a,c systematic. The Hot Leg and Cold Leg Streaming Biases due to fluid stratification are not considered when determining RCS Flow Measurement Uncertainty because these biases add conservatism to the determination of total RCS flow.

The cold leg enthalpy and specific volume uncertainties are impacted by T_C and the pressure in the cold leg (which is determined by PG&E by adding a correction factor to the pressurizer pressure). Table 3 notes the T_C instrument uncertainty and Table 4 provides the sensitivities.

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 4 loop uncertainty equation (with biases) is as follows:

$$\begin{aligned} Flow = \{&(FW_V)^2 + \{(\rho_T + h_{f_T} - F_{a_T})^2\}/3 + (F_{a_M})^2 + (\rho_p - h_{f_p})^2 + (SGBD)^2 \\ &+ (h_{s_{Moist}})^2 + (NPHA)^2 + \{(\Delta P)^2 + (h_{s_p})^2 + (h_{H_T})^2 + (h_{H_{TSR}})^2 + (h_{C_T} + v_{C_T})^2\}/N \\ &+ (h_{H_p} - h_{C_p} - v_{C_p})^2 + (h_{H_{TSS}})^2\}^{1/2} + (\rho_p\ Bias) - (h_{f_p}\ Bias) \\ &- (h_{s_p}\ Bias) + (h_{H_p}\ Bias) - (h_{C_p}\ Bias) - (v_{C_p}\ Bias) \end{aligned}$$

+a,c

[ ]

Based on four (4) loops, the number, type and measurement method of RTDs, and the vessel Delta-T, the uncertainty for the precision RCS flow measurement is:

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

TABLE 3
CALORIMETRIC RCS FLOW MEASUREMENT INSTRUMENTATION UNCERTAINTIES

+a,c

(% SPAN)		FW TEMP	FW PRES	FW d/p	STM PRESS*	T_H**	T_C**	PRZ PRESS
SRA	=							
SCA	=							
SMTE	=							
SPE	=							
STE	=							
SD	=							
SD_{BIAS}	=							
BIAS	=							
RCA	=							
RMTE	=							
RTE	=							
RD	=							
$RCA_{EAI(ERI)}$	=							
$RTE_{EAI(ERI)}$	=							
$RD_{EAI(ERI)}$	=							
RCA_{EAO}	=							
RTE_{EAO}	=							
RD_{EAO}	=							
NUMBER OF INSTRUMENTS USED		3	1	2/LOOP	1/LOOP	3/LOOP	1/LOOP	1
SPAN	=	500 °F	2000 psi	115%FLOW	1200 psi	100 °F **	100 °F **	1250 psi
		°F	psi	%Δp span	psi	°F	°F	psi
INST UNC. (RANDOM)	=							
INST UNC. (BIAS)	=							
NOMINAL	=	430	855 PSIA	100%FLOW	820 PSIA	600	540	2250 PSIA

+a,c

* Uses uncertainties associated with Barton transmitters. These values bound the Rosemount values for the RCS Flow Calorimetric function.

** These values are in % Tavg Span.

*** Bias due to additional temperature effect on Barton transmitters identified in Reference 16 and location of transmitters per Reference 17.

Feedwater pressure is assumed. TH and TC are calculated as read from the MMI. All other parameters are calculated as read by the process computer. A 35°F temperature rise is assumed for the EAGLE-21 racks and a 50°F temperature rise is assumed for the process computer. The static pressure span effect for the feedwater flow Δp transmitter is based on a feedwater pressure of 905PSIA and maximum transmitter output.

TABLE 4
CALORIMETRIC RCS FLOW MEASUREMENT SENSITIVITIES

FEEDWATER FLOW [+a,c]

F_a
- TEMPERATURE =
- MATERIAL =

DENSITY
- TEMPERATURE =
- PRESSURE =

DELTA P =

FEEDWATER ENTHALPY
- TEMPERATURE =
- PRESSURE =

h_s	=	1198.5 BTU/LBM
h_f	=	408.3 BTU/LBM
Dh(SG)	=	790.2 BTU/LBM

SG BLOWDOWN = 0.009246 %/gpm

NET PUMP/SYSTEM HEAT = 0.1202 %/MWt

STEAM ENTHALPY [+a,c]
- PRESSURE =
- MOISTURE =

HOT LEG ENTHALPY
- TEMPERATURE =
- PRESSURE =

h_H	=	612.7 BTU/LBM
h_C	=	534.5 BTU/LBM
Dh(VESS)	=	78.3 BTU/LBM
$Cp(T_H)$	=	1.419 BTU/LBM-°F

COLD LEG ENTHALPY [+a,c]
- TEMPERATURE =
- PRESSURE =

$Cp(T_C)$ = 1.217 BTU/LBM-°F

COLD LEG SPECIFIC VOLUME [+a,c]
- TEMPERATURE =
- PRESSURE =

TABLE 5

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTY

+a,c

COMPONENT	INSTRUMENT ERROR	FLOW UNCERTAINTY
FEEDWATER FLOW		
VENTURI		
THERMAL EXPANSION COEFFICIENT		
TEMPERATURE		
MATERIAL		
DENSITY		
TEMPERATURE		
PRESSURE		
DELTA P		
FEEDWATER ENTHALPY		
TEMPERATURE		
PRESSURE		
STEAM ENTHALPY		
PRESSURE		
MOISTURE		
SG BLOWDOWN		
NET PUMP HEAT ADDITION		
HOT LEG ENTHALPY		
TEMPERATURE		
STREAMING, RANDOM		
STREAMING, SYSTEMATIC		
PRESSURE		
COLD LEG ENTHALPY		
TEMPERATURE		
PRESSURE		
COLD LEG SPECIFIC VOLUME		
TEMPERATURE		
PRESSURE		

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

TABLE 5 (CONTINUED)

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTY

COMPONENT		FLOW UNCERTAINTY +a,c
BIAS VALUES		
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)	
4 LOOP UNCERTAINTY	(WITHOUT BIAS VALUES)	
4 LOOP UNCERTAINTY	(WITH BIAS VALUES)	

Cold Leg Elbow Tap RCS Flow Indicator Uncertainty

As noted earlier, the calorimetric RCS flow measurement is used as the reference for the normalization of the cold leg elbow tap RCS flow indicators at the beginning of each fuel cycle. The Technical Specification surveillance requirement can be met either through the process computer or by reading the control board indicators. This calculation assumes the use of the board indicators which bounds the computer readout. Table 6 notes the instrument uncertainties for normalization of the elbow taps, assuming three elbow tap RCS flow indicators per reactor coolant loop. The Δp transmitter uncertainties are converted to % flow in a similar manner to the feedwater venturi Δp. The elbow tap RCS flow indicator uncertainties are combined with the calorimetric RCS flow measurement uncertainty for determination of the total elbow tap RCS flow indicator uncertainty.

The total elbow tap RCS flow indicator uncertainty is:

# of loops	flow uncertainty (% flow)
4	$\pm$ 2.24

The corresponding ITDP value would be:

# of loops	standard deviation (% flow)
4	[ ]$^{+a,c}$

TABLE 6

COLD LEG ELBOW TAP RCS FLOW INDICATOR UNCERTAINTY

INSTRUMENT UNCERTAINTIES

+a,c

		% Δp SPAN	% FLOW
PMA	=		
PEA	=		
SRA	=		
SCA	=		
SMTE	=		
SPE	=		
STE	=		
SD	=		
BIAS	=		
RCA_{IND}	=		
$RMTE_{IND}$	=		
RTE_{IND}	=		
RD_{IND}	=		
RDOUT	=		
RCA_{EAI}	=		
$RMTE_{EAI}$	=		
RTE_{EAI}	=		
RD_{EAI}	=		
RCA_{EAO}	=		
$RMTE_{EAO}$	=		
RTE_{EAO}	=		
RD_{EAO}	=		
FLOW CALORIM. BIAS	=		
FLOW CALORIMETRIC	=		
INSTRUMENT SPAN	=		

+a,c

SINGLE LOOP ELBOW TAP FLOW UNC (USE OF 3 RCS FLOW INDICATORS)	=	
4 LOOP RCS FLOW UNCERTAINTY (WITHOUT BIAS VALUES)	=	
4 LOOP RCS FLOW UNCERTAINTY (WITH BIAS VALUES)	=	

4. REACTOR POWER MEASUREMENT UNCERTAINTY

Diablo Canyon Units 1 and 2 perform 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:

$$RP = \frac{\{(N)\{Q_{SG} - Q_P + (Q_L/N)\}\}(100)}{H} \qquad \text{(Eq. 10)}$$

where;

RP	=	Core power (% RTP)
N	=	Number of primary side loops
Q_{SG}	=	Steam generator thermal output (BTU/hr) as defined in Eq. 8
Q_p	=	RCP heat adder (Btu/hr) as defined in Eq. 7
Q_L	=	Primary system net heat losses (Btu/hr) as defined in Eq. 7
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. 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 measurement equations and effects are the same as those noted for the precision RCS flow calorimetric measurement (secondary side portion), equations 8 and 9, except for the feedwater venturi flow coefficient (K). An uncertainty of 1.42 % on K has been determined by PG&E to account for the use of an ultrasonic flowmeter to benchmark and trend feedwater flow. The measurements and calculations are presented schematically on Figure 2. 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 calculated are the same as those noted for the secondary side on Table 4. As noted on Table 8, Westinghouse has determined the dependent sets in the calculation and the direction of interaction. This is the same as that performed for the RCS flow measurement, but applicable only to power.

Using the power uncertainty values noted on Table 8, the 4 loop uncertainty (with bias values) equation is as follows:

$$\left[\qquad \qquad \right]^{+a,c}$$

Based on four (4) loops and the instrument uncertainties for the four parameters, the uncertainty for the secondary side power calorimetric measurement is:

# of loops	power uncertainty (% RTP)
4	$[\qquad]^{+a,c}$

The actual value used in the ITDP analysis was based on a power uncertainty of 2.0% RTP and is therefore bounding with respect to this calculation.

TABLE 7

DAILY POWER MEASUREMENT INSTRUMENTATION UNCERTAINTIES

+a,c

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

NUMBER OF INSTRUMENTS USED

	3	1	2/LOOP	1/LOOP
INST SPAN =	500 °F	2000 psi	115%FLOW	1200 psi
	°F	psi	%Δp span	psi
INST UNC (RANDOM) =				
INST UNC (BIAS) =				
NOMINAL =	430	855PSIA	100%FLOW	820PSIA

+a,c

* Uses uncertainties associated with Rosemount transmitters. These values bound the Barton values for the Power Calorimetric function. EAI and EAO uncertainties apply only to the Steam Pressure signal.

** Bias accounts for location of the transmitter per Reference 17.

All parameters are read by the process computer, except feedwater pressure which is an assumed value. A 35°F temperature rise is assumed for the EAGLE-21 racks and a 50°F temperature rise is assumed for the process computer. The static pressure span effect for the feedwater flow Δp transmitter is based on a feedwater pressure of 905PSIA and maximum transmitter output.

TABLE 8

DAILY POWER MEASUREMENT UNCERTAINTY

+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			
SG BLOWDOWN			
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)		
4 LOOP UNCERTAINTY	(WITHOUT BIAS VALUES)		
4 LOOP UNCERTAINTY	(WITH POSITIVE BIAS VALUES)		

IV. CONCLUSIONS

The preceding sections provide the methodology to account for pressure, temperature, power and RCS flow uncertainties for the ITDP analysis. The plant-specific instrumentation and procedures have been reviewed for Diablo Canyon Units 1 and 2 and the uncertainty calculations are completed for 30 month surveillance intervals. The values used in the ITDP analysis are more conservative than those listed below.

+a,c

Pressurizer pressure uncertainty

Temperature (Tavg) uncertainty

Power measurement uncertainty

RCS flow uncertainty - cold leg elbow tap RCS flow indicators normalized to a calorimetric RCS flow measurement

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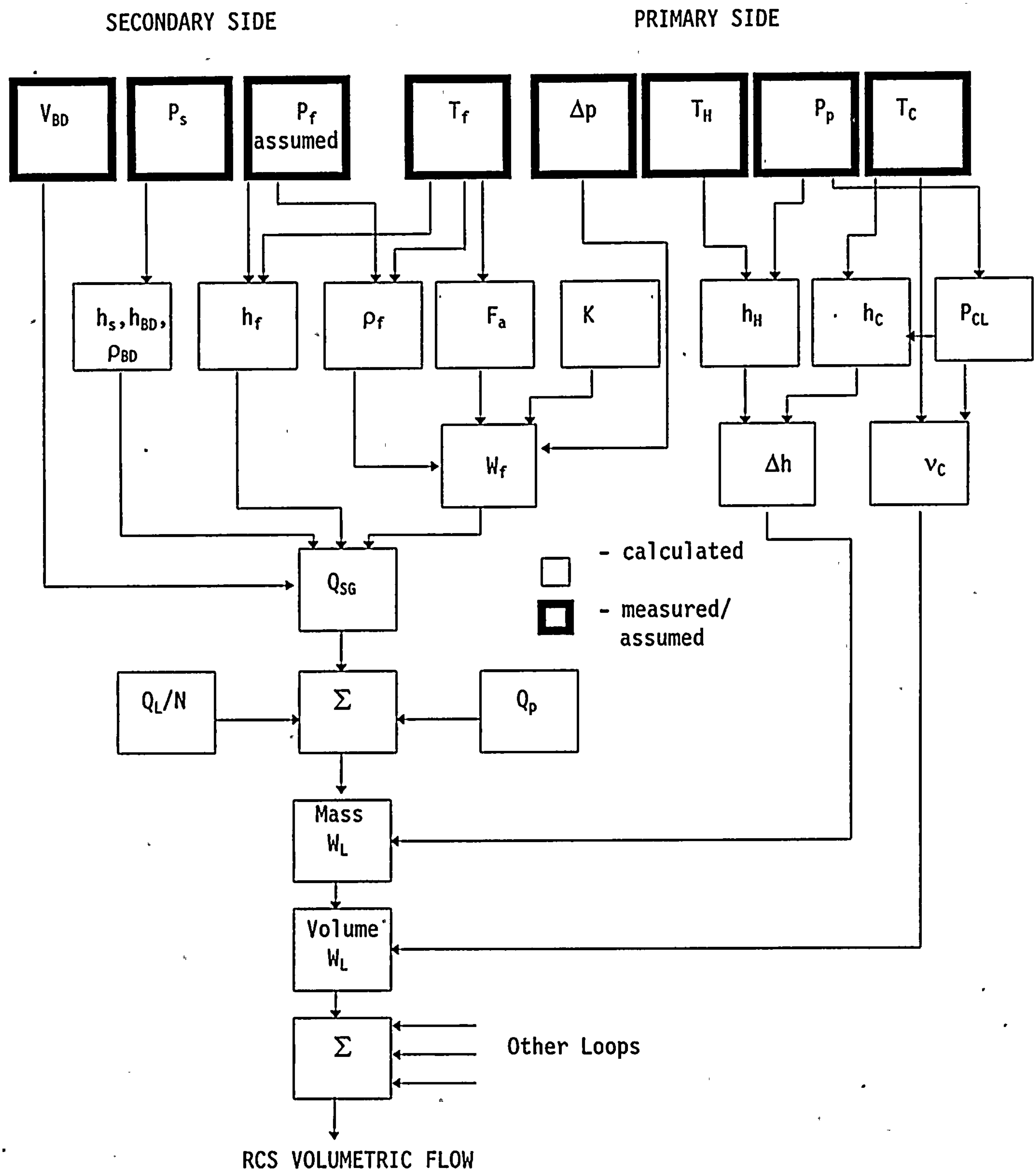

Figure 1
CALORIMETRIC RCS FLOW MEASUREMENT

SECONDARY SIDE

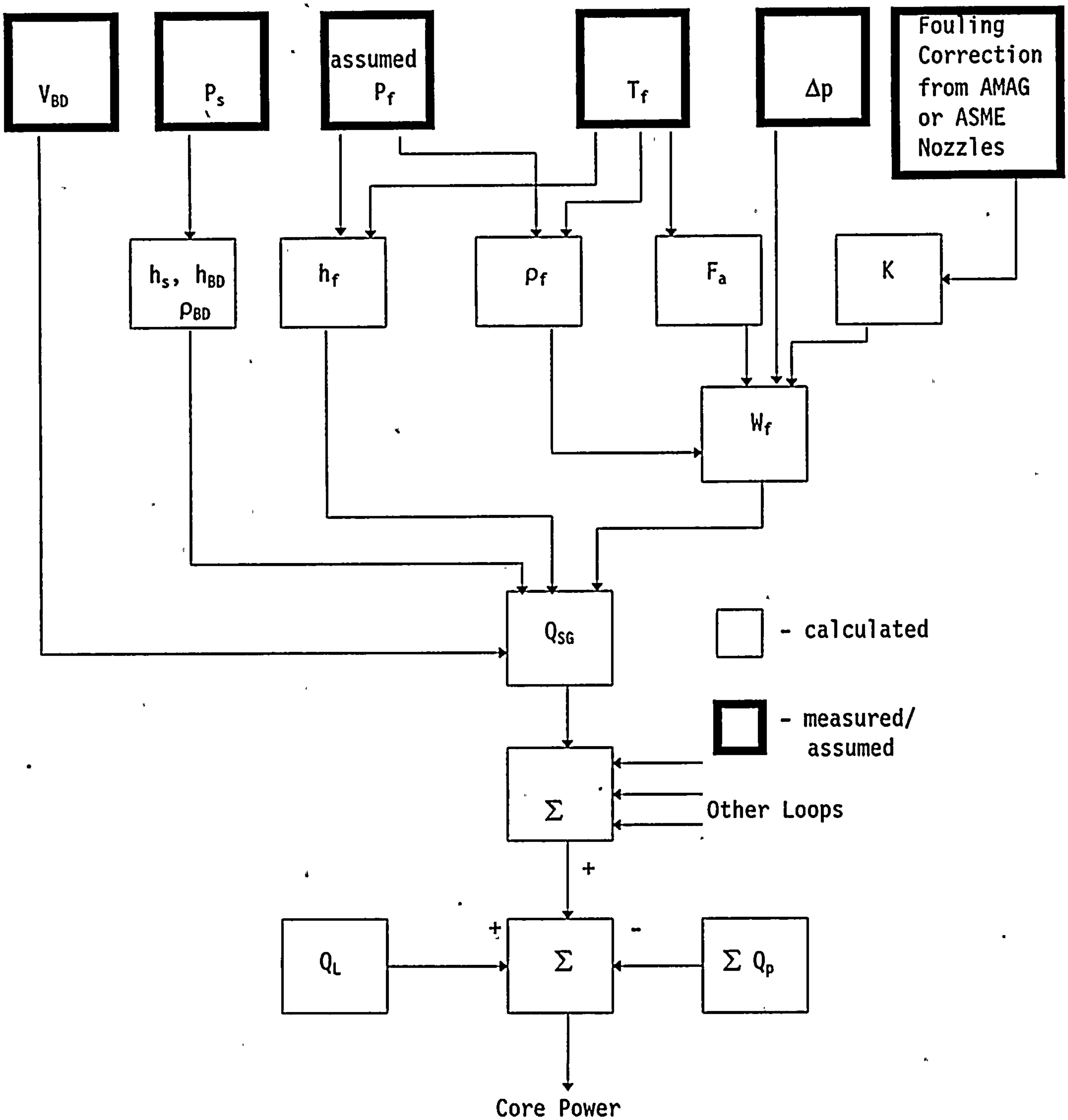

FIGURE 2
CALORIMETRIC POWER MEASUREMENT