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WESTINGHOUSE NON-PROPRIETARY CLASS 3

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WESTINGHOUSE INSTRUMENT UNCERTAINTY METHODOLOGY FOR REACTOR COOLANT SYSTEM FLOW MEASUREMENT TENNESSEE VALLEY AUTHORITY WATTS BAR

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WESTINGHOUSE INSTRUMENT UNCERTAINTY METHODOLOGY FOR REACTOR COOLANT SYSTEM FLOW MEASUREMENT TVA - WATTS BAR

I. INTRODUCTION

Reactor Coolant System (RCS) Flow is monitored by the performance of a secondary side heat balance or calorimetric measurement after every refueling to comply with the Watts Bar Technical Specifications and for verification of the RCS flow assumption used in the Watts Bar safety analysis. The RCS calorimetric flow measurement is also used to normalize the installed loop RCS flow indicators after every refueling to provide a simple method for verifying RCS flow on a daily basis (with a small increase in uncertainty). The combined uncertainty of the calorimetric RCS Flow measurement and the installed loop RCS Flow indicators is used in the Watts Bar Technical Specifications to develop the minimum RCS Flow requirement. This report provides the basis for the RCS flow measurement uncertainty and is applicable for 18 month fuel cycles.

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 initial plant condition assumptions 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. The sum of both sides is equal to the range for that parameter, e.g., Rack Drift is typically [ ]$^{+a,c}$, the range for this parameter is [ ]$^{+a,c}$. This technique has been utilized before as noted above, and has been endorsed by the NRC staff[6,7,8,9] and various industry standards[10,11].

The relationships between the uncertainty components and the instrument channel uncertainty allowance are variations of the basic Westinghouse Setpoint Methodology[12] and are defined as follows:

1. For parameter indication utilizing Eagle-21 instrumentation and the plant process computer, with as-left/as-found recording for determination of transmitter and rack calibration and drift uncertainties, without 3-up/3-down transmitter calibrations, without trending of transmitter calibration and drift data, and with separate calibration of the EAI, ERI, EAO cards and A/D plant computer inputs;

[ ]$^{+a,c}$ Eq. 1

2. For precision parameter indication using Special Test Equipment or a DVM at the input to the racks, with as-left/as-found recording for determination of transmitter calibration and drift uncertainties, without 3-up/3-down transmitter calibrations, and without trending of transmitter calibration and drift data;

[ ]$^{+a,c}$ Eq. 2

3. For the loop RCS flow indicators utilizing Eagle-21 instrumentation and either the P2500 plant computer or control board indicators, with as-left/as-found recording for determination of transmitter and rack calibration and drift uncertainties, without 3-up/3-down transmitter calibrations, without trending of transmitter calibration and drift data, and with separate calibration of the EAI, ERI, EAO cards, A/D plant computer inputs, and control board indicators;

+a,c

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_x	=	Rack Calibration Accuracy of device X
$RMTE_x$	=	Rack Measurement and Test Equipment Accuracy of device X
RTE_x	=	Rack Temperature Effects of device X
RD_x	=	Rack Drift of device X
RDOUT	=	Readout Device Accuracy
BIAS	=	Uncertainties determined to have a preferential direction or sign, i.e., not random.

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

PMA - non-instrument related measurement uncertainties, e.g., temperature stratification of a fluid in a pipe,

PEA - uncertainties due to a metering device, e.g., elbow, venturi, orifice, SRA - reference (calibration) accuracy for a sensor/transmitter,

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

SMTE - sensor measurement and test equipment accuracy determined by the square root of the sum of the squares of the uncertainty (accuracy) of the input M&TE device and the output M&TE device, e.g., for a transmitter, this is the square root of the sum of the squares of the uncertainties for a pressure gauge on the input and a digital voltmeter on the output,

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

STE - change in input-output relationship due to a change in ambient temperature for a sensor/transmitter,

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

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

RMTE - rack measurement and test equipment accuracy determined by the square root of the sum of the squares of the uncertainty (accuracy) of the input M&TE device and the output M&TE device, e.g., for a rack module, this is the square root of the sum of the squares of the uncertainties for a digital voltmeter on the input and a digital voltmeter on the output,

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,

EAI - the uncertainty component is associated with an Eagle-21 input card,

EAO - the uncertainty component is associated with an Eagle-21 output card,

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. REACTOR COOLANT SYSTEM FLOW MEASUREMENT UNCERTAINTY

Calorimetric RCS Flow Measurement Uncertainty (Using Feedwater Venturis)

Watts Bar Technical Specifications require a calorimetric RCS flow measurement every 18 months above 90% of Rated Thermal Power. It is assumed for this uncertainty analysis that the RCS flow measurement is performed at 90% of Rated Thermal Power and within six (6) months of the hot leg and cold leg RTD cross-calibration procedure. It is assumed that the plant transmitters used in the RCS flow measurement are calibrated on the refueling frequency schedule, that the plant process instrumentation is calibrated and verified per the Watts Bar Technical Specification requirements, that the P2500 plant computer inputs are calibrated on the refueling frequency schedule, that the Eagle-21 Thot and Tcold temperature channels are calibrated within two (2) weeks of the RCS flow measurement, and that the special test equipment is calibrated within 30 days of the RCS flow measurement. It is also assumed that the RCS flow measurement is performed before feedwater venturi fouling is significant, i.e., no allowances have been made for feedwater venturi fouling.

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.,

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

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

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

where;

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

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

$$Q_{SG} = (h_s - h_f)W_f + (h_s - h_f)W_{tmp} + (h_{sgbd} - h_s)W_{sgbd} \qquad \text{Eq. 6}$$

where;

h_s	=	Steam enthalpy (Btu/lb)
h_f	=	Feedwater enthalpy (Btu/lb)
h_{sgbd}	=	Steam generator blowdown enthalpy (Btu/lb)
W_f	=	Main feedwater flow (lb/hr)
W_{tmp}	=	Main feedwater tempering flow (lb/hr)
W_{sgbd}	=	Steam generator blowdown flow (lb/hr).

The steam enthalpy is based on measurement of steam generator outlet steam pressure, assuming saturated conditions. The feedwater enthalpy is based on the measurement of feedwater temperature and feedwater pressure. The main feedwater flow is determined by measurements from main feedwater flow venturis and the following calculation:

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

where;

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

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

The main feedwater tempering flow is the feedwater flow through the upper steam generator inlet nozzle, and is determined by measurements from the main feedwater tempering flow orifices and the following calculation:

$$W_{tmp} = (K)(F_a)(a)\ \{(2)(g_c)(p_f)(d/p)\}^{1/2} \qquad \text{Eq. 8}$$

where; K = Main feedwater tempering flow orifice flow coefficient

F_a = Main feedwater tempering flow orifice correction for thermal expansion

a = Main feedwater tempering flow orifice area

g_c = gravitational constant (32.174 ft/sec^2)

p_f = Main feedwater tempering flow density (lb/ft^3)

d/p = Main feedwater tempering flow orifice pressure drop (inches H_2O).

The main feedwater tempering flow orifice flow coefficient (K) is the product of a number of constants including as-built dimensions of the orifice and pipe internal diameter. The thermal expansion correction is based on the coefficient of expansion of the orifice material and the difference between feedwater temperature and calibration temperature. Feedwater density is based on the measurement of feedwater temperature and feedwater pressure. The orifice pressure drop is obtained from the output of the differential pressure transmitter.

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

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

Steamline pressure (P_s)
Feedwater temperature (T_f)
Feedwater pressure (P_f)
Main feedwater flow venturi differential pressure (d/p)
Main feedwater tempering flow orifice differential pressure (d/p)
Steam generator blowdown flow orifice differential pressure (d/p)(if not secured)
Hot leg temperature (T_H)
Cold leg temperature (T_C)
Pressurizer pressure (P_p)
Charging flow
Letdown flow

and on the following calculated values:

Main feedwater flow venturi flow coefficients (K)
Main feedwater flow venturi thermal expansion correction (F_a)
Main feedwater tempering flow orifice flow coefficients (K)
Main feedwater tempering flow orifice thermal expansion correction (F_a)
Main feedwater tempering flow orifice area (a)
Feedwater density (ρ_f)
Feedwater enthalpy (h_f)
Steam enthalpy (h_s)
Steam generator blowdown enthalpy (h_{sgbd})
Steam generator blowdown density
Moisture carryover (impacts h_s)
Primary system net heat losses (Q_L)
Charging enthalpy
Letdown enthalpy
RCP heat addition (Q_p)
Hot leg enthalpy (h_H)
Cold leg enthalpy (h_C).

These measurements and calculations are presented schematically on Figure 1. The derivation of the measurement uncertainties and the calorimetric RCS flow measurement uncertainties on Table 3 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 four areas are specifically identified on Table 3.

For measurement of the main feedwater flow, each feedwater flow 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 a conservative overall flow coefficient (K) uncertainty of [ ]$^{+a,c}$. Since 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 venturi fouling. The effect of fouling is to result in an indicated flow higher than actual which is non-conservative for the safety analysis.

The uncertainty applied to the main feedwater flow 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 changes F_a by [ ]$^{+a,c}$ 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 the main 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 1 notes the instrument uncertainties for the hardware used to perform the measurements. Table 2 lists the various sensitivities which are specific to the operating conditions at 90% of Rated Thermal Power and are affected by the magnitudes of the instrument uncertainties noted in Table 1. As can be seen on Table 2, feedwater temperature uncertainties have an impact on venturi F_a, feedwater density and feedwater enthalpy. Feedwater pressure uncertainties impact feedwater density and feedwater enthalpy.

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

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

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

For measurement of the main feedwater tempering flow, each main feedwater tempering flow orifice is assigned an accuracy of [ ]$^{+a,c}$ based on "Flow Measurement Engineering Handbook", 2nd Edition, R.W. Miller. An additional uncertainty factor of [ ]$^{+a,c}$ is included for installation effects, and for the difference between the main feedwater tempering flow rate and the orifice design flow rate, resulting in an conservative overall flow coefficient (K) uncertainty of [ ]$^{+a,c}$. Since 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 orifice fouling. The effect of fouling is to result in an indicated flow higher than actual which is non-conservative for the safety analysis.

The uncertainty applied to the main feedwater tempering flow orifice thermal expansion correction (F_a) is based on the uncertainties of the measured feedwater temperature and the coefficient of thermal expansion for the 304 stainless steel orifice material. For this material, a change of ±1 °F in the nominal feedwater temperature changes F_a by [ ]$^{+a,c}$ and the steam generator thermal output by [ ]$^{+a,c}$.

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

The main feedwater tempering flow orifice d/p uncertainties are converted to % feedwater flow using a similar conversion factor as for main feedwater flow. 2.24 % of rated feedwater flow is the assumed maximum amount of main feedwater tempering flow. The uncertainty for the d/p measurement is [ ]$^{+a,c}$.

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

An additional [ ]$^{+a,c}$ uncertainty was included for the P2500 Computer Steam Table algorithm. The impact of this uncertainty is approximately [ ]$^{+a,c}$.

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

System heat losses	-2.0 MWt	
Component conduction and convection losses	-1.0	
Pump heat adder	+17.0	
Net Heat input to RCS	+14.0 MWt	(difference between rated reactor power and rated NSSS power)

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

<u>Primary Side</u>

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 3. 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 1 and the sensitivities are provided on Table 2. The hot leg streaming is split into random and systematic components. For Watts Bar with RTDs located in thermowells (bypass manifolds eliminated), the streaming uncertainty is, [ ]$^{+a,c}$ random and [ ]$^{+a,c}$ systematic.

The cold leg enthalpy and specific volume uncertainties are impacted by T_c and pressurizer pressure. Table 1 notes the T_c instrument uncertainty and Table 2 provides the sensitivities.

Noted on Table 3 is the plant specific RTD cross-calibration systematic allowance. When necessary, an allowance is made for a systematic temperature uncertainty due to the RTD cross-calibration procedure. No allowance was necessary for Watts Bar.

As noted on Table 3, 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). 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 RCS flow higher than actual, which is non-conservative for the safety analysis.

Using the RCS flow uncertainty values noted on Table 3, the 4 loop uncertainty (with bias values) equation is as follows:

[ ]$^{+a,c}$

Based on four (4) loops, and the instrument uncertainties for the measured parameters, the uncertainty for the calorimetric RCS flow measurement is:

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

TABLE 1 - CALORIMETRIC RCS FLOW MEASUREMENT INSTRUMENTATION UNCERTAINTIES (USING FEEDWATER VENTURIS)

FOUR LOOP OPERATION

(% SPAN)	FW TEMP	FW PRES	FW d/p (main)	FW d/p (tempering)	STM PRESS	SG BLOWDOWN FLOW	T_H	T_C	PRZ PRESS
SRA =									
SCA =									
SMTE =									
SPE =									
STE =									
SD =									
BIAS =									
RCA_{EAI} =									
$RMTE_{EAI}$ =									
RTE_{EAI} =									
RD_{EAI} =									
RCA_{EAO} =									
$RMTE_{EAO}$ =									
RTE_{EAO} =									
RD_{EAO} =									
$RCA_{A/D}$ =									
$RMTE_{A/D}$ =									
$RTE_{A/D}$ =									
$RD_{A/D}$ =									
RDOUT =									
CSA =									
	2/HEADER	1/LOOP	2/LOOP	1/LOOP	1/LOOP	1/LOOP	3/LOOP	2/LOOP	4
	°F	psi	% d/p	%FLOW	psi	%FLOW	°F	°F	psi
INST SPAN =		1300.	103%FLOW	2% FLOW	1300.	1%FLOW	150.0	150.0	800
INST UNC (RANDOM) =									
INST UNC (BIAS) =									
NOMINAL =	440.0	1055PSIA	88%FLOW	2%FLOW	955PSIA	1%FLOW	618.1	558.4	2250 PSIA

+a,c

+a,c

+a,c

TABLE 2
CALORIMETRIC RCS FLOW MEASUREMENT SENSITIVITIES
(USING FEEDWATER VENTURIS)
FOUR LOOP OPERATION

FEEDWATER FLOW
F_a(MAIN)
TEMPERATURE =
MATERIAL =
DENSITY
TEMPERATURE =
PRESSURE =
DELTA P =
F_a(TEMPERING)
TEMPERATURE =
MATERIAL
DENSITY
TEMPERATURE =
PRESSURE =
DELTA P =
FEEDWATER ENTHALPY
TEMPERATURE =
PRESSURE =

[ ] +a,c

h_s = 1193.9 BTU/LBM
h_f = 419.4 BTU/LBM
Dh(SG) = 774.5 BTU/LBM

STEAM ENTHALPY

PRESSURE =
MOISTURE =

[ ] +a,c

BLOWDOWN ENTHALPY

PRESSURE = [ ] +a,c

TABLE 2 (continued)
CALORIMETRIC RCS FLOW MEASUREMENT SENSITIVITIES
(USING FEEDWATER VENTURIS)
FOUR LOOP OPERATION

HOT LEG ENTHALPY

TEMPERATURE =
PRESSURE =

[ ] +a,c

h_H = 639.4 BTU/LBM
h_C = 557.3 BTU/LBM
Dh(VESS) = 82.1 BTU/LBM
$Cp(T_H)$ = 1.541 BTU/LBM-°F

COLD LEG ENTHALPY

TEMPERATURE =
PRESSURE =

[ ] +a,c

$Cp(T_C)$ = 1.262 BTU/LBM-°F

COLD LEG SPECIFIC VOLUME

TEMPERATURE =
PRESSURE =

[ ] +a,c

TABLE 3
CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTY
(USING FEEDWATER VENTURIS)
FOUR LOOP OPERATION

COMPONENT	INSTRUMENT UNCERTAINTY	FLOW UNCERTAINTY +a,c
FEEDWATER FLOW (MAIN)		
VENTURI (FLOW COEFFICIENT)		
THERMAL EXPANSION COEFFICIENT		
TEMPERATURE		
MATERIAL		
DENSITY		
TEMPERATURE		
PRESSURE		
DELTA P		
FEEDWATER FLOW (TEMPERING)		
ORIFICE (FLOW COEFFICIENT)		
THERMAL EXPANSION COEFFICIENT		
TEMPERATURE		
MATERIAL		
DENSITY		
TEMPERATURE		
PRESSURE		
DELTA P		
FEEDWATER ENTHALPY		
TEMPERATURE (main)		
TEMPERATURE (tempering flow)		
PRESSURE (main)		
PRESSURE (tempering flow)		
STEAM ENTHALPY		
PRESSURE		
MOISTURE		
NET PUMP HEAT ADDITION		
STEAM GENERATOR BLOWDOWN FLOW		
DELTA P		
STEAM GENERATOR BLOWDOWN ENTHALPY		
PRESSURE		
HOT LEG ENTHALPY		
TEMPERATURE		
STREAMING, RANDOM		
STREAMING, SYSTEMATIC		
PRESSURE		
COLD LEG ENTHALPY		
TEMPERATURE		
PRESSURE		
COLD LEG SPECIFIC VOLUME		
TEMPERATURE		
PRESSURE		
RTD CROSS-CAL SYSTEMATIC ALLOWANCE		

TABLE 3 (continued)

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTY

(USING FEEDWATER VENTURIS)

FOUR LOOP OPERATION

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

COMPONENT		FLOW UNCERTAINTY
BIAS VALUES		+a,c
FEEDWATER PRESSURE	DENSITY	
	ENTHALPY	
STEAM PRESSURE	ENTHALPY	
PRESSURIZER PRESSURE	ENTHALPY - HOT LEG	
	ENTHALPY - COLD LEG	
	SPECIFIC VOLUME - COLD LEG	
RCS FLOW BIAS - TOTAL VALUE		
SINGLE LOOP UNCERTAINTY	(WITHOUT BIAS VALUES)	
4 LOOP UNCERTAINTY	(WITHOUT BIAS VALUES)	
4 LOOP UNCERTAINTY	(WITH BIAS VALUES)	

TABLE 4
WATTS BAR INSTRUMENTATION
FOR CALORIMETRIC RCS FLOW MEASUREMENT

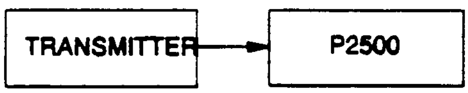
Main Feedwater Flow Transmitters (total of 8) (Rosemount model 3051C DP transmitter)(SPECIAL TEST EQUIPMENT):

0 - 3.9 x 10^6 lb/hr (0 - 500" H_2O)

serial number	tap set number	flow element number	transmitter
37738-1	1	1-FE-003-0035	special test transmitter
37738-1	2	1-FE-003-0035	special test transmitter
37738-2	1	1-FE-003-0048	special test transmitter
37738-2	2	1-FE-003-0048	special test transmitter
37738-3	1	1-FE-003-0090	special test transmitter
37738-3	2	1-FE-003-0090	special test transmitter
37738-4	1	1-FE-003-0103	special test transmitter
37738-4	2	1-FE-003-0103	special test transmitter

Feedwater Pressure Transmitter (total of 4) (Foxboro E11GM transmitter):

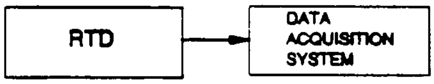
0 - 1300 psig



1-PT-3-37
1-PT-3-50
1-PT-3-92
1-PT-3-105

TABLE 4 (continued)
WATTS BAR INSTRUMENTATION
FOR CALORIMETRIC RCS FLOW MEASUREMENT

Feedwater Temperature RTDs (total of 2)(DIN 385)(SPECIAL TEST EQUIPMENT):



Steam Pressure Transmitter (total of 12) (Foxboro N-E11GM transmitters, Foxboro E11GM transmitters, Barton 763 Lot 7 transmitters):

0 - 1300 psig

1-PT-1-2A	(Loop 1)	(Foxboro N-E11GM)
1-PT-1-2B	(Loop 1)	(Foxboro N-E11GM)
1-PT-1-5	(Loop 1)	(Foxboro E11GM)
1-PT-1-9A	(Loop 2)	(Barton 763 Lot 7)
1-PT-1-9B	(Loop 2)	(Barton 763 Lot 7)
1-PT-1-12	(Loop 2)	(Barton 763 Lot 7)
1-PT-1-20A	(Loop 3)	(Barton 763 Lot 7)
1-PT-1-20B	(Loop 3)	(Barton 763 Lot 7)
1-PT-1-23	(Loop 3)	(Barton 763 Lot 7)
1-PT-1-27A	(Loop 4)	(Foxboro N-E11GM)
1-PT-1-27B	(Loop 4)	(Foxboro N-E11GM)
1-PT-1-30	(Loop 4)	(Foxboro E11GM)

TABLE 4 (continued)
WATTS BAR INSTRUMENTATION
FOR CALORIMETRIC RCS FLOW MEASUREMENT

Main Feedwater Tempering Flow Transmitter (total of 4) (Rosemount 1151DP3 transmitter):

0 - 5" WC => 0 - 84.51 x 10^3 lb/hr

flow element number	transmitter number
1-FE-3-235	1-FT-3-235A
1-FE-3-238	1-FT-3-238A
1-FE-3-241	1-FT-3-241A
1-FE-3-244	1-FT-3-244A

Steam Generator Blowdown Flow Transmitter (total of 4) (Rosemount 1153DB3RB transmitter):

0 - 15" WC => 0 - 90 gpm

flow element number	transmitter number
1-FE-1-152	1-FT-1-152
1-FE-1-156	1-FT-1-156
1-FE-1-160	1-FT-1-160
1-FE-1-164	1-FT-1-164

TABLE 4 (continued)
WATTS BAR INSTRUMENTATION
FOR CALORIMETRIC RCS FLOW MEASUREMENT

Narrow range Thot RTD (total of 12)(RdF RTD)(SPECIAL TEST EQUIPMENT):

530-650°F

Narrow range Tcold RTD (total of 8)(RdF RTD)(SPECIAL TEST EQUIPMENT):

510-630°F

Pressurizer Pressure Transmitter (total of 4)(Barton 763)(SPECIAL TEST EQUIPMENT):

1700-2500 psig

Loop RCS Flow Indicator Uncertainty

As noted earlier, the calorimetric RCS flow measurement is used as the reference for the normalization of the loop RCS flow indicators (cold leg elbow taps) at the start of each fuel cycle. With the loop RCS flow d/p transmitters feeding the plant computer or control board indicators, it is a simple matter to perform the Technical Specification surveillance requirement. Table 5a notes the instrument uncertainties for normalization of the loop RCS flow indicators using a P2500 plant computer readout, assuming two loop RCS flow indicators per reactor coolant loop. Table 5b notes the instrument uncertainties for normalization of the loop RCS flow indicators using Control Board readouts, assuming two loop RCS flow indicators per reactor coolant loop. The d/p transmitter uncertainties are converted to % flow on the same basis as the feedwater venturi d/p uncertainties. The uncertainties for the loop RCS flow indicators are combined with the calorimetric RCS flow measurement uncertainty for the determination of the total loop RCS flow indicator uncertainty.

The total loop RCS flow indicator uncertainty for four loop operation and the P2500 Plant Computer readout is:

# of loops	loop RCS flow indicator uncertainty (% flow)
4	$\pm$ 1.6

The total loop RCS flow indicator uncertainty for four loop operation and the Control Board readout is:

# of loops	loop RCS flow indicator uncertainty (% flow)
4	$\pm$ 1.9

TABLE 5a
LOOP RCS FLOW INDICATOR UNCERTAINTY
PLANT COMPUTER READOUT
FOUR LOOP OPERATION

INSTRUMENT UNCERTAINTIES

Plant Computer Readout - 2 RCS flow channels per Reactor Coolant Loop

		% d/p SPAN	% FLOW
			+a,c
PMA	=		
PEA	=		
SRA	=		
SCA	=		
SMTE	=		
SPE	=		
STE	=		
SD	=		
BIAS	=		
RCA_{EAI}	=		
$RMTE_{EAI}$	=		
RTE_{EAI}	=		
RD_{EAI}	=		
RCA_{EAO}	=		
$RMTE_{EAO}$	=		
RTE_{EAO}	=		
RD_{EAO}	=		
$RCA_{A/D}$	=		
$RMTE_{A/D}$	=		
$RTE_{A/D}$	=		
$RD_{A/D}$	=		
FLOW CALORIM. BIAS	=		
FLOW CALORIMETRIC	=		
INSTRUMENT SPAN	=		

+a,c

SINGLE LOOP RCS FLOW INDICATOR UNC =
(1 RCS FLOW CHANNEL)

SINGLE LOOP RCS FLOW INDICATOR UNC =
(2 RCS FLOW CHANNELS)

4 LOOP RCS FLOW UNCERTAINTY
(WITHOUT BIAS VALUES) =

4 LOOP RCS FLOW UNCERTAINTY
(WITH BIAS VALUES) = 1.6

TABLE 5b
LOOP RCS FLOW INDICATOR UNCERTAINTY
CONTROL BOARD READOUT
FOUR LOOP OPERATION

INSTRUMENT UNCERTAINTIES

Control Board Readout - 2 RCS flow channels per Reactor Coolant Loop

		% d/p SPAN	% FLOW	
				+a,c
PMA	=			
PEA	=			
SRA	=			
SCA	=			
SMTE	=			
SPE	=			
STE	=			
SD	=			
BIAS	=			
RCA_{EAI}	=			
$RMTE_{EAI}$	=			
RTE_{EAI}	=			
RD_{EAI}	=			
RCA_{EAO}	=			
$RMTE_{EAO}$	=			
RTE_{EAO}	=			
RD_{EAO}	=			
RCA_{IND}	=			
$RMTE_{IND}$	=			
RTE_{IND}	=			
RD_{IND}	=			
RDOUT	=			
FLOW CALORIM. BIAS	=			
FLOW CALORIMETRIC	=			
INSTRUMENT SPAN	=			

			+a,c
SINGLE LOOP RCS FLOW INDICATOR UNC (1 RCS FLOW CHANNEL)	=		
SINGLE LOOP RCS FLOW INDICATOR UNC (2 RCS FLOW CHANNELS)	=		
4 LOOP RCS FLOW UNCERTAINTY (WITHOUT BIAS VALUES)	=		
4 LOOP RCS FLOW UNCERTAINTY (WITH BIAS VALUES)	=	1.9	

TABLE 6
WATTS BAR INSTRUMENTATION
FOR LOOP RCS FLOW INDICATORS

Loop RCS Flow Transmitter (total of 12)

0-110% of Indicated Flow

OR

IV. CONCLUSIONS

The preceding section provides the methodology to account for the RCS flow measurement uncertainty for the Watts Bar Technical Specifications. The Watts Bar-specific instrumentation and procedures have been reviewed and the uncertainty calculations are completed for 18 month fuel cycles. The following or more conservative values are used in the Watts Bar Technical Specifications.

RCS flow measurement uncertainty (loop RCS flow indicators), i.e., plant computer readout normalized to calorimetric RCS flow measurement	± 1.6% flow	4 loop operation
RCS flow measurement uncertainty (loop RCS flow indicators), i.e., control board indicators normalized to calorimetric RCS flow measurement	± 1.9% flow	4 loop operation

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

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

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

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

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

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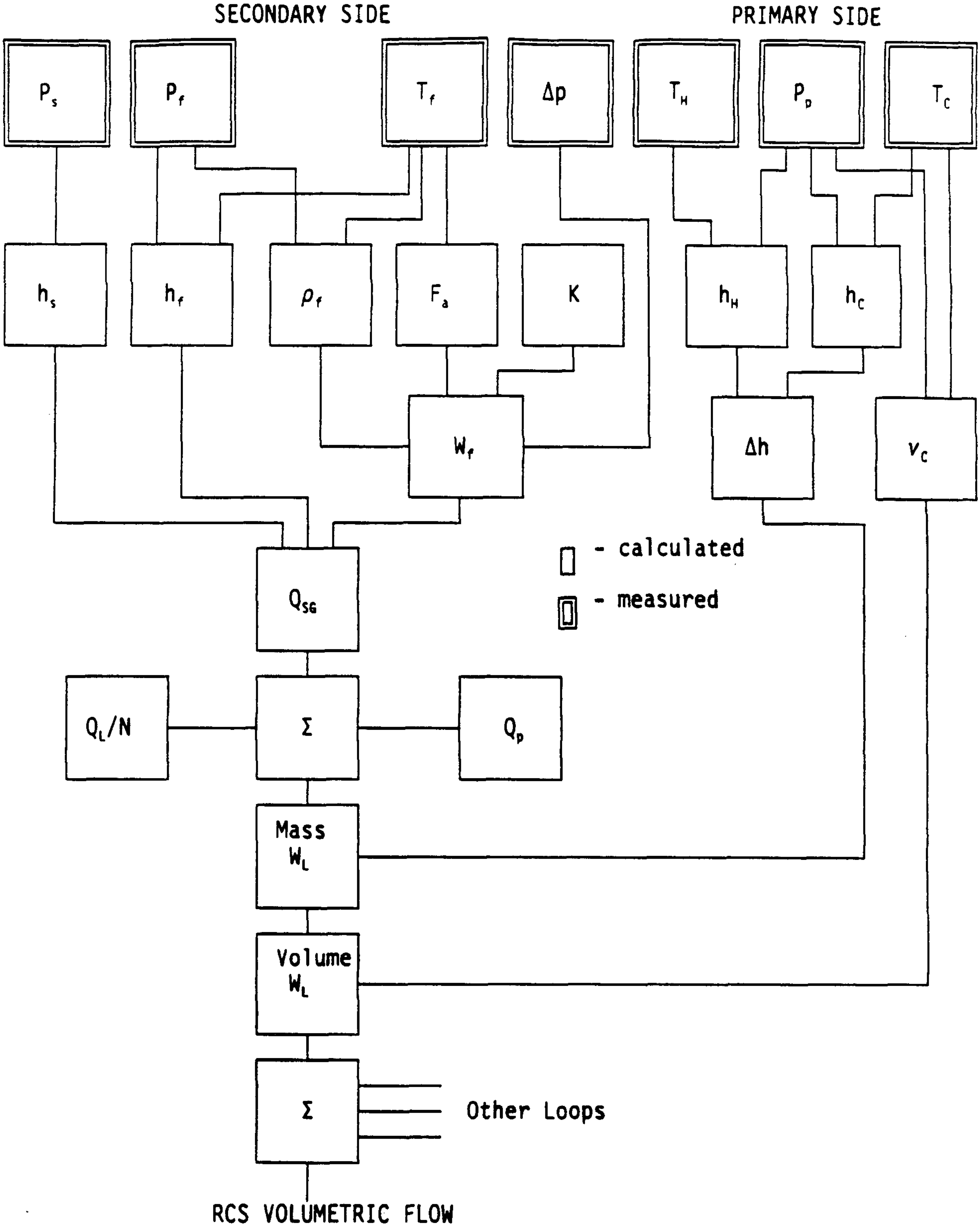

Figure 1
CALORIMETRIC RCS FLOW MEASUREMENT
(USING FEEDWATER VENTURIS)