ENCLOSURE 3
(NON-PROPRIETARY)

The attached document has been modified to reflect the use of Rosemount RTDs and is identified by the use of section, table and page numbers followed by the letter "b". A separate document reflecting the use of RdF RTDs has been written and is identified by the letter "a".

Questions:

1. Provide and justify the variances and distributions for input parameters.

2. Justify that the nominal conditions used in the analyses bound all permitted modes of plant operation.

3. Provide a block diagram depicting sensor, processing equipment, computer, and readout devices for each parameter channel used in the uncertainty analysis. Within each element of the block diagram identify the accuracy, drift, range, span, operating limits, and setpoints. Identify the overall accuracy of each channel transmitter to final output and specify the minimum acceptable accuracy for use with the new procedure. Also identify the overall accuracy of the final output value and maximum accuracy requirements for each input channel for this final output device.

Response: Rosemount RTDs

I. INTRODUCTION

Four operating parameter uncertainties are used in the uncertainty analysis of the Improved Thermal Design Procedure (ITDP). These operating parameters are pressurizer pressure, primary coolant temperature (T_{avg}), reactor power, and reactor coolant system flow. These parameters are monitored on a regular basis and several are used for control purposes. The reactor power is monitored by the performance of a secondary side heat balance (power calorimetric measurement) at least once every 24 hours. The 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 same surveillance schedule. Pressurizer pressure is a controlled parameter and the uncertainty for the Improved Thermal Design Procedure reflects the use of the control system. T_{avg} is a controlled parameter through the use of the temperature input to the Control Rod control system; the uncertainty presented here reflects the use of this control system.

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 the ITDP 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 u ed by Westinghouse is the [

]$^{+a,c,e}$ 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

3. For parameters which have control systems;

[ ]$^{+a,c}$

Eq. 3

where:

CSA = Channel Statistical Allowance
PMA = Process Measurement Accuracy
PEA = Primary Element Accuracy
SCA = Sensor Calibration Accuracy
SD = Sensor Drift

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
CA = Controller 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,

CA - allowance for the accuracy of a controller, not including deadband.

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

III. Instrumentation Uncertainties

The instrumentation uncertainties will be discussed first for the two parameters which are controlled by automatic systems, Pressurizer pressure, and T_{avg} (through Rod Control). The uncertainties for both of these parameters are listed on Table 1b, Typical Instrumentation Uncertainties.

1.b. Pressurizer Pressure

Pressurizer pressure is controlled by a system that compares the measured pressure against a reference value. The pressure is measured by a pressure cell connected to the vapor space of the pressurizer. Allowances are made as indicated on Table 1b for the sensor/transmitter and the process racks/controller. As noted, the CSA for this function is [$]^{+a,c}$ which corresponds to a control accuracy of [$]^{+a,c}$. The accuracy assumed in the ITDP analysis is [$]^{+a,c}$, thus, margin exists between analysis and the plant. Being a controlled parameter, the nominal value of 2235 psig is reasonable and bounded by ITDP error analysis assumptions, i.e., assuming a normal, two sided distribution for CSA and a 95+% probability distribution (which will be documented later in this response), σ for the noted CSA equals [$]^{+a,c}$. Assuming a normal, two sided distribution for the ITDP assumption of [$]^{+a,c}$ and a 95+% probability distribution results in a σ = [$]^{+a,c}$. Thus,

PROPRIETARY CLASS III

TABLE 1b

TYPICAL INSTRUMENTATION UNCERTAINTIES
(Using Rosemount RTDs)

	Pressurizer Pressure Control (1)	Rod Control (Temperature) Tavg (1)	1st Stage Turbine Impulse Pressure (1)	Steamline Pressure Indication (Computer (1)	Feedwater Temperature Indication (Computer) (1)	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												
Span	800 psi	100°F	100°F	1200 psi	400°F	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) Determined using Eq. 3
(4) Determined using Eq. 1
(5) Determined using Eq. 2
(6) Corresponds to an accuracy of [ ]+a,c

margin exists between the expected and assumed standard deviations for Pressurizer pressure.

2.b. T_{AVG}

T_{avg} is controlled by a system that compares the auctioneered high T_{avg} from the loops with a reference derived from the First Stage Turbine Impulse Pressure. T_{avg} is derived from the average of the narrow range T_H and T_C from the bypass manifolds. The highest loop T_{avg} is then used in the controller. Allowances are made as noted on Table 1b for the sensor/transmitter and the process racks/controller. As noted, the CSA for this function is [ ]$^{+a,c}$ which corresponds to an instrumentation accuracy of [ ]$^{+a,c}$. Assuming a normal, two sided distribution for CSA and a 95+% probability distribution results in a standard deviation, σ = [ ]$^{+a,c}$.

However, this does not include the controller deadband of $\pm$ 1.5°F. To determine the controller accuracy the instrumentation accuracy must be combined with the deadband. Westinghouse has determined that the probability distribution for the deadband is [

].$^{+a,c}$ The variance for the deadband uncertainty is then:

[ ]$^{+a,c}$

and the standard deviation, $\sigma \approx$ [ ]$^{+a,c}$.

Combining statistically the standard deviations for instrumentation and deadband results in a controller standard deviation of:

$$\sigma_T = \sqrt{\sigma_1^2 + \sigma_2^2} = [\quad]^{+a,c}.$$

Therefore, the controller uncertainty for a 95+% normal probability distribution is ∿ [ ].[+a,c] This is the uncertainty assumed for the ITDP error analysis and reasonably bounds the nominal value corresponding to the full power T_{avg}.

3.b. Reactor Power

Generally a plant performs a primary/secondary side heat balance once every 24 hours when power is above 15% Rated Thermal Power. This heat balance is used to verify that the plant is operating within the limits of the Operating License and to adjust the Power Range Neutron Flux channels when the difference between the NIS and the heat balance is greater than that allowed by the plant Technical Specifications.

Assuming that the primary and secondary sides are in equilibrium; the core power is determined by summing the thermal output of the steam generators, correcting the total secondary power for steam generator blowdown (if not secured), subtracting the RCP heat addition, adding the primary side system losses, and dividing by the core rated Btu/hr at full power. The equation for this calculation is:

$$RP = \left(\frac{\sum^{N} [Q_{SG} - Q_p] + Q_L}{H} \right) 100 \qquad \text{Eq. 4}$$

where;

RP	=	Core power (% RTP)
N	=	Number of primary side loops
Q_{SG}	=	Steam Generator thermal output (Btu/hr)
Q_p	=	RCP heat adder (Btu/hr)
Q_L	=	Primary system net heat losses (Btu/hr)
H	=	Core rated Btu/hr at full power.

For the purposes of this uncertainty analysis (and based on H noted above) it is assumed that the plant is at 100% RTP when the measurement is taken. Measurements performed at lower power levels will result in

different uncertainty values. However, operation at lower power levels results in increased margin to DNB far in excess of any margin losses due to increased measurement uncertainty.

The thermal output of the steam generator is determined by a calorimetric measurement 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 the 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 a calculation based on the following:

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

where:

K = Feedwater venturi flow coefficient
F_a = Feedwater venturi correction for thermal expansion
ρ_f = Feedwater density (lb/ft^3)
Δp = Feedwater venturi pressure drop (inches H_2O).

The feedwater venturi flow coefficient is the product of a number of constants including as-built dimensions of the venturi and calibration tests performed by the vendor. The thermal expansion correction is based on the coefficient of expansion of the venturi material and the

difference between feedwater temperature and calibration temperature. Feedwater density is based on the measurement of feedwater temperature and 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 calcuated sum for full power operation is used for these losses/heat inputs.

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

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

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 adder (Q_p)

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 hydraulic 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 steam generator thermal output is proportional to feedwater flow, the flow coefficient uncertainty is expressed as [$]^{+a,c}$ % power.

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 $\pm$ 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 total uncertainty in F_a and steam generator output of [$]^{+a,c}$ %.

Based on data introduced into the ASME code, the uncertainty in F_a for 304 stainless steel is ±5 percent. 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 the analysis (detailed breakdown of this value is provided in the steam enthalphy 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.

Table 1b provides a listing of the instrumentation errors for feedwater Δp (including an allowance for the venturi as defined above) assuming display on the process computer. With the exception of the computer readout error, the electronics errors are in percent %Δp span and must be translated into percent feedwater flow at full power conditions. This is accomplished by multiplying the error in percent Δp span by the conversion factor noted below:

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

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

As noted in Table 2b, 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. Table 1b provides the detailed error breakdown for this temperature measurement assuming indication on the process computer. Statistically summing these errors (utilizing Eq. 2) results in a total temperature error of [ ]$^{+a,c}$ % span. Assuming a span of [ ]$^{+a,c}$ results in a temperature error of [ ].$^{+a,c}$ A conservative, bounding value of [ ]$^{+a,c}$ was assumed for this analysis. Assuming smaller spans results in smaller temperature errors.

Using the ASME steam tables (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 [ ]$^{+a,c}$ %. A conservative value (based on round-off effects of individual instrumentation errors) of [ ]$^{+a,c}$ % for h_f uncertainty is used in this analysis (as noted on Table 2b).

Steam Enthalpy

The steam enthalpy has two contributors to the calorimetric error, steamline pressure and the moisture content. For steamline pressure the errors are as noted on Table 1b, assuming display on the process computer. This results in a total instrumentation error (utilizing Eq. 2) of [ ]$^{+a,c}$ % span. Based on a 1200 psig span this equals [ ].$^{+a,c}$ A conservative value of [ ]$^{+a,c}$ is assumed in this analysis. The feedwater pressure is assumed to be 100 psi higher than the steamline pressure with a conservatively high measurement error of [ ].$^{+a,c}$ Table 1b provides a breakdown of expected errors if feedwater pressure is measured directly and displayed

on the process computer. The results indicate an expected error of [ ]$^{+a,c}$, well within the assumed value.

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 (h_s) is [ ]$^{+a,c}$ % in steam generator thermal output. Thus a total instrumentation error of [ ]$^{+a,c}$ in steamline pressure results in an uncertainty of [ ]$^{+a,c}$ % in steam generator thermal output.

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.

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 loop power. Within each loop these components are independent effects (or formed into independent quantities) 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, is the accumulation of crud on the feedwater venturis, which can effect 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. All reported cases of venturi fouling have been associated with a significant loss in electrical output, indicating that the actual thermal power has been below the measured power rather than above it. Losses in net power generation which have been correlated with venturi fouling have occurred in about half of the more than 20 Westinghouse pressurized water reactors operating in the United States. These power losses have been generally in the range of two to three percent. Power losses have also occurred in at least three, and possibly five plants out of the more than ten Westinghouse plants operating abroad. In no case has venturi fouling been reported which resulted in a non-conservative feedwater flow measurement. Because the venturi crud formations have resulted in a conservative, reduced power condition, no uncertainty has been included in the analysis of power measurement error for this phenomenon.

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:

Systems 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 system heat losses, which are 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 equivalent to [$]^{+a,c}$ % of core power.

The Total Loop Power uncertainty (noted in Table 2 as [$]^{+a,c}$ %) is the statistical sum of the Loop Power uncertainty (Q_{SG}), [$]^{+a,c}$ %, and the Net Pump Heat Addition, [$]^{+a,c}$ %. The Total Secondary Power uncertainty is the statistical combination of the Loop Power uncertainty and the number of primary side loops in the plant. As noted in Table 2b, the Secondary Power uncertainty for N loops is as follows:

N = 4	uncertainty =	± 1.2 % power
3		± 1.4 % power
2		± 1.7 % power

In all cases the total Secondary Power uncertainty is less than or equal to the historically used value of ± 2 % power. For ITDP, credit is taken for the increased knowledge of reactor power and the values noted above are used in the ITDP error analysis, i.e., the standard deviation for reactor power, at the 95+% probability level is:

FIGURE 1
POWER CALORIMETRIC SCHEMATIC

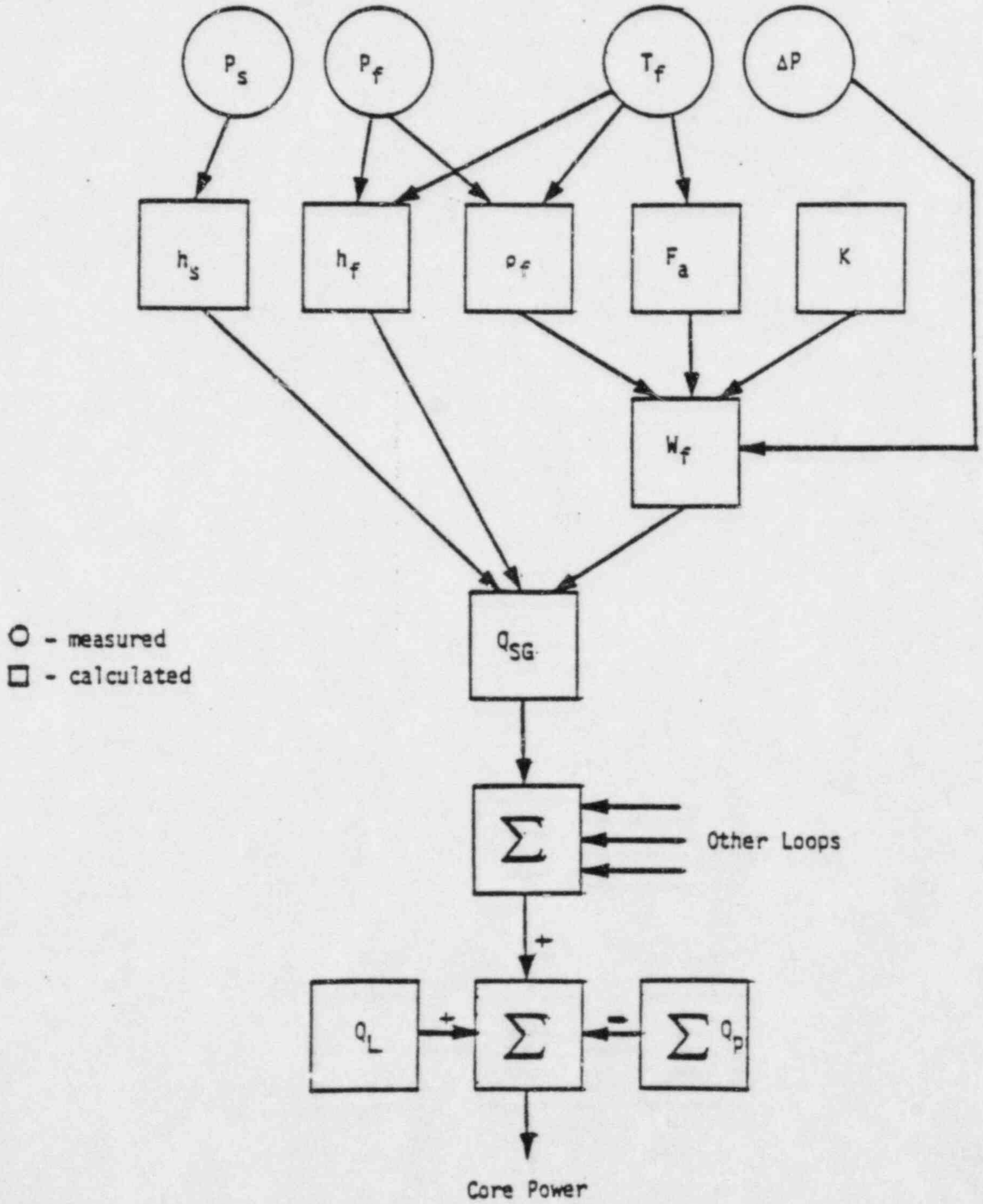

TABLE 2 b

SECONDARY POWER CALORIMETRIC MEASUREMENT UNCERTAINTIES

Component	Instrument Error	Power Uncertainty
Feedwater Flow		+a,c
Venturi, K		
Thermal Expansion Coefficient		
Temperature		
Material		
Density		
Temperature		
Pressure		
Electronics		
Δp Cell Calibration		
Sensor Pressure Effects		
Sensor Temperature Effects		
Sensor Drift		
Rack Calibration		
Rack Temperature Effects		
Rack Drift		
Computer Isolator Drift		
Computer Readout		
Total Electronics Error $\sqrt{\Sigma(e)^2}$		
Total Feedwater Flow Error $\sqrt{\Sigma(e)^2}$		

TABLE 2b (Cont)

SECONDARY POWER CALORIMETRIC MEASUREMENT UNCERTAINTIES

Component	Instrument Error	Power Uncertainty	
Feedwater Enthalpy			
Temperature (Electronics)			+a,c
RTD Calibration			
R/I Converter			
Rack Accuracy			
Rack Temperature Effects			
Rack Drift			
Computer Isolator Drift			
Computer Readout			
Total Electronics Error $\sqrt{\Sigma(e)^2}$			
Feedwater Temperature Error Assumed			
Pressure			
Total Feedwater Enthalpy Error $\sqrt{\Sigma(e)^2}$			
Steam Enthalpy			
Steamline Pressure (Electronics)			
Pressure Cell Calibration			
Sensor Temperature Effects			
Sensor Drift			
Rack Calibration			
Rack Temperature Effects			

TABLE 2 b (Cont)

SECONDARY POWER CALORIMETRIC MEASUREMENT UNCERTAINTIES

Component	Instrument Error	Power Uncertainty
Steam Enthalpy (Cont)	[ ]+a,c	[ ]+a,c
Rack Drift		
Computer Isolator Drift		
Computer Readout		
Total Electronics Error $\sqrt{\Sigma(e)^2}$		
Steamline Pressure Error Assumed		
Moisture Carryover		
Total Steam Enthalpy Error $\sqrt{\Sigma(e)^2}$		
Loop Power Uncertainty $\sqrt{\Sigma(e)^2}$		
Net Pump Heat Addition Uncertainty		
Total Loop Power Uncertainty (8)		
Total Secondary Power Uncertainty $\sqrt{[\Sigma(e)^2]/N}$		
where N = 4 loops		± 1.2%
3 loops		± 1.4%
2 loops		± 1.7%

NOTES FOR TABLE 2 b

1. Temperature effect on Thermal Expansion Coefficient is assumed to be linear with an uncertainty of [ ]$^{+a,b,c}$ per 2°F change.

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. In this analysis assumed an error of [ ]$^{+a,c}$ and a maximum swing in feedwater pressure from no load to full power of [200 psi].$^{+a,c}$

5. [ ]$^{+a,c}$

6. [ ]$^{+a,c}$ span of [ ]$^{+a,c}$ equals [ ]$^{+a,c}$ which equals [ ]$^{+a,c}$ power.

7. Conservative assumption for instrumentation error for this analysis.

8. Statistical sum of Loop Power Uncertainty and Net Pump Heat Addition Uncertainty.

N = 4 σ = [ ]$^{+a,c}$ power

3 [ ] power

2 [ ] power

4.b. RCS FLOW

The Improved Thermal Design Procedure (ITDP) and some 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.,

$$W_{RCS} = \sum W_L \quad . \qquad \text{(Eq. 7)}$$

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:

$$W_L = \frac{(\gamma)\left\{Q_{SG} - Q_p + \left(\frac{Q_L}{N}\right)\right\}(V_C)}{\left[h_H - h_C\right]} \qquad \text{(Eq. 8)}$$

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 2.

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 3b, 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. Therefore, the error breakdown for feedwater temperature is as noted on Table 1b. 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 3b.

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 1b. 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 [ ]+a,c 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 measuredon 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 3b.

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 3b 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 1b. 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 1b 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 1b. 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),

FIGURE 2
RCS FLOW CALORIMETRIC SCHEMATIC

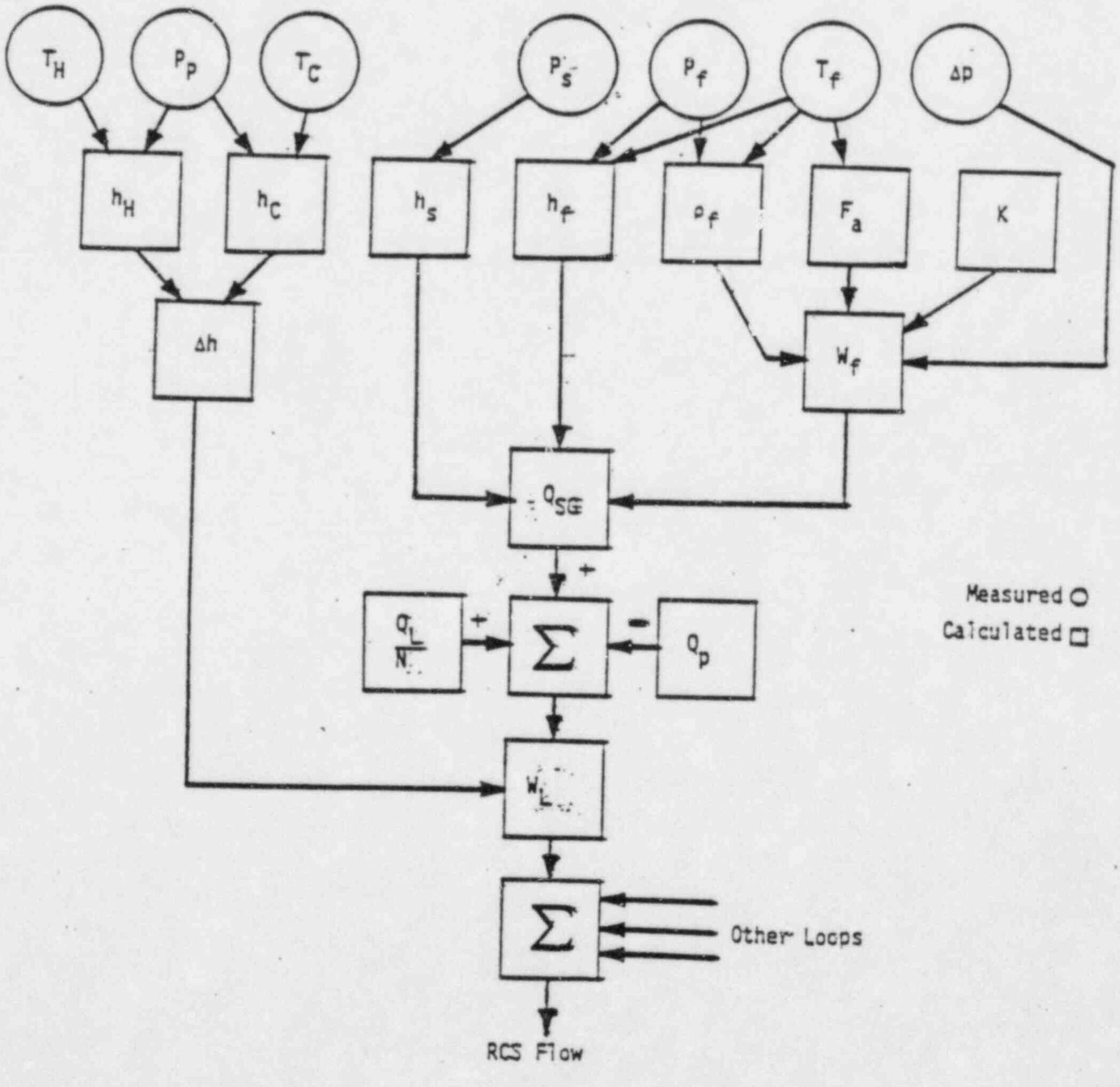

TABLE 3b

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTIES

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		
DVM Accuracy		
Total Temperature Error $\sqrt{\Sigma(e)^2}$		
Pressure		
Total Feedwater Enthalpy Error $\sqrt{\Sigma(e)^2}$		

+a,c

TABLE 3b (Cont)

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTIES

Component	Instrument Error(1)	Flow Uncertainty
		+a,c
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	± 20%	
Total Secondary Side Loop Power Uncertainty $\sqrt{\Sigma(e)^2}$		
Primary Side Enthalpy		
T_H (Electronics)		
RTD Calibration		
DVM Accuracy		
T_H Instrumentation Error $\sqrt{\Sigma(e)^2}$		
T_H Temperature Streaming Error		
T_H Temperature Error $\sqrt{\Sigma(e)^2}$		

TABLE 3b (Cont)

CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTIES

+a,c

Component	Instrument Error(1)	Flow Uncertainty
T_C (Electronics)		
RTD Calibration		
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		$\pm$ 1.5%
3 loops		$\pm$ 1.75%
2 loops		$\pm$ 2.1%

NOTES FOR TABLE 3b

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 3b, the RCS Flow uncertainty for N loops is:

N=4	uncertainty	=	$\pm$ 1.5 % flow
3		=	$\pm$ 1.75 % flow
2		=	$\pm$ 2.1 % flow.

For ITDP, credit is taken for the increased knowledge of RCS flow and the values noted above are used in the ITDP error analysis, i.e., the standard deviation for RCS flow, at the 95+% probability level is:

+a,c

N=4	σ	=	[ ] % flow
3		=	[ ] % flow
2		=	[ ] % flow

5. USE OF AN LEFM

If a plant uses a Leading Edge Flow Meter (LEFM), from the Oceanics Division of Westinghouse, for the measurement of feedwater flow, several changes are made in the calorimetric power and flow uncertainty analyses. The following are typical LEFM uncertainties in mass flow (lbs/hr):

a. A nominal accuracy of [ ]$^{+a,c}$ flow. This is based on a feedwater temperature uncertainty of [ ]$^{+a,c}$ and a feedwater pressure uncertainty of [ ]$^{+a,c}$.

b. For each [ ]$^{+a,c}$ increase in Feedwater temperature uncertainty, the mass flow uncertainty increases by [ ]$^{+a,c}$.

c. For a feedwater pressure uncertainty greater than [ ]$^{+a,c}$ but less than [ ]$^{+a,c}$, the mass flow uncertainty increases by [ ]$^{+a,c}$.

Thus, for a typical LEFM installation with a feedwater temperature uncertainty of [ ]$^{+a,c}$ and a pressure uncertainty less than [ ]$^{+a,c}$, the mass flow uncertainty is [ ]$^{+a,c}$ flow.

The effect of the use of an LEFM is seen primarily in the measurement of Reactor Power. The following table provides a comparison of the uncertainties for a power calorimetric using a feedwater venturi and an LEFM. It is assumed for these calculations that a measurement device (either a venturi or an LEFM) is in the feedwater line to each steam generator.

TABLE 4b

COMPARISON OF VENTURI VS. LEFM POWER CALORIMETRIC UNCERTAINTIES

	Venturi*	LEFM	
Reactor Power			+a,c
Feedwater Temperature			
Feedwater Flow			
Feedwater Enthalpy			
Steam Enthalpy			
Loop Power Uncertainty			
Total Loop Power Uncertainty			
Total Secondary Power Uncertainty			
4 loops	± 1.2% RTP	± 0.4% RTP	
3 loops	± 1.4% RTP	± 0.4% RTP	
2 loops	± 1.7% RTP	± 0.5% RTP	

* from Table 2

** due to [ ]$^{+a,c}$ assumption

The impact of the LEFM on RCS Flow measurement is considerably less (primarily due to the [ ]$^{+a,c}$ feedwater temperature error already being assumed and the prime error contributors being T_H and T_C for primary side Δh). However, the following table notes the differences between the two measurements for an RCS Flow calorimetric measurement. For these calculations it is assumed that a measurement device (either a venturi or an LEFM) is in the feedwater line to each steam generator.

TABLE 5b

COMPARISON OF VENTURI VS. LEFM FLOW CALORIMETRIC UNCERTAINTIES

	Venturi*	LEFM
RCS Flow	[	]+a,c
Feedwater Flow		
Feedwater Enthalpy		
Steam Enthalpy		
Secondary Loop Power Uncertainty		
Total Secondary Power Uncertainty		
Primary Enthalpy		
Primary Loop Flow Uncertainty		
Total RCS Flow Uncertainty		
4 loops	± 1.5% flow	± 1.45% flow
3 loops	± 1.75% flow	± 1.7% flow
2 loops	± 2.1% flow	± 2.05% flow

* from Table 3b

** due to [ ]+a,c assumption

Therefore, if a plant has installed an LEFM to measure feedwater flow credit would be taken in the ITDP error analysis for the lower uncertainty in Reactor Power, but no credit would be taken in RCS flow.

6.b NORMALIZED ELBOW TAPS FOR RCS FLOW MEASUREMENT

Based on the results of Table 3b, in order for a plant to assure operation within the ITDP 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 at 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 it's 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 consistent with the ITDP assumptions, 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 3b 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 =	[$]^{+a,c}$ flow
4	
3	
2	

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	± 1.7% flow
3 loops	± 2.0
2 loops	± 2.3

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 3b 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
3	
2	

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	± 1.6% flow
3 loops	± 1.8
2 loops	± 2.2

The following table summarizes RCS flow measurement uncertainties.

TABLE 6b

TOTAL FLOW MEASUREMENT UNCERTAINTIES

Loops	4	3	2
Calorimetric uncertainty*	± 1.5	± 1.75	± 2.1
Total uncertainty 3 elbow taps/loop	± 1.6	± 1.8	± 2.2
Total uncertainty 1 elbow tap/loop	± 1.7	± 2.0	± 2.3

* Calorimetric uncertainty noted assumes feedwater measurement with a venturi, however, use of an LEFM for feedwater measurement results in essentially the same value.

IV. PROBABILITY JUSTIFICATION

As noted in Section III, it is Westinghouse's belief that the total uncertainty for Pressurizer Pressure, T_{avg}, Reactor Power, and RCS Flow are normal, two sided, 95+% probability distributions. This section will substantiate that position with a comparison between three approaches, the first being that noted in Section II, the second involves determination of the variance assuming a uniform probability distribution for each uncertainty and then determination of the 95% probability value assuming a one sided normal distribution, and the third involves determination of the variance assuming a normal, two sided probability distribution for each uncertainty and then determination of the 95% probability value assuming a two sided normal distribution.

Table 7b lists the results of the three approaches. Column 1 lists the values noted for CSA on Table 1b which are determined through the use of equations 1, 2, or 3, whichever is applicable to that particular function. Column 2 lists the variance for each function assuming the uncertainty for each of the parameters listed in Section 2 is a uniform probability distribution. For this assumption,

$$\sigma^2 = \frac{R^2}{12} \qquad \text{Eq. 9}$$

where R equals the range of the parameter. The variance for the function equals the arithmetic sum of the parameter variances. From a safety point of view deviation in the direction of non-conservatism is important. Therefore, Column 3 lists the one sided 95% probability values based on the variances provided in Column 2, i.e., the one sided 95% probability value for a near normal distribution can be reasonably approximated by: $1.645\sqrt{\sigma^2}$.

Column 4 lists the variance for each function assuming the uncertainty for each of the parameters listed in Section 2 is a near normal, two sided probability distribution. Efforts have been made to conservatively determine the probability value for each of the parameters, see Table 8. For example, [

]+a,c The corresponding Z value listed on Table 8 is from the standard normal curve where:

$$Z = (x - \mu)/\sigma \qquad \text{Eq. 10}$$

The variance for a parameter is then the square of the uncertainty divided by its Z value:

$$\sigma^2 = \left(\frac{\text{uncertainty}}{Z}\right)^2 \qquad \text{Eq. 11}$$

The variance for the function equals the arithmetic sum of the parameter variances. From the variance the two sided 95% probability value for a normal distribution can be calculated: $1.96\sqrt{\sigma^2}$.

To summarize; Column 1 is the results of Equations 1, 2, and 3. Column 2 is the total variance assuming uniform probabilty distributions, i.e.,

$$\sigma^2 = \frac{R_1^{\,2} + R_2^{\,2} + \ldots}{12} = \frac{(2\ \text{unc}_1)^2 + (2\ \text{unc}_2)^2 + \ldots}{12} \qquad \text{Eq. 12}$$

Column 3 is $1.645\sqrt{\sigma^2}$.

Column 4 is the total variance assuming near normal probability distributions, i.e.,

$$\sigma^2 = \left(\frac{\text{unc}_1}{Z_1}\right)^2 + \left(\frac{\text{unc}_2}{Z_2}\right)^2 + \ldots \qquad \text{Eq. 13}$$

Column 5 is $1.96\sqrt{\sigma^2}$.

A comparison of Columns 1, 3, and 5 will show that the approach used in Section 2 results in values more conservative than those of Columns 3 and 5. Thus, it can be concluded that the results presented in Section 3 are total uncertainties with probabilities in excess of 95%.

Confidence limits are applicable only to a particular data set, which in this case not available. Therefore, based on the relatively small number of reports indicating large values of deviation, i.e., the number of instances where a channel fails a functional test is very small as compared to the many thousands of functional tests performed, Westinghouse believes that the total uncertainties presented on Table 1b are 95% probability values at a high confidence level.

V. CONCLUSIONS

The preceding sections provide what is believed to be a reasonable means of accounting for instrument and measurement errors for four parameters used in the ITDP analysis. The assumptions used in this response are generic and conservative. It is the intent of this response to generically resolve any concerns with the measurement and control of Reactor Power, RCS Flow, Pressurizer Pressure and T_{avg} as they are applied to ITDP. As such, plant specific responses will provide only that information which indicates that, 1) the instrument and measurement uncertainties for that plant are consistent with or conservative with respect to those presented here, or 2) specific instrument and/or measurement uncertainties for that plant are not consistent with those presented. In the second case the impact of the inconsistency on the four parameters will be provided with corresponding new total uncertainties if the impact is sufficiently large.

TABLE 7b

COMPARISON OF STATISTICAL METHODS

	1 Method 1	2 Variance Method 2	3 95% Probability Method 2	4 Variance Method 3	5 95% Probability Method 3
Pressurizer Pressure - Control					
T_{avg} - Control					
Steamline Pressure - Computer					
Feedwater Temperature - Computer					
Feedwater Pressure - Computer					
Feedwater Δp - Computer					
Pressurizer Pressure - DVM					
Steamline Pressure - DVM					
Feedwater Temperature - DVM					
T_H - DVM					
T_C - DVM					

+a,c

Notes for Table 7b

1. Uncertainties presented in columns 1, 3, and 5 are in % span.

2. While values noted are listed to the second decimal place, values are accurate only to the first decimal place. Second place is noted for round-off purposes only.

TABLE 8

UNCERTAINTY PROBABILITIES

+a,c

	Two Sided Normal Probability (%)	Two Sided Normal, Z Value
PMA		
PEA		
SCA		
SD		
STE		
SPE		
RCA		
RD		
RTE		
DVM		
ID		
A/D		
CA		

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4. Westinghouse letter NS-TMA-1835, T. M. Anderson to E. Case, NRC, dated 6/22/78.

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".

ENCLOSURE 4
(PROPRIETARY)

TABLE 1

MCGUIRE ITDP

+(a,c)

Parameter	Nominal Value	Range	Uncertainty Equivalent Standard Deviation	Sensitivity (% DNBR/% Parameter) Typical Cell	Sensitivity (% DNBR/% Parameter) Thimble Cell
Power	100% Power	90-120%	.60% Power	-2.13	-1.98
Inlet Temperature	559.6°F	529.6-610°F	1.95°F	-8.10	-7.10
Pressure	2280 psia	1805-2430 psia	15.2 psia	2.07	1.71
Vessel Flow	393600	275520 - 402000 GPM	0.85% Flow	1.41	1.26
Effective Flow Fraction (Bypass)	0.94	---	.866% Flow	1.41	1.26
$F_{\Delta H}^{N}$	1.49	1.49 - 1.72	2.43% $F_{\Delta H}^{N}$	-2.42	-2.16
$F_{\Delta H,1}^{E}$	1.0	1.0 - 1.021	.0182	-0.96	-0.89
THINC IV	-	---	2% DNBR	1.0	1.0
Transient Code	-	---	.5% DNBR	1.0	1.0

TABLE 2

CALCULATION OF DESIGN DNBR LIMIT FOR TYPICAL CELL

$$\left(\frac{\sigma_y}{\mu_y}\right)^2 = S_1^{\,2}\left(\frac{\sigma_1}{\mu_1}\right)^2 + S_2^{\,2}\left(\frac{\sigma_2}{\mu_2}\right)^2 + \ldots S_n^{\,2}\left(\frac{\sigma_n}{\mu_n}\right)^2$$

where σ = standard deviation

μ = mean

S = sensitivity

Parameter	Mean (μ)	σ	σ/μ	S	$S^2(\frac{\sigma}{\mu})^2$
Power	1.0	.0060	.006000	-2.13	.0001633
T_{in}	559.6	1.95	.003485	-8.10	.0007968
Pressure	2280	15.2	.006667	2.07	.0001905
Flow	1.0	.0085	.008500	1.41	.0001436
Bypass	.94	.00866	.009213	1.41	.0001687
$F^N_{\Delta H}$	1.49	.0362	.024300	-2.42	.0034581
$F^E_{\Delta H,1}$	1.0	.0182	.018200	-0.96	.0003053
THINC 4	1.0	.02	.020000	1.0	.0004000
Transient Code	1.0	.005	.005000	1.0	.0000250

+(a,c)

Σ = .0056513

$$\left(\frac{\sigma_y}{\mu_y}\right) = \sqrt{\Sigma \;\; S_n^{\,2}\left(\frac{\sigma_n}{\mu_n}\right)^2} = .075175$$

$$\text{Design DNBR Limit} = \frac{\text{Correlation Limit}}{1-(\text{Combined }\sigma)(1.645)} = \frac{1.17}{1-(.075175)(1.645)}$$

Design DNBR Limit = 1.335

TABLE 3

CALCULATION OF DESIGN DNBR LIMIT FOR THIMBLE CELL

$$\left(\frac{\sigma_y}{\mu_y}\right)^2 = S_1^{\,2}\left(\frac{\sigma_1}{\mu_1}\right)^2 + S_2^{\,2}\left(\frac{\sigma_2}{\mu_2}\right)^2 + \ldots S_n^{\,2}\left(\frac{\sigma_n}{\mu_n}\right)^2$$

where σ = standard deviation

μ = mean

S = sensitivity

Parameter	Mean (μ)	σ	σ/μ	S	$S^2(\frac{\sigma}{\mu})^2$
Power	1.0	.0060	.006000	-1.98	.0001411
T_{in}	559.6	1.95	.003485	-7.10	.0006122
Pressure	2280	15.2	.006667	1.71	.0001300
Flow	1.0	.0085	.008500	1.26	.0001147
Bypass	.94	.00866	.009213	1.26	.0001347
$F^N_{\Delta H}$	1.49	.0362	.024300	-2.16	.0027550
$F^E_{\Delta H,1}$	1.0	.0182	.018200	-0.89	.0002624
THINC 4	1.0	.02	.020000	1.0	.0004000
Transient Code	1.0	.005	.005000	1.0	.0000250

+(a,c)

Σ = .0045751

$$\left(\frac{\sigma_y}{\mu_y}\right) = \sqrt{\Sigma\ S_n^{\,2}\left(\frac{\sigma_n}{\mu_n}\right)^2} = .067639$$

$$\text{Design DNBR Limit} = \frac{\text{Correlation Limit}}{1-(\text{Combined }\sigma)(1.645)} = \frac{1.17}{1-(.067639)(1.645)}$$

Design DNBR Limit = 1.316

ENCLOSURE 4
(NON-PROPRIETARY)

TABLE 1

MCGUIRE ITDP

Parameter	Nominal Value	Range	Uncertainty Equivalent Standard Deviation	Sensitivity (% DNBR/% Parameter) Typical Cell	Thimble Cell
Power	100% Power				
Inlet Temperature	559.6°F				
Pressure	2280 psia				
Vessel Flow	393600				
Effective Flow Fraction (Bypass)	0.94				
$F_{\Delta H}^{N}$	1.49				
$F_{\Delta H,1}^{E}$	1.0				
THINC IV	-				
Transient Code	-				

+(a,c)

TABLE 2

CALCULATION OF DESIGN DNBR LIMIT FOR TYPICAL CELL

$$\left(\frac{\sigma_y}{\mu_y}\right)^2 = S_1^2\left(\frac{\sigma_1}{\mu_1}\right)^2 + S_2^2\left(\frac{\sigma_2}{\mu_2}\right)^2 + \dots S_n^2\left(\frac{\sigma_n}{\mu_n}\right)^2$$

where σ = standard deviation
μ = mean
S = sensitivity

+(a,c)

Parameter	Mean (μ)	σ	σ/μ	S	$S^2(\frac{\sigma}{\mu})^2$
Power	1.0				
T_{in}	559.6				
Pressure	2280				
Flow	1.0				
Bypass	.94				
$F^N_{\Delta H}$	1.49				
$F^E_{\Delta H,1}$	1.0				
THINC 4	1.0				
Transient Code	1.0				

Σ = .0056513

$$\left(\frac{\sigma_y}{\mu_y}\right) = \sqrt{\Sigma\ S_n^2\left(\frac{\sigma_n}{\mu_n}\right)^2} = .075175$$

$$\text{Design DNBR Limit} = \frac{\text{Correlation Limit}}{1-(\text{Combined } \sigma)(1.645)} = \frac{1.17}{1-(.075175)(1.645)}$$

Design DNBR Limit = 1.335

TABLE 3

CALCULATION OF DESIGN DNBR LIMIT FOR THIMBLE CELL

$$\left(\frac{\sigma_y}{\mu_y}\right)^2 = S_1^{\,2}\left(\frac{\sigma_1}{\mu_1}\right)^2 + S_2^{\,2}\left(\frac{\sigma_2}{\mu_2}\right)^2 + \ldots S_n^{\,2}\left(\frac{\sigma_n}{\mu_n}\right)^2$$

where σ = standard deviation

μ = mean

S = sensitivity

Parameter	Mean (μ)	σ	σ/μ	S	$S^2(\frac{\sigma}{\mu})^2$
Power	1.0				
T_{in}	559.6				
Pressure	2280				
Flow	1.0				
Bypass	.94				
$F^N_{\Delta H}$	1.49				
$F^E_{\Delta H,1}$	1.0				
THINC 4	1.0				
Transient Code	1.0				

+(a,c)

Σ = .0045751

$$\left(\frac{\sigma_y}{\mu_y}\right) = \sqrt{\Sigma\ S_n^{\,2}\left(\frac{\sigma_n}{\mu_n}\right)^2} = .067639$$

$$\text{Design DNBR Limit} = \frac{\text{Correlation Limit}}{1-(\text{Combined } \sigma)(1.645)} = \frac{1.17}{1-(.067639)(1.645)}$$

Design DNBR Limit = 1.316