ATTACHMENT 8

Letter from Thomas Coutu (NMC)

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WCAP-15592, "Westinghouse Revised Thermal Design Procedure Instrument Uncertainty Methodology - Kewaunee Nuclear Plant (Power Uprate to 1757 MWt-NSSS Power with Feedwater Venturis, or 1780 MWt-NSSS Power with Ultrasonic Flow Measurements, and 54F Replacement Steam Generators)," Revision 1, December 2002, Non-Proprietary

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Revision 1

December 2002

Westinghouse Revised Thermal Design Procedure Instrument Uncertainty Methodology - Kewaunee Nuclear Plant (Power Uprate to 1757 MWt-NSSS Power with Feedwater Venturis, or 1780 MWt-NSSS Power with Ultrasonic Flow Measurements, and 54F Replacement Steam Generators)

Westinghouse

WCAP-15592
Rev. 1

Westinghouse Revised Thermal Design Procedure Instrument Uncertainty Methodology Kewaunee Nuclear Plant (Power Uprate to 1757 MWt-NSSS Power with Feedwater Venturis, or 1780 MWt-NSSS Power with Ultrasonic Flow Measurements, and 54F Replacement Steam Generators)

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(Power Uprate to 1757 MWt - NSSS Power with Feedwater Venturis, or
1780 MWt - NSSS Power with Ultrasonic Flow Measurements, and
54F Replacement Steam Generators)

I. INTRODUCTION

This report was completed to support the transition to Westinghouse nuclear fuel with Replacement Steam Generators, and at an uprated condition of 1757 MWt - NSSS power using the feedwater venturis, for the Kewaunee Nuclear Plant (KNP). The fuel product to satisfy the intended requirements is the Westinghouse 14 x 14 422 Vantage + fuel assembly. To utilize this new fuel assembly at the uprated conditions, a new accident analysis was required in addition to recalculating and revising the Instrument Uncertainty Methodology.

This report was also completed to support an additional 1.4% uprate from the uprated condition of 1757 MWt - NSSS power. This 1.4% uprate is possible due to the installation of ultrasonic flow meters (UFMs) and ultrasonic temperature measurements (UTMs) on the feedwater loops. These UFMs and UTMs will be used to perform the required daily calorimetric power measurement and continuous Reactor Thermal Output (RTO) calculation on the Plant Process Computer System (PPCS). The fuel analysis was performed at 2% above the rated full power value of 1757 MWt - NSSS. This 2% accounted for the power measurement uncertainty when using the feedwater venturis. Therefore, the improved UFM-UTM power measurement will allow an additional power increase equivalent to the difference between the 2% and the reduced power measurement uncertainty obtained using the UFMs and UTMs. The new power measurement uncertainty is included in this revision.

Four operating parameter uncertainties are used in the uncertainty analysis of the Revised Thermal Design Procedure (RTDP). These parameters are Pressurizer Pressure, Primary Coolant Temperature (T_{avg}), Reactor Power, and Reactor Coolant System (RCS) 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 measurement) at least 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 loop flow indicators are evaluated against the calorimetric RCS flow measurement. Pressurizer pressure is a controlled parameter and the uncertainty reflects the control and indication system. T_{avg} is a controlled parameter via the temperature input to the rod control system, and the uncertainty reflects this control and indication system. The RTDP[1] 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 are justified. The purpose of the following evaluation is to define the specific Kewaunee Nuclear Plant instrument uncertainties for the four primary system operating parameters which are used to predict the plant safety analysis DNBR design limit via the RTDP, and to determine the starting points of certain plant parameters in some of the accident analyses.

A calorimetric RCS flow measurement uncertainty using the UFMs and UTMs is included in this report. An additional power measurement uncertainty using the UFMs without the UTMs is also included in this report.

Westinghouse has been involved with the development of several techniques to treat instrumentation uncertainties. An early version used the methodology outlined in WCAP-8567, "Improved Thermal Design Procedure," [2,3,4] which is based on the conservative assumption that the uncertainties can be described with uniform probability distributions. Another approach is based on the more realistic assumption that the uncertainties can be described with random, normal, two-sided probability distributions.[5] This approach is used to substantiate the acceptability of the protection system setpoints for many Westinghouse plants, e.g., D. C. Cook 2[6], V. C. Summer, Wolf Creek, Millstone Unit 3 and others. The second approach is now utilized for the determination of all instrumentation uncertainties for the RTDP parameters and protection functions.

The purpose of this WCAP is to document the determination of pressure, temperature, power and RCS flow uncertainties that are applicable for the Kewaunee Nuclear Plant for power levels up to 1757 MWt - NSSS power when using the feedwater venturis, or 1780 MWt - NSSS power when using the UFMs and UTMs, for 18-month fuel cycles + 25% per the plant Technical Specifications, and for a full power T_{avg} window from 556.3 to 573.0°F.

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 that are statistically independent. Those uncertainties that are dependent are combined arithmetically into independent groups, which are then systematically combined. The uncertainties used are considered to be random, two-sided distributions. 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 [7,8,9,10] and various industry standards [11,12]. This report meets the requirements of ISA Standard S67.04, 1994[12] and Regulatory Guide 1.105, Revision 2 [9].

The relationships between the error components and the channel instrument error allowance are variations of the basic Westinghouse Setpoint Methodology[13] that are based on KNP-specific procedures and processes, and are defined as follows:

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

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

2. For parameter indication utilizing the plant process computer;

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

3. For parameters with closed-loop automatic control systems, the calculation takes credit for [ ]$^{+a,c}$.

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

where:

CSA	=	Channel Statistical Allowance
PMA	=	Process Measurement Accuracy
PEA	=	Primary Element Accuracy
SRA	=	Sensor Reference Accuracy
SCA	=	Sensor Calibration Accuracy
SMTE	=	Sensor 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
CA	=	Controller Allowance
CMTE	=	Controller Measurement and Test Equipment Accuracy
COMP	=	Plant Computer
REF	=	Reference signal for automatic control system
IND	=	Indicator.

PMA and PEA terms are not included in Equations 1 and 2 since the equations are to determine instrumentation uncertainties only. PMA and PEA terms are included in the determination of control system uncertainties.

The parameters above are defined in References 5 and 12 and are based on ISA S51.1-1979[14]. 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 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 differential pressure (d/p) transmitter.
- STE - change in input-output relationship due to a change in ambient temperature for a sensor or transmitter.
- SD - change in input-output relationship over a period of time at reference conditions for a sensor or transmitter.
- RCA - 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 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 data acquisition system, a digital voltmeter or multimeter on its most accurate applicable range for the parameter measured, or 1/2 the smallest increment on an indicator (readability).

CA - allowance of the controller 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 controller rack module(s) that perform(s) the comparison between the controlled parameter and the reference signal.

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

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

IND - allowance for the uncertainty associated with the use of an indication meter. Control board indicators are typically used.

BIAS - a one directional uncertainty for a sensor/transmitter or a process parameter with a known magnitude. The instrumentation indicates higher than the actual parameter for a (+) bias. The instrumentation indicates lower than the actual parameter for a (-) bias. If a sign is not identified, the bias can result in either a high or low indication.

A more detailed explanation of the Westinghouse methodology noting the interaction of several parameters is provided in References 6 and 13.

Westinghouse typically reports uncertainty values to one decimal place using the conventional technique of rounding down numbers < 5 and rounding up numbers ≥ 5. Parameters reported as "0.0" have been identified as having a value of ≤ 0.04. Parameters reported as "0" or blank are not present (i.e., have no value) for that channel. For power measurement uncertainties less than 1 %, the calculated uncertainty is rounded to the next highest tenth of a percent of rated power. Sensitivities used in the calorimetric measurement uncertainties are rounded to one significant digit.

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III. INSTRUMENTATION UNCERTAINTIES

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

1. Pressurizer Pressure

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 accounts for the closed-loop control system design where [ ]$^{+a,c}$. The control channel uncertainties for the automatic control system include allowances for the pressure transmitters, the process racks/indicators, and the control system reference setpoint. The pressurizer pressure control system reference setpoint is generated by the setting of a variable potentiometer on the Main Control Board manual/automatic station. The reference setpoint (Pref) is adjusted and verified by the plant operators with the control board indicators. This uncertainty calculation also includes the control board indicators for performance verification of the automatic control system.

On Table 1, the calculated electronics uncertainty for this function using Equation 3 is [ ]$^{+a,c}$ with a [ ]$^{+a,c}$ bias. 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. An allowance of [ ]$^{+a,c}$ is made for this effect. The total control system uncertainty including indication is [ ]$^{+a,c}$ with a [ ]$^{+a,c}$ bias which results in a standard deviation of [ ]$^{+a,c}$ for a normal, two-sided probability distribution.

The Core Operating Limits Report (COLR) DNB Parameter for pressurizer pressure has been determined for the following methods of surveillance:

Control Board Indicators (average of 4 channels)	> 2217 psig
Computer Indications (average of 4 channels)	> 2219 psig

TABLE 1

PRESSURIZER PRESSURE CONTROL SYSTEM AND INDICATION UNCERTAINTIES

All Values in % Span*

Term		Value [+a,c]
REF	=	
PMA	=	
PEA	=	
SRA	=	
SCA	=	
SMTE	=	
STE	=	
SD	=	
BIAS	=	
RCA	=	
RMTE	=	
RTE	=	
RD	=	
RCA_{IND}	=	
$RMTE_{IND}$	=	
RD_{IND}	=	
$RDOUT_{IND}$	=	
CA	=	
CMTE	=	

RANGE = 1700 - 2500 psig, *SPAN = 800 psi
CHANNELS P-429, -430, -431 & -449

ELECTRONICS UNCERTAINTY = [ ]+a,c
PLUS
CONTROLLER UNCERTAINTY =

Note A: Module PM-429A = [ ]+a,c
Module PM-429D =
Note B: Module PC-431K =

2. $\underline{T_{avg}}$

T_{avg} is controlled by a system that compares the high T_{avg} from the loops with a reference derived from the Turbine First Stage Impulse Chamber Pressure. T_{avg} is the average of the narrow range T_H and T_C values for a loop. The high loop T_{avg} is then used for rod control. Allowances are made (as noted on Table 2) for hot and cold leg temperature streaming, RTDs, turbine pressure transmitter, process racks/indicators and controller. Based on one T_H and one T_C RTD per channel to calculate T_{avg} and with the RTDs located in the hot and cold leg bypass manifolds, the calculated electronics uncertainty using Equation 3 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 deadband of [$]^{+a,c}$ associated with the automatic control. The T_{avg} 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:

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

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

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

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

A bias of [$]^{+a,c}$ for T_{cold} streaming (in terms of T_{avg}) based on a conservative [$]^{+a,c}$ T_{cold} streaming uncertainty is included in Table 2. Another bias of [$]^{+a,c}$ for the turbine first stage impulse chamber pressure transmitter is included in Table 2. Therefore, the total uncertainty of the controller with the biases is [$]^{+a,c}$ random and [$]^{+a,c}$ bias.

The Core Operating Limits Report (COLR) DNB Parameter for T_{avg} has been determined for the following methods of surveillance:

Control Board Indicators (average of 4 channels)	< 576.7°F
Computer Indications (average of 4 channels)	< 576.5°F

TABLE 2

T_{AVG} ROD CONTROL SYSTEM AND INDICATION UNCERTAINTIES

		% T_{avg} Span*	% Turbine Pressure Span** (P-485,-486) +a,c
PMA_1	=		
PMA_2	=		
PMA_3	=		
SRA	=		
SCA	=		
SMTE	=		
STE	=		
SD	=		
BIAS	=		
R/E	=		
R/E_MTE	=		
R/E_RD	=		
RCA	=		
RMTE	=		
RTE	=		
RD	=		
RCA_{IND}	=		
$RMTE_{IND}$	=		
RD_{IND}	=		
$RDOUT_{IND}$	=		
CA	=		
CMTE	=		

*	Tavg span	= 100 °F	(range: 520-620°F)
**	Turbine pressure span	= 650 psi	(range: 0-650 psig)
***	% R/E span &&		
&&	R/E span	= 150 °F	(range 500-650°F for Hot Leg) (range 500-650°F for Cold Leg)
	# Hot Leg RTDs	= 1/Channel	#Cold Leg RTDs = 1/Channel

			+a,c
Note A:	Module TM401BB	=	
	Module TM401C	=	
	Module TM401EE	=	
	Module TM401D	=	
	Module TM401H	=	
	Module TM401M	=	
	Module TC401L	=	
Note B:	Module PM485A	=	
	Module TM401P	=	
	Module TM401N	=	
	Module TM401I	=	

TABLE 2 (Continued)

T_{AVG} ROD CONTROL SYSTEM AND INDICATION UNCERTAINTIES

Electronics Uncertainty	=	[
Electronics Sigma	=	
Controller Sigma	=	
Controller Uncertainty	=	
Controller Bias	=	] +a,c

**** Includes the controller deadband of [ ]+a,c.

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3. RCS Flow

3.1.a Calorimetric RCS Flow Measurement Uncertainty
(Using Venturi on the Feedwater Bypass Loop, limited to 1757 MWt-NSSS Power)

The Technical Specifications require an RCS flow measurement during steady-state power operation to be satisfied by an RCS flow measurement following each refueling between 90% and 100% of Rated Thermal Power (RTP). A calorimetric RCS flow measurement is performed at the beginning of every fuel cycle between 90% and 100% RTP operation, typically every 18 months, to verify RCS flow and to normalize the RCS flow instrument channels. Interim surveillances performed with the plant computer ensure that the RCS flow is maintained above the assumed safety analysis values, i.e., Minimum Measured Flow (MMF).

It is assumed for this uncertainty analysis that a calorimetric RCS flow measurement is performed within 30 days of calibrating the measurement instrumentation. Therefore, except where necessary due to sensor location, drift effects are limited to 30 days. The feedwater bypass loop will be used for the calorimetric RCS flow measurement at the beginning of each fuel cycle. No allowances have been made for feedwater bypass loop venturi fouling. Instrument drift allowances are identified for this uncertainty analysis for hot and cold leg RTDs, feedwater RTDs, and for feedwater flow, feedwater pressure, steam pressure and pressurizer pressure transmitters.

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.,

$$W_{RCS} = \Sigma_{i=1}^{N}(W_L)_i. \qquad \text{Eq. 4}$$

The individual primary loop volumetric flows are determined by correcting the thermal output of each 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	=	Constant conversion factor 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 each steam generator is determined by a secondary side calorimetric measurement that 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 (feedwater bypass loop flow)(lb/hr).

The steam enthalpy is based on the measurement of steam generator outlet steam pressure assuming saturated conditions. The feedwater enthalpy is based on the measurement of feedwater temperature and a calculated feedwater pressure. Total feedwater flow is determined by a delta-p measurement on the feedwater bypass loop and the following calculation:

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

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).

A calibrated feedwater flow venturi is installed on the feedwater bypass loop to determine total feedwater flow. 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 a calculated 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 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 calorimetric RCS flow measurement is thus based on the following plant measurements:

Steamline pressure (P_s)
Feedwater temperature (T_f)
Feedwater pressure (P_f)
Feedwater venturi differential pressure (Δp)
Hot leg temperature (T_H)
Cold leg temperature (T_C)
Pressurizer pressure (P_p)
Steam generator blowdown flow (if not secured)*
* However, steam generator blowdown operation will have minimal effect on the calorimetric RCS flow measurement uncertainty.

and on the following calculated values:

Feedwater venturi flow coefficient (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).

These measurements and calculations are presented schematically in Figure 1. The derivation of the measurement and flow uncertainties on Table 5a are noted below.

Secondary Side

The secondary side uncertainties are in four principal areas, feedwater flow, feedwater enthalpy, steam enthalpy and net pump heat addition. These areas are specifically identified on Table 5a.

For the measurement of feedwater flow, the feedwater venturi is calibrated by the vendor in a hydraulics laboratory under controlled conditions to an accuracy of [ ]$^{+a,c}$. The calibration data that 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. The venturi should be inspected, and cleaned if necessary, prior to performance of the calorimetric measurement. If fouling is present but not removed, it's effects must be treated as a flow bias.

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 [ ]$^{+a,c}$ 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 NBS/NRC Steam Tables it is possible to determine the sensitivities of various parameters to changes in feedwater temperature and pressure. Table 3a notes the instrument uncertainties for the hardware used to perform the measurements. Table 4a lists the various sensitivities. As can be seen on Table 5a, feedwater temperature uncertainties have an impact on feedwater flow and feedwater enthalpy. Feedwater pressure uncertainties impact feedwater flow and feedwater enthalpy.

Feedwater venturi Δp uncertainties are converted to % feedwater flow using the following conversion factor:

$$\% \text{ flow} = (\Delta p \text{ uncertainty})(1/2)(\text{transmitter span}/ 90)^2$$

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

Using the NBS/NRC Steam Tables, it is possible to determine the sensitivity of steam enthalpy to changes in steam pressure and steam quality. Table 3a notes the uncertainty in steam pressure and Table 4a 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 4a.

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

- \- System heat losses (MWt)
- \- Component conduction and convection losses (MWt)
- \+ Pump heat adder (MWt)
- = Net Heat input to RCS of + 8.0 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 Unit 2 and by input power measurements from several other 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 addition 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 5a. 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 3a and the sensitivities are provided on Table 4a. The hot leg streaming is split into random and systematic components. For Kewaunee where the RTDs are located in RTD bypass loop manifolds, the hot leg temperature streaming uncertainty components are [ ]$^{+a,c}$ random and [ ]$^{+a,c}$ systematic.

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

Parameter dependent effects are identified on Table 5a. 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 5a, the 2 loop uncertainty equation (with biases) is as follows:

[ ]+a,c

Based on the number of loops; number, type and measurement method of RTDs, and the vessel Delta-T, the flow uncertainty is:

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

TABLE 3a

FLOW CALORIMETRIC INSTRUMENTATION UNCERTAINTIES
(Feedwater Bypass Loop, limited to 1757 MWt-NSSS Power)
(% Span)

	FW Temp.	FW Pres.	FW Δp	Steam Pres.	T_H	T_C	PRZ Pres.
							+a,c
SRA =							
SCA =							
SMTE =							
SPE =							
STE =							
SD =							
BIAS =							
R/E =							
RCA =							
RMTE =							
RTE =							
RD =							
A/D =							
A/D_MTE =							
A/D_TE =							
A/D_D =							
RDOUT =							
CSA =							
# OF INSTRUMENTS USED	1/Loop	1/plant	1/plant	3/Loop	2/Loop	2/Loop	4
	°F	psi	% Δp	psi	°F	°F	psi
INST SPAN =	200 (1)	1600 (2)	103.3% flow (3)	1400 (4)	150 (5)	150 (5)	800 (6)
							+a,c
INST UNC. (RANDOM) =							
INST UNC. (BIAS) =							
NOMINAL =	435.3°F	869 psia	90% Flow	769 psia	608.5°F	542.1°F	2250 psia

(1) Temperature (TE-15043, -15044) is measured with RTDs and the plant computer. TE-14137 (RTD), TT-22050 (transmitter) and digital acquisition system measure feedwater bypass loop temperature for density correction.
(2) Pressure (PT-21196) is measured with a transmitter and digital acquisition system on the feedwater bypass loop.
(3) Flow (FT-23153) is measured with a transmitter and digital acquisition system on the feedwater bypass loop venturi.
(4) Pressure (PT-21094, -21095, -21096, -21097, -21098, -21099) is measured with transmitters, the process instrumentation, and the plant computer.
(5) Temperature is measured with digital voltmeters at the output of the R/E process instrumentation modules.
(6) Pressure (PT-21079, -21080, -21081, -21082) is measured with transmitters, the process instrumentation and the plant computer.

TABLE 4a

FLOW CALORIMETRIC SENSITIVITIES
(Feedwater Bypass Loop, limited to 1757 MWt-NSSS Power)

FEEDWATER FLOW			+a,c
F_a			
TEMPERATURE	=		
MATERIAL	=		
DENSITY			
TEMPERATURE	=		
PRESSURE	=		
DELTA P	=		
FEEDWATER ENTHALPY			
TEMPERATURE	=		
PRESSURE	=		
h_s	=	1199.9	BTU / lbm
h_f	=	414.1	BTU / lbm
Δh (SG)	=	785.9	BTU / lbm
			+a,c
STEAM ENTHALPY			
PRESSURE	=		
MOISTURE	=		
HOT LEG ENTHALPY			
TEMPERATURE	=		
PRESSURE	=		
h_H	=	625.0	BTU / lbm
h_C	=	537.1	BTU / lbm
Δh (VESS)	=	87.9	BTU / lbm
			+a,c
COLD LEG ENTHALPY			
TEMPERATURE	=		
PRESSURE	=		
COLD LEG SPECIFIC VOLUME			
TEMPERATURE	=		
PRESSURE	=		

TABLE 5a

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTY
(Feedwater Bypass Loop, limited to 1757 MWt-NSSS Power)

Component	Instrument Uncertainty	Flow Uncertainty (% Flow)
		+a,c
FEEDWATER FLOW		
VENTURI		
THERMAL EXPANSION COEF.		
TEMPERATURE		
MATERIAL		
DENSITY		
TEMPERATURE		
PRESSURE		
DELTA P		
FEEDWATER ENTHALPY		
TEMPERATURE		
PRESSURE		
STEAM ENTHALPY		
PRESSURE		
MOISTURE		
NET PUMP HEAT ADDITION		
HOT LEG ENTHALPY		
TEMPERATURE		
STREAMING, RANDOM		
STREAMING, SYSTEMATIC		
PRESSURE		
COLD LEG ENTHALPY		
TEMPERATURE		
PRESSURE		
COLD LEG SPECIFIC VOLUME		
TEMPERATURE		
PRESSURE		

*, **, +, ++ Indicates sets of dependent parameters

TABLE 5a (Continued)

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTY
(Feedwater Bypass Loop, limited to 1757 MWt-NSSS Power)

Component		Flow Uncertainty
BIAS VALUES		
STEAM PRESSURE - ENTHALPY		[ ]+a,c
PRESSURIZER PRESSURE		
HOT LEG ENTHALPY		
COLD LEG ENTHALPY		
COLD LEG SPECIFIC VOLUME		
FLOW BIAS TOTAL VALUE		
2 LOOP UNCERTAINTY	(RANDOM)	[ ]+a,c
	(BIAS)	

3.1.b Calorimetric RCS Flow Measurement Uncertainty
(Using UFMs and UTMs, limited to 1780 MWt-NSSS Power)

A calorimetric RCS flow measurement is performed at the beginning of each fuel cycle as described in Section 3.1.a. In this section the feedwater venturi flow measurement on the feedwater bypass loop is replaced with a UFM on each feedwater loop, and the feedwater temperature RTD measurements on each feedwater loop are replaced with a UTM on each feedwater loop.

This section summarizes the calorimetric RCS flow measurement uncertainty calculation using the UFMs and UTMs. The methodology in Section 3.1.a is applicable with the following changes.

W_f = Feedwater flow (system flow based on loop UFM measurements)(lb/hr).

Using Table 5b, the 2 loop uncertainty equation (with biases) is as follows:

[ ] +a,c

Based on the number of loops; number, type and measurement method of RTDs, and the vessel Delta-T, the flow uncertainty is:

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

TABLE 3b

FLOW CALORIMETRIC INSTRUMENTATION UNCERTAINTIES
(UFMs and UTMs, limited to 1780 MWt-NSSS Power)
(% Span)

	FW Temp.	FW Pres.	FW Flow	Steam Pres.	T_H	T_C	PRZ Pres
							+a,c
UFM =							
UTM =							
SRA =							
SCA =							
SMTE =							
SPE =							
STE =							
SD =							
BIAS =							
R/E =							
RCA =							
RMTE =							
RTE =							
RD =							
A/D =							
A/D_MTE =							
A/D_TE =							
A/D_D =							
RDOUT =							
CSA =							
# OF INSTRUMENTS USED							
	1/Loop	not measured	treated as 1/plant	3/Loop	2/Loop	2/Loop	4
	°F	psi	% flow	psi	°F	°F	psi
INST SPAN =	(1)	(2)	(3)	1400(4)	150(5)	150(5)	800(6)
							+a,c
INST UNC. (RANDOM) =							
INST UNC (BIAS) =							
NOMINAL =	437.1°F	909 psia	100% flow	809 psia	606 8°F	539.2°F	2250 psia

(1) Temperature is measured with Crossflow UTMs on each feedwater loop, and the signals are sent to the plant computer

(2) Feedwater pressure is not measured. It is inferred from steam pressure.

(3) Flow is measured with Crossflow UFMs on each feedwater loop, and the signals are sent to the plant computer. The uncertainty is the total feedwater flow system uncertainty

(4) Pressure (PT-21094, -21095, -21096, -21097, -21098, -21099) is measured with transmitters, the process instrumentation, and the plant computer.

(5) Temperature is measured with digital voltmeters at the output of the R/E process instrumentation modules.

(6) Pressure (PT-21079, -21080, -21081, -21082) is measured with transmitters, the process instrumentation and the plant computer.

TABLE 4b

FLOW CALORIMETRIC SENSITIVITIES
(UFMs and UTMs, limited to 1780 MWt-NSSS Power)

FEEDWATER FLOW			+a,c
DENSITY			
TEMPERATURE	=		
PRESSURE	=		
FEEDWATER ENTHALPY			
TEMPERATURE	=		
PRESSURE	=		
h_s	=	1198.8	BTU / lbm
h_f	=	416.1	BTU / lbm
Δh (SG)	=	782.7	BTU / lbm
			+a,c
STEAM ENTHALPY			
PRESSURE	=		
MOISTURE	=		
HOT LEG ENTHALPY			
TEMPERATURE	=		
PRESSURE	=		
h_H	=	622.5	BTU / lbm
h_C	=	533.6	BTU / lbm
Δh (VESS)	=	89.0	BTU / lbm
			+a,c
COLD LEG ENTHALPY			
TEMPERATURE	=		
PRESSURE	=		
COLD LEG SPECIFIC VOLUME			
TEMPERATURE	=		
PRESSURE	=		

TABLE 5b

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTY
(UFMs and UTMs, limited to 1780 MWt-NSSS Power)

Component	Instrument Uncertainty	Flow Uncertainty (% Flow)
		+a,c
FEEDWATER FLOW (HEADER)		
UFM		
FEEDWATER DENSITY		
TEMPERATURE		
PRESSURE		
FEEDWATER ENTHALPY		
TEMPERATURE		
PRESSURE		
STEAM ENTHALPY		
PRESSURE		
MOISTURE		
NET PUMP HEAT ADDITION		
HOT LEG ENTHALPY		
TEMPERATURE		
STREAMING, RANDOM		
STREAMING, SYSTEMATIC		
PRESSURE		
COLD LEG ENTHALPY		
TEMPERATURE		
PRESSURE		
COLD LEG SPECIFIC VOLUME		
TEMPERATURE		
PRESSURE		

*, **, +, ++ Indicates sets of dependent parameters

TABLE 5b (Continued)

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTY
(UFMs and UTMs, limited to 1780 MWt-NSSS Power)

Component		Flow Uncertainty
BIAS VALUES		
STEAM PRESSURE - ENTHALPY		[ ]+a,c
PRESSURIZER PRESSURE		
HOT LEG ENTHALPY		
COLD LEG ENTHALPY		
COLD LEG SPECIFIC VOLUME		
FLOW BIAS TOTAL VALUE		
2 LOOP UNCERTAINTY	(RANDOM)	[ ]+a,c
	(BIAS)	

3.2 Loop RCS Flow Measurement Uncertainty (Using Plant Computer)

As noted earlier, the calorimetric RCS flow measurement is used as the reference for normalizing the loop RCS flow measurement from the cold leg elbow tap transmitters. Since the cold leg elbow tap transmitters feed the plant computer, it is a simple matter to perform a RCS flow surveillance. Table 6 notes the instrument uncertainties for determining flow by using the loop RCS flow channels and the plant computer, assuming two loop RCS flow channels are averaged per reactor coolant loop. The Δp transmitter uncertainties are converted to percent flow using the following conversion factor:

$$\% \text{ flow} = (\Delta p \text{ uncertainty})(1/2)(\text{Flow}_{max} / \text{Flow}_{nominal})^2$$

where Flow_{max} is the maximum value of the loop RCS flow channel. The loop RCS flow uncertainty is then combined with the limiting calorimetric RCS flow measurement uncertainty from section 3.1. This combination of uncertainties results in the following total flow uncertainty:

# of loops	flow uncertainty (% flow)
2	±2.9 (random) 0.1 (bias)

The corresponding value used in RTDP is:

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

TABLE 6

LOOP RCS FLOW MEASUREMENT UNCERTAINTY
PLANT COMPUTER

INSTRUMENT UNCERTAINTIES
2 LOOP RCS FLOW CHANNELS AVERAGED PER REACTOR COOLANT LOOP
(F-411, -412, -413, -414, -415, -416)

		% d/p Span	% Flow
			+a,c
PMA	=		
PEA	=		
SRA	=		
SCA	=		
SMTE	=		
SPE	=		
STE	=		
SD	=		
BIAS	=		
RCA	=		
RMTE	=		
RTE	=		
RD	=		
A/D	=		
A/D_MTE	=		
A/D_TE	=		
A/D_D	=		
FLOW CALORIMETRIC	=		
FLOW CALORIMETRIC BIAS	=		
INSTRUMENT SPAN	=		

SINGLE LOOP ELBOW TAP FLOW UNCERTAINTY = [ ] +a,c

2 LOOP RCS FLOW UNCERTAINTY

(RANDOM)	=	±2.9% flow
(BIAS)	=	0.1% flow

Note A: Module FM-411, -412, -413, -414, -415, -416 = 0.5% d/p span

* Zero values due to normalization to calorimetric RCS flow measurement

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4. <u>Reactor Power</u>

4.1 Calorimetric Power Measurement Uncertainty
(Using Venturis, limited to 1757 MWt-NSSS Power)

The plant is required to perform a primary/secondary side heat balance at least every 24 hours when power is above 15% RTP. This heat balance is used to verify that the plant is operating within the limits of the Operating License (1749 MWt-Core power) or 1757 MWt-NSSS power when using the feedwater venturis, and to adjust the Power Range Neutron Flux channels when the difference between the Power Range Neutron Flux channels and the heat balance is greater than allowed by the plant Technical Specifications. KNP also continuously calculates the reactor thermal output (RTO) to ensure that the power limit is not exceeded.

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 Btu/hr at rated full power. The equation for this calculation is:

$$RP = \frac{\{ \sum_{i=1}^{N} [Q_{SG} - Q_P + (Q_L/N)]_i \}(100)}{H} \qquad \text{Eq. 8}$$

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 addition (BTU/hr)
Q_L	=	Primary system net heat losses (BTU/hr)
H	=	Rated core power (BTU/hr).

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 feedwater flow is determined by multiple measurements from the feedwater flow venturis for each steam generator and Equation 7.

where;

W_f	=	Feedwater loop flow (lb/hr)
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 steam pressure. The venturi pressure drop is obtained from the output of the differential pressure transmitter connected to the venturi.

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

Steamline pressure (P_s)
Feedwater temperature (T_f)
Feedwater venturi differential pressure (Δp)
Steam generator blowdown flow (if not secured)

and on the following calculated values:

Feedwater pressure (P_f)
Feedwater venturi flow coefficient (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)

<u>Secondary Side</u>

The secondary side power calorimetric equations and effects are the same as those noted for the calorimetric RCS flow measurement (secondary side portion), Equation 6. The measurements and calculations are presented schematically on Figure 2.

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 that 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 steam generator thermal output is proportional to feedwater flow, the flow coefficient uncertainty is expressed as [$]^{+a,c}$. It should be noted that no allowance is made for feedwater venturi fouling. The effect of fouling results in an indicated power higher than actual, which is conservative.

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 ±1.0°F in the nominal feedwater temperature range changes F_a by [ ]$^{+a,c}$ 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 power.

Using the NBS/NRC Steam Tables, it is possible to determine the sensitivities of various parameters to changes in feedwater temperature and pressure. Table 7 notes the instrument uncertainties for the hardware used to perform the measurements. Table 8 lists the various sensitivities. As can be seen on Table 8, 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:

$$\% \text{ flow} = (\Delta p \text{ uncertainty})(1/2)(\text{Flow}_{max} / \text{Flow}_{nominal})^2$$

The feedwater flow transmitter span (Flow_{max}) is 117.5% of nominal flow.

Since it is necessary to make this determination daily, the plant computer is used for the calorimetric power measurement. As noted in 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. It should be noted that Westinghouse does not include any allowance for feedwater venturi fouling. The effect of fouling is to result in an indicated power higher than actual, which is conservative.

Using the power uncertainty values noted on Table 9, the 2 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, the uncertainty for the secondary side power calorimetric measurement using the feedwater flow venturis is:

# of loops	power uncertainty (% power)
2	[ ] +a,c

TABLE 7

POWER CALORIMETRIC INSTRUMENTATION UNCERTAINTIES
(Using Venturis, limited to 1757 MWt-NSSS Power)
(% Span)

		FW Temp.	FW Pres.	FW ΔP	Steam Pres.
					+a,c
SRA	=				
SCA	=				
SMTE	=				
SPE	=				
STE	=				
SD	=				
BIAS	=				
RCA	=				
RMTE	=				
RTE	=				
RD	=				
RCA_A/D	=				
RMTE_A/D	=				
RTE_A/D	=				
RD_A/D	=				
CSA	=				
# OF INSTRUMENTS USED		1/Loop	not measured	1/Loop	2/Loop
		°F	psi	% Δp	psi
INST SPAN	=	200(1)	(2)	117.5%(3) flow	1400(4)
					+a,c
INST UNC. (RANDOM)	=				
INST UNC. (BIAS)	=				
NOMINAL	=	435.3°F	724 psia	100 % flow	624 psia

(1) Temperature (T-15043, -15044) is measured with an RTD on each loop, and the signals are sent to the plant computer.
(2) Feedwater pressure is not measured. It is inferred from steam pressure.
(3) Flow (F-23003, -23004, -23009, and –23011) is measured with transmitters, the process instrumentation, and the plant computer.
(4) Pressure (P-21094, -21095, -21096, -21097, -21098, and -21099) is measured with transmitters, the process instrumentation, and the plant computer.

TABLE 8

POWER CALORIMETRIC SENSITIVITIES
(Using Venturis, limited to 1757 MWt-NSSS Power)

FEEDWATER FLOW			[ ]+a,c
F_a			
TEMPERATURE	=		
MATERIAL	=		
DENSITY			
TEMPERATURE	=		
PRESSURE	=		
DELTA P	=		
FEEDWATER ENTHALPY			
TEMPERATURE	=		
PRESSURE	=		
h_s	=	1203.3	BTU / lbm
h_f	=	414.0	BTU / lbm
Δh (SG)	=	789.3	BTU / lbm
STEAM ENTHALPY			[ ]+a,c
PRESSURE	=		
MOISTURE	=		

TABLE 9

SECONDARY SIDE POWER CALORIMETRIC MEASUREMENT UNCERTAINTY
(Using Venturis, limited to 1757 MWt-NSSS Power)

Component	Instrument Uncertainty	Power Uncertainty (% Power)
		+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		
STEAM PRESSURE - ENTHALPY		
POWER BIAS TOTAL VALUE		
2 LOOP UNCERTAINTY	(RANDOM)	
	(BIAS)	

*, ** Indicates sets of dependent parameters

4.2 Calorimetric Power Measurement Uncertainty
(Using UFMs and UTMs, limited to 1780 MWt-NSSS Power)

A calorimetric power measurement can be performed on a daily basis as described in Section 4.1 by replacing the loop venturi feedwater flow measurements with the UFMs. The calorimetric power measurement can also be performed by replacing the feedwater temperature RTD measurements with the UTMs. This section summarizes the calorimetric power measurement uncertainty calculation using the UFMs and the UTMs. With the UFMs and UTMs operable, Kewaunee is limited to 1780 MWt-NSSS power.

The methodology described in Section 4.1 is applicable with the following change. The thermal output of the Steam Generator is determined by a secondary side calorimetric measurement that is defined by Equation 9 as:

$$Q_{SG} = (h_s - h_f)W_f - (h_s - h_{sgbd})W_{sgbd} \qquad \text{Eq. 9}$$

where;

h_s = Steam enthalpy (BTU/lb)
h_f = Feedwater enthalpy (BTU/lb)
h_{sgbd} = Steam generator blowdown enthalpy (BTU/lb)
W_f = Feedwater flow (system flow based on a UFM in each loop)(lb/hr).
W_{sgbd} = Steam generator blowdown flow (lb/hr).

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

Steamline pressure (P_s)
Feedwater temperature (T_f - from UTMs)
Feedwater flow (from UFMs)
Steam generator loop blowdown flow (if not secured);

and on the following calculated values:

Feedwater enthalpy (h_f)
Steam enthalpy (h_s)
Steam generator blowdown enthalpy (h_{sgbd})
Moisture carryover (impacts h_s)
Primary system net heat losses (Q_L)
RCP heat addition (Q_p)

Using the power uncertainty values noted on Table 12, the 2-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, the uncertainty for the secondary side power calorimetric measurement using the UFMs and UTMs is:

# of loops	power uncertainty (% power)
2	±0.6% (random) 0.0% (bias)

TABLE 10

POWER CALORIMETRIC INSTRUMENTATION UNCERTAINTIES
(Using UFMs and UTMs, limited to 1780 MWt-NSSS Power)
(% Span)

	FW Temp	FW Pres.	FW Flow	Steam Pres.	SG Blowdown Flow
					+a,c
UFM =					
UTM =					
SRA =					
SCA =					
SMTE =					
SPE =					
STE =					
SD =					
BIAS =					
RCA =					
RMTE =					
RTE =					
RD =					
A/D =					
A/D_MTE =					
A/D_TE =					
A/D_D =					
RDOUT=					
CSA =					
# OF INSTRUMENTS USED	1/Loop	not measured	treated as 1/plant	2/Loop	1/Loop
	°F	psi	% flow	psi	% flow
INST SPAN =	(1)	(2)	(3)	1400(4)	1.0% rated feedwater flow(rfwf)(5)
					+a,c
INST UNC. (RANDOM) =					
INST UNC (BIAS) =					
NOMINAL =	437.1°F	909 psia	100 % flow	809 psia	

(1) Temperature is measured with Crossflow UTMs on each loop, and the signals are sent to the plant computer.
(2) Feedwater pressure is not measured. It is inferred from steam pressure.
(3) Flow is measured with Crossflow UFMs on each loop, and the signals are sent to the plant computer. The uncertainty is the total feedwater flow system uncertainty.
(4) Pressure (PT-21094, -21095, -21096, -21097, -21098, -21099) is measured with transmitters, the process instrumentation, and the plant computer.
(5) Steam generator loop blowdown flow (F-23070 and-23071) is measured with turbine flow meters (0-100 gpm/loop)

TABLE 11

POWER CALORIMETRIC SENSITIVITIES
(Using UFMs and UTMs, limited to 1780 MWt-NSSS Power)

FEEDWATER DENSITY			+a,c
TEMPERATURE	=		
PRESSURE	=		
FEEDWATER ENTHALPY			
TEMPERATURE	=		
PRESSURE	=		
h_s	=	1198.8	BTU / lbm
h_f	=	416.1	BTU / lbm
Δh (SG)	=	782.7	BTU / lbm
STEAM ENTHALPY			+a,c
PRESSURE	=		
MOISTURE	=		
SG BLOWDOWN FLOW			
DENSITY PRESSURE	=		
SG BLOWDOWN ENTHALPY			
PRESSURE	=		

TABLE 12

SECONDARY SIDE POWER CALORIMETRIC MEASUREMENT UNCERTAINTY
(Using UFMs and UTMs, limited to 1780 MWt-NSSS Power)

Component	Instrument Uncertainty	Power Uncertainty (% Power)
		+a,c
FEEDWATER FLOW		
UFM (treated as system flow)		
FEEDWATER DENSITY		
TEMPERATURE		
PRESSURE		
FEEDWATER ENTHALPY		
TEMPERATURE		
PRESSURE		
STEAM ENTHALPY		
PRESSURE		
MOISTURE		
NET PUMP HEAT ADDITION		
STEAM GENERATOR LOOP BLOWDOWN FLOW		
DENSITY PRESSURE		
FLOW		
STEAM GENERATOR BLOWDOWN ENTHALPY		
PRESSURE		
BIAS VALUES		
POWER BIAS TOTAL VALUE		0.0
2 LOOP UNCERTAINTY	(RANDOM)	0.6
	(BIAS)	0.0

*, **,*** Indicates sets of dependent parameters

4.3 Calorimetric Power Measurement Uncertainty
(Using UFMs and RTDs, limited to 1777 MWt-NSSS Power)

A calorimetric power measurement can be performed on a daily basis as described in Section 4.1 by replacing the loop venturi feedwater flow measurements with the UFMs. If the UTMs identified in Section 4.2 are inoperable, the calorimetric power measurement can be performed with the feedwater temperature RTD measurements. This section summarizes the calorimetric power measurement uncertainty calculation using the UFMs and the RTDs. With the UFMs and RTDs operable, Kewaunee is limited to 1777 MWt-NSSS power.

The methodology described in Section 4.2 is applicable. The thermal output of the Steam Generator is determined by a secondary side calorimetric measurement that is defined by Equation 9 where:

where;

h_s	=	Steam enthalpy (BTU/lb)
h_f	=	Feedwater enthalpy (BTU/lb)
h_{sgbd}	=	Steam generator blowdown enthalpy (BTU/lb)
W_f	=	Feedwater flow (system flow based on a UFM in each loop)(lb/hr).
W_{sgbd}	=	Steam generator blowdown flow (lb/hr).

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

Steamline pressure (P_s)
Feedwater temperature (T_f - from RTDs)
Feedwater flow (from UFMs)
Steam generator loop blowdown flow (if not secured);

and on the following calculated values:

Feedwater enthalpy (h_f)
Steam enthalpy (h_s)
Steam generator blowdown enthalpy (h_{sgbd})
Moisture carryover (impacts h_s)
Primary system net heat losses (Q_L)
RCP heat addition (Q_p)

Using the power uncertainty values noted on Table 15, the 2-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, the uncertainty for the secondary side power calorimetric measurement using the UFMs and RTDs is:

# of loops	power uncertainty (% power)
2	±0.8% (random) 0.0% (bias)

TABLE 13

POWER CALORIMETRIC INSTRUMENTATION UNCERTAINTIES
(Using UFMs and RTDs, limited to 1777 MWt-NSSS Power)
(% Span)

		FW Temp	FW Pres.	FW Flow	Steam Pres.	SG Blowdown Flow
						+a,c
UFM	=					
SRA	=					
SCA	=					
SMTE	=					
SPE	=					
STE	=					
SD	=					
BIAS	=					
RCA	=					
RMTE	=					
RTE	=					
RD	=					
A/D	=					
A/D_MTE	=					
A/D_TE	=					
A/D_D	=					
RDOUT	=					
CSA	=					
# OF INSTRUMENTS USED		1/Loop	not measured	treated as 1/plant	2/Loop	1/Loop
		°F	psi	% flow	psi	% flow
INST SPAN	=	200(1)	(2)	(3)	1400(4)	1.0% rated feedwater flow(rfwf)(5)
						+a,c
INST UNC. (RANDOM)	=					
INST UNC. (BIAS)	=					
NOMINAL	=	437.1°F	909 psia	100 % flow	809 psia	

(1) Temperature (T-15043, -15044) is measured with an RTD on each loop, and the signals are sent to the plant computer.
(2) Feedwater pressure is not measured. It is inferred from steam pressure.
(3) Flow is measured with Crossflow UFMs on each loop, and the signals are sent to the plant computer. The uncertainty is the total feedwater flow system uncertainty.
(4) Pressure (P-21094, -21095, -21096, -21097, -21098, -21099) is measured with transmitters, the process instrumentation, and the plant computer.
(5) Steam generator loop blowdown flow (F-23070 and-23071) is measured with turbine flow meters (0-100 gpm/loop).

TABLE 14

POWER CALORIMETRIC SENSITIVITIES
(Using UFMs and RTDs, limited to 1777 MWt-NSSS Power)

FEEDWATER DENSITY		[ ]+a,c	
TEMPERATURE	=		
PRESSURE	=		
FEEDWATER ENTHALPY			
TEMPERATURE	=		
PRESSURE	=		
h_s	=	1198.8	BTU / lbm
h_f	=	416.1	BTU / lbm
Δh (SG)	=	782.7	BTU / lbm

STEAM ENTHALPY		[ ]+a,c	
PRESSURE	=		
MOISTURE	=		
SG BLOWDOWN FLOW			
DENSITY PRESSURE	=		
SG BLOWDOWN ENTHALPY			
PRESSURE	=		

TABLE 15

SECONDARY SIDE POWER CALORIMETRIC MEASUREMENT UNCERTAINTY
(Using UFMs and RTDs, limited to 1777 MWt-NSSS Power)

Component	Instrument Uncertainty	Power Uncertainty (% Power)
		+a,c
FEEDWATER FLOW		
UFM (treated as system flow)		
FEEDWATER DENSITY		
TEMPERATURE		
PRESSURE		
FEEDWATER ENTHALPY		
TEMPERATURE		
PRESSURE		
STEAM ENTHALPY		
PRESSURE		
MOISTURE		
NET PUMP HEAT ADDITION		
STEAM GENERATOR LOOP BLOWDOWN FLOW		
DENSITY PRESSURE		
FLOW		
STEAM GENERATOR BLOWDOWN ENTHALPY		
PRESSURE		
BIAS VALUES		
POWER BIAS TOTAL VALUE		0.0
2 LOOP UNCERTAINTY	(RANDOM)	0.8
	(BIAS)	0.0

*, **, *** Indicates sets of dependent parameters

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IV. RESULTS/CONCLUSIONS

The preceding sections provide the methodology to account for pressure, temperature, power and RCS flow uncertainties for the RTDP analysis. The uncertainty calculations have been performed for Kewaunee with the plant specific instrumentation and calibration procedures. The following table summarizes the results and the uncertainties that are used in the Kewaunee safety analysis.

Parameter	Calculated Uncertainty	Uncertainty Used in Safety Analysis
Pressurizer Pressure	+a,c	±50.0 psi (random) 15.0 psi (bias)
Tavg		±6.0°F (random) -1.1°F (bias)
Power (feedwater venturis)		±2.0% power (random) 0.4% power (bias) (at 1757 MWt-NSSS power)
Power (UFMs and UTMs)	±0.6% power (random)	±0.6% power (random) (at 1780 MWt-NSSS power)
Power (UFMs and RTDs)	±0.8% power (random)	±0.8% power (random) (at 1777 MWt-NSSS power)

Parameter	Calculated Uncertainty	Uncertainty Used in Safety Analysis
RCS Flow		
(calorimetric measurement based on venturi in feedwater bypass loop, limited to 1757 MWt-NSSS power)	[ ] +a,c	±4.3% flow (random) 0.1% flow (bias)
(calorimetric measurement based on UFMs and UTMs, limited to 1780 MWt-NSSS power)	[ ] +a,c	(at 1780 MWt-NSSS power)
(plant computer)	±2.9% flow (random) 0.1% flow (bias)	

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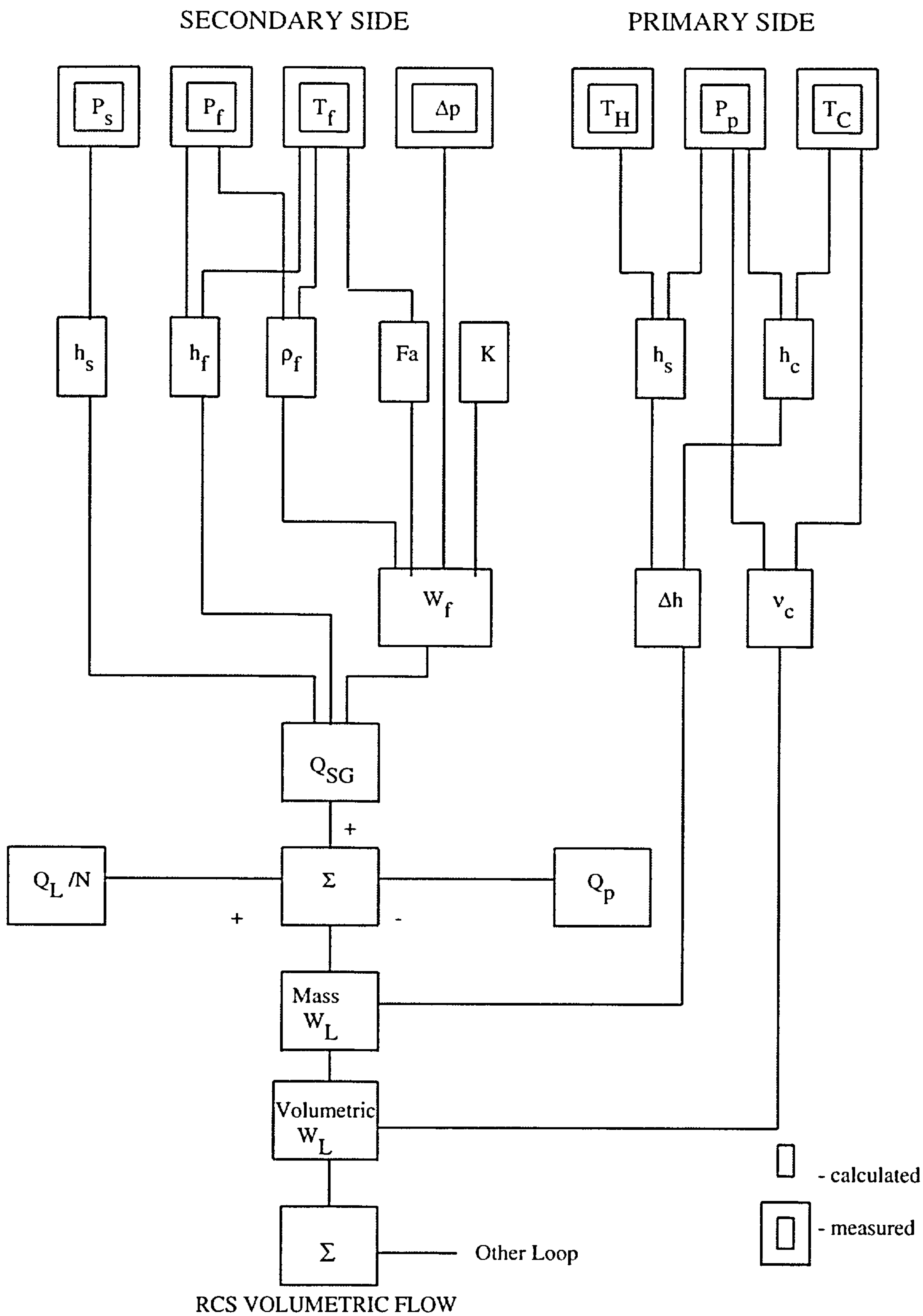

Figure 1
Calorimetric RCS Flow Measurement (Using Venturi on Feedwater Bypass Loop)

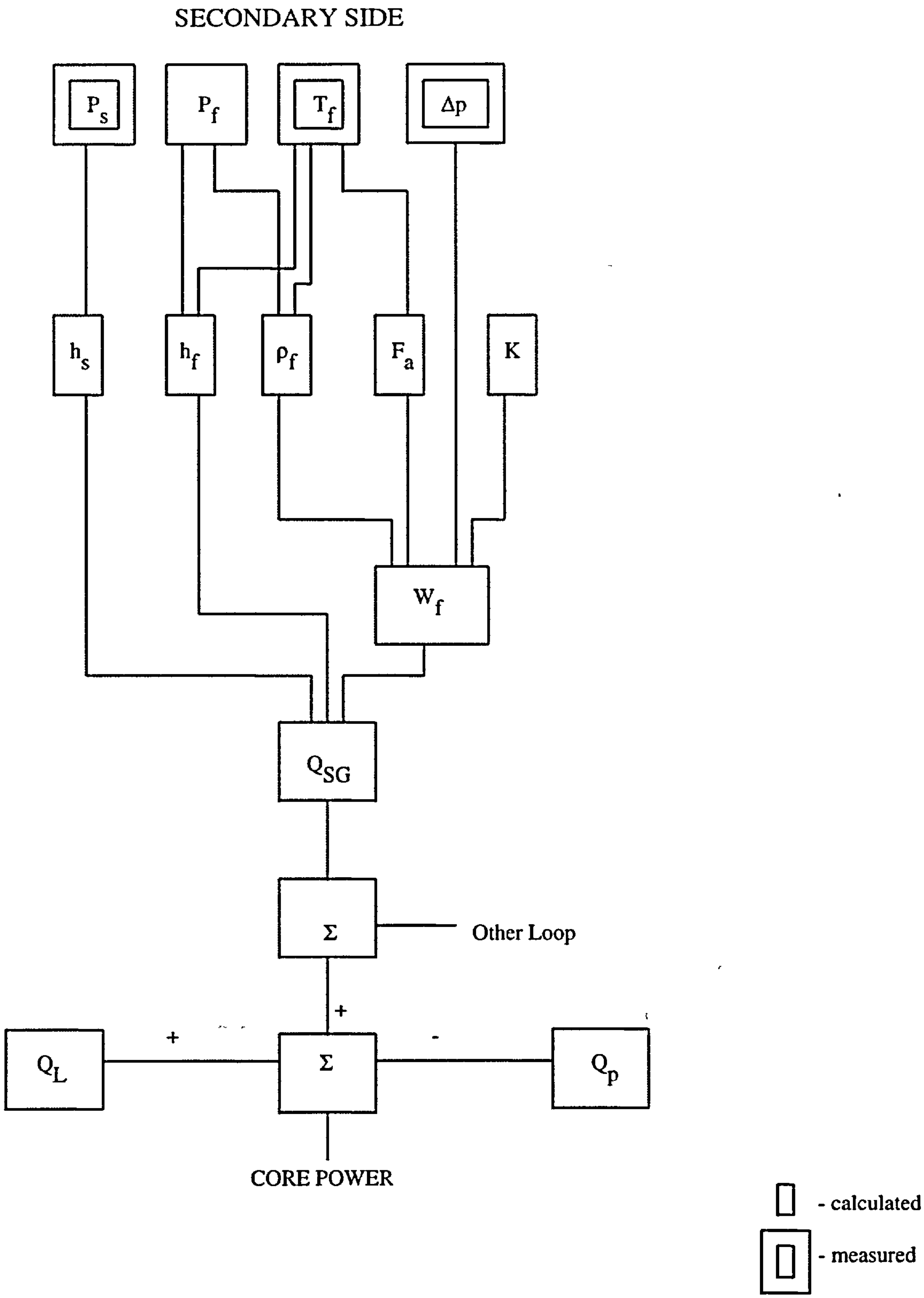

Figure 2
Calorimetric Power Measurement (Using Venturis)

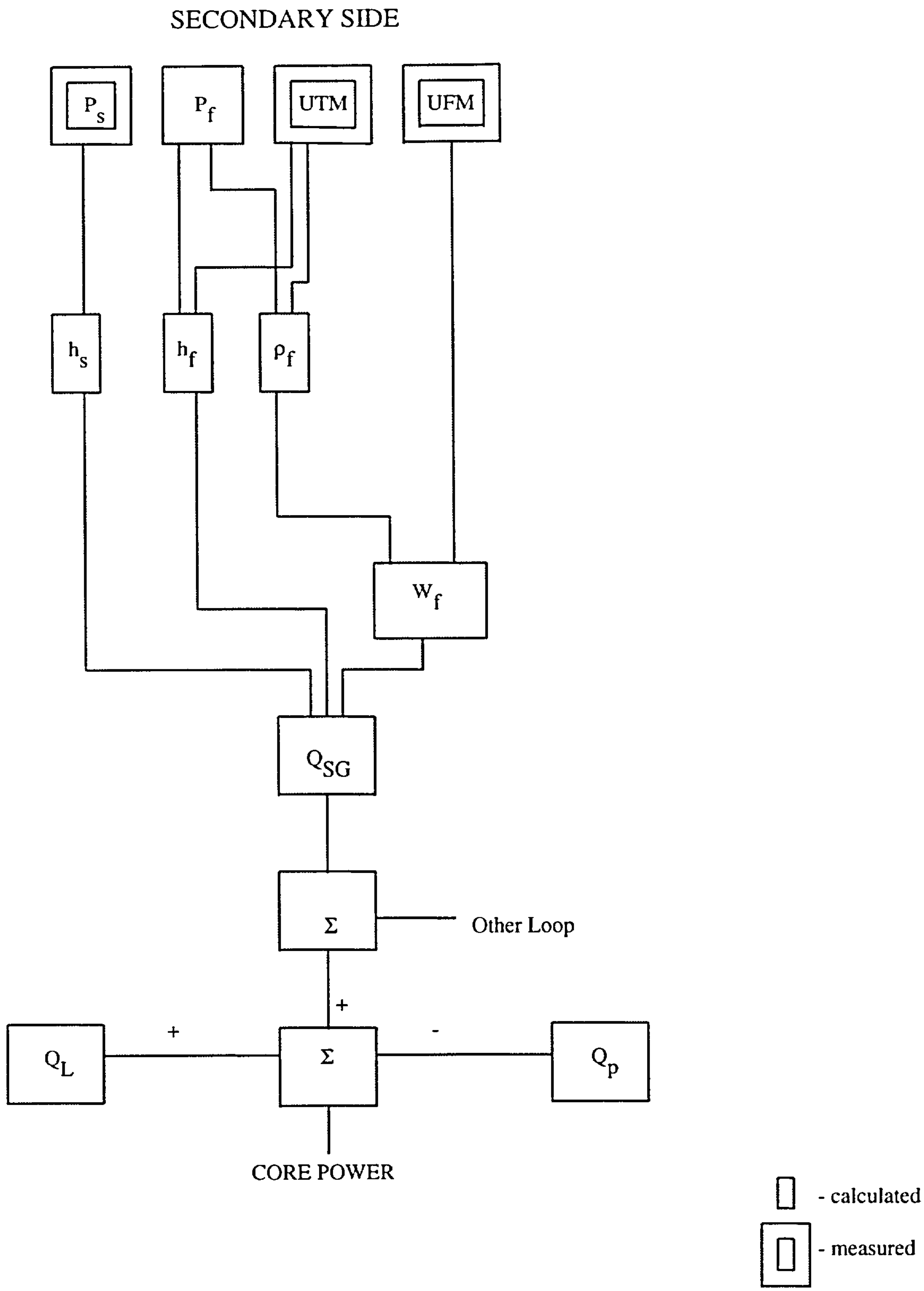

Figure 3
Calorimetric Power Measurement (Using UFMs and UTMs)