PSNH
Public Service of New Hampshire

SEABROOK STATION
Engineering Office:
1671 Worcester Road
Framingham, Massachusetts 01701
(617) - 872 - 8100

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SBN-502
T. F. B7.1.2

United States Nuclear Regulatory Commission
Washington, D. C. 20555

Attention: Mr. George W. Knighton, Chief
Licensing Branch No. 3
Division of Licensing

References: (a) Construction Permits CPPR-135 and CPPR-136, Docket Nos. 50-443 and 50-444

Subject: Response to SER Outstanding Issue #7 (SER Section 4.4.5.2, Core Performance Branch)

Dear Sir:

Enclosed are:

1. Two (2) copies of PSNH response to NRC questions on Flow Measurement Uncertainty (Westinghouse Proprietary Class 2).

2. Two (2) copies of PSNH response to NRC questions on Flow Measurement Uncertainty (Westinghouse Non-Proprietary Class 3).

PBO1

Also enclosed are:

1. One (1) copy of Application for Withholding, CAW-83-14 (Non-Proprietary)

2. One (1) copy of Affidavit (Non-Proprietary).

The enclosed report provides a discussion of the measurement uncertainties associated with the measurement of Reactor Coolant System total flow rate for Westinghouse four loop plants (Technical Specification 3/4.2.3). The statistical error combination technique that will be used on Seabrook is the same as that used by Westinghouse on Byron/Braidwood and McGuire. For the combination of instrumentation uncertainties, the technique used is identical to that approved on V. C. Summer (Safety Evaluation Report, NUREG-0717, Supplement No. 4, August 1982). Included is the methodology and assumptions used to perform the calorimetric calibration of the flow measuring elbow taps. This submittal supersedes our response to RAI 492.2 (Amendment 45, June 1982).

The total flow measurement uncertainties for four loop operation is:

± 1.9% using three elbow taps per loop with digital volt meter readout

or

± 2.0% using one elbow tap per loop with computer readout

The increase in total uncertainty from the ± 1.5% indicated in the response to RAI 492.2 is due to the use of different RTDs for measurement of reactor coolant temperature in Seabrook Station than those assumed in the previous RAI response.

A bias due to feedwater flow venturi fouling is not included as we will confirm that fouling does not exist by one of the following methods:

a. Visual inspection for discoloration or presence of deposits on the stainless steel throat as part of the refueling activities immediately preceding the calorimetric flow calibration.

b. Trending plant perfomance.

Data that would be trended includes:

- Venturi flow measurements vs. flow measured by the sonic flow meter in series with each venturi
- Feed flow vs. steam flow
- Reactor power vs. core differential temperature
- Reactor power vs. generator output with consideration for secondary cycle efficiency
- Excore vs. incore power indication

In response to concerns raised about measurement errors due to crud buildup in the pressure taps on the venturi and flow elbow, we have determined that this is not expected and has not been detected at any Westinghouse reactor.

The venturi taps penetrate the side of the pipe to avoid crud that would tend to collect on the bottom of the pipe. Westinghouse has determined that crud buildup has been restricted to the venturi throat.

Crud buildup in the elbow taps is not expected due to the tight primary chemistry control and use of corrosion resistant material that minimize the formation of corrosion products and by the presence of highly turbulent flow (loop velocities are approximately 40 fps) that would tend to sweep any crud out of the taps. Westinghouse has not experienced any significant crud deposition in any portion of the primary loop and has not detected any change in the correlation between loop flows determined by the calorimetric flow calibration and observed differential pressures.

This submittal contains proprietary information of Westinghouse Electric Corporation. In conformance with the requirements of 10CFR Section 2.790, as amended, of the Commission's regulations, we are enclosing with this submittal an application for withholding from public disclosure by the Commission.

Correspondence with respect to the affidavit or application for withholding should reference CAW-83-14 and should be addressed to R. A. Wiesemann, Manager, Regulatory and Legislative Affairs, Westinghouse Electric Corporation, P.O. Box 355, Pittsburgh, Pennsylvania 15230.

Very truly yours,

YANKEE ATOMIC ELECTRIC COMPANY

J. DeVincentis
Project Manager

ALL/pf

Enclosure

cc: Atomic Safety and Licensing Board Service List - Non-Proprietary Information Only

ASLB SERVICE LIST

Rep. Beverly Hollingworth
Coastal Chamber of Commerce
209 Winnacunnet Road
Hampton, NH 03842

William S. Jordan, III, Esquire
Harmon & Weiss
1725 I Street, N.W.
Suite 506
Washington, DC 20006

E. Tupper Kinder, Esquire
Assistant Attorney General
Office of the Attorney General
208 State House Annex
Concord, NH 03301

Roy P. Lessy, Jr., Esquire
Office of the Executive Legal Director
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Robert A. Backus, Esquire
116 Lowell Street
P.O. Box 516
Manchester, NH 03105

Philip Ahrens, Esquire
Assistant Attorney General
Department of the Attorney General
Augusta, ME 04333

David L. Lewis
Atomic Safety and Licensing
Board Panel
U.S. Nuclear Regulatory Commission
Rm. E/W-439
Washington, DC 20555

Mr. John B. Tanzer
Designated Representative of
the Town of Hampton
5 Morningside Drive
Hampton, NH 03842

Roberta C. Pevear
Designated Representative of
the Town of Hampton Falls
Drinkwater Road
Hampton Falls, NH 03844

Mrs. Sandra Gavutis
Designated Representative of
the Town of Kensington
RFD 1
East Kingston, NH 03827

Edward J. McDermott, Esquire
Sanders and McDermott
Professional Association
408 Lafayette Road
Hampton, NH 03842

Jo Ann Shotwell, Esquire
Assistant Attorney General
Environmental Protection Bureau
Department of the Attorney General
One Ashburton Place, 19th Floor
Boston, MA 02108

Ms. Olive L. Tash
Designated Representative of
the Town of Brentwood
R.F.D. 1, Dalton Road
Brentwood, NH 03833

Edward F. Meany
Designated Representative of
the Town of Rye
155 Washington Road
Rye, NH 03870

Calvin A. Canney
City Manager
City Hall
126 Daniel Street
Portsmouth, NH 03801

Response

I. INTRODUCTION

RCS flow is monitored by the performance of a precision flow calorimetric measurement at the beginning of each cycle. The RCS loop elbow taps can then be normalized against the precision calorimetric and used for monthly surveillance (with a small increase in total uncertainty) or a precision flow calorimetric can be performed on the small surveillance schedule. The analysis presented in this report documents both measurements, i.e., the calorimetric and the elbow tap normalization uncertainties.

Since 1978 Westinghouse has been deeply involved with the development of several techniques to treat instrumentation uncertainties, errors, and allowances. The earlier versions of these techniques have been documented for several plants; one approach uses 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. The other approach is based on the more realistic assumption that the uncertainties can be described with normal probability distributions. This assumption is also conservative in that the "tails" of the normal distribution are in reality "chopped" at the extremes of the range, i.e., the ranges for uncertainties are finite and thus, allowing for some probability in excess of the range limits is a conservative assumption. This approach has been used to substantiate the acceptability of the protection system setpoints for several plants with a Westinghouse NSSS, e.g., D. C. Cook II[4], North Anna Unit 1, Salem Unit 2, Sequoyah Unit 1, V. C. Summer, and McGuire Unit 1. Westinghouse now believes that the latter approach can be used for the determination of the instrumentation errors and allowances for all the parameters. The total instrumentation errors presented in this response are based on this approach.

II. METHODOLOGY

The methodology used to combine the error components for a channel is basically the appropriate statistical combination of those groups of components which are statistically independent, i.e., not interactive. Those errors which are not independent are combined arithmetically to form independent groups, which can then be systematically combined. The statistical combination technique used by Westinghouse is the [ ] +a,c,e

[ ]+a,c,e of the instrumentation uncertainties. The instrumentation uncertainties are 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 staff[5,6,7] and various industry standards[8,9].

The relationship between the error components and the statistical instrumentation error allowance for a channel is defined as follows:

1. For parameter indication in the racks using a DVM;

[ ]+a,c

Eq. 1

2. For parameter indication utilizing the plant process computer;

[ ]+a,c

Eq. 2

where:

CSA = Channel Statistical Allowance
PMA = Process Measurement Accuracy
PEA = Primary Element Accuracy
SCA = Sensor Calibration Accuracy
STE = Sensor Temperature Effects
SPE = Sensor Pressure Effects
RCA = Rack Calibration Accuracy
RD = Rack Drift
RTE = Rack Temperature Effects
DVM = Digital Voltmeter Accuracy
ID = Computer Isolator Drift
A/D = Analog to Digital Conversion Accuracy

The parameters above are as defined in reference 4 and are based on SAMA standard PMC-20-1973[10]. However, for ease in understanding they are paraphrased below:

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

PEA - errors due to metering devices, e.g., elbows, venturis, orifices,

SCA - reference (calibration) accuracy for a sensor/transmitter,

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

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

SPE - change in input-output relationship due to a change in static pressure for a Δp cell,

RCA - reference (calibration) accuracy for all rack modules in loop or channel assuming the loop or channel is tuned to this accuracy. This assumption eliminates any bias that could be set up through calibration of individual modules in the loop or channel.

RD - change in input-output relationship over a period of time at reference conditions for the rack modules,

RTE - change in input-output relationship due to a change in ambient temperature for the rack modules,

DVM - the measurement accuracy of a digital voltmeter or multimeter on it's most accurate applicable range for the parameter measured,

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

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

A more detailed explanation of the Westinghouse methodology noting the interaction of several parameters is provided in reference 4.

III. Instrumentation Uncertainties

The Seabrook plant Technical Specifications require an RCS flow measurement with a high degree of accuracy. It is assumed for this error analysis, that this flow measurement is performed within seven days of calibrating the measurement instrumentation therefore, drift effects are not included (except where necessary due to sensor location). It is also assumed that the calorimetric flow measurement is performed at the beginning of a cycle, so no allowances have been made for feedwater venturi crud buildup.

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 (Δh) 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.,

$$W_{RCS} = \sum W_L \qquad \text{(Eq. 3)}$$

The individual primary loop 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 specific volume of the RCS cold leg. The equation for this calculation is:

$$W_L = \frac{(\gamma)\left\{Q_{SG} - Q_P + \left(\frac{Q_L}{N}\right)\right\}(V_C)}{[h_H - h_C]} \qquad \text{(Eq. 4)}$$

where; W_L = Loop flow (gpm)

γ = 0.1247 gpm/(ft^3/hr)

Q_{SG} = Steam Generator thermal output (Btu/hr)

Q_P = RCP heat adder (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 the same calorimetric measurement as for reactor power, which is defined as:

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

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

The steam enthalpy is based on measurement of steam generator outlet steam pressure, assuming saturated conditions. The feedwater enthalpy is based on the measurement of feedwater temperature and an assumed feedwater pressure based on steamline pressure plus 100 psi. The feedwater flow is determined by multiple measurements and the same calculation as used for reactor power measurements, which is based on the following:

$$W_f = (K)\ (F_a)\{\sqrt{\rho_f \Delta p}\} \qquad \text{(Eq. 6)}$$

where; K = Feedwater venturi flow factor
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 feedwater pressure. The venturi pressure drop is obtained from the output of the differential pressure cell connected to the venturi.

The RCP heat adder is determined by calculation, based on the best estimates 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 full power operation is used for these losses/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)
Feedwater venturi differential pressure (Δp)
Hot leg temperature (T_H)
Cold leg temperature (T_C)
Pressurizer pressure (P_p)
Steam generator blowdown (if not secured)

and on the following calculated values:

Feedwater venturi flow coefficients (K)
Feedwater venturi thermal expansion correction (F_a)
Feedwater density (ρ_f)
Feedwater enthalpy (h_f)
Steam enthalpy (h_s)
Moisture carryover (impacts h_s)
Primary system net heat losses (Q_L)

RCP heat adder (Q_p)
Hot leg enthalpy (h_H)
Cold leg enthalpy (h_C).

These measurements and calculations are presented schematically on Figure 1.

Starting off with the Equation 6 parameters, the detailed derivation of the measurement errors is noted below.

Feedwater Flow

Each of the feedwater venturis is calibrated by the vendor in a hydraulics laboratory under controlled conditions to an accuracy of [$]^{+a,b,c}$ % of span. The calibration data which substantiates this accuracy is provided for all of the plant venturis by the respective vendors. An additional uncertainty factor of [$]^{+a,c}$ % is included for installation effects, resulting in an overall flow coefficient (K) uncertainty of [$]^{+a,c}$ %. Since RCS loop flow is proportional to steam generator thermal output which is proportional to feedwater flow, the flow coefficient uncertainty is expressed as [$]^{+a,c}$ % flow.

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 ± 2°F in the feedwater temperature range changes F_a by [$]^{+a,b,c}$ % and the steam generator thermal output by the same amount. For this derivation, an uncertainty of [$]^{+a,c}$ in feedwater temperature was assumed (detailed breakdown for this assumption is provided in the feedwater enthalpy section). This results in a negligible impact in F_a and steam generator output.

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. A conservative value of [$]^{+a,c}$ % is used in this analysis.

Using the ASME Steam Tables (1967) for compressed water, the effect of a [ ]$^{+a,c}$ error in feedwater temperature on the $\sqrt{\rho_f}$ is [ ]$^{+a,c}$ % in steam generator thermal output. An error of [ ]$^{+a,c}$ in feedwater pressure is assumed in this analysis (detailed breakdown of this value is provided in the steam enthalpy section). This results in an uncertainty in $\sqrt{\rho_f}$ of [ ]$^{+a,c}$ % in steam generator thermal output. The combined effect of the two results in a total $\sqrt{\rho_f}$ uncertainty of [ ]$^{+a,c}$ % in steam generator thermal output.

It is assumed that the Δp cell (usually a Barton or Rosemount) is read locally and soon after the Δp cell and local meter are calibrated (within 7 days of calibration). This allows the elimination of process rack and sensor drift errors from consideration. Therefore, the Δp cell errors noted in this analysis are [ ]$^{+a,c}$ % for calibration and [ ]$^{+a,c}$ % for reading error of the special high accuracy, local gauge. These two errors are in % Δp span. In order to be useable in this analysis they must be translated into % feedwater flow at full power conditions. This is accomplished by multiplying the error in % Δp span by the conversion factor noted below:

$$\left(\frac{1}{2}\right)\left(\frac{\text{span of feedwater flow transmitter in percent of nominal flow}}{100}\right)^2$$

For a feedwater flow transmitter span of [ ]$^{+a,c}$ % nominal flow, the conversion factor is [ ]$^{+a,c}$ (which is the value used in this analysis).

As noted in Table 2, the statistical sum of the errors for feedwater flow is [ ]$^{+a,c}$ % of steam generator thermal output.

Feedwater Enthalpy

The next major error component is the feedwater enthalpy used in Equation 5. For this parameter the major contributor to the error is the uncertainty in the feedwater temperature. It is assumed that the feedwater temperature is determined through the use of an RTD or thermocouple whose output is read by a digital voltmeter (DVM) or digital

multimeter (DMM) (at the output of the RTD or by a Wheatstone Bridge for RTD's, or at the reference junction for thermocouples). It is also assumed that the process components of the above are calibrated within 7 days prior to the measurement allowing the elimination of drift effects for all but the RTDs. Therefore, the error breakdown for feedwater temperature is as noted on Table 1 . The statistical combination of these errors results in a total feedwater temperature error of [ ]+a,c.

Using the ASME Steam Table (1967) for compressed water, the effect of a [ ]+a,c error in feedwater temperature on the feedwater enthalpy (h_f) is [ ]+a,c % in steam generator thermal output. Assuming a [ ]+a,c error in feedwater pressure (detailed breakdown provided in the steam enthalpy section) results in a [ ]+a,c % effect in h_f and steam generator thermal output. The combined effect of the two results in a total h_f uncertainty of [ ]+a,c % steam generator thermal output, as noted on Table 2.

Steam Enthalpy

The steam enthalpy has two contributors to the calorimetric error, steamline pressure and the moisture content. For steamline pressure the error breakdown is as noted on Table 1. This results in a total instrumentation error of [ ]+a,c %, which equals [ ]+a,c for a 1200 psi span. For this analysis a conservative value of [ ] is assumed for the steamline pressure. The feedwater pressure is assumed to be 100 psi higher than the steamline pressure with a conservatively high measurement error of [ ]+a,c. If feedwater pressure is measured on the same basis as the steamline pressure (with a DVM) the error is [ ]+a,c % span, which equals [ ]+a,c for a 1500 psi span. Thus, an assumption of an error of [ ]+a,c is very conservative.

Using the ASME Steam Tables (1967) for saturated water and steam, the effect of a [ ]+a,c ([ ]+a,c) error in steamline pressure on the steam enthalpy is [ ]+a,c % in steam generator thermal output. Thus, a total instrumentation error of [ ]+a,c results in an uncertainty of [ ]+a,c % in steam generator thermal output, as noted on Table 2.

The major contributor to h_s uncertainty is moisture content. The nominal or best estimate performance level is assumed to be [ ]$^{+a,c}$ % which is the design limit to protect the high pressure turbine. The most conservative assumption that can be made in regards to maximizing steam generator thermal output is a steam moisture content of zero. This conservatism is introduced by assigning an uncertainty of [ ]$^{+a,c}$ % to the moisture content, which is equivalent through enthalpy change to [ ]$^{+a,c}$ % of thermal output. The combined effect of the steamline pressure and moisture content on the total h_s uncertainty is [ ]$^{+a,c}$ % in steam generator thermal output.

Secondary Side Loop Power

The loop power uncertainty is obtained by statistically combining all of the error components noted for the steam generator thermal output (Q_{SG}) in terms of Btu/hr. Within each loop these components are independent effects since they are independent measurements. Technically, the feedwater temperature and pressure uncertainties are common to several of the error components. However, they are treated as independent quantities because of the conservatism assumed and the arithmetic summation of their uncertainties before squaring them has no significant effect on the final result.

The only effect which tends to be dependent, affecting all loops, would be the accumulation of crud on the feedwater venturis, which can affect the Δp for a specified flow. Although it is conceivable that the crud accumulation could affect the static pressure distribution at the venturi throat pressure tap in a manner that would result in a higher flow for a specified Δp, the reduction in throat area resulting in a lower flow at the specified Δp is the stronger effect. No uncertainty has been included in the analysis for this effect. If venturi fouling is detected by the plant, the venturi should be cleaned, prior to performance of the measurement. If the venturi is not cleaned, the effect of the fouling on the determination of the feedwater flow, and thus, the steam generator power and RCS flow, should be measured and treated as a bias, i.e., the error due to venturi fouling should be added to the statistical summation of the rest of the measurement errors.

The net pump heat uncertainty is derived in the following manner. The primary system net heat losses and pump heat adder for a four loop plant are summarized as follows:

System heat losses	-2.0 MWt
Component conduction and convection losses	-1.4
Pump heat adder	+18.0
Net Heat input to RCS	+14.6 MWt

The uncertainties for these quantities are as follows: The uncertainty on systems 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 the system hydraulics tests performed at Prairie Island II and by input power measurements from several plants, so the uncertainty for the pump heat adder is estimated to be [ ]$^{+a,c}$ % of the best estimate value. Considering these parameters as one quantity which is designated the net pump heat uncertainty, the combined uncertainties are less than [ ]$^{+a,c}$ % of the total, which is [ ]$^{+a,c}$ % of core power.

The Total Secondary Side Loop Power Uncertainty (noted in Table 2 as [ ]$^{+a,c}$ %) is the statistical sum of the secondary side loop power uncertainty (Q_{SG}), [ ]$^{+a,c}$ %, and the net pump heat addition, [ ]$^{+a,c}$ %.

Primary Side Enthalpy

The primary side enthalpy error contributors are T_H and T_C measurement errors and the uncertainty in pressurizer pressure. The instrumentation errors for T_H are as noted on Table 1. These errors are based on the assumption that the DVM has been recently calibrated (within 7 days prior to the measurement) and the DVM is used to read the output of the RTD, or a bridge, thus allowing the elimination of drift effects in

the racks. The statistical combination of the above errors results in a total T_H uncertainty of [ ]$^{+a,c}$.

Table 1 also provides the instrumentation error breakdown for T_C. The errors are based on the same assumptions as for T_H, resulting in a total T_C uncertainty of [ ]$^{+a,c}$.

Pressurizer pressure instrumentation errors are noted on Table 1 A sensor drift allowance of [ ]$^{+a,c}$ % is included due to the difficulty in calibrating while at power. It is assumed calibration is performed only as required by plant Technical Specifications.

Statistically combining these errors results in the total pressurizer pressure uncertainty equaling [ ]$^{+a,c}$ % of span, which equals [ ]$^{+a,c}$ for an [ ]$^{+a,c}$ span. In this analysis a conservative value of [ ]$^{+a,c}$ is used for the instrumentation error for pressurizer pressure.

The effect of an uncertainty of [ ]$^{+a,c}$ in T_H on h_H is [ ]$^{+a,c}$ % of loop flow. Thus, an error of [ ]$^{+a,c}$ in T_H introduces an uncertainty of [ ]$^{+a,c}$ percent in h_H. An error of [ ]$^{+a,c}$ in T_C is worth [ ]$^{+a,c}$ % in h_c. Therefore, an error of [ ]$^{+a,c}$ in T_C results in an uncertainty of [ ]$^{+a,c}$ % in h_c and loop flow. An uncertainty of [ ]$^{+a,c}$ in pressurizer pressure introduces an error of [ ]$^{+a,c}$ % in h_H and [ ]$^{+a,c}$ % in h_c. Statistically combining the hot leg and cold leg temperature and pressure uncertainties results in an h_H uncertainty of [ ]$^{+a,c}$ %, an h_c uncertainty of [ ]$^{+a,c}$%, and a total uncertainty in Δh of [ ]$^{+a,c}$ % in loop flow.

Statistically combining the Total Secondary Side Loop Power Uncertainty (in Btu/hr) with the primary side enthalpy uncertainty (in Btu/lb),

TABLE 1

TYPICAL INSTRUMENTATION UNCERTAINTIES
(using RdF RTDs)

	Feedwater Pressure Indication (Computer) (1)	Feedwater Δp Indication (Computer) (1)	Pressurizer Pressure Indication (DVM (1)	Feedwater Temperature Indication (DVM) (1)	Steamline Pressure Indication (DVM) (1)	T_H Indication (DVM) (1)	T_C Indication (DVM) (1)
PMA							
PEA							
SCA							
SD							
STE							
SPE							
RCA							
RD							
RTE							
DVM							
ID							
A/D							
CA							
CSA							
	1500 psi	100%Δp	800 psi	400°F	1200 psi	100°F	100°F

+a,c

(1) % instrument span
(2) Corresponds to an accuracy of [ ]+a,c
(3)
(4) Determined using Eq. 1
(5) Determined using Eq. 2
(6) Corresponds to an accuracy of [ ]+a,c
(7) Corresponds to a drift of [ ]+a,c

FIGURE 1
RCS FLOW CALORIMETRIC SCHEMATIC

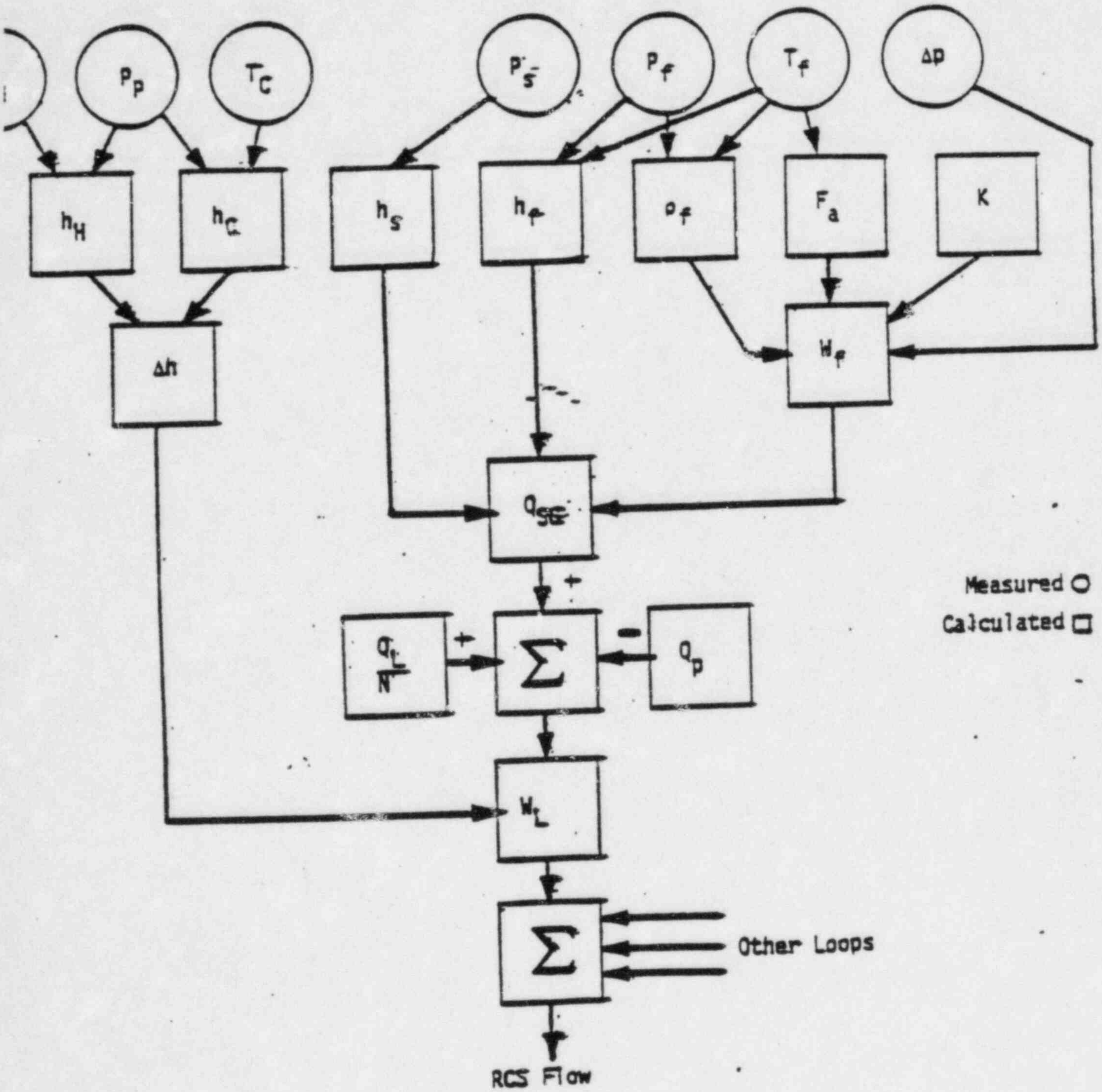

TABLE 2

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTIES

+a,c

Component	Instrument Error(1)	Flow Uncertainty
Feedwater Flow		
Venturi, K		
Thermal Expansion Coefficient		
Temperature		
Material		
Density		
Temperature		
Pressure		
Instrumentation		
Δp Cell Calibration		
Δp Cell Gauge Readout		
Total Instrumentation Error $\sqrt{\Sigma(e)^2}$		
Total Feedwater Flow Error $\sqrt{\Sigma(e)^2}$		
Feedwater Enthalpy		
Temperature (Electronics)		
RTD Calibration		
Sensor Drift		
DVM Accuracy		
Total Temperature Error $\sqrt{\Sigma(e)^2}$		
Pressure		
Total Feedwater Enthalpy Error $\sqrt{\Sigma(e)^2}$		

TABLE 2 (Cont)

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTIES

+a,c

Component	Instrument Error(1)	Flow Uncertainty
Steam Enthalpy		
Steamline Pressure (Electronics)		
Pressure Cell Calibration		
Sensor Temperature Effects		
Rack Calibration		
Rack Temperature Effects		
DVM Accuracy		
Total Electronics Error $\sqrt{\Sigma(e)^2}$		
Steamline Pressure Error Assumed-		
Moisture Carryover		
Total Steam Enthalpy Error $\sqrt{\Sigma(e)^2}$		
Secondary Side Loop Power Uncertainty $\sqrt{\Sigma(e)^2}$		
Net Pump Heat Addition Uncertainty		
Total Secondary Side Loop Power Uncertainty $\sqrt{\Sigma(e)^2}$		
Primary Side Enthalpy		
T_H (Electronics)		
RTD Calibration		
Sensor Drift		
DVM Accuracy		
T_H Instrumentation Error $\sqrt{\Sigma(e)^2}$		
T_H Temperature Streaming Error		
T_H Temperature Error $\sqrt{\Sigma(e)^2}$		

TABLE 2 (Cont)

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTIES

+a,c

Component	Instrument Error(1)	Flow Uncertainty
T_C (Electronics)		
RTD Calibration		
Sensor Drift		
DVM Accuracy		
T_C Instrumentation Error $\sqrt{\Sigma(e)^2}$		
Pressurizer Pressure (Electronics)		
Pressure Cell Calibration		
Sensor Temperature Effects		
Sensor Drift		
Rack Calibration		
Rack Temperature Effects		
DVM Accuracy		
Total Pressurizer Pressure Error $\sqrt{\Sigma(e)^2}$		
Pressurizer Pressure Error Assumed		
T_H Pressure Effect		
T_H Total Error $\sqrt{\Sigma(e)^2}$		
T_C Pressure Effect		
T_C Total Error $\sqrt{\Sigma(e)^2}$		
Total Δh Uncertainty $\sqrt{\Sigma(e)^2}$		
Primary Side Loop Flow Uncertainty $\sqrt{\Sigma(e)^2}$		
Total RCS Flow Uncertainty $\sqrt{[\Sigma(e)^2]/N}$ where N = 4 loops		± 1.9%

NOTES FOR TABLE 7

1. Measurements performed within 7 days after calibration thus Rack Drift, and where possible Sensor Drift, effects are not included in this analysis.

2. Conservative assumption for value, particularly if steamline pressure + 100 psi is assumed value. Uncertainty for steamline pressure noted in steam enthalpy.

3. To transform error in percent Δp span to percent of feedwater flow at 100% of nominal feedwater flow; multiply the instrument error by:

$$\left(1/2\right)\left(\frac{\text{Span of feedwater flow transmitter in percent of nominal flow}}{100}\right)^2$$

   In this analysis the feedwater flow transmitter span is assumed to be [ ]+a,c % of nominal flow.

4. Reading error for multiple readings of a Barton gauge.

5. Conservative assumption for instrumentation error for this analysis.

6. Maximum allowed moisture carryover to protect HP turbine.

7. Calibration accuracy of [ ]+a,c% span of [ ]+a,c which equals [ ]+a,c.

8. Credit taken for the 3 tap scoop RTD bypass loop in reducing uncertainties due to temperature streaming.

9. Convoluted sum of T_H Temperature Error and T_H Pressure Effect.

10. Convoluted sum of T_C Instrumentation Error and T_C Pressure Effect.

11. Convoluted sum of T_H Total Error and T_C Total Error.

results in a Primary Side Loop Flow Uncertainty of [ ]$^{+a,c}$ % loop flow. The RCS flow uncertainty is the statistical combination of the primary side loop flow error and the number of primary side loops in the plant. As noted in Table 2 the RCS Flow uncertainty for 4 loops is ±1.9%flow.

NORMALIZED ELBOW TAPS FOR RCS FLOW MEASUREMENT

Based on the results of Table 2, in order for a plant to assure operation within the analysis assumptions an RCS flow calorimetric would have to be performed once every 31 EFPD. However, this is an involved procedure which requires considerable staff and setup time. Therefore, many plants perform one flow calorimetric of the beginning of the cycle and normalize the loop elbow taps. This allows the operator to quickly determine if there has been a significant reduction in loop flow on a shift basis and to avoid a long monthly procedure. The elbow taps are forced to read 1.0 in the process racks after performance of the full power flow calorimetric, thus, the elbow tap and its Δp cell are seeing normal operating conditions at the time of calibration/normalization and 1.0 corresponds to the measured loop flow at the time of the measurement.

For monthly surveillance to assure plant operation two means of determining the RCS flow are available. One, to read the loop flows from the process computer, and two, to measure the output of the elbow tap Δp cells in the process racks with a DVM. The uncertainties for both methods and their convolution with the calorimetric uncertainty are presented below.

Assuming that only one elbow tap per loop is available to the process computer results in the following elbow tap measurement uncertainty:

	%Δp span	% flow
PMA		
PEA		
SCA		
SPE		
STE		
SD		

+a,c

	%Δp span	% flow
RCA		
RTE		
RD		
ID		
A/D		
Readout		

+a,c

Δp span is converted to flow on the same basis as provided in Note 3 of Table 2 for an instrument span of [ ]$^{+a,c}$. Using Eq. 2 results in a loop uncertainty of [ ]$^{+a,c}$ flow per loop. The total uncertainty for N loops is:

N = 4 [ ]$^{+a,c}$ flow

The instrument/measurement uncertainties for normalized elbow taps and the flow calorimetric are statistically independent and are 95+% probability values. Therefore, the statistical combination of the standard deviations results in the following total flow uncertainty at a 95+% probability:

4 loops ≈ ± 2.0% flow

Another method of using normalized elbow taps is to take DVM readings in the process racks of all three elbow taps for each loop. This results in average flows for each loop with a lower instrumentation uncertainty for the total RCS flow. The instrumentation uncertainties for this measurement are:

	%Δp span	% flow
PMA		
PEA		
SCA		
SPE		
STE		

[ ]$^{+a,c}$

	%Δp span	% flow
SD		
RCA		
RTE		
RD		
DVM		
Readout		

[ ]$^{+a,c}$

Δp span is converted to flow on the same basis as provided in Note 3 of Table 2. for an instrument span of [ ]$^{+a,c}$. Using Eq. 1 results in a channel uncertainty of [ ]$^{+a,c}$ flow. Utilizing three elbow taps (which are independent) results in a loop uncertainty of [ ]$^{+a,c}$ flow per loop. The total uncertainty for N loops is:

N = 4 [ ]$^{+a,c}$ flow

The calorimetric and the above noted elbow tap uncertainties can be statistically combined as noted earlier. The 95+% probability total flow uncertainties, using three elbow taps per loop are:

4 loops ≈ ± 1.9% flow

The following table summarizes RCS flow measurement uncertainties.

TABLE 3

TOTAL FLOW MEASUREMENT UNCERTAINTIES

	Loops 4
Calorimetric uncertainty	± 1.9
Total uncertainty 3 elbow taps/loop	± 1.9
Total uncertainty 1 elbow tap/loop	± 2.0

REFERENCES

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

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

6. 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.

7. NRC proposed Regulatory Guide 1.105 Rev. 2, "Instrument Setpoints", dated 12/81 for implementation 6/82.

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

9. ANSI/N719 ISA Standard S67.04, Draft F, 5/22/79, "Setpoints for Nuclear Safety-Related Instrumentation Used in Nuclear Power Plants".

10. Scientific Apparatus Manufacturers Association, Standard PMC-20-1-1973, "Process Measurement and Control Terminology".